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Cattle dung biogas as a renewable energy source for rural laboratories

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ABSTRACT: The paper investigated the use of cattle dung as an alternative and renewable energy source for Nigerian rural laboratories. The non-availability of electric power supply in most Nigerian rural areas has made it difficult for the researchers in the areas to utilize their wealth of knowledge and experience for reasonable and developmental scientific researches. A digester made of mild steel of radius 0.3m, length 0.6m and 2mm thickness was used based on the design pressure of 1.7MN/m² (16.93 bars). Both pressure and thermometer gauges were installed on the top surface of the digester. Pressures and temperatures were monitored at 12 noon daily, for two weeks. The biogas was compressed in to a gas cylinder after being refined through aqueous sodium hydroxide using a sooter. The compressed gas was then tested for combustion. The results indicated that cattle dung had a short hydraulic retention time of 13 days for combustion of the biogas to occur. Chromatography results showed that 56.20% CH₄, 39.51% CO₂, 0.53% NH₃, 1.92% CO, and 1.84% H₂S were the constituents of the unrefined biogas while the refined one comprised 70.29% CH₄, 27.82% CO₂, 0.00% NH₃, 1.55% CO, and 0.34% H₂S. The calorific values of the raw and refined biogas were 19.15MJ/m³ and 22.62 MJ/m³ respectively.

Key words: biogas, renewable, energy, laboratory, rural, development

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INTRODUCTION

The concept of judicious energy use with little or no wastage has been the problem of man for ages. The so called wastages are always in some other forms of energy due to conversion from one form to the other. These wastes are always not required at the point of their production and therefore pose serious challenges to human health, environment and economic development (Mshandete and Parawira, 2009). It is believed that this has been the cause of global energy crises. This energy conversion crisis is not peculiar to any nation but has inverse

relationship with the level of development of the country concerned. The challenges of the energy crises and attempt to find ways of minimizing them have been the causes of competition among nations and sometimes the causes of war between one nation and another or between one nation and nations with common interests.

To arrest these energy crises, attempts have been made to explore all possible sources of energy which include renewable and non-renewable resources. Non-renewable energy sources are

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those which are depleted with use; these include fossil fuels like petroleum and coal. Besides, fossil fuel emits large amount of greenhouse gases (GHGs) such as carbon dioxide, sulphur dioxide and other pollutants during usage. This phenomenon is principally responsible for global warming and consequently climate change. On the other hand, renewable sources of energy are those that cannot be depleted with time as they are used but instead get refurnished and have negligible or low carbon dioxide emission to the atmosphere. Some of the examples are solar energy, hydropower energy and biogas energy.

Biogas, being a renewable energy source, has a lot of applications ranging from domestic use like cooking to industrial such as generation of electricity and even as fuel for vehicular use. 2008 study of the United States collected by the children and science magazine revealed that methane biogas production would be sufficient to produce 100 billion kilowatt hours which would be enough to power millions of homes across America. The study further stated that methane biogas has been tested to reduce 99 million metric tons of greenhouse gas (GHG) emission or about 4% of the GHGs produced by the United States (Amanda and Webber, 2008). This is a mitigation of GHGs emissions of methane and global warming. Ezekoye and Ezekoye (2009) reported that raw biogas contains about 55-65% methane, 30-45% carbon dioxide, traces of hydrogen and fractions of water vapour. Beddoes *et al*, (2007) reported that biogas has the heating value of 212MJ/m³. On their own, Vijay, *et al* (2006) worked on biogas purification and bottling. The purification process removed carbon dioxide, hydrogen sulphide and moisture through water scrubbing to upgrade the biogas. This upgraded biogas was tested as fuel in four stroke three cylinder engine car and proved to be a good alternative

energy source to compressed natural gas (CNG). They also asserted that when this technology is made in a large scale it would ensure sustainable development and energy security with employment generation in the rural areas using cattle dung and biomass. Prasad (2012) worked on biogas production from cow dung, pig manure and fowl droppings at room, mesophilic and thermophilic temperatures. He reported that the mixture of cow dung and pig manure had the highest biogas production at mesophilic temperature while cow alone recorded the highest volume of biogas at room temperature. Biogas production was relatively low at thermophilic temperature. Narayani and Priya (2012) also studied the production of biogas at ambient temperature from the co-digestion of fruit wastes with rice husk and cow dung. They found out that the mixture of 75% fruit waste and 25% cow dung produced biogas with highest methane content. Diboma and Bikai (2013) reported that biogas production from cattle dung followed a three successive phases in the incubation period of 66 days. The first phase was the latency stage characteristic of low biogas production, lasted till the 11th day. The second phase recorded exponential biogas production between the 12th and 31st day while the last stage witnessed low biogas production. They also reported that chromatographic results using thermal conductivity detector (TCD) showed that the biogas contained 56.4% methane on the 17th day, 61.51% on the 34th day and 59.6% on the 51st day of digestion.

Adegun and Yaru (2008) reported that among the substrates investigated, cattle dung was the best for biogas production. Yaru (2007) opined that animal wastes were better substrates than plant wastes.

Utilizing biogas in the laboratories and workshops in our educational institutions especially at post primary and tertiary levels

could solve the problem of energy requirement in these areas and therefore enhances research and development. Besides, this would stem the falling standard of education with respect to science and technology based courses. The objective of this paper therefore is to produce biogas for laboratory use as it is cheap, readily available renewable energy source and can be easily generated in rural areas. It can also serve as a means of environmental sanitation and employment generation.

Theory of biogas production

Biogas is a product of metabolism of methane bacteria and is created when bacteria decompose a mass of organic material anaerobically. The bacteria can only work and produce the biogas if the substrate is sufficiently bloated with water of at least 50% (Vindin et al, 2008). It is produced from a three-phase process; namely hydrolysis, acid-forming (acidogenesis) and methane-forming (methanogenesis). In the hydrolysis

phase extracellular enzymes secreted break down the complex organic substances into simple soluble molecules. The acidogenesis stage involves the breakdown of the simple molecules to volatile fatty acids (VFAs) such as propionic and butyric acids, carbon dioxide, ammonia and hydrogen while the methanogenesis phase converts the VFAs to methane, carbon dioxide, nitrogen, and hydrogen sulphide. Fusarium fungi and staphylococcus bacteria are involved in the anaerobic digestion process (Itodo, 2007). Enzymatic activities of micro-organisms responsible for the bioconversion of substrates to biogas are affected by temperature. Psychrophilic temperature range being 20°C and below, the mesophilic temperature range, 20-40°C and the thermophilic temperature range is 40-65°C. Thermophilic temperature range allows for shorter retention time and because of the high temperature of this phase there is little or no room for pathogens to thrive (Yadvika, et al, 2004).

MATERIALS AND METHOD

Design of the Digester

(a) Volume of the digester

The volume of digester was obtained from equation (1)

$$V_T = \frac{\pi d^2 h}{4} \quad (1)$$

Where: V_T = Total Volume of the digester
 d = diameter of the digester (0.3m)
 h = height of the digester (0.6m)

(b) Maximum pressure in the digester

The calculation for the expected pressure was based on the following assumptions:

- the biogas to be produced would comprise principally methane 60% and Carbon dioxide 40% by volume.

- it was assumed that the substrate would occupy half the total volume of the digester.
- that a maximum temperature of 40°C (313K) was attainable in the digester
- 1kg of cow dung can produce 0.037m³ of biogas (Rouf and Haque, 2008)

The maximum expected pressure therefore is given by equation (2):

$$P_T = P_{CH_4} + P_{CO_2} \quad (2)$$

where: P_T = maximum expected pressure

P_{CH_4} = Partial pressure of methane

P_{CO_2} = Partial pressure of Carbon dioxide

$$P_{CH_4} = \frac{2M_{CH_4}R_0T}{V_T} \quad (3)$$

$$P_{CO_2} = \frac{2M_{CO_2} R_0 T}{V_T} \quad (4)$$

R_0 is the Specific gas constant (J/K)

T is the maximum absolute temperature attainable (313K)

M is the molecular mass of the component gas
For Carbon dioxide, $M = 44\text{kg}$ and Methane, $M = 16\text{kg}$

Hence, both P_{CH_4} and P_{CO_2} were estimated to be 0.14MN/m^2 and 0.33MN/m^2 respectively using equations (3) and (4). From equation (2) P_T was estimated to be 16.93 bar.

Design Calculation for the Thickness of Digester Vessel (Mild Steel)

Based on the factor of safety of 2, the thickness of the vessel was designed as follows:

$$\sigma_1 = \frac{\sigma_y}{n} \quad (5)$$

$$t = \frac{P_T d}{2\sigma_1} \quad (6)$$

$$\sigma_2 = \frac{P_T d}{4t} \quad (7)$$

Where,

σ_1 is the allowable working stress

n is factor of safety (2)

σ_y is yield stress of mild steel (270MN/m^2)

σ_2 is longitudinal stress

A mild steel material of 2mm thickness was used for the digester.

For a thin wall pressure vessel, $\frac{r}{t} > 10$

(Gere, 2002)

$$\frac{r}{t} = \frac{.3}{2 \times .002} = 75$$

Since the ratio of the radius (r) to the thickness of the digester is more than 10 then the digester can be considered as a thin wall pressure vessel.

Biogas Generation

The digester was fed from the top. The pressure and the temperature were measured inside the digester as well as the ambient temperature. On its side at about ninety five per cent height from the bottom a valve was installed for the discharge of the biogas for collection and testing.

The digester was loaded with 8 kg of cattle dung mixed with equal mass of water and thoroughly stirred before tightening the lid of the digester. This arrangement was kept in an environment of a mesophilic temperature of not less than 25°C . The biogas production was always detected by connecting a hose through the discharge valve into a container containing water. Bubbling of the water usually confirmed the onset of the gas production.

The biogas was equally tested daily for combustion. On the 13th day, it burned with blue flame. This is a day shorter than the optimum



Plate 1: Test for burning of biogas from the digester

hydraulic retention time (HRT) of 14 days for biogas production from cow dung as reported by Vivekanandan and Kamraj (2011). They also reported that 15 days HRT is the best for maximum production of biogas from cattle dung. A shorter HRT would result in accumulation of Volatile fatty acids (VFA) and longer HRT other than 15 days would not make the digester

components fully utilized. Plate 1 above shows the burning of the biogas from the digester. The burner was connected to the valve of the digester through a rubber hose. The gas burnt as a rich mixture of air. The digester pressure and temperature and the ambient temperature of the environment were daily monitored to 12 noon and this is shown in Table 1.

Table 1: Digester Pressure, Temperature and Ambient Temperature for 14 days retention time

Number of days (Retention time)	Digester pressure (bar)	Digester temperature (°C)	Ambient temperature (°C)
1	0	30	30
2	.005	28	30
3	.005	30	31
4	.007	29	34
5	.007	28	32
6	.05	28	31
7	.07	29	31
8	.08	28	31
9	.085	29	32
10	.09	28	27
11	.10	29	32
12	.10	29	30
13	.11	29	30
14	.15	26	28

Collection of Biogas from Digester

The biogas, after being tested for combustion, either directly or through a burner, was then collected in to a gas cylinder as shown in the Plate 2.

The arrangement was such that the biogas was made to pass through a hose from the discharge valve of the digester to a sooter which is a pump like mechanism by which the biogas was compressed to the gas cylinder. The biogas from the digester was first passed through a solution of sodium hydroxide for the absorption of carbon dioxide and hydrogen sulphide components of the biogas and through a filter

dryer to (dehydrate) absorb the moisture that may have accompanied it before passing to the sooter and then compressing it in to the gas cylinder.

Equations (7a) and (7b) show absorption reactions of carbon dioxide and hydrogen sulphide respectively as the biogas was passed through aqueous sodium hydroxide.

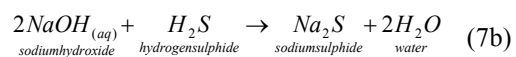
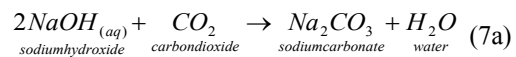




Plate 2: A picture showing the collection of biogas from the digester

Confirmation of the Biogas in the Cylinder

The biogas was then tested for combustion from the cylinder to ascertain its status as shown in the Plate 3. The hose was connected to the gas valve of the gas cylinder at one end and the other end to the burner. As the valve was opened the biogas flowed through to the burner at the other end and burned with a blue flame.



Plate 3: A picture showing the combustion of biogas from the cylinder

Gas Analyses

Gas Chromatography (GC)

The chromatography system is composed of the gas chromatography equipment and a recorder for plotting chromatographs. The experiment was conducted using thermal conductivity detector (TCD) at Multi- Environmental Management Consultants Ltd, Igbe, Ikorodu, Lagos, Nigeria. The equipment model is Hp6890 with HP ChemStation and Rev. A09.01 (1206) software. The carrier gas was helium at 20ml/min flow rate with the inlet temperature of 145°C while the inflow of the carrier gas was 26ml/min in the column with dimensions and type of $30m \times \frac{1}{8} mm \times 0.85 \mu m$ and Heysep DB 100/120; Deerfield, Illinois respectively. The oven temperature was programmed at 140°C in 6 min and ramped at 50°C/min to and maintained at 175°C.

The results for raw and refined biogas are shown in Tables 2 and 3 respectively.

Table 2: Chromatograph results for the raw biogas (un-refined product)

Gas	Percentage
CH ₄	56.20
NH ₃	0.53
CO	1.92
H ₂ S	1.84
CO ₂	39.51

Table 3: Chromatograph results for the raw biogas (refined product)

Gas	Percentage
CH ₄	70.28
CO	1.55
H ₂ S	0.34
CO ₂	27.82

Gas Calorific value determination

The calorific values of the biogas samples were determined using the open flame calorimeter. The principle is such that specific amount of the biogas was burnt in an open flame with the gas calorimeter Junkers. The heat of combustion released by the burner was transferred to a heat absorbing air through a heat exchanger which resulted in the temperature rise of the fluid. This temperature increase was a measure of the calorific value of the gas.

Table 4: Calorific value for un-refined and re-fined biogas

S/N	Sample	Calorific Value (MJ/m ³)
1.	Raw Biogas	19.5
2.	Refined Biogas	22.62

RESULTS AND DISCUSSIONS

The raw and the refined biogas from the digester burned with blue flame which confirmed that biogas is really a source of energy from biodegradable materials. See Plates 1 and 3. In addition, the test for combustion in this work showed that the retention time for the biogas produced was 13 days. This retention time is the time taken to produce a combustible biogas. As shown in Table 1, the digester gauge pressures monitored for the 14 days rose from zero on the first day through to 0.15 bars on the 14th day of incubation. None of these pressures went even close to the expected maximum design pressure of 16.93 bars as the design temperature was not attained. This equally confirmed that

the digester was safe for the work. The ambient temperatures were also observed to be higher than those of the digester for the same period under discussion. This was because the digester was not placed in a controlled environment and so the flow of air in the laboratory over the digester would have affected heat transfer to its surrounding. From Tables 2,3 & 4; it is depicted that the raw (unrefined) biogas comprised 56.20% CH₄, 39.51% CO₂, 0.53% NH₃, 1.92% CO, and 1.84% H₂S while the refined one was composed of 70.29% CH₄, 27.82% CO₂, 0.00% NH₃, 1.55% CO, and 0.34% H₂S. The calorific value of the raw biogas was 19.15MJ/m³ and the refined biogas was 22.62 MJ/m³.

CONCLUSION

The biogas from cow dung was generated, tested for combustion, analysed using gas chromatography and the calorific values

determined. Its use will definitely encourage research in laboratories especially in the rural areas.

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