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Techno-Economic Evaluation of Biogas Generation from Selected Substrates in a Teaching and Research Farm in Ibadan, Oyo State, Nigeria

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Abstract:- Biogas, a form of renewable energy (biofuel) and whose by-products include methane, carbon-dioxide and other gases, depending on substrate type is producible from various substrates, with varying degrees of yield level and quality. However, the climatic and energy requirements in realising the optimum yield remain uncertain and vary with the environment. Therefore, this work was centred towards determining the substrate(s) that would give the optimum yield of methane and carbon-dioxide, under Nigerian climatic conditions. Two different substrates were collected and processed by means of anaerobic digestion for twenty-one days using a continuous flow digester. The synthesized gases were tested for a period of two days at varying atmospheric temperature, and humidity for methane, carbon-dioxide, energy yields, and other gases for each day, using AZ77535 gas analyzer and a gas detector. Economic analysis of the data obtained was also conducted. The substrates collected were cow-dung and pig-dung from University of Ibadan's teaching and research farm. While pig dung yielded 59% and 53% of methane with 35% and 39% of carbon-dioxide at 33.7^{0}C, 71% and 26^{0}C, 50.1%;cow dung yielded 52% and 44% of methane with 30% and 33% of carbon-dioxide at32.6^{0}C, 65% and 27^{0}C, 52%,as well as energy contents 18,266KJ/m^3; 17,311KJ/m^3 and 16,177KJ/m^3; 13,817KJ/m^3 for days one and two respectively. Pig dung gave a higher yield of methane and carbon-dioxide than cow dung, regardless of the working atmospheric temperature and humidity. Economic analysis of the biogas yield showed a potential saving of $267.24for the first year of production. This information is useful in setting up biogas processing plants in Nigeria.

Keywords:- *Bio fuel, energy content, humidity, substrates, temperature, yield*

I. INTRODUCTION

The roles of energy towards the industrialization, social and economic growth of a nation cannot be overemphasized (Shah et. al., 2016). Energy can be from a renewable source or non-renewable source. Renewable energy is gradually gaining universal acceptance in sourcing alternative means to fossil fuels which come chiefly from coal, oil and natural gas and which are likely going to finish one day, as they are not replenishable (Grace, 2017; Renewable Energy World, 2017), aside their being expensive, scarce and having the ability to produce greenhouse gases (Horvath et. al., 2016). Present trend globally includes frantic efforts to transit from the use of non renewable energy (fossil-fuel or nuclear-based) to renewable means of energy (Wiley, 2013). Common types of alternative means of energy cover solar energy, wind energy, hydro power, geothermal power and bioenergy which include biofuels, biopower and bioproducts (Renewable Energy World, 2017). In its own case, the use of biofuel is becoming more and more popular, as biogas, a typical biofuel continues to find applications in both developed and developing countries (Jorgensen, 2009), because in addition to being an alternative source of energy that does not require a far too advanced technology for its generation, it is still useful for irrigation purpose, cooking and lighting purposes, powering of internal combustion engines, fertilizer production and so on. Biogas synthesis is a means of converting waste materials to useful resources and wealth (Biogas planet, 2018b). However, Biogas, normally produced from breaking down organic matter anaerobically and whose constituents include methane (CH_4), carbon-dioxide (CO_2) and water vapour (H_2O) is usually accompanied by unwanted substances that are harmful to both human health and the environment on their release to the atmosphere (Peterson, 2013). For example, the hydrogen sulphide (H_2S) and carbon-monoxide (CO_2) therein makes the obtained crude (unprocessed) biogas very corrosive Kask et. al. (2007); Wojdyla et. al. (2012); Shah et. al. (2016); and explosive (Wojdyla et.al., 2012). Although rumours of naturally produced biogas have been in circulation as far back as the 17 th century, development of biogas systems did not start until around middle of the 19 th century (Jorgensen, 2009). Since then, wide uses of the gas have been reported in many developing countries, particularly India and China, wherein more than one million small simple plants are in existence. Interestingly, while quality of biogas is determined to a large extent by presence of methane, energy content (calorific value) and concentration of contaminant gases (Sherman, 2016); the realisable biogas yield is dependent on the: potential of feed stock, design of digester, inoculum, nature of substrate, pH, temperature, loading rate, hydraulic retention time, C: N ratio, volatile fatty acids and other gases (Kavuma, 2012). It can thus be said that the constituents of biogas depend on the substrate being digested (Jorgensen, 2009). The colourless, odourless gas, methane, found in biogas is also the main component of the natural gas (Bothi, 2007). Its formation occurs as a result of the activities of the bacteria called methanogen, by means of a process called methanogenesis. Under anaerobic conditions, the formation of biogas takes place in four stages: Hydrolysis, acidogenesis, acetogenesis and methanogenesis..

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- *Acidogenesis:* This occurs during the second stage of biogas formation and involves a biological reaction in which the formed simple monomers from stage one are subsequently transformed to organic compounds, specifically, volatile fatty acids (CSU, 2015; Dutton, 2018; STANDS4, 2018).
- *Acetogenesis:* This occurs during the third stage and in its own case, involves a biological reaction. During the process, a category of bacteria, called acetogens attack and break down the fatty acids earlier produced in stage two into acetic acid, carbon-dioxide and hydrogen (Ragsdale and Pierce, 2008; Dutton, 2018; STANDS4, 2018).
- *Methanogenesis:* Is the fourth and last stage of biogas formation and in which certain anaerobic bacteria, called methanogens engage in biological reactions to principally synthesize methane, and CO_2 out of the acetate that resulted during the stage three (Ferry, 1992; Lessner, 2009; Dutton, 2018; STANDS4, 2018).

In essence, a lot of work has been done in relation to biogas generation, potentials and benefits globally, as biogas is produced from different substrates which give varying quantity and quality of the gas (Elsolh, 2010; Moller and Martinsen, 2013; Amare, 2015; Biogas planet, 2018a;Nielsen and Gregersen, 2018). However, information on its production and usage in Nigeria as reliable replacement to crude-oil and fossil fuels is scarce. Moreover, even if efforts intensified in producing biogas from organic matter (usually wastes), the particular amount of temperature, pressure, humidity, time, energy content, and so on among others needed to produce large quantity, high quality combustion methane in Nigeria remain proprietary. And as a result, the need for this research, evaluation of some selected substrates from University of Ibadan's teaching and research farm in Ibadan, Oyo State, Nigeria for biogas generation. Therefore, the objectives of this work include: (i) Collecting selected substrates from a major teaching and research farm in Ibadan, Oyo State, Nigeria and processing the collected substrates anaerobically in digesters for biogas generation. (ii) Analyzing mainly, the quantity of methane and carbon-dioxide realisable from these selected substrates. (iii) Valuating the monetary benefits derivable from biogas generation. Justification for this work is based on the fact that fossil fuels are scarce, expensive, non-renewable and with high tendency to evolve greenhouse gases, which therefore means that alternative means of generating energy must be sourced, such as the production of biogas, whose principal constituent is methane. As the quest to finding reliable and durable alternatives to fossil fuels and crude oil continues across the globe, the future of biogas seems bright for some time to come, based on its ease of producibility, wide applicability and cost effectiveness (Ghazil and Abbaspour, 2011; Meszaros *et. al*., 2014).

II. MATERIALS AND METHODS

A. Materials

These include: Substrates from 2 sources (animal dung 1 and animal dung 2 of 20kg each),water

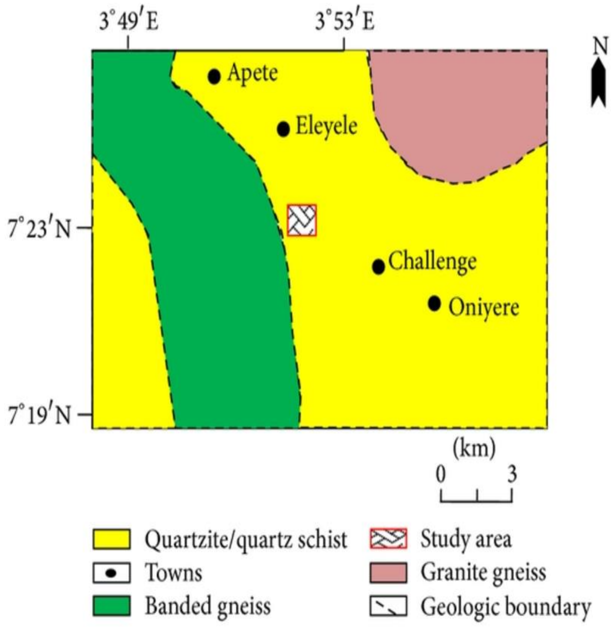

Fig 1:- Geological Map of University of Ibadan, Oyo State, South-Western Nigeria (Source: Dare and Fatoba, 2014).

B. Equipment

These include: Continuous feed digesters, gas analyzer (AZ77535 model), gas detector, gas pipes and hoses.

C. Methods

Two substrate types, collected from an animal farm and denoted as animal dung 1 and animal dung 2 were simultaneously fed into two separate digesters, mixed with water (ratio 1:1, in which 20kg of each of the animal dung type was mixed with 20 litres of water), covered, and subsequently allowed a retention time of a period of 21 days (to allow digestion to take place). Thereafter, gas pipes were separately connected to each digester through the gas inlet ports in order to link them up to a kitchen one- after-the-other. A gas analyzer (model AZ77535) was carefully fixed to a hose and connected tightly to the gas pipes already connected to the digesters. The temperature, humidity and pressure were determined, as well as CO_2 and other minor gases present (H_2S, N_2, H_2, *etc*.) in each of the digesters. The procedure was repeated with each digester now connected to a gas detector in order to analyze the methane gas likely present therein. Readings were thoroughly observed and recorded for 2 consecutive days, wherein for day 1, readings were first collected from digested slurry of animal dung 1 and for day 2, readings were first collected from digested slurry of animal dung 2. The energy content (calorific value), density and critical pressure were also deduced.

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Fig 2:- AZ77535 Gas analyzer

Fig 3:- Gas detector

Fig 4:- Checking dung-mix on day 19

Fig (a) Fig (b)

Fig 5:- (a) and (b).Connecting the AZ77535 Gas analyzer and Gas detector to a hose

Fig (a) (b)

Fig 6:- (a) and (b).Connecting AZ77535 Gas analyzer to a pipe in the kitchen and to a tube to determine CO_2 and other gas(es).

D. Terms, and symbols used in the research work

Pa = Ambient pressure (mbar)
Pg = Gauge pressure (mbar)
Pt = Total pressure (mbar)
Pstd = Standard pressure (1013mbar)
Tstd = Standard temperature (273K)
Hu,n = Enthalpy (50000KJ/Kg)
Hu = Energy content (KJ/m^3)
$\rho_{std}CH_4$ = Standard density of methane (0.72)
$\rho_{act}CH_4$ = Actual density of methane (0.62)
VCH_4= Quantity of methane realised (methane yield)

E.Mathematical equations used to analyse the results

Standard gas equation

$$PV = m\rho T \quad (1)$$

$$R = c_p - c_v \quad (2)$$

Constant volume process (V = constant)

$$\frac{P_2}{P_1} = \frac{T_1}{P_2} \quad (2)$$

Constant pressure process (P = constant)

$$\frac{r_2}{r_1} = \frac{V_2}{V_1} = \frac{T_1}{T_2} \quad (3)$$

Constant temperature process (T = constant)

$$\frac{P_1}{P_2} = \frac{V_2}{V_1} = \frac{\rho_1}{\rho_2} \quad (4)$$

Actual density of biogas

$$\rho_{CH_4\,act.} = \rho_{CH_4\,std.} \times \frac{P_{act}}{P_{std}} \times \frac{T_{std}}{T_{act}} \quad (4)$$

Actual Energy content of given biogas

$$H_{u(actual)} = \frac{V_{CH_4}}{V_{total}} \cdot \rho_{CH_4\,act.} \times H_{u,n} \quad (5)$$

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III. ANALYSIS OF RESEARCH RESULTS

Following the methods described under section 2.3 above, results obtained are as shown in Table 1.

Variables	Cow dung Day 1	Cow dung Day 2	Pig dung Day 1	Pig dung Day 2
Time am/pm	11:22am	1:36pm	11:35am	1:50pm
Temperature ^0C	32.6	27	33.7	26
Humidity %	65	52	71	50.1
CH_4%	52	44	59	53
CO_2%	30	33	35	39
Others (H_2S, N_2, H_2&etc.) %	18	23	6	8

Table 1. Yield from Cow Dung and Pig Dung Over 2 Days

A. *Yield from the selected substrate materials*

As shown in Table 1, the substrates collected include cow dung (animal 1) and pig dung (animal 2) sourced from University of Ibadan's teaching and research farm in Ibadan, Oyo State, South-Western Nigeria. For day 1, at 32.6^{0}C and 65% humidity, an amount of 52% methane (CH_4) and 30% Carbon dioxide (CO_2) and 18% minor gases were collected from the cow-dung digester, while at 33.7^{0}C and 71% humidity, an amount of 59% methane (CH_4) and 35% Carbon dioxide (CO_2) and 6% trace gases were collected from the pig-dung digester. Similarly, for day 2, at 27^{0}C and 52% humidity, an amount of 44% methane (CH_4) and 33% Carbon dioxide (CO_2) and 23% trace gases were collected from the cow-dung digester, while at 26^{0}C and 50.1% humidity, an amount of 53% methane (CH_4) and 39% Carbon dioxide (CO_2) and 8% minor gases were collected from the pig-dung digester. From the results obtained, it could be seen that for the two (2) days, CH_4 and CO_2 realised were higher in pig-dung slurry, compared to that of cow-dung. At the same time, the minor gases found in pig-dung was much lower, compared to what was found in the cow-dung.

Component	Composition
Methane (CH_4)	40 – 75%
Carbon dioxide (CO_2)	25 – 55%
Hydrogen Sulphide (H_2S)	50 – 5,000ppm
Water (H_2O)	0 – 10%
Nitrogen (N_2)	0 – 5%
Oxygen (O_2)	0 – 2%
Hydrogen (H_2)	0 – 1 %

Table 2. Typical Composition of Biogas for Comparison with Yields from Selected Substrates (Source: Rec, 2018)

B. *Comparison of yield with standard composition*

By comparing the yield ($CH_4$and CO_2) obtained from the digested cow-dung and pig-dung with a typical standard composition (Table 2), it could be seen that they both confirm.

C. *Relationship between the climatic conditions and yields obtained*

Furthermore, having made use of the expressions and equations stated under sections 2.4 and 2.5; results obtained are as shown in Table 3. From Table 3, it could be seen that both total pressure Pt and temperature T have a directly proportional relationship, such that as the temperature increased, the total pressure Pt also increased and vice-versa. From the methane yields, for the two days investigated, it could be seen that as the volume (quantity) realised increased, the corresponding energy (calorific value) increased. In terms of density, this was lower on day 1 of collection (0.62) for both substrates (cow-dung and pig-dung) than that of day 2 of collection (0.63).

IV. ECONOMIC ANALYSIS OF BIOGAS

The location of the biogas plant was considered, and this was located on the University of Ibadan Teaching and Research farm. This area focuses on agricultural activities, especially rearing of animals, meaning a cheap supply of the chief materials for biogas production (animal dungs, such as cow dungs, pig dungs, chicken wastes, *etc*.).

Variable (vsTime)	Pa (mbar)	Pg (mbar)	Pt (mbar)	Tstd (K)	T (^{0}C)	T (K)	Hu,n KJ/Kg	Pstd (mbar)	ρCH_4 Std	ρCH_4 act	VCH_4	Hu (KJ/m³)
Cow-dung Day 1; 11:22am	950	28	97800	273	32	305	50000	1013	0.72	0.62	0.52	16177
Day 2; 1:36pm	950	21	97100	273	27	300	50000	1013	0.72	0.63	0.44	13817
Pig-dung Day 1; 11:40am	950	28.7	97870	273	33.7	306.7	50000	1013	0.72	0.62	0.59	18266
Day 2; 1:50pm	950	20	97000	273	26	299	50000	1013	0.72	0.63	0.55	17311

Table 3. Obtained Values for Pressure, Temperature, Energy (Calorific Values), Density and Methane Contents from the Selected Substrates

Agricultural waste	Quantity
Cow dung	20kg
Pig dung	20kg
Total	40kg

Table 4. Amount of Input

The yield of the mixture of animal dung and water was left for 21 days, after which biogas was formed. The production time of the slurry was observed to be 20 days, after which it is recharged with compost already prepared and left for 21 days to ensure continuous supply of biogas.

Biogas retention period = 21 days

Biogas production period = 20days

Number of times of recharge = $\frac{365\ days}{21}$ = 17

From the research conducted, an input of 20kg of the cow dung yielded 52% of methane. Converting this to kg means: 52% * 20kg = 10.4kg

Similarly, an input of 20kg of the pig dung yielded 59% of methane, which in kg = 11.8kg. This is shown in Table 5.

	Agricultural waste	% methane realised	Amount of methane produced (kg)
Biogas	Cow dung	52	10.4
	Pig dung	59	11.8
	Total		22.2

Table 5. Amount of Biogas Produced

Estimating the volume of biogas generated in a year as shown in Table 6. The biodigester is recharged every 21 days, meaning 17 times within a year.

	Agricultural waste	Amount of Methane produced in 21 days (kg)	Amount of methane produced (kg)
Biogas	Cow dung	10.4	178.5
	Pig dung	11.8	200.6
	Total	22.2	379.1

Table 6. Annual Amount of Biogas Produced

The capital cost for establishing the biogas plant is shown in Table 7. A family size with an average of 5 members was considered. The plant is located close to the source of animal dungs with no transportation cost.

Item	Cost ($)
Purchase and installation of biodigester	85.71
Tubing	11.43
Hose	1.43
Design and construction	5.71
Total	104.28

Table 7. Cost of Biogas Production

Average daily gas usage for heating by an average family of 5 = 0.3kg
Annual gas usage = 109.5 kg
Cost of LPG gas = 0.98 $/kg
Therefore, the annual cost of purchasing LPG gas is:

$$= 109.5 \times 0.98$$
$$= \$107.31$$

With the production of biogas, 379.1 of methane gas is produced annually, resulting in an annual saving of 269.6 kg of methane gas. Therefore,

Total cost of biogas production = $104.28
Total value of biogas produced =379.1 × 0.98= $371.52
Total amount saved at the end of the first year =

$$371.52 - 104.28 = \$267.24$$

V. CONCLUSION

Generation of biogas from animal dungs (cow and pig), collected from University of Ibadan's teaching and research farm have been investigated. The substrates were collected, processed and subsequently analyzed for the presence of methane and carbon-dioxide majorly. Based on results obtained, the following conclusions can be drawn:

The use of pig-dung as a substrate material for biogas generation yielded higher and better results than cow-dung. The higher the yield of methane (CH_4), the higher is the obtainable energy (calorific values) and vice-versa for the examined substrates, meaning that a directly proportional relationship exists between biogas (methane) and calorific value (energy content). Furthermore, for the two substrates examined, yields of CH_4 and CO_2 were higher in day 1 of results collection (22nd day of digestion) than day 2 of results collection (23rd day of digestion) and yields of minor gases were higher in the day 2 than day 1. It can thus be said that after fermentation, as the retention time was prolonged, the CO_2/CH_4 contents decreased while the trace gases contents increased for the 2 substrates.

The economic analysis of the methane yield from both pig and cow dung showed potential savings from the purchase of gas for heating. Biogas production is a potential source of energy that is economically viable, leading to little or non-dependence on fossil fuels. Therefore, as the evaluation of biogas generation for methane yield proved to be economical, biogas generation may be useful as an alternative source of energy in Nigeria.

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