Improving Biogas Yield Using Organic Fraction of Plant and Animal Wastes by Co-Digestion

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\textbf{Abstract.} This study presented the effects of co-digestion and catalysts on the performance of biogas production. Poultry dropping and walnut waste were used as feedstock materials while clay, KOH and NaOH were used as catalysts. The experiment was divided into five setups. The retention time was 45 days. The digester temperature floated around 20-44°C while the PH varies from 5.7-8.7. Gas composition, physicochemical properties, calorific value as well as elemental composition of the organic waste were analyzed. The result revealed that the gas produced has high methane content ranging from 66.52 – 73.44% with low CO\textsubscript{2} concentration ranging from 9.97 -16.92%. The total volume of gas was noted to be 135.2l, 115.2l, 82.2l, 162.4l and 115.7l for each sample. The physicochemical properties revealed that the TS varies from 3.04% - 4.15%, while VS varies from 3.27% - 4.49%. The TOC ranges from 3.13% - 3.84% while the nitrogen content ranges within 0.112% - 0.392%, while Crude fibre ranges from 0.70 – 1.79%. Ash content ranges within 1.16 – 2.67% and moisture content varies between 87.77 – 92.34%. The COD and BOD were also obtained. The calorific values of the samples obtained ranges from 15,882 – 22,036KJ/kg. The phosphorus content was between 0.33% and 0.43% while potassium was between 0.29and 0.42% on average.

\textbf{Keywords:} Anaerobic Digestion, Co-Digestion, Composition, Physicochemical, Elemental composition

\textbf{1.0 Introduction}

Energy play vital roles in the development of a society as the level of its utilization places a society into a class. Globally, energy quest is tremendously increasing and up to 88% of this quest is attained by fossil fuels \cite{1} and the little percent of the quest are attained by other sources of energy. A critical look at the overdependence and the increasing demand of energy show that fossil fuels is depleting daily and it is expected to run out someday since it is non-renewable. Due to the present energy crisis in the country, unevenly distributions of fossil fuels to various parts of our country (especially the rural parts) and havoc caused by the emission of greenhouse gasses into the atmosphere as a result of the burning of fossil fuels, researchers have been motivated into harnessing alternatively, more friendly fuel production from renewable sources such as biomass resources \cite{2}. In addition, most of the natural resources are located in the regions...
that are politically unstable, and this has put the security of energy supply in question. For this reason, biogas technology becomes a solution to these challenges confronting energy in our country. Apart from being a replacement to conventional fuels, it also aimed at increasing agricultural productivity, waste management and reducing the volume of landfill [3].

1.1. Biogas Technology

Biogas technology is one of the renewable energy technologies that make use of different wastes to generate gas for various applications and organic fertilizers through the process of anaerobic digestion. The biogas generated is mainly used for heat production, electricity generation and steam generation. The major constituents of biogas are methane and carbon dioxide with 50 – 75% and 25 – 50% of volume respectively [1] with other traces of substances such as carbon mono-oxide, methanol, oxygen, hydrogen, ethanol, acetone, phenol, etc. Effective harnessing of this Renewable Energy technology, would raise the reliability of electricity supply, reduce greenhouse gases emissions, reduce energy insecurity, offset fossil fueled grid electricity, enhance availability of energy for socioeconomic activities and improve the standard of living of the country [4].

Biogas is produced from the bacterial decomposition of organic matter in the absence of air, by the biodegradation of organic material under anaerobic conditions. Some of the biogas raw materials are animal dung, industrial wastes, household wastes, plant wastes and crop residues. Mixing different types of wastes yield more biogas energy [5].

Various studies have shown that co-digestion improved the quality and quantity of biogas production. Co-digestion plays vital roles in waste digestion as it balances the nutrient demand, improves rate of digestion, increases soil fertility when using the digested slurry as fertilizer, improves biodegradability of the feedstock, increases biogas yield, proper sanitization and hygienic [6]; [7]. Also, co-digestion will greatly adjust the PH value and provide the normal carbon-nitrogen ratio required for proper functioning of anaerobic process. The overall goals of co-digestion include environmental, technological and economic benefits as compared with single digestion of substrates [8]. Catalysts had also been observed to enhance the performance of biogas yield, [9]; [10] and [11] reported that addition of catalysts improves the quality and quantity of biogas produced and also increase the rate of biogas formation.

1.2. The principles of biogas production

Biogas production is mainly an anaerobic process. It is the gas generated by biodegradation of organic matter with the help of the activities of microbes in the absence of oxygen. Biogas production involves conversion of energy from wastes into useful energy. This conversion involves four stages with different independent micro-organisms working actively at each stage.

The first stage is called hydrolytic stage. At this stage, the complex insoluble organic matter such as carbohydrates, proteins; lipids, etc are converted into simpler soluble compounds such as sugar, amino and fatty acids by the actions of the hydrolytic microbes [12].

The second stage is called acidification stage. At this stage, the simpler soluble organic compound is converted into volatile fatty acid (VFA) and carbon dioxide (CO₂) by the acid forming bacteria. This stage is preceded by acetogenesis stage where the product in the second
stage is further converted to acetic acid, hydrogen and CO₂ by acetogens. This creates an enabling environment for anaerobic digestion [13].

The last stage which is methanogenesis involves conversion of acetic acid, hydrogen and carbon dioxide by the methane forming bacteria (methanogens) into methane (CH₄) and CO₂ including other traces of gases. It is important to note that the bacteria at this last stage is very sensitive to environmental change [12].

Anaerobic digestion is highly affected by environmental factors such as temperature and pH value, others include; hydraulic retention time, loading rate, concentration of feedstock, carbon-nitrogen ratio, toxicity, moisture content, air tightness and agitation. Although these factors are strongly depend on the biological, climate and the operational conditions [14].

Digesters are instruments designed to create an enabling environment for anaerobic processes. Series of Digesters are in use today, and they are constructed according to the material to be digested [15]. Series of Digesters are in use today, but the nature of the organic substrates and operational condition is highly influencing the choice of digester as the available substrates usually affects the operating system [16]. Digesters can be group into three classes depending on the operating system: (1) passive system, the generated gas is added to the existing waste treatment with little control of digestion process. (2) The low rate system, the wastes flow through the digester and leaves at the end of the retention time. (3) The high rate system, the methane forming bacteria is enclosed in the digester in order to enhance the performance of the biogas production [17]. And they are constructed according to the material to be digested [15]; [18].

2.0 Materials and Methods

The materials used as apparatus in this work include 5 32litres fixed doom digesters, thermometer, pH meter, pressure gauge (in mmHg), calibrated white plastic bucket, rubber tube of length 3m long and diameter of 0.8m, gas compressor, gas cylinder, weighing balance, distilled water and the stirrer. Poultry dropping and walnut waste were used as substrates, potassium hydroxide (KOH), sodium hydroxide (NaOH), and clay as catalysts.

2.1 Preparation of the digesters and samples

The 5 32litres fixed doom digesters were washed thoroughly with tap water and allowed to dry under the sun for a day and they were then painted black so that the digesters can have good absorbing surfaces and also to avoid rusting and corrosion. Thereafter, they were allowed to dry for five days before used.

50kg bag of poultry dropping were collected from a poultry farm within Nsukka, clay was collected from the department of Fine and Applied of the University of Nigeria, Nsukka. Walnut waste was also collected within Nsukka area and stored in bags till the time for used. KOH and NaOH were purchased in a Chemist shop within the university. All the substrates were allowed to decay for some time before used as this allowed microbes to act on them for easy anaerobic digestion.
2.2 Experimental detail
This experiment demonstrated the performance of biogas production by anaerobic digestion of poultry dropping with plant waste and catalysts. The experiment was divided into 5 experimental setups (say samples A, B, C, D and E).

Sample1A was done to determine the biogas production by single digestion of poultry dropping with water at the ratio of 1:3.
Procedure: 6kg of poultry dropping was weighed and poured into a 32litres digester, and 18kg of water was added. The contents were stirred thoroughly to ensure uniform mixing and also to have good contact between the substrates and microbes. Then a small fraction of the mixture was collected for analysis.

Sample1B was done to determine the effect of co-digestion of poultry dropping and walnut waste with water on biogas production at the ratio of 3:1.
Procedure: 3kg of poultry dropping was mixed with 3kg of walnut waste and were poured into a digester. 18kg of water was added and the contents were stirred and a little fraction of it was collected for analysis.

Sample1C was done to determine the effect of clay as a catalyst on the performance of biogas production through anaerobic digestion of poultry dropping.
Procedure: 5.5kg of poultry dropping was mixed with 18kg of water into a digester; 0.5kg of clay was added and stirred.

Sample1D was done to determine the effect of potassium hydroxide (KOH) as a catalyst on the performance of biogas production through anaerobic digestion of poultry dropping.
Procedure: 6kg of poultry dropping was mixed with 17.5kg of water in a digester and 3g of KOH was dissolved in 500 miligram of water inside a measuring cylinder. They were then poured into the digester and the whole contents were stirred.

Sample1E was done to determine the effect of sodium hydroxide (NaOH) as a catalyst on the performance of biogas production through anaerobic digestion of poultry dropping.
Procedure: 6kg of poultry dropping was mixed with 17.5kg of water into a digester and 3g of NaOH was dissolved in 500 miligram of water inside a measuring cylinder. They were then poured into the digester and the whole contents were stirred. Afterwards the whole setups were air tightly sealed and allowed to run for the period of 45days. The samples for analysis were collected three times: on the charging date; secondly, on the 21st day and lastly, on the 42nd day.

2.3 Measurement of parameters affecting biogas production
The parameters affecting anaerobic digestion such as the ambient temperature, the digester temperature, the PH value including pressure and the volume of the gas were measured daily at the peak hour of sunshine. The volume of gas produced was measured using water displacement method and the gas produced in each of the samples was collected and stored in five different cylinders for gas chromatograph analysis. The measurements were summarized in the table 1 below.
Table 1: Daily Measurements of Some Parameters.

| Feedstock | Ambient Temp.°C | Sludge Temp.°C | PH     | Pressure (mmhg) | Vol. (litre) | Total Vol. |
|-----------|-----------------|---------------|--------|-----------------|-------------|------------|
| Sample A  | 21-32           | 20-44         | 8.3-5.7| 4-44            | 0.2-8.3     | 135.9      |
| Sample B  | 21-32           | 20-44         | 8.7-6.2| 4 - 30          | 0.8-5.5     | 115.2      |
| Sample C  | 21-32           | 20-44         | 8.9-5.8| 4 - 26          | 0.6 4.9     | 82.2       |
| Sample D  | 21-32           | 20-44         | 8.8-5.5| 4 - 44          | 1.2-8.7     | 162.4      |
| Sample E  | 21-32           | 20-44         | 9.0-5.9| 4 - 30          | 0.5-5.7     | 115.7      |

Flammability test was done with the aid of lighter to know the combustion rate of the gas. It was observed that the gas takes much time before combusting. In Digester A, the gas started burning on the 24th day of the experiment, digester B on the 15th day, digester C on the 27th day while digester D and E were on 30th and 29th days respectively.

Physicochemical characteristics of organic wastes were analyzed. BOD, VS and TVC were analyzed three times in order to evaluate the amount of molecular oxygen used, volatile solid and the active microbes acting on the substrates at different interval of the experiment. Elemental compositions such as N, P and K were analyzed twice to determine the usefulness of the post digested sludge, while other analysis in this study was done once as presented in table 3, 4, and 5 below.

3.0 Results and Discussion

The result of the daily measurement of temperature, PH, pressure and volume, showed that the ambient temperature varies from 21-32°C while the sludge maintained the mesophilic range of temperature at 20-44°C. The initial PH were at 8.3, 8.7, 8.9, 8.8 and 9.0 for digester A, B, C, D and E respectively but as the experiment continued, the pH started fluctuating from these values to 5.7, 6.2, 5.8, 5.5 and 5.9 for the respective digesters. The pressure and volume of the gas swings and maintained neither constant volume nor pressure. The highest biogas yield was recorded on the 8th day with maximum value of 8.3 litres for sample A while sample B, C, D and E recorded their highest volume on the 21st, 29th, 14th and 13th days with their maximum values at 5.5, 4.9, 8.7 and 5.7 litres respectively.

Biogas produced was analyzed using the gas chromatograph to ascertain the composition of the gas. Methane content was determined using flammable ionization detector FID while carbon dioxide and other traces of gases were detected by the use of thermal conductivity detector. Syringe injection method was used with Helium gas as the carrier gas. The temperatures of the detectors were maintained at 50°C, 180°C, and 310°C. From the analysis, it was shown that the methane content ranges from 66.5% - 73.4%; CO₂ ranges from 9.96% - 16.91% with other traces of gas such as carbon mono-oxide, acetone, methanol, oxygen, hydrogen, acetic acid, ethanol and phenol making up 9.69 – 23.54%.
3.1. Evaluation of the performance of the digesters
Both the quantity and quality of the biogas produced from each of the digesters in the experiment were evaluated and the results obtained were as follow: Sample A has a total biogas yield of 135.9L with 69.54% CH₄ content and 12.1% of CO₂. Sample B, has a total of 115.2L biogas yield with 69.50% and 13.1% of CH₄ and CO₂ content respectively.

Table 2: Presented The Composition of Biogas Produced.

| Components of biogas produced | A          | B          | C          | D          | E          |
|-------------------------------|------------|------------|------------|------------|------------|
| Net weight of the sampled gas | 76.0068    | 82.7907    | 88.8256    | 148.5679   | 147.0610   |
| Methane (CH₄ %)               | 69.54      | 69.50      | 73.44      | 66.52      | 70.79      |
| CO₂ %                         | 12.10      | 13.11      | 9.97       | 16.92      | 16.52      |
| CO %                          | 0.77       | 1.23       | 0.93       | 1.13       | 0.72       |
| Acetone %                     | 3.38       | 2.48       | 2.02       | 3.11       | 3.14       |
| Acetic acid %                 | 0.78       | 0.71       | 0.82       | 0.60       | 0.60       |
| Methanol %                    | 2.25       | 2.47       | 2.32       | 4.12       | 4.16       |
| Oxygen %                      | 6.54       | 6.02       | 6.44       | 2.01       | -          |
| Hydrogen %                    | 2.03       | 2.15       | 2.05       | 3.30       | 2.14       |
| Ethanol %                     | 1.21       | 1.11       | 1.03       | 1.25       | 1.96       |
| Phenol %                      | 1.42       | 1.21       | 0.97       | 1.05       | 0.08       |

Although the volume of gas in Sample A was about 14.7% higher than the volume of gas in Sample B but the difference in their CH₄ content was of no significant. Sample C has the lowest biogas yield of 88.2L with the highest CH₄ content of 73.4%, while Sample D has the highest volume of biogas yield but least CH₄ content. It has a total volume of 162.4L with 66.5% and 16.91% of CH₄ and CO₂ respectively. Sample E also has higher methane content of 70.8% and 115.7 as the total volume biogas yield.

Physicochemical characteristics of organic wastes were also studied and the results are presented in table 3 below.

Table 3: Physicochemical Characteristics of Organic Wastes

| Parameters             | Sample A | Sample B | Sample C | Sample D | Sample E |
|------------------------|----------|----------|----------|----------|----------|
| Total solid TS (%)     | 3.85     | 4.14     | 3.97     | 3.19     | 3.17     |
| Volatile solid VS (%)  | 3.45     | 3.41     | 3.27     | 3.49     | 3.39     |
| Ave                    |          |          |          |          |          |
| Ash content %          | 1.59     | 2.38     | 2.67     | 1.30     | 1.16     |
| Crude fibre %          | 1.79     | 2.39     | 1.50     | 0.70     | 0.80     |
| Crude fat (%)          | 0.70     | 1.75     | 0.40     | 0.50     | 0.50     |
| Protein (%) Ave        | 2.47     | 1.83     | 1.29     | 2.25     | 2.12     |
Sample A: Poultry dropping alone; Sample B: poultry dropping with walnut waste, Sample C: poultry dropping with clay; sample D: poultry dropping with KOH and Sample E: poultry dropping with NaOH.

The total solid content and volatile solid were calculated using these formulas

The total solid TS (%) \(= \frac{X \times 100}{Y} \quad (1)\)

Where \(X\) = weight of dry matter,

\(Y\) = weight of residue

Volatile solid VS (%) \(= \frac{X-Y}{G} \times \frac{100}{1} \quad (2)\)

Where \(G\) = weight of the sample

| Nitrogen (%) | 0.392 | 0.222 | 0.112 | 0.307 | 0.286 |
| Carbon content (%) | 3.19 | 4.52 | 3.84 | 3.19 | 3.13 |
| C/N | 8:1 | 20:1 | 34:1 | 10:1 | 11:1 |
| Moisture content (%) | 92.3 | 87.8 | 89.3 | 90.5 | 91.2 |
| BOD (mg/l) Ave | 50.7 | 45.3 | 40.0 | 60.3 | 57.1 |
| COD (mg/l) | 208 | 128 | 150 | 218 | 224 |

Based on the analyses, the total solid TS varies from 3.04\% - 4.15\% with the lowest observed in Sample E and the highest in Sample B. The volatile solid VS varies from 3.27\% - 4.49\% with the least observed in Sample C and highest in Sample D. The total organic carbon TOC ranges from 3.13\% - 4.52\% with Sample B having the highest and Sample E the least while the nitrogen content ranges between 0.112\% - 0.392\%. Therefore, the C/N ratios are 8:1, 20:1, 34:1, 10:1, and 11:1 for Samples A, B, C, D and E respectively. The C/N in Sample B has proven that co-digestion provide the normal carbon-nitrogen ratio required for proper functioning of anaerobic process, which is in agreement with literature, [7]; [19]; [20]. The low biogas yield in Sample C maybe resulted from higher C/N ratio which may cause reduction in biogas production [13] or maybe due to technical reason. The low C/N ratio observed in A, D and E indicate that the feedstock contain mainly protein which lead to low C/N ratio [21]; [22]. Crude fat has a range of 0.40 – 1.75\% while crude fibre ranges from 0.70 – 1.79\%. Ash content ranges within 1.16 – 2.67\% and moisture content varies between 87.77 – 92.34\%. The chemical oxygen demand COD obtained was at the range of 128 – 224mg/l while the biological oxygen demand BOD ranges within 40 -60.26mg/l on average. The calorific values of each of the samples were also determined and the values obtained were 21,280, 22,039, 15,882, 21,534 and 21,726 KJ/Kg for Samples A, B, C, D and E respectively. These show high calorific values.
3.3. Total Viable Count (TVC)
This is the number of microbes working actively for the biodegradation of substrates in each of the digester. The results showed that the highest microbial count was observed in the 2nd analysis followed by the 1st and the least were observed in the 3rd analysis. Least TVC observed in Sample C showed that there was starvation of some microbes due to lack of nutrient resulted from higher C/N ratio.

Table 4: TVC of Microbes at Different Interval

| Analyses     | A          | B          | C          | D          | E          |
|--------------|------------|------------|------------|------------|------------|
| 1st analysis | 6.4 × 10⁶  | 4.3 × 10⁴  | 3.8 × 10⁴  | 5.6 × 10⁴  | 5.7 × 10⁴  |
| 2nd analysis | 2.8 × 10⁸  | 3.1 × 10⁶  | 2.3 × 10⁶  | 4.0 × 10⁶  | 3.5 × 10⁶  |
| 3rd analysis | 5.1 × 10³  | 5.4 × 10³  | 4.7 × 10³  | 7.2 × 10³  | 6.0 × 10³  |

3.4. Elemental Composition
The elemental composition such as nitrogen, phosphorus and potassium were also analyzed twice to ascertain the usefulness of the post fermented sludge, The results obtained showed the presence of both nitrogen, phosphorus and potassium which proved that the post fermented sludge is a very good fertilizer when compost. It was observed that both elements increased as digestion progress. Table 5 below presented the elemental composition of the digesting sludge.

Table 5: Presented the Elemental Composition of the Slurries

| Analyses     | Elements | A    | B    | C    | D    | E    |
|--------------|----------|------|------|------|------|------|
| 1st analysis | N        | 0.392| 0.222| 0.112| 0.307| 0.286|
|              | P        | 0.26 | 0.38 | 0.30 | 0.24 | 0.22 |
|              | K        | 0.18 | 0.12 | 0.08 | 0.15 | 0.13 |
| 2nd analysis | N        | 0.399| 0.362| 0.301| 0.411| 0.391|
|              | P        | 0.38 | 0.41 | 0.33 | 0.46 | 0.43 |
|              | K        | 0.35 | 0.39 | 0.29 | 0.42 | 0.41 |
4.0 Conclusion
This study presented the effects of co-digestion and catalysts improving biogas yield. Both the quantity and quality of the biogas produced from each of the digesters in the experiment were evaluated and the results obtained were as follow: Sample A has a total biogas yield of 135.9L with 69.54% CH₄ content and 12.1% of CO₂. Sample B has a total of 115.2L biogas yield with 69.50% and 13.1% of CH₄ and CO₂ content. Sample C has the lowest biogas yield of 88.2L with the highest CH₄ content of 73.4%, while sample D has the highest volume of biogas yield but least CH₄ content. It has a total volume of 162.4L with 66.5% and 16.91% of CH₄ and CO₂ respectively. Sample E also has higher methane content of 70.8% and 115.7 as the total volume biogas yield. This indicates that clay was the best catalyst for digestion of poultry dropping as a feedstock in terms of methane production. This study confirmed that co-digestion of organic fraction of plant and animal waste improves the C/N of a feedstock. The elemental composition revealed the presence of NPK which is an indication that the post-digested slurries contain quality fertilizer and if compost can be used for agricultural purposes.
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Reference

[1]. Bharathiraja, B., Sudharsana, T., Jayamuthunagai, J., Praveenkumar, R., Chozhavendhan, S., & Iyyappan, J. 2018. Biogas production – A review on composition, fuel properties, feed stock and principles of anaerobic digestion. Renewable and Sustainable Energy Reviews, 90(April), 570–582. https://doi.org/10.1016/j.rser.2018.03.093

[2]. International Energy Agency. 2015. Energy and climate change: world energy outlook special report. Paris: OECD/IEA. Substrate compositions in the methane fermentation process. International Agrophysics, 29(3), 313–321. https://doi.org/10.1515/intag-2015-0037

[3]. Bharathiraja, B., Sudharsana, T., Jayamuthunagai, J., Praveenkumar, R., Chozhavendhan, S., & Iyyappan, J. 2018. Biogas production – A review on composition, fuel properties, feed stock and principles of anaerobic digestion. Renewable and Sustainable Energy Reviews, 90(April), 570–582. https://doi.org/10.1016/j.rser.2018.03.093

[4]. Ilenikhena P., Ezemonye L. 2010. Solar Energy Applications in Nigeria. WEC Montreal; 2. Available from:〈www.worldenergy.org/documents/congresspapers/135〉.

[5]. Shaaban, M., & Petinrin, J. O. 2014. Author’s personal copy Renewable energy potentials in (Nigeria ): Meeting rural energy needs.

[6]. Sosnowski P, Wieczorek A, Ledakowicz S 2003. Anaerobic co- digestion of sewage sludge and organic fraction of municipal solid wastes. Adv Environ Res 7:609 –616. doi:10.1016/S1093-0191(02)00049-7

[7]. Avs, F. T. Y. 2016. Effects of co-substrate on biogas production from cattle manure : a review. 2303–2312. https://doi.org/10.1007/s13762-016-1069-1

[8]. Brown D, Li Y 2013 Solid state anaerobic co-digestion of yard waste and food waste for biogas production. Bioresour Technol., 127:275–280.

[9]. Journal, I., Engineering, M., & Publishing, P. 2016. No Title. 13(2), 3503–3517.

[10]. Bagudo, B. U., Dangoggo, S. M., Hassan, L. G., & Garba, B. 2010. Influence of catalyst (Yeast) on the Biomethanization of Selected Organic Waste Materials Department of Pure and Applied Chemistry Usman Danfodiyo University Sokoto . Energy Commission of(Nigeria) Abuja . ES products + E. 18, 209–216.

[11]. Kumar, A., Miglani, P., & Bhattacharya, T. K. 2006. Impact of Ni ( II ), Zn ( II ) and Cd ( II ) on biogassification of potato waste. 27(January), 61–66.

[12]. Weiland, P. 2010 "Biogas production: current state and perspectives," Appl Microbiol Biotechnol 85, 849–860, 2010.

[13]. Kigozi, R., Aboyade, A., & Muzenda, E. 2014. Biogas Production Using the Organic Fraction of Municipal Solid Waste as Feedstock. International Journal of Research in Chemical, Metallurgical and Civil Engineering Engg.(IJRCMCE), 1(1), 107–114.
[14]. Rasul, G. 2019. ScienceDirect Opportunities for solar assisted biogas plant in subtropical climate and Cooling climate Opportunities for International solar assisted biogas in subtropical in Australia: A review Assessi. Energy Procedia, 160(2018), 683–690. https://doi.org/10.1016/j.egypro.2019.02.192

[15]. Ward, A. J., Hobbs, P. J., Holliman, P. J., & Jones, D. L. 2008. Bioresource Technology Optimisation of the anaerobic digestion of agricultural resources. 99, 7928–7940. https://doi.org/10.1016/j.biortech.2008.02.044

[16]. Caruso M C, Braghieri, A., Capece, A., Napolitano, F., Romano, P., Galgano, F., Ambientali, A. 2019. Applied sciences Recent Updates on the Use of Agro-Food Waste for Biogas Production. https://doi.org/10.3390/app9061217

[17]. Villages, J. 2019. Portable Biogas Digesters for Domestic Use.

[18]. Rajendran K., Aslanzadeh, S, & Taherzadeh, M J. 2012. Household Biogas Digesters—A Review. https://doi.org/10.3390/en5082911

[19]. Abbasi T, Tauseef S, Abbasi SA 2011. Biogas energy, 2. Springer Science & Business Media, (New York).

[20]. Ghasimi S, Idris A, Chuah T, Tey B 2009 The effect of C: N: P ratio, volatile fatty acids and na levels on the performance of an anaerobic treatment of fresh leachate from municipal solid waste transfer station. Afr J Biotechnol., 8:4572–4581

[21]. Lalak, J., Kasprzycka, A., Paprota, E. M., Tys, J., & Murat, A. 2015. Development of optimum substrate compositions in the methane fermentation process. International Agrophysics, 29(3), 313–321. https://doi.org/10.1515/intag-2015-0037

[22]. Cuetos M.J., Go´mez X., Otero M., and Morá’n A., 2010. Anaerobic digestion and co-digestion of slaughterhouse waste (SHW): influence of heat and pressure pre-treatment in biogas yield. Waste Manage, 30, 1780-1789