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Biogas Production by Anaerobic Digestion and Co-digestion of some Large Available Organic Solid Wastes of Madagascar

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Abstract— The first part of this work is focused on the determination of the Biochemical Methane Potential (BMP) of a wide range of substrates that are largely available in Madagascar in order to determine the amount of methane (CH_4) that could be produced from their treatment (by monodigestion and by co-digestion) in an anaerobic reactor. Then a simple and easy technique to determine the CH4 content of biogas is presented in the second part. The experiments from BMP tests from the treated substrates showed results between 108mL.CH_4/g.VS and 399mL.CH_4/g.VS in monodigestion and a highest methane production increase of 22.13% was observed from co-digestion of mixture of substrates compared to the sum of BMP that can be obtained from each substrate constituting the mixture. The comparison of results from the syringe method used in this work to determine the CH_4 of the biogas and the results from gas chromatography analyzer shows good accuracy with values of R^2 higher than 0.84. This simple technique can be applied at any case gas chromatography analyzer is not available.

Keywords— Keywords: Biochemical Methane Potential (BMP), biogas, Co-digestion, coefficient of determination R^2, Syringe method.

1 Introduction

According to a study commissioned by the Antananarivo City Development Office included in one of Gevalor's projects [1], the daily amount of household waste to be collected was estimated at 665 tons for the Urban Municipality of Antananarivo in 2005, of which 62% is biodegradable organic waste. The majority of this waste, generally landfilled without control, consists of agricultural waste (vegetable and fruit waste from major markets) but also household and livestock waste. In suburban areas, cow dung is abundant and available for free all year, but it is only used as fertilizer for agriculture [2]. On the other hand, the invasion of water hyacinth clogs the flow into several sewage channels of the city [3]. Apart from the landfilling of these solid wastes, neither treatment nor energy recovery system are yet available to manage them. Pollution of water, air and soil as well as related visual and olfactory nuisances represent health risks for urban dwellers [4–7]. In addition, the higher water content and rapid biodegradability of the abovementioned green wastes result in high leachate production related to their eventual landfilling and other problems associated with their eventual incineration [8].

These solid wastes represent considerable energy resources if they undergo biological treatments such as anaerobic digestion which is not only one of the best ways to treat various types of organic waste, be it liquid or solid waste but also contributes greatly in reducing environmental pollution. Moreover, biogas resulting from anaerobic treatment of biodegradable organic waste can be valorized and used as a source of green energy and can be an alternative source of energy to replace fossil fuel [9–12]. It is worth noting that anaerobic digestion has taken an important place in the research field in recent decades. Anaerobic co-digestion which is the simultaneous digestion of two or more organic wastes in the same reactor became more and more attractive these last decades due to its numerous advantages including, for example, methane production improvement, substrate biodegradability, and stability of the anaerobic digestion process [13,14].

The characteristics of agricultural wastes, in particular fruit and vegetables, having higher content of volatile solid (VS) and lower total solid (TS) value, facilitate their hydrolysis and promote large accumulation of acid within the digester, resulting in the inhibition of the phase methanogenesis [15,16]. Several authors [17–19] recommended the co-digestion of these agricultural wastes with other types of substrates to improve the performance of the anaerobic digestion process.

In this study, we focused on the anaerobic treatment of 10 types of substrates which are widely available in the City of Antananarivo, Madagascar. Thus, the first part of this work concerns the anaerobic treatment of these organic wastes in order to determine their BMPs and the advantages of their co-digestion while the second part consists of the use of a simple, rapid and low-cost technique to determine the CH_4 content of a biogas.

2 Materials and Methods

2.1 Substrates

10 types of waste were used as substrates for the anaerobic treatment in this study: cow dung, carrot, potato, tomato, green cabbage, banana (peel, pulp and whole banana), and water hyacinth (roots and leaves). Before BMP experiments, each substrate was chopped and milled into small particle size using a laboratory mill, then mixed and stored at -20°C before use. Thereafter, the samples were characterized by determin-

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ing their total solids (TS) and volatile solids (VS) concentration respectively at 105°C and at 550°C.

2.2 BMP Test

The BMP Test protocol was based on the adaptation of different methods [20–22]. A known amount of organic matter and inoculum taken from the effluents from a sugar refinery were introduced in a plasma bottle of 500mL of volume. The content of the bottle were then flushed with N2 to remove the oxygen and immediately closed. Once closed, the bottle was placed in an agitator for homogenization of its content under mesophilic condition (35±1°C). Another bottle containing only inoculum and another bottle containing microcrystalline cellulose were also placed with the other bottles to respectively measure the amount of methane that can be produced by endogenous respiration and to allow validation of the gas measurement procedure. Each batch anaerobic test was carried out in triplicate.

The BMP was evaluated by determining the amount of methane that can be produced by each substrate until degradation, usually after 30 days [23]. Gas chromatograph analyzer (Perkin Elmer Clarus 480) and a manometric method using a Mano2000 LEO2 KELLER were respectively used to determine the biogas composition and to measure the amount of biogas produced from each bottle. The pressure data from manometer were subsequently converted to biogas volume according to the ideal gas law:

$$PV = nRT \qquad (1)$$

In which P, V, T and n are respectively the pressure (Pa), the volume (m3), the temperature (K) and the mole number of biogas (mol) while R denotes the constant of the ideal gases (8.3145J/mol.K).

2.3 Anaerobic reactors for Co-digestion

Co-digestion experiments were performed in double-walled glass reactors of 6 L effective volume. Each reactor was kept at mesophilic condition using a thermostat bath. Agitation of each reactor was done using magnetic stirring system and the volume of biogas production from each reactor was measured online by a Milligascounter flow meter MGC-1 V3.1 PMMA which is connected to a computer for data collection.

2.4 Method for estimating the instantaneous amount of produced biogas

Several methods enable to estimate the instantaneous amount of produced biogas during the anaerobic degradation of an organic matter. The simplest model, given by equation (2) and developed by Boshoff [24], was used in this work.

$$y_t = y_m(1 - e^{-kt}) \qquad (2)$$

Where y_t (mL) is the amount of biogas at the time t (d) while ym (mL) represents the total amount of biogas that can be produced and k is the biogas production rate constant (day^{-1}).

Method for estimating the instantaneous amount of produced biogas

2.5 Syringe method for assessing the CH4 content of biogas

A simple and low cost technique which has already been developed by Bassard et al., [25] and is based on the works of Harris, Mittweg et al., Rao and Baral and Raposo et al., [26–29] is used in this study to determine the CH4 content of a biogas. This technique focuses on the reaction of a strong solution of NaOH with biogas CO2. More precisely, it consists in capturing the amount of CO2 of a biogas sample by a solution of 3M NaOH according to the following chemical reaction.

$$CO_2 + 2NaOH \rightarrow Na_2CO_3 + H_2O \qquad (3)$$

500mL of flask, butyl rubber stopper, syringe of 10mL and 3M NaoH solution were used in this technique.

The first step of this technique consists of sampling a biogas from an anaerobic reactor using a syringe of 10mL. The volume of biogas inside the syringe is the noted at the level of its piston. The biogas sample is then injected into the flask containing the NaOH solution and the syringe is removed before vigorously shaking the content of the flask during about 30s to capture the biogas CO2. The syringe is then reconnected by its needle to the flask bottle and the non-CO2 of the biogas pushes the piston of the syringe up. Once again, the level of the piston is noted as it corresponds approximately to the volume of the CH4 of the biogas sample. All the operation was done at ambient temperature.

3 Results and Discussion

3.1 Characteristics and BMP of substrates

The substrates investigated in this work are in general green and vegetable wastes. Solid content (TS (%), VS (%) and TS/VS (%)), average CH_4 content of the biogas, and the BMP (mL.CH_4/g.VS) of each substrate compared to BMPs from other sources are given in Table 1. The average VS/TS for all the 10 substrates in this study is 89.8%. The lowest BMP was that of water hyacinth roots with 108mL.CH_4/g.VS while the highest was observed from the whole banana yielding 399 mL.CH_4/g.VS.

Cow dung is one of the most studied organic matters in terms of anaerobic treatment. Its BMP is widely different from one study to another. Cow dung from literature [30–33] was between 21.7 and 242.7 mL.CH_4 while 172mL.CH_4/g.VS was observed in this study. BMPs respectively were 355, 359, 380, and 325mL.CH_4/g.VS for carrots, tomato, potato and cabbage. These results are quite similar to the average BMP from the other studies as referenced in Table1. From water hyacinth roots and leaves, BMPs respectively were 108 and 240mL.CH_4/g.VS. Results from other previous studies show BMP between 143 to 320mL.CH_4/g.VS (non-separated water hyacinth).

The BMPs for banana pulp, banana peel and whole banana obtained in this study respectively were 322, 340 and 399mL.CH_4/g.VS. Pisutpaisal [34] found a BMP of 77mL.CH_4/g.VS for banana peel while a maximum of 331mL.CH_4/g.VS was observed by Sanjaya [35].

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Table 1. Characteristics of substrates (TS, VS, TS/VS and BMP profile)

Substrate		TS (%)	VS (%)	VS/TS (%)	CH_4 (%)	BMP from this work ($mL.CH_4/g.VS$)	CH_4 yield (mL.CH4/g of raw material)	BMP from literature (mL.CH4/g.VS)	References
Cow dung		15.9	14.5	91.2	66.3	172	24.9	21.7, 150, 51, 242.7	[30], [31], [32], [33]
Carrots		12.6	11.3	89.7	63.2	355	40.1	388, 309, 319	[36], [37], [38]
Tomato		4.7	4.1	87.2	64.3	359	14.7	277, 347, 387	[39], [37], [38]
Potato		19.2	18.9	98.4	63.9	380	71.8	334.5, 267, 390, 322	[33], [40], [36], [38]
Green cabbage		7.9	7.1	89.9	63.7	325	23.1	305, 277, 347, 256.5	[37], [41], [38],[33]
Water hya-cinth	Roots	4.3	3.7	86.0	62.9	108	4.0	267, 190-320, 193-143, 185	[42], [43], [44], [18]
	Leaves	5.5	4.6	83.6	62.6	240	11.0		
Banana	Pulp	21.3	20.5	96.2	60.6	322	66.0	289[a], 268-331[b], 77[b], 361[a], 342[b]	[36], [45], [34], [37], [35]
	Peel	8.5	7.2	84.7	61.9	340	24.5		
	Whole	16.5	15.4	93.3	60.5	399	61.4		

3.2 BMP curves

Biogas production curves can have different shapes depending on the nature and characteristics of the organic substrates. Figure 1 shows ten methane production curves from the anaerobic treatment of the ten substrates in this work during 30, 40 and 45 days of BMP test in monodigestion. The evolution of methane that can be obtained from easily-degradable substrates (respectively banana pulp, whole banana, banana peel, carrot, tomato, green cabbage, water hyacinth leaves and potato) is depicted in Figure 1A, 1B, 1C, 1E, 1F, 1G, 1I and 1J while the others (1D and 1H) depict the methane yield from cow dung and water hyacinth roots which are slowly-degradable substrates. Comparison of the observed result and the model from the equation (2) was made for each data. We can assert from Figure 1 that theoretical curves roughly fit the experimental ones for each BMP test. The difference that is generally observed between these curves mostly during the first twenty days can be explained by the insufficiency of the opted model parameters in equation (2) as well as the lack of knowledge of the constituent fractions of each tested substrate.

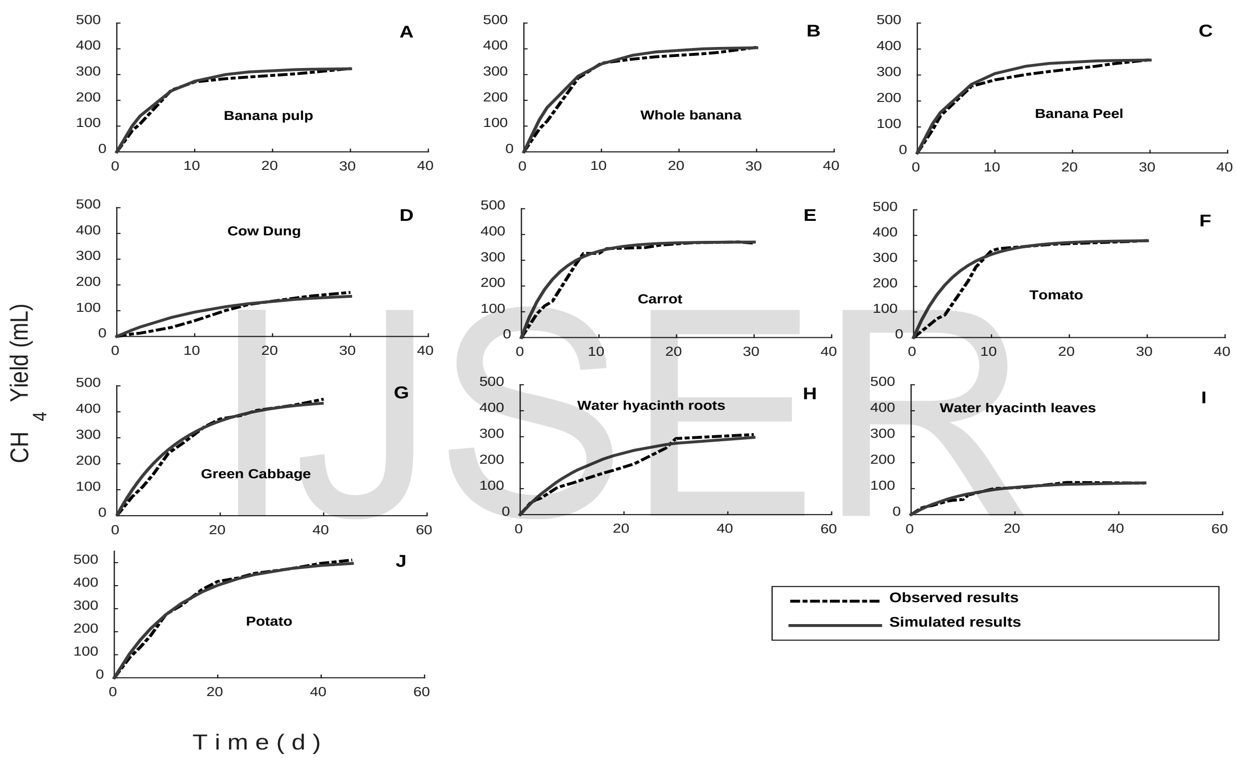

Figure 1. Comparison between experimental and theoretical curves of the cumulative methane volume of some substrates

3.3 Co-digestion of substrates

Characteristics of the substrates mixtures M_j, (j=1,…,5) with their respective proportion ((%) per g.VS/L) are shown in Table 2. Results and comparison of methane potential test observed from co-digestion of cow dung with other co-substrates are shown in Figure 2. Each BMP result obtained from each mixture of substrates was compared to the sum of the BMP (BMP_{sum}) that can be obtained from each substrate constituting it.

$$BMP_{SUM} = \sum_k VS_k BMP_k \,/\, \sum_k VS_k \quad (5)$$

Where BMP_k and VS_k are respectively the BMP and the volatile solid content of the substrate k (k = cow dung, carrot, banana peel, green cabbage, potato, tomato, water hyacinth (roots, leaves))

Table 2. Characteristics of the substrate mixtures

	Substrate mixtures	Concentration (g.VS/L)	Proportion (% per g.VS/L)
M_1	Cow dung, carrot, banana peel, green cabbage, potato, tomato.	1	{16.7:16.7:16.7:16.7:16.7:16.7}
M_2	Cow dung, carrot, banana peel, green cabbage, potato, tomato.	1	{25: 16.7: 16.7: 16.7: 16.7: 8.3}
M_3	Cow dung, carrot, banana peel, green cabbage, potato.	1	{33.3:16.7:16.7:16.7:16.7}
M_4	Cow dung, carrot, water hyacinth roots.	1	{33.3:33.3:33.3}
M_5	Cow dung, water hyacinth leaves, water hyacinth roots, tomato.	0.5	{33.3:16.7:16.7: 33.3}

The results of the co-digestion tests on these 5 mixtures of substrates show the significant role of co-digestion for increasing the amount of produced biogas. Co-digesting cow dung (33.3%) with water hyacinth (leaves, 16.7% and roots 16.7%) and tomato (33.3%) in M_5 allows to get the highest increase of methane production of 22.13% (287mL.CH_4/g.VS) compared to the sum of BMP from each substrate (235mL.CH_4/g.VS) constituting M5 while an increase of 5.66% of methane yield (224 mL.CH_4/g.VS) was observed by treating cow dung and water hyacinth (leaves and roots) at the same proportion of 33.3% (per g.VS added) in M_4.

The increases of methane production when mixing cow dung with other co-substrates in M2 and M3 respectively were 8.67% and 3.82%. The mixture M1 containing the same proportion of cow dung, carrot, banana peel, green cabbage, potato and tomato shows no significant change in methane yield compared to the sum of methane that can be achieved from the sum of the BMPs from each of its substrates.

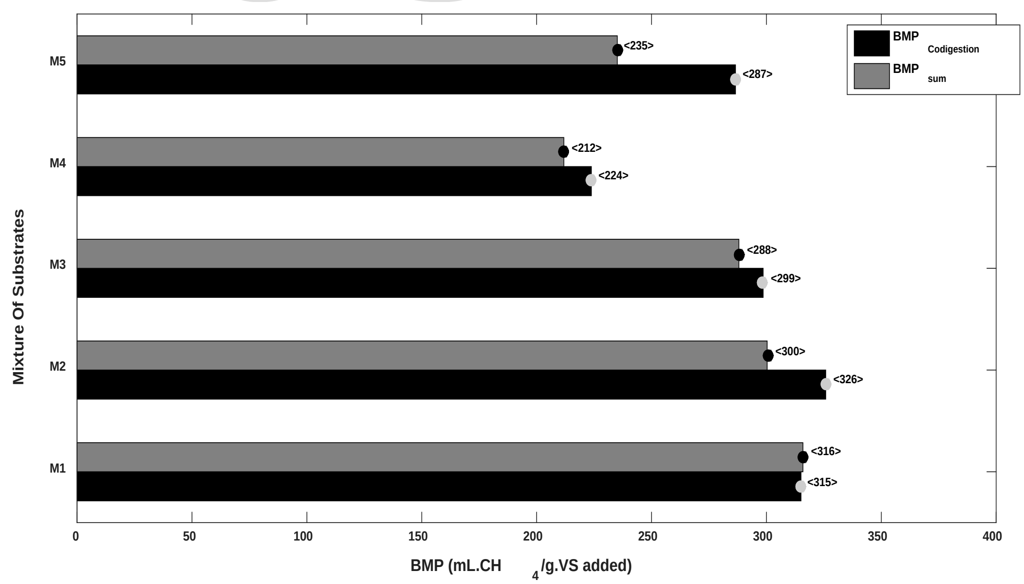

Figure 2. Comparison of the BMP by co-digestion of some substrates and the sum of the BMP of each substrate constituting each mixture M_i

Evolution of the biogas production for the series of co-digestion of multiple substrates is shown in Figure 3 including a comparison with the theoretical biogas production using equation (2). Mixture M_1, M_2, M_3 and M_5 (figure 3A, 3B, 3C and 3E) show good rate of

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biogas production during the first 100 hours of the experiment before reaching an asymptote. At that level, the biogas rate decreases slowly before being negligible at a certain time.
Biogas production, for the M_4 (Figure 3D), however still evolves but the operation stopped before the first 200 hours of experiment due a technical problem. Nevertheless, there is good agreement with both theoretical curves and the observed data for all the 5 co-digestion experiments.

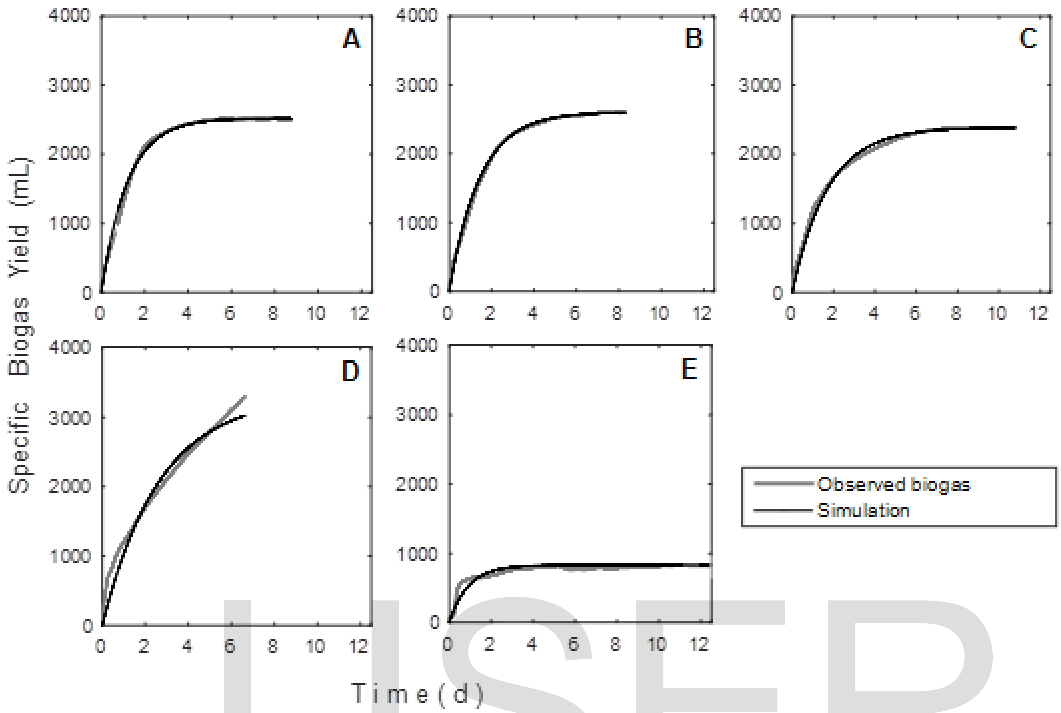

Figure 3. Cumulative produced biogas volume from co-digestion of the considered substrates mixtures (A – M_1, B – M_2, C – M_3, D – M_4 and E – M_5).

3.4 Results of biogas content analysis from syringe method

Anaerobic treatment of organic waste produces biogas consisting mainly of CH_4 and CO_2 with some traces of H2S and other elements. Several devices are available to determine the proportion of these biogas elements. The analysis on a gas chromatograph is the best known and the most used method as it allows obtaining results with very good accuracy. However, it has drawbacks mainly on its high cost and the duration of each analysis of gas sample.
Measurement of methane content of the biogas using this syringe method was carried out on 4 reactors each treating only one substrate and, on a reactor, treating a mixture of substrates. Analysis of each biogas sample using this technique took less than 2 minutes while it took 5 minutes with the gas chromatography analyzer. The results from this method were validated by comparing them with those obtained by chromatographic analysis of the same biogas samples [25]. The results presented in the figure 4 indicate that the method used has acceptable results with values of the coefficient of determination R2 greater than 0.84 for the two sets of data. It is worth noting that the 3M NaOH solution can be used several times up to a certain limit of its neutralization.

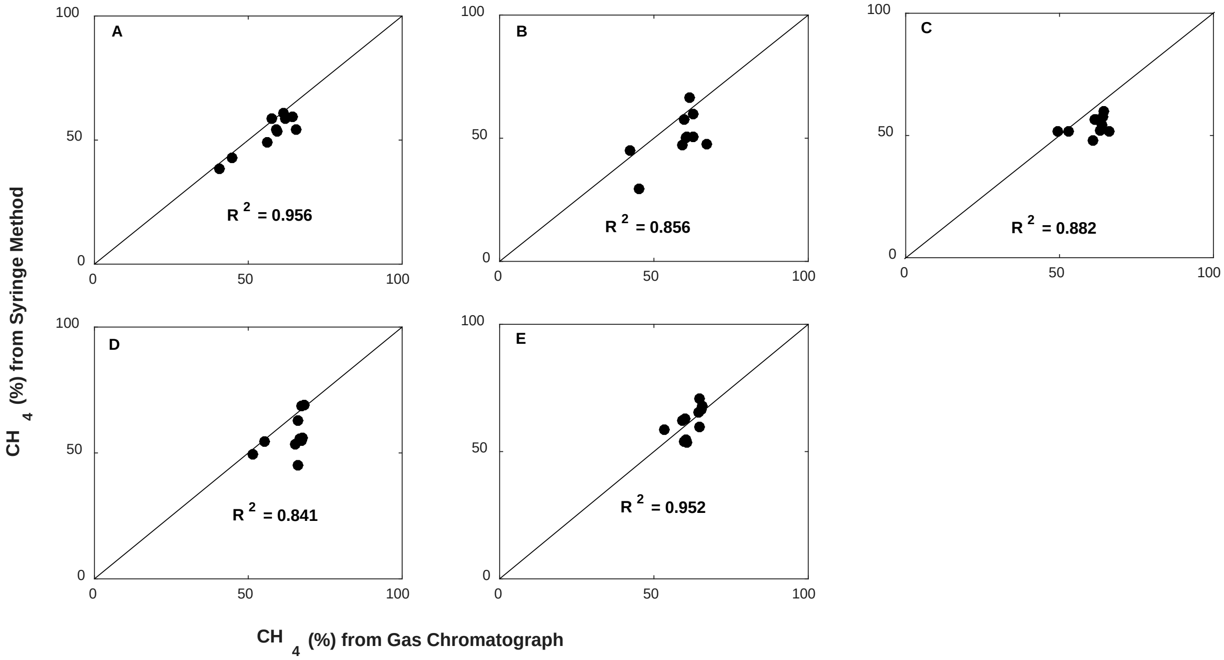

Figure 4. Comparison of the methane content of biogas respectively obtained from the syringe method and gas chromatographic analysis (A – Banana pulp, B – Whole banana, C – Banana Peel, D – Cow dung, E – Co-digestion)

4 Conclusion

The BMP tests are a good way to assess the methane production from the anaerobic treatment of organic wastes. Substrates from this study give good potential in terms of biomethane production being between 107 and 399mL.CH_4/g.VS. The co-digestion of multiple substrates together allows to increase the methane production when compared to the sum of the methane that can be produced from each substrate in single digestion. The syringe method used in this work to discriminate the CO_2 of the biogas show acceptable results with values of R^2 around 0.9. This technique is very helpful and can be used without having a specific tool for biogas analysis.

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References

[1] Gevalor, Identification des opportunités de recyclage et évaluation rapide du secteur de la gestion des déchets solides à Antananarivo (Madagascar), 2012.

[2] Haladová D., Cundr, O. Pecen, J., Selection of Optimal Anaerobic Digestion Technology for Family Sized Farm Use – Case Study of Southwest Madagascar. Agric. Trop. Subtrop. 2011, vol. 44, pp.127–133.

[3] Rajaonahy, M. R., Rakotondramiarana H. T., Rakotoarisoa L. L, Ranarivelo M. N., Experimental Investigation of Anaerobic Co - Digestion of some Organic Wastes in Madagascar. J. Multidiscip. Eng. Sci. Technol. 2016, vol. 3, pp. 3676–3682.

[4] Etsay, H., Meles, K., Hailu, G., Hintsa, K., Determinants for adoption decision of small scale biogas technology by rural households in Tigray , Ethiopia. Energy Econ. 2017, vol. 66, pp. 272–278.

[5] Periou, C., Le Courtois, A., Ymelé, J-P., Dukhan, A., et al., Waste: the challenges facing developing countries, 2012.

[6] Zhang, L., Lee, Y., Jahng, D., Bioresource Technology Anaerobic co-digestion of food waste and piggery wastewater : Focusing on the role of trace elements. Bioresour. Technol. 2011, vol. 102, pp. 5048–5059.

[7] Ganesh, R., Torrijos, M., Sousbie, P., Lugardon, A., et al., Effect of increasing proportions of lignocellulosic cosubstrate on the single-phase and two-phase digestion of readily biodegradable substrate. Biomass and Bioenergy. 2015, vol. 80, pp. 243–251.

[8] Cheng, H., Hu, Y., Improving China's water resources management for better adaptation to climate change. Clim. Change 2011, pp. 253–282.

[9] Murto, M., Mattiasson, B., Björnsson, L., Impact of food industrial waste on anaerobic co-digestion of sewage sludge and pig manure. J. Environ. Manage. 2004, vol. 70, pp. 101–107.

[10] Pain, F., Phillips, R., West, R., Mesophilic Anaerobic Digestion of Dairy Cow Slurry on a Farm Scale: Energy Considerations. J. Agric. Eng. Res. 1988, vol. 39, pp. 123–135.

[11] Sims, R. E. H., Richards, K. M., Anaerobic digestion of crops and farm wastes in the United Kingdom. Agric. Ecosyst. Environ. 1990, vol. 30, pp. 89–95.

[12] Yen, H-W., Brune, D. E., Anaerobic co-digestion of algal sludge and waste paper to produce methane Bioresour. Technol. 2007, vol. 98, pp. 130–134.

[13] Mshandete, A. M., Parawira, W., Biogas technology research in se-

lected sub-Saharan African countries – A review. African J. Biotechnol. 2009, vol. 8, pp. 116–125.
[14] Sol, M., Lansing, S., Characterizing food waste substrates for co-digestion through biochemical methane potential (BMP) experiments. Waste Manag. 2013, vol. 33, pp. 2664–2669.
[15] Jiang, Y., Heaven, S., Banks, C. J., Strategies for stable anaerobic digestion of vegetable waste. Renew. Energy. 2012, vol. 44, pp. 206–214.
[16] Ward, A. J., Hobbs, P. J., Holliman, P. J., Jones, D. L., Optimisation of the anaerobic digestion of agricultural resources. Bioresour. Technol. 2008, vol. 99, pp. 7928–7940.
[17] Bouallagui, H., Lahdheb, H., Ben Romdan, E., Rachdi, B. Hamdi, M., Improvement of fruit and vegetable waste anaerobic digestion performance and stability with co-substrates addition. J. Environ. Manage. 2009, vol. 90, pp. 1844–1849.
[18] Patil, J. H., Antonyraj, M. A. L., Shankar B., Kumar, M., Anaerobic Co-Digestion of Water Hyacinth and Sheep Waste. Energy Procedia. 2014, vol. 52, pp. 572–578.
[19] Capson-Tojo, G., Rouez, M., Crest, M., Steyer, J-P., et al., Food waste valorization via anaerobic processes : a review Rev Env. Sci Biotechnol. 2016.
[20] Angelidaki, I. Sanders, W., Assesment of the anaerobic biodegradabilty of macropollutants. Rev. Environ. Sci. Biotechnol. 2004, vol. 3, pp. 117–129.
[21] Owen, W. F., Stuckey, D. C., Healy, J. B., Young, L. Y., McCarty, P. L., Bioassay for monitoring biochemical methane potential and anaerobic toxicity. Water Res. 1979, vol. 13, pp. 485–492.
[22] Holliger, C., Alves, M., Andrade, D., Angelidaki, I., et al., Towards a standardization of biomethane potential tests Czech Republic. Water Sci. Technol. 2016, pp. 2515–2522.
[23] Esposito, G., Frunzo, L., Liotta, F., Panico, A., Pirozzi, F., Bio-Methane Potential Tests To Measure The Biogas Production From The Digestion and Co-Digestion of Complex Organic Substrates. Open Environ. Eng. J. 2012, vol. 5, pp. 1–8.
[24] Boshoff., Methane gas production by batch and continuous fermentation methods. Trop. Sci. 1963, vol. 5, pp. 155–165.
[25] Bassard, D., André, L., Valentin, L., Pauss, A., Ribeiro, T., A simple and rapid one-time method to evaluate the non-acidic gas content from bioprocesses. Bioprocess Biosyst. Eng. 2016, vol. 37, pp. 337–341.
[26] Harris, P., Carbon dioxide content of biogas by syringe protocol. University of Adelaide, 2013.
[27] Mittweg, G., Oechsner, H., Reinhardt-hanisch, A., Repeatability of a laboratory batch method to determine the specific biogas and methane yields. Eng. Life Sci. 2012, vol. 12, pp. 270–278.
[28] Rao, P. V., Baral, S. S., Experimental design of mixture for the anaerobic co-digestion of sewage sludge. Chem. Eng. J. 2011, vol. 172, pp. 977–986.
[29] Raposo, F., Rubia, M. A., Borja, R., Anaerobic digestion of solid organic substrates in batch mode : An overview relating to methane yields and experimental procedures. Renew. Sustain. Energy Rev. 2011, vol. 16, pp. 861–877.
[30] Van-Sice, K., Bourassa, G., Miller, K., Biological Methane Potential Test Methods Development for The Evergreen State College 2017, pp. 1–10.
[31] Shehu, B., Umar, I., Nasir, I., Anaerobic Digestion of Cow Dung for Biogas Production. ARPN J. Eng. Appl. Sci. 2012, vol. 7, pp. 169–172.
[32] Yeqing, L., Zhang, R., Liu, G., Chen, C., et al., Comparison of methane production potential , biodegradability , and kinetics of different organic substrates. Bioresour. Technol. 2013, vol. 149, pp. 565–569.
[33] Labatut, R. A., Angenent, L. T., Scott, N. R., Biochemical methane potential and biodegradability of complex organic substrates. Bioresour. Technol. 2011, vol. 102, pp. 2255–2264.
[34] Pisutpaisal, N., Boonyawanich, S., Saowaluck, H., Feasibility of Biomethane Production from Banana Peel Energy Procedia 2014, vol. 50, pp. 782–788.
[35] Sanjaya, A. P., Cahyanto, M. N., Millati, R., Mesophilic batch anaerobic digestion from fruit fragments. Renew. Energy 2016, vol. 98, pp. 135–141.
[36] Buffiere, P., Loisel, D., Bernet, N., Delgenes, J., Towards new indicators for the prediction of solid waste anaerobic digestion properties. Water Sci. Technol. 2006, vol. 53, pp. 233–241.
[37] Kouas, M., Torrijos, M., Sousbie, P., Steyer, J., Sayadi, S., Robust assessment of both biochemical methane potential and degradation kinetics of solid residues in successive batches. Waste Manag. 2017, pp. 1–12.
[38] García-gen, S., Sousbie, P., Rangaraj, G., Lema, J. M., et al., Kinetic modelling of anaerobic hydrolysis of solid wastes , including disintegration processes. Waste Manag. 2015, vol. 35, pp. 96–104.
[39] Ferrer, P., Cambra-lópez, M., Cerisuelo, A., Peñaranda, D. S., Moset, V., The use of agricultural substrates to improve methane yield in anaerobic co-digestion with pig slurry : Effect of substrate type and inclusion level. Waste Manag. 2014, vol. 34, pp. 196–203.
[40] Gunaseelan, V. N., Biochemical methane potential of fruits and vegetable solid waste feedstocks. Biomass and Bioenergy 2004, vol. 26, pp. 389–399.
[41] Cho, J. K., Park, S. C., Chang, H. N., Biochemical methane potential and solid state anaerobic digestion of Korean food wastes. Bioresour. Technol. 1995, pp. 245–253.
[42] O'Sullivan, C., Rounsefell, B., Grinham, A., Clarke, W., Udy, J., Anaerobic digestion of harvested aquatic weeds: Water hyacinth (Eichhornia crassipes), cabomba (Cabomba Caroliniana) and salvinia (Salvinia molesta). Ecol. Eng. 2010, vol. 36, pp. 1459–1468.
[43] Chynoweth, D., Turick, C., Owens, J., Jerger, D. E., Peck, M., Biochemical Methane Potential of Biomass and Waste Feedstocks. Biomass and Bioenergy 1993, vol. 5, pp. 95–111.
[44] Barua, B. V., Kalamdhad, A. S., Biochemical methane potential test of untreated and hot air oven pretreated water hyacinth : A comparative study. J. Clean. Prod. 2017, vol. 166, pp. 273–284.
[45] Jesuyemi, M., Charnnok, B., Saritpongteeraka, K., Chaiprapat, S., Effects of size and thermophilic pre-hydrolysis of banana peel during anaerobic digestion, and biomethanation potential of key tropical fruit wastes. Waste Manag. 2017, vol. 68, pp. 128–138.