Studii şi Cercetări Ştiinţifice
Chimie şi Inginerie Chimică, Biotehnologii, Industrie Alimentară

2017, **18** (2), pp. 213 – 224

Scientific Study & Research
Chemistry & Chemical Engineering, Biotechnology, Food Industry

ISSN 1582-540X

ORIGINAL RESEARCH PAPER

OPTIMIZATION OF BIOGAS PRODUCTION FROM ORGANIC FRACTION OF MUNICIPAL SOLID WASTE: EXPERIMENTAL TEST USING LIQUID FROM WASTE FERMENTATION

Mahamadi Nikiema[1,2], Narcis Barsan[2*], Marius K. Somda[1], Desiré Traore[1], Dayéri Dianou[3], Valentin Nedeff[2], Alfred S. Traore[1]

[1]Universté Ouaga I, Pr Joseph KI-ZERBO, Centre de Recherche en Sciences Biologiques Alimentaires et Nutritionnelles (CRSBAN), 03 BP 7131 Ouagadougou 03, Burkina Faso
[2]"Vasile Alecsandri" University of Bacau, Department of Environmental Engineering and Mechanical Engineering, 157, Calea Marasesti, 600115, Bacau, Romania
[3]Centre National de la Recherche Scientifique et Technologique (CNRST), 03 BP 7192 Ouagadougou 03, Burkina Faso

*Corresponding author: narcis.barsan@ub.ro

Received: May, 29, 2017
Accepted: June, 28, 2017

Abstract: The present study aimed to produce biogas using liquid from OFMSW fermentation. In this study the physic-chemical parameters of liquid from OFMSW were determined. Anaerobic digestion using liquid from OFMSW and 2 % (w/v) of OFMSW as substrate load was carried out both in batch anaerobic digesters during 25 days. The *p*H, ammonium nitrogen and gas (CO_2, CH_4 and H_2S) were followed during anaerobic digestion. The concentration of ammonium nitrogen ranged respectively 3 g NH_4-N·L^{-1} to 6 g NH_4-N·L^{-1} and 5 g NH_4-N·L^{-1} to 9 g NH_4-N·L^{-1} in anaerobic digestion from liquid from OFMSW and 2 % of OFMSW. This technology has permit to obtain good quality of biogas (57 % CH_4, 3 % CO_2 and 20 ppm H_2S) in a short time of 20 days.

Keywords: *anaerobic digestion, biogas, liquid from OFMSW, Municipal Solid Waste*

INTRODUCTION

The world knows today an increase in municipal solid waste (MSW) generation with ever-increasing populations. According to Amoo and Fagbenle [1], as of 2011 the world generates estimated 2 billion tons of municipal solid wastes each year. Almost 54 % of the US's annual production of about 243 million tons [2] is still landfilled. Similarly in 2008, Canadians produced 34 million tons of MSW of which 76 % was disposed in landfills [3]. In Burkina Faso, precisely in Ouagadougou solid waste production is estimated at 300 000 tons per year since 2012 by sustainable development department. Only 50 % of waste is collected and disposed directly to the landfill. None evacuated waste pile up on vacant lots or in uncontrolled landfills. As a direct result of environmental pollution and degradation of living conditions (including health) populations (microbial contamination, infestation of the atmospheric air by noxious odors, etc.). This form of management is not sustainable and leads to production of leachate and uncontrolled greenhouse gas emissions. So, energy issue in Burkina Faso is of great concern and hinders its development. The government has taken steps to diversify the energy mix and put the emphasis on renewable. The organic fraction of municipal solid waste (OFMSW) is a large and renewable potential energy source that can be exploited on a sustained basis if treated under controlled conditions to reduce the environmental impact and recover energy; this is demonstrated by many studies [4 – 7]. Anaerobic digestion is a most cost-effective bioconversion technology that has been implemented worldwide for commercial production of electricity, heat, and compressed natural gas from organic materials [8, 9]. Anaerobic digestion is a biological process wherein diverse group of microorganism convert the complex organic matter into a simple and stable end products in the absence of oxygen [10].

This processes participle strongly on the other hand in the management of waste for bioconversion of different high-strength biowaste, such as municipal primary and secondary sludge, organic portion of kitchen waste, pulp and paper sludge, agricultural off farm and on-farm residues including animal manure into methane-rich biogas [11 – 13]. Anaerobic digestion is all biochemical reactions that involve several phases [14, 15]. The first phase, hydrolysis and acidogenic are ensured by hydrolytic bacteria. These bacteria convert the complex organic matter (lipids, cellulose, starch, protein...) into simpler compounds, volatile fatty acids (AVG) (acetic acid, propionic acid, butyric acid ...) and alcohols (methanol, ethanol ...). In this phase there is also the production of hydrogen (H_2) and carbon dioxide (CO_2) from the reduction of lipids and proteins. During the second phase (acidogenesis), the products are converted into acetate (CH_3COO-) and hydrogen (H_2). During the third phase, methanogenic bacteria hydrogenophiles reduce CO_2 to methane (CH_4) using hydrogen and acetoclastes methanogenic bacteria convert acetate to CH_4. These phases are a series of interlinked reactions proceeding spatially as well as temporally in consecutive and parallel steps and hence, influence one another [16]. According to several author, hydrolysis is the limiting step of anaerobic digestion process [14, 15]. When methanogenesis is not rapid enough due to some upset, volatile fatty acids (VFA) accumulate, which may lead to a decrease in *p*H and a cessation of the methane production. Returning to normal operating conditions can be costly a time-consuming. Remedy actions include reducing the organic loading rate to the point where the VFA production rate is less than their maximum consumption rate. This which allow for consumption of the excesses VFA

and a return of neutral *p*H until stable conditions occur again. If this measure is not sufficient, decrease in loading must be coupled with the addition of appropriate chemicals for *p*H correction [17, 18].
Many optimization techniques have been developed in recent years to minimize acidification during the methanization and increase biogas production. It's the case of alkali pretreatment process prior to anaerobic digestion [19], recirculation leachate in batch mode solid-state anaerobic digestion [20]. Other studies realize separation of hydrolysis phase; it is a pretreatment before anaerobic digestion step [9 – 21]. Physical and chemical pretreatments of waste are expensive because demand a lot of energy. Also according to Bisaria and Ghose [22] thermo-chemical treatment or physico-chemical properties of plant polymers generate hydroxymethylfurfural and furfural compounds which are highly toxic to microorganisms.
Biological pretreatment includes both anaerobic and aerobic methods, as well as the addition of specific enzymes such as peptidase, carbohydrolase and lipase to the anaerobic digestion system [23]. Carrère *et al.* [24] and Ge *et al.* [25] considered the hydrolytic-acidogenic step (first step) of a two-phase anaerobic digestion process as a biological pretreatment method. This treatment can result in a higher methane production [26]. Others studies consider it as a process configuration of anaerobic digestion, but not a pretreatment method [27, 28].
The objective of this study is to provide a waste by anaerobic digestion processing technology, using liquid from OFMSW fermentation.

MATERIALS AND METHODS

Sampling and preparation for experiment

Sampling of municipal solid waste was carried out in three (3) centers pre-collects of Ouagadougou's town. Each tank three trash (3) repetitions were performed. The first center is located in the district 2 (North latitude: 12° 22'; West longitude: 1° 32' and altitude: 335 m), the 2nd in the district 12 (North latitude: 12° 19', West longitude: 1° 31' and altitude: 349 m), and the third center in the district 3 (North latitude: 12° 23'; west longitude: 1° 32' and altitude: 326 m). Waste sampled were mixed, sorted and dried in the sun for 7 days, then crushed and sieved (size ≤ 1 mm).

Determination of physical chemical parameters of wastes

The *p*H, acidity, conductivity and salinity were measured using a WTW's digital multi-parameter system (inoLab Multi 9420 IDS, Germany). Dry matter (DM) was determined according to standardized method AFNOR NF U 44-171 of October 1982. 5 g of quantity of sample was placed in the oven (POL-EKO-APARATURA, Pologne) at 105 ± 2 °C until constant weight, approximately 24 hours. Mineral matter or total was determined using TAPPI T 211 CM-86 norm [29]. 1 g of waste powder was introduced into a crucible (Nabertherm GmbH, Germany) and placed in the oven at 575 °C for 3 h. The organic matter content in a sample was obtained by the difference between dry matter and total ash (mineral matter). Klason method according to Tappi Standard 222 [30] was used to determine lignin tenor. Lignin tenor was performed with

0.1 g of OFMSW in 1.5 mL of 72 % H_2SO_4 in a 50 mL polypropylene centrifuge tube and let to act for 2 h at 20 °C. The mixture was diluted with 56.2 mL of distilled water and filtered under vacuum using the previously weighed crucible, washing with distilled water and drying in a ventilated oven. Calorific value of municipal solid organic waste sample was determined using the e2k bomb calorimeter systems combustion calorimeter manufactured by Digital Data Systems (Pty) Ltd (Brownstone Asia) device.

Anaerobic digestion

Inoculums preparation and liquid from OFMSW

Cow dung was used as inoculums after enrichment. The medium component was NH_4Cl 2 $g \cdot L^{-1}$, K_2HPO_4 2 $g \cdot L^{-1}$, NaCl 13 $g \cdot L^{-1}$, $CaCl_2$, $6H_2O$ 0.17 $g \cdot L^{-1}$, $FeCl_3$ 0.1 $g \cdot L^{-1}$, $CuSO_4$, $5H_2O$ 0.1 $g \cdot L^{-1}$, acetic acid 1.5 $g \cdot L^{-1}$, sodium acetate 5 $g \cdot L^{-1}$, peptone 1 $g \cdot L^{-1}$. The *p*H was adjusted at 7 ± 0.2 with NaOH 2N. Enrichment was performed during 6 days.

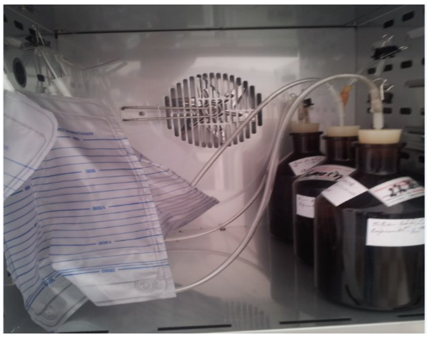
The prefermentation step of waste powder was conducted in a 20 L vessel for 10 days. The substrate concentration (waste powder) was 15 % (w/v) in a reaction medium of composition: 2 g K_2HPO_4 and 2 g NH_4Cl to 1000 mL. At the end of fermentation, the reaction phase was filtered in order to obtain the liquid.

Anaerobic batch test

Batch test were conducted in glass bottles as anaerobic digester (capacity 1000 mL). The experimental design used Angelidaki method [31] and was showed in Figure 1. In digester N°1, 500 mL of liquid from OFMSW was used as substrate with inoculums 10% (v/v). In digester N°2 (2 % (m/v) of OFMSW), OFMSW was taken as 10 g in 500 mL of phosphate buffer (2 g K_2HPO_4 and 2 g NH_4Cl in 1000 mL distilled water) and 50 mL of inoculums (10 % (v/v)). Digester N°3 was used as control (without substrate). It was composed only by 500 mL phosphate buffer and 10 % (v/v) of inoculums.

The biogas volume from the reactors was collected in bag and quantified. Digesters were incubated at 37 °C.

a)



b)

Figure 1. *Pictures of reactors setup: (a) view; (b) incubation at 37 °C*

Chemicals products were provided by S.C. Chim Reactiv, S.R.L (Romania).

Monitoring anaerobic digestion

The ammonia content (NH_4-N) was analyzed by Spectroquant® photometer NOVA 60 from Merck Millipore (United States) following the instrument's protocol. The gas composition was analyzed using Biogas 5000 from Geotech (France).

RESULTS AND DISCUSSION

Physico-chemical characteristics of OFMSW sample

Characteristic of OFMSW is shown in Table 1. Characteristic present 92.79 % of Total solid, 80.10 % of Total volatile solid, 29.21 % of lignin, 17.11 % of ash and C/N rapport 31.65. The very high Total solid is due to pretreatment of waste, sorting, drying and reduced sizes. Total volatile solid (80.10 %) was values similar to those previously reported [32, 33].

The high proportion of lignin in the sample (29.21 %) is due to presence of rich waste that matter like grass debris, leaves and branches. According to Eleazer *et al.* [34], these components of the waste have high lignin 5 to 43.8 %. Lignocellulosic biomass has complexity and variability chemical structures; this substrate is resist to biodegradation. The off for outers as Hendriks and Zeeman [35], Zheng *et al.* [9] report necessity to pretreated recalcitrant lignocellulosic biomass before anaerobic digestion process. According to Zhou *et al.* [21] our sample can be classified in food residue samples, wood waste samples and rubber. In this group, ash content varies from 7 % to 19 %; volatile mater varies from 63 % to 74 %; the fixed carbon content varies from 15 % to 26 % and heating value locates between 20 and 25 $MJ \cdot kg^{-1}$. The C/N ratio of the sample 31.65 is favorable for biodegradation because it is very proximate to the optimum between 25 and 30 [36, 37]. These chemical profiles make samples good candidates for methanization.

Table 1. *Physico-chemical characteristics of OFMSW*

Composition	Average
Total solid (TS) [%]	92.79 ± 0.09
Total volatile solid [% TS]	80.10 ± 0.32
Total ash [% TS]	17.11 ± 0,30
Combustible [% TS]	46.57 ± 0.32
Lignin [% TS]	29.21 ± 0.03
CV [$MJ \cdot kg^{-1}$]	17.48 – 11.49
C/N	31.65 ± 0.05

Physico-chemical characteristics of extract juice

Table 2 shows the physico-chemical characteristics of liquid from OFMSW was compared to organic fraction of MSW, waste dairy and Juice apples fermented used for anaerobic digestion. Liquid extract from OFMSW present respectively 5.21, 4.90 $g \cdot L^{-1}$, 8.70 $mS \cdot cm^{-1}$, 8.69 $g \cdot L^{-1}$ and 5.36 $g \cdot L^{-1}$ for *p*H, salinity, conductivity, Total Dissolved Solutes (TDS) and ammonium concentration (NH_4-N). The main of these parameters were higher than value found by El-Chakhtoura *et al.* [38] and Quezada [39] for

OFMSW, waste dairy and apples fermented juice. Moletta [13] conducted tests on anaerobic digestion of marine microalgae, obtained highest yield of CH_4 with 15 $g \cdot L^{-1}$ of salinity. The increase of salinity is implied in decrease of CH_4 yield. Chen *et al.* [40] showed that salinity 15 $g \cdot L^{-1}$ corresponding to concentration of 4.6 $g \cdot L^{-1}$ of NaCl which was lower to toxic concentration recommended. According to Soto *et al.* [41] sodium was more toxic than propionic acid and acetic acid coming of volatile fatty acid deterioration during bacteria metabolism. The extract juice which constitutes substrate in this study had lower salinity values to 15 $g \cdot L^{-1}$ suitable for anaerobic digestion. Zeng *et al.* [42] found similar TDS values 6.80 $g \cdot L^{-1}$ but a high conductivity of 13.61 $mS \cdot cm^{-1}$ during anaerobic digestion of animal dung. Graterol [43] found conductivity and TDS values respectively of 2.58 at 4.28 $mS \cdot cm^{-1}$ and 16.13 at 26.75 $g \cdot L^{-1}$ in anaerobic digestion of industrial wastewater.

***Table 2**. Physico-chemical characteristics of liquid from OFMSW*

Parameters	Average
*p*H	5.21 ± 0.00
Salinity [$g \cdot L^{-1}$]	4.90 ± 0.00
Conductivity [$mS \cdot cm^{-1}$]	8.70 ± 0.05
Total dissolved solutes [$g \cdot L^{-1}$]	8.69 ± 0.04

Monitoring of *p*H and NH_4-N during anaerobic digestion

Figure 2 shows the change in *p*H over time depending on the type of treatment. The *p*H was adjusted for all the reactors close to the neutral *p*H by adding 2N NaOH to the feeding solution during the incubation. Only the digester N°3 (control) did not show a significant change in *p*H. This can be explained by the absence of substrate in medium. Milaiti *et al.* [44] and Nikiema *et al.* [18] showed weak acidification with 2 % load substrate. Liquid extract from OFMSW has the same characteristic with 2 % load substrate; the *p*H is stabilized at 10th day of process. Bacteria deteriorate gradually organic macromolecules and free organic acid in the medium.

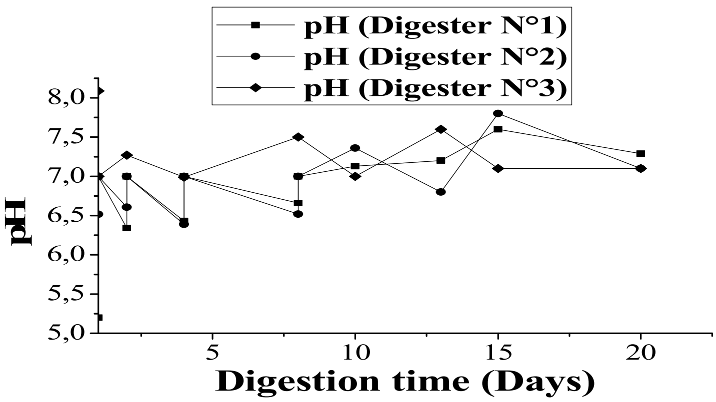


***Figure 2.** pH variation during anaerobic digestion*

Ammonium nitrogen is essential to microbial metabolisms and is used by the bacteria for growth. The excess of ammoniacal nitrogen, not used by the microorganisms remains in the form of a mixture of ammonia (NH_3) and ammonium (NH_4^+) in acid-base balance according *p*H-dependent and temperature. An optimal ammonia concentration ensures sufficient buffering capacity in the anaerobic digestion system thus increasing the stability of process, while high ammonia is reported as a strong inhibitor of biogas production [40, 45]. In this study, the concentration of ammonium nitrogen range from respectively 3 g NH_4-N·L^{-1} - 6 g NH_4-N·L^{-1} and 5 g NH_4-N·L^{-1} - 9 g NH_4-N·L^{-1} in digester N°1 and digester N°2 (Figure 3). Chen *et al.* [40] reported that the inhibiting concentration of total ammonia nitrogen (TAN) which decrease methane yield at 50 % was ranged from 1.7 to 14 g·L^{-1}. Our values were correlated to this range. Some off for have mentioned tan anaerobic digester operated with best yield even concentrations of NH_4^+-N ranged from 6 to 8 g NH_4^+-N·L^{-1} [46].

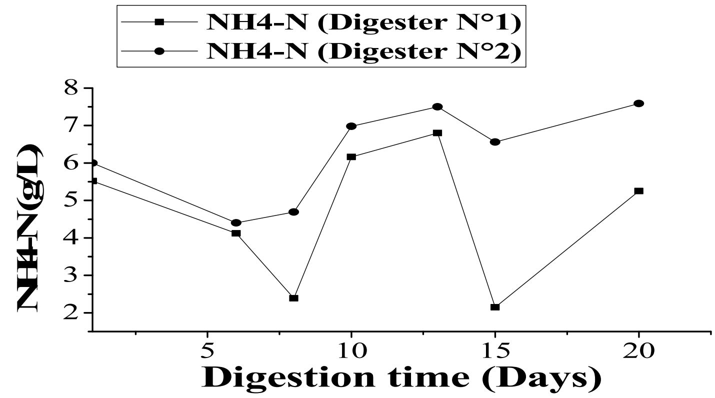


Figure 3. *NH_4-N variations during anaerobic digestion*

Evolution of biogas during anaerobic digestion

The preparations and waste pretreatment aim to change the waste and improve the parameters of degradation, so the quality of biogas and biomethane yield will be positively impacted. The concentrations of hydrogen sulfide of different types of treatment are shown in Figure 4.

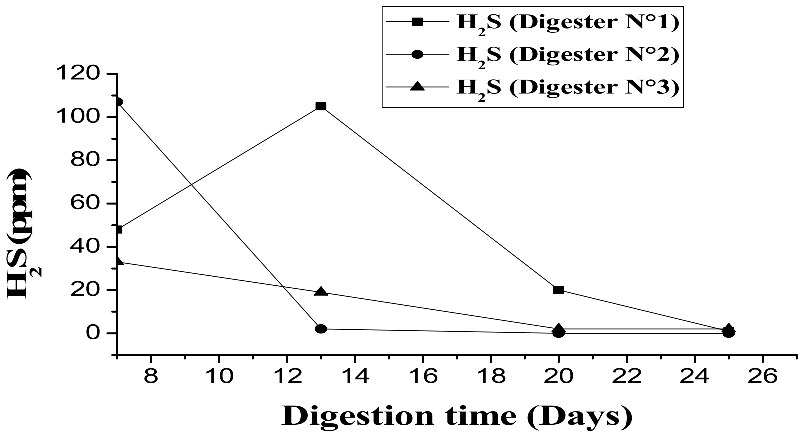


Figure 4. *Evolution of H_2S during anaerobic digestion*

The aerobic pre-treatment has an impact on the production of H_2S. The H_2S concentration increases from 48 ppm to 120 ppm before decreasing the 20th day to 20 ppm in digester N°1. In digester N°2, the level of H_2S was downed 107 to 2 ppm and completely reduced at a 20th day.

Briand and Morand [47] mentioned that a level of H_2S measured in the biogas produced during anaerobic digestion was about 10.000 – 20.000 ppm. Among the undesirable substances present in the biogas, hydrogen sulfide is the most problematic element because of its toxicity and corrosively action on the equipment. Also its combustion leads to the production of sulfur dioxide [48]. The concentrations of H_2S obtained in our study are below to the maximum concentration of H_2S specified by co-generator manufacturers which is around 150 mg·m^{-3} (equivalent to 100 ppm) [49].

The evolution of CH_4 and CO_2 from different types of treatment was showed in Figure 5. According to Burke [50] dairy waste biogas will typically be composed of 55 to 65 % methane and 35 to 45 % carbon dioxide. The monitoring of biogas production was carried out during 25 days. Extract juice gave a maximum of 57 % CH_4 at the 20th day (Figure 5). The fall in production of CH_4 in the case of extract juice is due to substrate depletion in the medium at the 25 days.

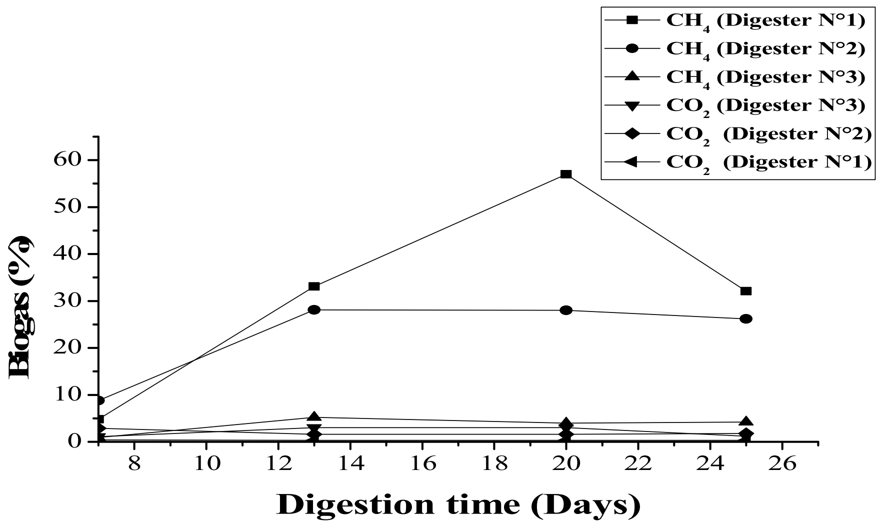


Figure 5. *Evolution of biogas (CH4, CO2) during anaerobic digestion*

After fermentation, there is a production of organic compounds which are been used during the first 20 days of anaerobic digestion. Parawira *et al.* [51] reported that hydrolysis stage could stimulate the acidogenic microorganisms to produce more specific enzymes, thus resulting in more extended degradation of substrates. At level of 2 % (m/v) of solid waste, production of CH_4 reached 28 % at 20th day and became constant (Figure 5). This can be explained by the fact that the solid substrate in the batch system is continually degraded by microorganisms and used over time. Production of methane in the 20th day in digester N°1, 2 and 3 was showed in Table 3. Analysis Of Variance (ANOVA) at probability level of 0.05 and the Student Newman-Keuls (SNK) tests using the Statistical Analysis System (SAS, Version8.1) software show very highly significant different ($p < 0.0001$) with CH_4 production in digester N°1 (Liquid from OFMSW), digester N°2 (2 % of waste) and digester N°3 (Control).

Table 3. *Methane production in the 20th day*

Digesters	CH_4 [%]	*p*
Digester N°1	57	< 0.0001
Digester N°2	28	
Digester N°3	5,2	

Another observation made was the low production of CO_2 (1 to 3 %). This low level of CO_2 content in the biogas could be explained by a long period of aerobic prefermentation (10 days). According to Dictor *et al.* [52], at the first 20 days of biogas production, the gas was composed of 5 - 6 % CH_4, 72 % CO_2 and 10 % H_2S. They added that methanogens phase takes place after 36th days. Also CH_4 and CO_2 production was stabilized with proportions respectively between 56 - 75 % and 32 - 42 %. During the 20 days of production using liquid from OFMSW the proportion of CH_4 and CO_2 were range respectively 57 % and 3 %. Wang *et al.* [53] showed that the time from 0 to 20 days is a period of adaptation of microorganisms to the substrate, after that, the stabilization happen at 21 days. Our experiment with liquid from OFMSW fermentation has presented a short time of adaptation.

CONCLUSIONS

The results showed that liquid from OFMSW fermentation can be anaerobically treated well and could be a good potential source for biogas production. The physico-chemical characteristics of substrate showed that it could be compared to animal dung, industrial wastewater, fermented juice apples and dairy waste concerning its utilization for anaerobic digestion. Good quality of biogas (57 % CH_4, 3 % CO_2 and 20 ppm H_2S) has been obtained in a relatively short time of 20 days. It is preferable to perform this type of treatment to avoid overloads that would create shutdown process as a result of acidification. Also this technology could help treat high quantity of municipal organic waste.

ACKNOWLEDGEMENTS

This work was supported in 2016 by a research grant from Francophone University Agency (Agence Universitaire de la Francophonie - AUF), scholarship program "Eugen Ionescu" of Romanian Government. The authors would like to express their appreciation to "Vasile Alecsandri" University of Bacau (Romania), Department of Environmental Engineering and Mechanical Engineering.

REFERENCES

1. Amoo, O.M., Fagbenle, R.L.: Renewable municipal solid waste pathways for energy generation and sustainable development in the Nigerian context, *International Journal of Energy and Environnemental Engineering*, **2013**, 4, 42-59;

2. USEPA: *Municipal Solid Waste Generation, Recycling and Disposal in the United States: Facts and Figs*, **2009**, https://www.epa.gov/smm/advancing-sustainable-materials-management-facts-and-figures;
3. Statistics Canada: *Waste Management Industry Survey: Business and Government Sectors, Statistics Canada, Environment Accounts and Statistics Division, Environmental Protection Accounts and Surveys*, **2008**, 23;
4. Cooper, C.D., Kim, B., MacDonald, J.: Estimating the lower heating values of hazardous and solid wastes, *Journal of the Air and Waste Management Association*, **1999**, **49** (4), 471-476;
5. Menikpura, S.N.M., Basnayake, B.F.A.: New applications of 'Hess Law' and comparisons with models for determining calorific values of municipal solid wastes in the Sri Lankan context, *Renewable Energy*, **2009**, **34**, 1587-1594;
6. Shahriari, H., Warith, M., Hamoda, M., Kennedy, KJ.: Anaerobic digestion of organic fraction of municipal solid waste combining two pretreatment modalities, high temperature microwave and hydrogen peroxide, *Waste Management*, **2012**, **32**, 41-52;
7. Tang, J.P., Lam, H.L., Aziz, M.K.A., Morad, N.A.: Enhanced biomass characteristics index in palm biomass calorific value estimation, *Applied Thermal Engineering*, **2016**, **105** (25), 941-949;
8. Demirel, B., Scherer, P.: Production of methane from sugar beet silage without manure addition by a single-stage anaerobic digestion process, *Biomass and Bioenergy*, **2008**, **32** (3), 203-209;
9. Zheng, Y., Zhao, J., Xu, F., Li, Y.: Pretreatment of lignocellulosic biomass for enhanced biogas production, *Progress in Energy and Combustion Science*, **2014**, **42**, 35-53;
10. Koupaie, E.H., Leiva, M.B., Eskicioglu, C., Dutil, C.: Mesophilic batch anaerobic co-digestion of fruit-juice industrial waste and municipal waste sludge: Process and cost-benefit analysis, *Bioresource Technology*, **2014**, **152**, 66-73;
11. Li, Y., Park, S.Y., Zhu, J.: Solid-state anaerobic digestion for methane production from organic waste, *Renewable and Sustainable Energy Reviews*, **2011**, **15** (1), 821-826;
12. Lin, Y., Wang, D., Wu, S., Wang, C.: Alkali pretreatment enhances biogas production in the anaerobic digestion of pulp and paper sludge, *Journal of Hazardous Materials*, **2009**, **170** (1), 366-373;
13. Moletta, R.: La digestion anaérobie des déchets municipaux, *L'Eau, l'Industrie, Les Nuisances*, **2002**, **275**, 75-82;
14. Schink, B.: Energetics of syntrophic cooperation in methanogenic degradation, *Microbiology and Molecular Biology Reviews*, **1997**, **61** (2), 262-280;
15. Mangenda, H.H., Nedeff, V., Kunyima, K., Barsan, N., Mosnegutu, E., Tomozei, C.: Aspects regarding the Kinshasa urban landfills assessment and proposals for sustainable development, *Journal of Engineering Studies and Research*, **2015**, **20** (1), 48-57;
16. Batstone, D.J., Keller, J., Angelidaki, I., Kalyuzhnyi, S.V., Pavlostathis, S.G., Rozzi, A., Sanders, W., Siegriest, H., Vavilin, V.A.: The IWA anaerobic digestion model n°1 (ADM1), *Water Science and Technology*, **2002**, **45** (10), 65-73;
17. Zhao, Z., Zhang, Y., Ma, W., Sun, J., Sun, S., Quan, X.: Enriching functional microbes with electrode to accelerate the decomposition of complex substrates during anaerobic digestion of municipal sludge, *Biochemical Engineering Journal*, **2016**, **111**, 1-9;
18. Nikiema, M., Sawadogo, J.B., Somda, M.K., Traore, D., Dianou, D., Traore, A.S.: Optimisation de la production de biométhane à partir des déchets organiques municipaux, *International Journal of Biological and Chemical Sciences*, **2015**, **9** (5), 2743-2756;
19. Tyagi, V.K., Lo, S.L.: Enhancement in mesophilic aerobic digestion of waste activated sludge by chemically assisted thermal pretreatment method, *Bioresource Technology*, **2012**, **119**, 105-113;
20. Degueurce, A., Tomas, N., Le Roux, S., Martinez, J., Peu, P.: Biotic and abiotic roles of leachate recirculation in batch mode solid-state anaerobic digestion of cattle manure, *Bioresource Technology*, **2015**, **200**, 388-95;
21. Zhou, H., Long, Y., Meng, A., Li, Q., Zhang, Y.: Classification of municipal solid waste components for thermal conversion in waste-to-energy research, *Fuel*, **2015**, **145**,151-157;
22. Bisaria, V.S., Ghose, T.K.: Sorption characteristics of cellulases on cellulosic substances, in: *Bioconversion of Cellulosic Substances into Energy, Chemicals and Microbial Protein: symposium proceedings,* (Editor: Ghose, T.K.), IIT, New Delhi, **1978**, 155-164;
23. Ariunbaatar, J., Panico, A., Esposito, G., Pirozzi, F., Lens, P.N.L.: Pretreatment methods to enhance anaerobic digestion of organic solid waste, *Applied Energy*, **2014**, **123**, 143-156;

24. Carrère, H., H., Dumas, C., Battimelli, A., Batsone, D.J., Delgenès, J.P., Steyer, J.P., Ferrer, I.: Pretreatment methods to improve sludge anaerobic degradability: A review, *Journal of Hazardous Materials*, **2010**, **183** (1-3), 1-15;
25. Ge, H., Jensen, P.D., Batstone, D.J.: Pre-treatment mechanisms during thermophilic–mesophilic temperature phased anaerobic digestion of primary sludge, *Water Research*, **2010**, **44** (1), 123-130;
26. Hartmann, H., Ahring, B.K.: Strategies for the anaerobic digestion of the organic fraction of municipal solid waste: an overview, *Water Science and Technology*, **2006**, **53** (8), 7-22;
27. Carlsson, M., Lagerkvist, A., Morgan-Sagastume, F.: The effects of substrate pretreatment on anaerobic digestion: A review, *Waste Management*, **2012**, **32** (9),1634-1650;
28. Charnay, F.: *Compostage des déchets urbains dans les Pays en Développement : élaboration d'une démarche méthodologique pour une production pérenne de compost*, PhD Thesis, Université de Limoges, **2005**, p. 229;
29. TAPPI (Technical Association of the Pulp and Paper Industry): *Ash in Wood and Pulp*, T. CM-86, **2002**;
30. TAPPI (Technical Association of the Pulp and Paper Industry): *Acid-Insoluble Lignin in Wood and Pulp*, T. OM-02, **2002**;
31. Angelidaki, I., Alves, M., Bolzonella, D., Borzacconi, L., Campos, J.L., Guwy, A.J., Kalyuzhnyi, S., Jenicek, P., van Lier, J.B.: Defining the biomethane potential (BMP) of solid organic wastes and energy crops: a proposed protocol for batch assays, *Water Science & Technology – WST*, **2009**, **59** (5), 927-934;
32. ADEME: La Composition des Ordures Ménagères en France (Données et Références), ADEME Editions, **1999**, p. 60;
33. World Bank: *Municipal Solid Waste Incineration (Technical Guidance Report)*, Washington, D.C., **1999**, http://web.mit.edu/urbanupgrading/urbanenvironment/resources/references/pdfs/MunicipalSWIncin.pdf;
34. Eleazer, W.E., Odle, W.S., Wang, Y.-S., Barlaz, M.A.: Biodegradability of municipal solid waste components in laboratory-scale landfills, *Environmental Science and Technology*, **1997**, **31** (3), 911-917;
35. Hendriks, A.T.W.M., Zeeman, G.: Pretreatments to enhance the digestibility of lignocellulosic biomass, *Bioresource Technology*, **2009**, **100** (1), 10-18;
36. Ostrem, K.: Greening waste : anaerobic digestion for treating the organic fraction of municipal solid wastes karena ostrem greening waste : anaerobic digestion for treating the organic fraction of municipal, M.S. thesis, Columbia University, **2004**, p. 54;
37. Lacour, J., Bayard, R., Emmanuel, E., Gourdon, R.: Evaluation du potentiel de valorisation par digestion anaérobie des gisements de déchets organiques d'origine agricole et assimilés en Haïti, *Déchets Sciences & Techniques - Révue Francophone d'Ecologie Industrielle*, **2011**, **60**, 31-41;
38. El-Chakhtoura, J., El-Fadel, M., Rao, H. A., Li, D., Ghanimeh, S., Saikaly, P. E.: Electricity generation and microbial community structure of air-cathode microbial fuel cells powered with the organic fraction of municipal solid waste and inoculated with different seeds, *Biomass and bioenergy*, **2014**, **67**, 24-31;
39. Quezada, B.C.: *Traitement de déchets issus de l'industrie agro-alimentaire par pile a combustible microbienne*, Thesis, Université de Toulouse, **2009**, p.193;
40. Chen, Y., Cheng, J.J., Creamer, K.S.: Inhibition of anaerobic digestion process: a review, *Bioresources and Technology*, **2008**, **99** (10), 4044-4064;
41. Soto, M., Mendéz, R., Lema, J.M.: Sodium inhibition and sulphate reduction in the anaerobic treatment of mussel processing wastewaters, *Journal of Chemical Technology and Biotechnology*, 1**993**b, **58**, 1-7;
42. Zeng, L., Mangan, C., Li, X.: Ammonia recovery from anaerobically digested cattle manure by steam stripping, *Water Science and Technology*, **2006**, **54** (8), 137-145;
43. Graterol, E.M.G.: *Biological treatment of industrial wastewater for biogas production*, Master Thesis, University of Stavanger, **2011**, p. 54;
44. Milaiti, M., Traore, A., Moletta, R.: Essais de fermentation à partir de *Calotropis procera* : production de CH4 en fonction de la charge en substrat et en fonction de la température, *Revue CAMES*, Série A, **2003**a, **02**, 73-78;

45. Rajagopal, R., Massé, D.I., Singh, G.: A critical review on inhibition of anaerobic digestion process by excess ammonia, *Bioresources Technology*, **2013**, **143**, 632-641;
46. De Vrieze, J., Hennebel, T., Boon, N., Verstraete, W.: *Methanosarcina*: The rediscovered methanogen for heavy duty biomethanation, *Bioresource Technology*, **2012**, **112**, 1-9;
47. Briand, X., Morand, P.: Anaerobic digestion of Ulva sp. 1: relationship between Ulva composition and methanisation, *Journal of Applied Phycology*, **1997**, **9** (6), 511-524;
48. Cirne, D.G., van der Zee, F.P., Fernandez-Polanco, M., Fernandez-Polanco, F.: Control of sulphide during anaerobic treatment of S-containing wastewaters by adding limited amounts of oxygen or nitrate, *Reviews in Environmental Science and Biotechnology*, **2008**, **7** (2), 93-105;
49. Peu, P., Sassi, J.-F., Girault, R., Picard, S., Saint-Cast, P., Béline, F., Dabert, P: Sulphur fate and anaerobic biodegradation potential during co-digestion of seaweed biomass (*Ulva* sp.) with pig slurry, *Bioresource Technology*, **2011**, **102** (23), 10794-10802;
50. Burke, D.A.: *Dairy Waste Anaerobic Digestion Handbook: Options for Recovering Beneficial Products From Dairy Manure*, Environmental Energy Company, **2001**, http://www.makingenergy.com/Dairy%20Waste%20Handbook.pdf;
51. Parawira, W., Murto, M., Read, J.S., Mattiasson, B.: Profile of hydrolases and biogas production during two-stage mesophilic anaerobic digestion of solid potato waste, *Process Biochemistry*, **2005**, **40** (9), 2945-2952;
52. Dictor, M.-C., Joulian, C., Touzé, S., Ignatiadis, I., Guyonnet, D.: Electro-stimulated biological production of hydrogen from municipal solid waste, *International Journal of Hydrogen Energy*, **2010**, **35** (19), 10682-10692;
53. Wang, Q., Peng, L., Su, H.: The effect of a buffer function on the semi-continuous anaerobic digestion, *Bioresource Technology*, **2013**, **139**, 43-49.