The International Journal of Engineering and Science (IJES)
|| Volume || 8 || Issue || 12 || Series II || Pages || PP 30-36|| 2019 ||
ISSN (e): 2319 – 1813 ISSN (p): 23-19 – 1805

Energetic valorization of plantain banana stem in southern Benin by anaerobic digestion

[1]Dimitri Ghislain CHINCOUN, [1]Gontrand Comlan BAGAN, [2]Martine ZANDJANAKOU-TACHIN
(1) Rural Engineering Laboratory, Kétou, Bénin
(2) Horticulture Laboratory, Kétou, Bénin
Corresponding Author:Dimitri Ghislain Chincoun

---***ABSTRACT***---
Any biogas generation project must be subject to a techno-economic feasibility assessment. The bio-methane potential (BMP) or Specific Biogas Production (SBP) of residues to be valorized, is a key element of this assessment. Several studies have been done in Europe and Asia for the characterization of waste that can be digested while few works has been done in Africa and particularly in Benin. The aim of this study is to identify easy and reliable methods for determining the BMP of agricultural residues in developing Country. The batch test method with measurement of the volume of gas by water displacement was implemented for the determination of the BMP of banana pseudo stem (PTB). After 80 days of incubation, the biogas generation of PTB is 167 ± 8.6L / kg for dry material or 6.68 L / kg for raw material. The deposit of 39 600 t of banana waste in southern Benin therefore represents an energy potential of more than 264 528 m3 of biogas, i.e. 330.660 MWh, or 17 253 bottles (6kg) of GPL, per year.
KEYWORDS;-*Graph, Biochemical Methane Potential, Biogas, Pseudo-stem, Banana wastes, Digester*

Date of Submission: 20-12-2019 Date of Acceptance: 31-12-2019

I. INTRODUCTION

Agriculture remains the main economic activity in Benin and in many other sub-Saharan Africa countries [1]. This agriculture produces significant amount of waste. These agricultural wastes are mainly composed of organic material and represent significant energy potential. According to the study conducted by UNDP on identifying potential and operating procedures of renewable energy across the country in 2010, nearly 505 834 114 MWh could be drawn from this deposit [2]. However, this potential is still less exploited, whereas, Benin is deficient in energy like other countries in sub-Saharan Africa.

Several recovery ways exist depending on the physicochemical characteristics of the waste, to produce energy. The thermochemical techniques includes combustion, gasification and pyrolysis carbonization and the biochemical techniques comprises the alcoholic fermentation and anaerobic digestion [3]. Anaerobic digestion has the advantage of being a simple and already proven technology, and allows both energy production and agricultural fertilizers [4], [5].

High water content wastes are extracted and are often left in the field or beside processing sites where they represent sources of pollution and nests for the development of pathogens [6]. This is the case of banana waste.

In recent years, Banana bunchy top virus (BBTV) prevail in many plantations in southern Benin [7] limiting production in quality and quantity. The methods most used to control this disease consist of mechanical eradication of infected plants. In other words, the plant is uprooted, chopped, and collected to be thrown away; ii) injection of herbicide in infected plant by plant. These control methods generates a lot of waste. Added to the normal wastes of banana after harvesting, the crop is a major source of biomass. Several ways of this biomass usage exist but are not implemented. OSSENI, S.O.G (2017), worked on the use of banana fiber to reinforce cement mortar as thermal insulation of buildings [8]. Bilba et al. also worked on the same subject in 2005 [9]. Cordeiro et al. (2004) and Li et al. (2010) demonstrated through the analysis of the pulp of banana that it could be used in papermaking [10][11]. The analyzes of the biochemical composition made by Li et al. (2010) and Thomsen et al (2014) showed that residues of banana stem consist essentially of cellulose and hemicellulose (60% to 72%) outside of the lignin which is only 12% of the organic matter [10], [12]. The hemicellulose and cellulose contained in the non-lignin degrade rapidly in anaerobic fermentation and produces 50% CO_2 and 50% CH_4 [13] and such characteristics can be use in the energy production.

Therefore, the banana stem could be an interesting input for the biogas production. As with any residue valorization project through anaerobic digestion, it is important to determine the Bio-Methane Potential (BMP) to get the technical component necessary for the economic assessment.

There are several methods for estimating or determining BMP of a residue or a mixture of residues. Estimation can be made on the basis of the chemical or biochemical composition of the residue [14]. This estimate don't always take into account the biodegradability of the material, because the phenomena of inhibition due to certain substances contained in the material are not included [14], [15]. Anaerobic digestion tests is used to objectively assess the BMP.

There is little literature on agricultural residues in Sub-Saharan Africa and almost no regarding the banana stem.

This study aims to determine the BMP of samples of banana stem collected in South Benin, through the implementation and validation of a simple device. The batch test method is implemented and the results are subject to discussion and validation.

II. MATERIAL AND METHODS

Experimental apparatus

The experimental device consists of three 5L mini-batch digesters and a 700L continuous pilot digester with angular mixer.

The three mini digesters consist of a 5L plastic bottle with a tight lid, which serves as a reactor, and another 5L plastic bottle, which serves as a gasometer.

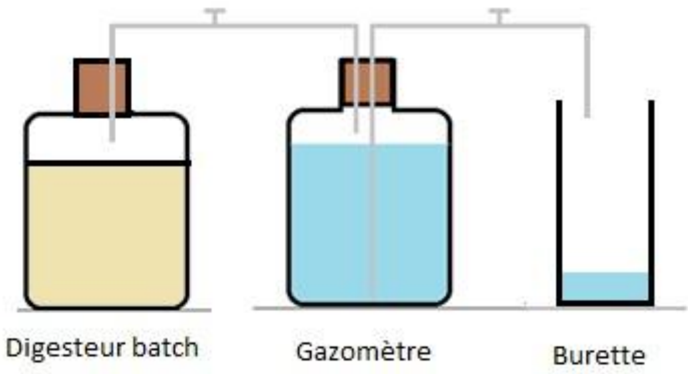

Figure 1: Experimental 5L mini digester

A hose connects the two bottles for the gas discharge while another pipe whose one end is at the bottom gasometer, allows the transfer of water thus to a gas supply. The working volume of the digester is kept at 3.5L.

Koch et al. (2015) [16] made a comparative study of test results in mini-reactors batch-type with one year measurement results on full-scale digester. This study focused on the digestion of sewage sludge and food remains. The work shows that long-term effects of co-digestion are relatively higher than the results of the batch tests. This would be due to the limited duration and mode of operation of batch tests, which are not suitable for measurement of the positive or negative synergistic effects for the mixture of different substrates. Nevertheless, BMP tests are an effective tool to evaluate the potential of a substrate, changes in the methane yield and degradation kinetics due to a substrate mixture, or adding co-substrate [15–17].

A full-scale test was therefore considered to assess the production of gas under these conditions. For this purpose, a pilot digester has been designed and built.For full-scale biogas production, continuous digesters are the most used. The pilot digester allows making a comparative evaluation of full-scale biogas production from different substrates.It is a continuous cylindrical digester with an oblique manual stirrer.

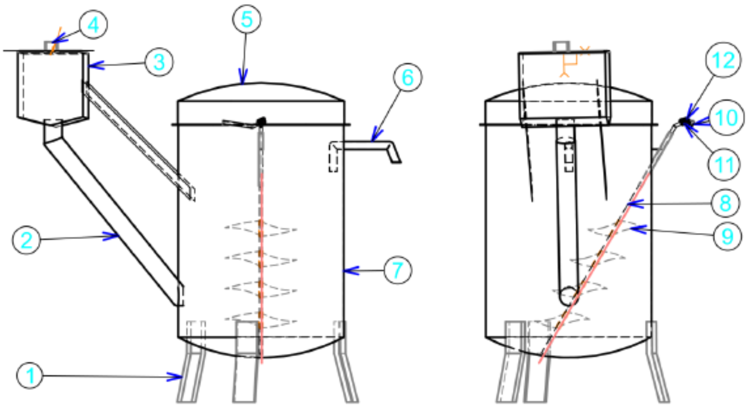

Figure 2: pilot digester

Feet (1) inlet pipe (2) filling box (3) Cover (4) upper dome (5) effluent outlet pipe (7) digestion tank with lower dome (7) agitator shaft (8) stirrer blades (9) crank (10) drive shaft (11) brace (12)

The digester is made with 650L metal tank: 488L for useful volume and 162L for gas storage. The digester is provided with a manual stirrer to homogenize the substrate for better digestion by the bacteria [18].

Organic materials

The biomass used is the banana stem. This is part of a component of BBTV eradication program called "BBTV Mitigation". Indeed this research stream focuses on the management of banana residues from the removal of plants affected by BBTV, since small producers usually complain of the management of residues from destruction.

The banana suckers are therefore collected in Dangbo plantations (South Benin). The trunks are coarsely chopped and bagged for transport, which takes about two hours from the collection site to the research center. The collection is stored in bags indoors at room temperature for a week before loading. Prior to the introduction into the reactor, waste is chopped into about 5mm particles according to the recommendation of Chynoweth et al. (1993), indicating that between 1 and 8mm, size particle does not influence the kinetics of biogas and, beyond, the size can influence the kinetics without affecting the biogas yield [19].

Experimental protocol

The three mini batch-type digesters are charged respectively with Cattle Rumen Content (CRB), banana stem waste (PTB) and the mixture of CRB and PTB. Content in kg of raw material are summarized in Table 1.

Table 1: Composition of each experimental digester

	CRB	**B**	**Water**	**MS**
digester 1	3000g			300g
digester 2		800g	3000g	32g
digester 3	3000g	800g		332g

The measurement of the gas is made by water displacement. The gasometers are filled with water at beginning of the test. The gas entering the gasholder puts pressure on the water that is discharged into a graduated burette. Since the water outlet pipe being at atmospheric pressure, the volume of displaced water is the volume of gas produced. The pH test with pH paper introduced into the gasometer indicates that the water of the gasometer is neutral. Therefore, CO_2 is not trapped and the measured volume is the volume of complete biogas. The end of the digestion is considered reached when the change in gas production is less than 1% over three days [15]. The volume is measured twice a day until the end of digestion.The wastes mass was measured by an electronic 5000g balance with an accuracy of 1g.

At the end of digestion of each mini-digesters, gas Flammability test was done. The quality of the biogas is appreciated by the color of fire. In fact by experience, a blue flame indicates a biogas rich in methane, while an orange or yellow color indicates a relatively low content of methane [20].

The tests are done at room temperature between 24 ° C and 27 ° C. A temperature sensor tracks the temperature variations inside the digesters. The volume measurements are made every day by pouring the water displaced in a graduated burette. For the pilot digester an ignition test is done every day. Digesters are stirred once a day by manual stirring for mini digester and by manual rotation of the crank of the agitator for pilot digester. The measures have lasted a total of 80 days.

Processing and analysis of data

The daily volumes are compiled in a spreadsheet. The accumulated volume is calculated for each digester and the final value is the total volume of biogas produced.BMP in liters per kg of raw material (L / kg MB) was calculated as follows:

$$BMP_{brute} = \frac{V_{tot}}{\sum MB} (1)$$

BMP in liters per kg of dry matter (L / kg DM):

$$BMP = \frac{V_{tot}}{\sum MS} (2)$$

The conversion of these BMP in normal liter (NL) is made according to the formula:

$$V_0 = V\frac{(P-P_w)T_0}{P_0 T} (3)$$

III. RESULTS AND DISCUSSION

Daily production

The experiment lasted 80 days. Daily output curves are as follows for the various substrates incubated.

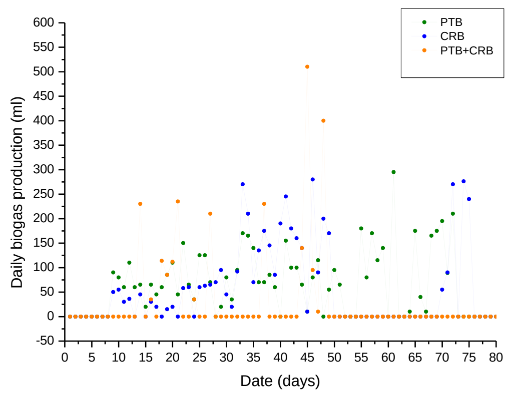

Figure 3: daily gas production for the three mini digesters

Gas production began 8 days for banana and cattle rumen contents, and 12 days for the mixture. These latent periods are not far from those seen by Afilal et al. (2014), for the BMP tests of pet waste [4]. However the latent period are relatively large compared to those obtained in the temperature controlled BMP tests by Aybek&Üçok, (2017) et Pham et al. (2013) [14], [21].

Daily gas production volume varies from zero to 295ml, 0 to 280ml and 0 to 510ml, respectively for the PTB, the CRB and mixture.The PTB and CRB productions are relatively stable compared to the mixture.The relatively high loading of the solids mixture from the digester 3 justify the instability of the production. This indicates that the manual stirring is not enough and the charge for the batch test should be low as recommended Holliger et al. (2016) in the proposed standards for BMP test.

Cumulative production

After 80 days at room temperature anaerobic digestion, the cumulative gas production is as follows, for the three mini-digesters.

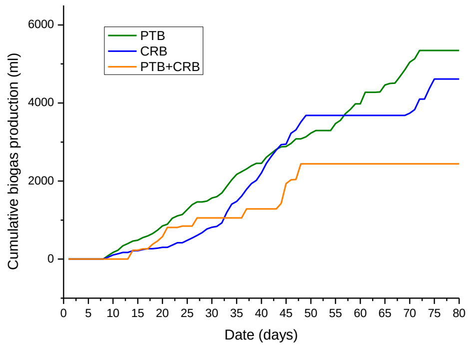

Figure 4: cumulative biogas production curves for three mini-digester

The cumulative production reached 5344ml, 4615ml and 2441ml, respectively for the PTB, the CRB and mixing.

Table 1 : Value of BMP obtained for different substrates

substrates	total gas production (ml)	crude SBP (L / kg)	crude SBP (L / kg DM)	Volume normalize (Nml)	crude SBP (NL / kg)	SBP (NL / kg DM)
PTB	5 344[a]	6.68	167.00[d]	4 742[e]	5.93	148.20
CRB	4 615[b]	1.54	153.83	4 095[e]	1.37	136.52
PTB + CRB	2 441[c]	0.81	49.87	2 166[e]	0.72	44.26

a: ± 275ml b: ± 205ml c: ± 70ml d: ± 8.6 e: average temperature of 25 ° C

The cumulative biogas production of banana stem has a linear shape (with $R^2 = 0.99$) according. This result is consistent with the work of Aybeck and Ucok (2017) which highlighted the linear shape of the cumulative biogas production of fruit and vegetable waste in the BMP tests with "Hohenheim Batch Test" method.

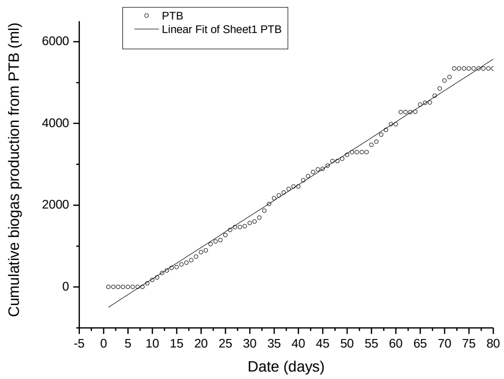

Figure 5: Linear regression of the cumulative gas production for the banana pseudo-stem

The digestion of banana residues seems faster. As for the mixture, production is very unstable. This would be due to the relatively high load of solids materials. Glanpracha and Annachhatre (2016) have shown that beyond a dry matter load threshold given by volume digester, gas production can be very unstable [22][22].

The retention time is 75 days beyond which no more production has been noted. It seems relatively long time unlike the BMP tests conducted in general. This is partially due to exposure digesters to temperature fluctuations, and to the relatively high load. However Martí-Herrero et al. (2018) [23] had retention times from 87 to 162 days for full-scale BMP tests for digesters fed only with fruit residues [23].

Estimated specific biogas production (SBP)

Equations 1, 2 and 3 allow us to determine the specific biogas production (SBP) of each substrate. The SBP obtained for the PTB waste is 6.68 ± 0,34L per kilogram of fresh PTB or 167 ± 8.6 L / kg of dry material (MS). This value is consistent with that obtained by Kalia et al. (2000) who [24] found that for banana stem slurry, SBP between 130L/kg to 271L/kg at 25 ° C [24].

Flammability tests
The flammability tests results were satisfactory for gas produced by all of three digester. The content of each gasometer burned with bright blue flame.

PTB CRB PTB + CRB

Figure 6: results of flammability tests

The three substrates produced combustible gas. These tests also showed that the PTB residues contain the bacteria responsible for anaerobic digestion, since flammable biogas produced without inoculum. It is therefore possible to produce biogas without animal manure or without inoculum from the anaerobic digestion of the banana stem wastes. A thorough comparative study will help assess the influence of the addition of inoculum for optimal biogas production.

Energy potential
Considering an average annual production of 39,600 tons of waste from PTB, the energy potential of this deposit can be estimated as in Table 3.

Table 2 : Estimated energy potential PTB residue deposit

Ton of PTB t / year	gross BMP L / kg of PTB	producible volume of gas m3 / year	energypotential GJ
39 600	6.68	264 528	4 732 934[a]

a: assuming a methane content of 50%
Anaerobic digestion of PTB therefore produce annually 264,528 m3 of biogas equivalent to 17,253 small bottle (6kg) of commercial gas and 330MWh of electricity.

IV. CONCLUSION

In this study, the batch test method used by many researchers to determine the biogas potential, has been implemented for the determination of SBP of banana pseudo-stem. The results of these tests revealed a real energy potential of 264 528 m3 of biogas equivalent to 330MWh of electricity or 169 tons of coal per year. This is an important resource in a context of energy deficit and especially non-conventional energy access in rural areas on the one hand, and secondly it would participate in the reduction of pressure on forests.
The conformity of these results with those found elsewhere shows that the evaluation of energy potential by anaerobic digestion can be done with simple devices and the results can be reliable.

Lacking determination of BMP, which requires complex equipment such as gas chromatography, the SBP tests, is a significant approach in developing countries where laboratories are poorly equipped.

Many agricultural residues and other organic wastes are still largely untapped in Benin whose economy is based on agriculture. Anaerobic digestion is a suitable technology for most waste and non-wood agricultural residues. A study of the potential of these wastes could open the way for projects for valorization of this waste at the local level as regional.

ACKNOWLEDGEMENTS

The authors thank the University of Queensland, Australia and the International Institute of Tropical Agriculture (IITA) through the fund of supporting one of the objective of the PhD students.

REFERENCES

[1] Benin overview. https://www.banquemondiale.org/fr/country/benin/overview .
[2] UNDP, Identification des potentialités et modalités d'exploitation des sources d'énergies renouvelables sur l'ensemble du territoire national, 2010.
[3] C. Couhert, Pyrolyse flash à haute température de la biomasse ligno-cellulosique et de ses composés : production de gaz de synthèse, Ecole Nationale Supérieure des Mines de Paris, 2007.
[4] M. E. Afilal, O. Elasri, and Z. Merzak, Organic waste characterization and evaluation of its potential biogas, Journal of Material and Environment Sciences, 5(4), 2014, 1160–1169.
[5] J. Lacour et al., Evaluation du potentiel de valorisation par digestion anaérobie des gisements de déchets organiques d'origine agricole et assimilés en Haïti, Déchets Sciences & Techniques, Revue Francophone d'écologie industrielle, 60, 2011, 31–41.
[6] Joaneson Lacour, Valorisation de la fraction organique des residus agricoles et autres déchets assimilés à l'aide de traitements biologiques anaérobies., (INSA Lyon, 2012).

[7] F. SODEDJI et al., Midterm report of banana bunchy top virus control strategies in two communities (Akpro-Missérété and Adjarra) in Benin Republic, Annales de la faculte des lettres, arts et sciences humaines, Université d'Abomey-Calavi (Bénin), 2(22), 2016, 312–321.
[8] S. O. G. Osseni et al., Investigation on the use of the cement mortar containing banana fibers as thermal insulator building, International Journal of Advanced Research (IJAR), 4(11), 2016, 1142–1152, doi:10.21474/IJAR01/2197.
[9] K. Bilba, M. A. Arsene, and A. Ouensanga, Study of banana and coconut fibers. Botanical composition, thermal degradation and textural observations, Bioresource Technology, 98(1), 2007, 58–68, doi:10.1016/j.biortech.2005.11.030.
[10] K. Li et al., Analysis of the chemical composition and morphological structure of banana pseudo-stem, Bioressources, 5(2), 2010, 576–585.
[11] N. Cordeiro et al., Chemical composition and pulping of banana pseudo-stems, Industrial Crops and Products, 19, 2004, 147–154, doi:10.1016/j.indcrop.2003.09.001.
[12] S. T. Thomsen, Z. Kadar, and J. E. Schmidt, Compositional analysis and projected biofuel potentials from common West African agricultural residues, Biomass and Bioenergy, 63, 2014, 210–217, doi:10.1016/j.biombioe.2014.01.045.
[13] K. Czepuck et al., Hohenheim Biogas Yield Test, Landtechnik, 2, 2006, 82–83.
[14] C. H. Pham et al., Validation and Recommendation of Methods to Measure Biogas Production Potential of Animal Manure, Asian-Australasian Journal of Animal Sciences, 26(6), 2013, 864–873, doi:http://dx.doi.org/10.5713/ajas.2012.12623.
[15] C. Holliger et al., Towards a standardization of biomethane potential tests, Water Science and Technology, 74(11), 2016, 2515–2522, doi:10.2166/wst.2016.336.
[16] K. Koch et al., Co-digestion of food waste in a municipal wastewater treatment plant : Comparison of batch tests and full-scale experiences, WASTE MANAGEMENT, 2015, 1–5, doi:10.1016/j.wasman.2015.04.022.
[17] I. Angelidaki et al., Defining the biomethane potential (BMP) of solid organic wastes and energy crops : a proposed protocol for batch assays, Water Science & Technology, 2009, 927–934, doi:10.2166/wst.2009.040.
[18] J. Lindmark et al., Effects of mixing on the result of anaerobic digestion : Review, Renewable and Sustainable Energy Reviews, 40, 2014, 1030–1047, doi:10.1016/j.rser.2014.07.182.
[19] D. P. Chynoweth et al., Bochemical methane potential of biomass and waste feedstocks, Biomass and Bioenergy, 5(1), 1993, 95–111.
[20] T. Oladeji, E. O. Olafimihan, and O. E. Itabiyi, Anaerobic Digestion of Cow Dung with Rumen Fluid, The Journal of Middle East and North Africa Sciences, 2(4), 2016, 58–60.
[21] A. Aybek and S. Üçok, Determination and evaluation of biogas and methane productions of vegetable and fruit wastes with Hohenheim Batch Test method, 10(4), 2017, 207–215, doi:10.25165/j.ijabe.20171004.2864.
[22] N. Glanpracha and A. P. Annachhatre, Anaerobic co-digestion of cyanide containing cassava pulp with pig manure, Bioresource Technology, 214, 2016, 112–121, doi:10.1016/j.biortech.2016.04.079.
[23] J. Martí-Herrero et al., Biogas from a full scale digester operated in psychrophilic conditions and fed only with fruit and vegetable waste, Renewable Energy, 2018, doi:10.1016/j.renene.2018.10.030.
[24] V. C. Kalia, V. Sonakya, and N. Raizada, Anaerobic digestion of banana stem waste, 73, 2000, 191–193.

Chincoun, D. G., Bagan, G. C., Zandjanakou-Tachin, M. "Energetic valorization of plantain banana stem in southern Benin by anaerobic digestion"The International Journal of Engineering and Science (IJES), 8.12 (2019): 30-36