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Evaluating the quantity of Biogas and its Calorific value in University of Maiduguri Student's Hostels, Nigeria

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ABSTRACT

The demand for sustainable energy in Nigeria is increasing due to population and developmental growth. The persistent energy crisis in Nigeria has weakened industrialization in the country. This has significantly undermined efforts to achieve sustained economic growth, increased competitiveness of indigenous industries in domestic, regional and global markets as well as employment generation. The realization of this fact necessitates the need for the nation to identify and promote the development and utilization of alternative sources of energy such as biomass to augment the existing ones. This study presents the potential of sewage generated and deposited at the University of Maiduguri for biogas production using experimental digester fabricated from locally sourced materials, to determine the quantity of biogas produced with its calorific value. A 500ml glass container was used as the digester. A total of 15 samples were collected in the digesters labeled A1-A5, B1-B5 and C1-C5 for accuracy. Each digester was fed with 406.25ml sewage according to the design considerations and the initial pH values checked on daily basis with a retention time of 30 days. The data obtained were recorded, analysed and presented using Microsoft Excel application. The results revealed that this Sewage has a potential of producing7981.959245±479.433m^3 biogas daily with a calorific value of 19.5MJ/kg (4657.19 kCal/m^3). This confirmed that sewage generated at University of Maiduguri could be used as resource to obtain biogas which is safer and cheaper. Use of the sewage for biogas production will also serves as a waste management source for the University.

Keywords: Biogas; Energy; Waste; Sewage; Calorific value.

1.0 INTRODUCTION

Based on the fact that the demand for energy is growing by the day globally, the need for exploring and exploiting new sources of energy which are renewable as well as environmentally friendly cannot be overemphasized. Biomass technology offers an attractive platform to utilize certain categories of biomass for meeting both urban and rural energy needs if it is properly harnessed. There exists a huge potential for the successful deployment of biomass energy in Nigeria, most especially in the rural agricultural areas [1].

It is estimated that Nigeria can produce 6.8million m^3 of biogas daily from fresh animal waste, as 1kg of fresh animal waste produces approximately 0.03m^3 gas and Nigeria generates about 227,500 tons of fresh animal wastes per day. Animal waste accounts for 61million tonnes/year of Nigeria's energy reserve. The most common domesticated livestock production in Nigeria comprises cattle, pigs, goats, sheep and chickens. The

wastes from these animals are one of the most suitable materials for biogas production through the process of anaerobic digestion. Although biogas technology is not common in Nigeria, various research works on the technology and policy aspects of biogas production have been carried by scientists in the country [2][3].

Biogas refers to a mixture of gases produced by the decay or fermentation of organic waste (like sewage, kitchen waste, animal manure, food scraps and plant material). When all of this organic waste is allowed to decay in the absence of oxygen, methane, carbon dioxide and some other gases are produced. Methane is the most important of all the produced gases because it is a very valuable fuel. Methane is a popular natural gas that is used for heating, lighting and cooking purposes in the home [4]. Biogas is formed in nature by the biological degradation of biomass under anaerobic conditions. The naturally occurring biogas escapes into the atmosphere where its main component, methane, is a significant contributor to global warming. Biogas is also an energy carrier and this has been recognised for hundreds of years, if not longer. Used as a simple fuel, biogas has been, and still is, used for cooking, heating and lighting at small scale in millions of units around the world [5].

The calorific value or heating value of a fuel is defined as the energy liberated by complete oxidation of unit mass or volume of a fuel. It is expressed in kJ/kg for solid and liquid fuels and kJ/m^3 for gases. Basically, all fuels contain carbon and hydrogen. During combustion process, carbon burns to carbon dioxide and hydrogen reacts with oxygen and forms water vapor. The magnitude of calorific value depends on the phase of water vapor in the products of combustion. A higher heating value, HHV or gross calorific value is obtained when the water formed by combustion is completely condensed. The lower calorific value (LHV) or net calorific value is the amount of heat released by complete combustion of unit quantity of fuel, when vapor carries its heat of vaporization [6].

2.0 LITERATURE REVIEW

Many studies have been carried out on biogas production from different biomass. [7] carried out a study to determine the biogas potential of the sewage at the Primary Sedimentation Tank (PST) at the Kwame Nkrumah University of Science and Technology (KNUST sewage treatment plant and its potential power production. The PST has total design capacity of 63.65m^3 and the volume of sludge displaced was estimated to be 17.86m^3. The estimation of the biogas potential of the quality of the sludge was analyzed and the result shows that an average liter of biogas produced is 525 liters (0.525m^3) of biogas /kg. [8] considered the prospect of generating biogas from human waste for cooking in the halls of residence in the University of Ibadan. Five 2 litres and two 3.5 litres plastic containers were used as a batch-type digester and a urine bag as gas holder. The digesters were sealed using top bond glue and the openings around the gas holder inlet was sealed with a mixture of smooth sawdust and top bond glue. Shaking the containers was manually done to agitate the system. The batch experiment yielded 0.00227m^3 of biogas, out of which 0.0013 m^3 is expected to be methane gas. A 540m^3 yearly production of biogas is projected. [9] investigated on two treatments consisting of 6kg of cow dung in 13litres of water (A) and 6kg of cow dung mixed with 0.5kg of food waste and 0.5kg of paper all in 13litres of water (B). The retention period was sixty days. Results obtained show that on the average treatment A generated 14.29grams (0.0119m^3) and treatment B generated 15grams (0.0125m^3) of combustible gas per day. Ignition test conducted on the biogas generated produced luminous blue flame. Also, gas analysis was carried out to know the percentage composition of each constituent in the generated biogas. It was discovered that the combustible biogas has a methane content of 60%. [10] carried out a research using the batch system digester with a capacity of 0.612m^3 and 0.24m^3 as gas holder. Laboratory and field analysis of the cow dung were carried out, followed by daily records of the volume of gas generated. The result of the research shows that the daily volume of biogas generated was 0.27915m^3 on the average, with a maximum daily record of 0.5165m^3 before declining after 73 days of the experiment and a cumulative volume of 77.62m^3 in 52 days of methane production. The sustainability of cooking trial utilized an overall volume of 1.17m^3 of the methane

gas in 1hr to cook 1.5 kg of rice with ingredients and 0.553m^3 in 1:35 hrs to boil 20 liters of water. [11] carried out investigation to determine the calorific value of biogas obtained from the biomass of manure from *Cavia porcellus* (guinea pig), for which a biodigester model Intermediate Bulk Container (IBC) with a capacity of 1m^3 was designed and built. 459kg of *Cavia porcellus* manure (guinea pig) was used, the weekly load was 233L of guinea pig mixture with water in a 30-day retention time. At the end of the process, biogas was obtained with a calorific value of 6527.3kcal /m^3, corresponding to 72.3% methane with a volume of 1m^3. [12] carried out an experimental work for the production of Biogas from poultry waste water. The Poultry waste was collected from farm near Nagercoil at Kanyakumari District. The experiment was carried out for 36 days to monitor the performance. Various parameters like pH, TS, were checked for every 24hours. The Production of biogas was measured by water displacement method. The methane content was analyzed by gas chromatography test. 12.4 litres of biogas was produced from 20 litres of Poultry wastewater.

Though, previous studies used Slurry of human waste, kitchen waste, cow dung, poultry droppings, sewage from treatment plant and co-digestion of cow dung with poultry droppings with known mix ratio for biogas production, the sewage generated and deposited at the University of Maiduguri student's hostels contains mixture of human waste, laundry waste and other waste materials with unknown mix ratio has not been investigated on its potential for Biogas production is not carried out extensively, and none in Maiduguri. Also, water displacement method was used in estimating the volume of biogas in most of earlier work, the present study uses U-tube manometer in estimating the volume of biogas.

3.0 MATERIALS AND METHODS

The data obtained in this study are recorded, analysed and presented using Microsoft Excel application.

3.1 The Study Area

The study area is University of Maiduguri, Maiduguri Borno state. University of Maiduguri is located at latitude $11^{\circ}30'00''N$, longitude $13^{\circ}00'00''E$ and houses about 40,000 people; students, staff and business owners [13]. The sewage deposit is situated behind the works department of the university. This waste is channel to the deposit site from the student hostels of the University by a well designed sewage system shown in Figure 1.



Figure 1: Deposit site of the sewage

3.2 Materials used for Experimentation

The materials for this research designed to provide the anaerobic environment essential for the bacterial activity that produces the biogas are : 500ml glass container, Cork, 500ml measuring cylinder, Thermometer, U-tube manometer, Flame lighter, Digital pH meter, Motor cycle tube, Silicon gum, Drip giving set, Junkers gas Calorimeter, 30l gallon and Digital weighing machine.

3.3 Methods

The quantity of the biogas produced and its Calorific value are determined as follow:

3.3.1 Sample Collection

The sewage samples were collected from the sewage system of the University of Maiduguri (Figure 2). Five (5) samples each is collected from the first manhole (A1-A5), middle manhole (B1-B5) and the final deposit site (C1-C5).



Figure 2: Samples being collected at Points A, B and C

3.3.2 Flammability Test

The presence of methane is tested by lighting flame on a burner connected to the tip of the experimental digester and the digester for gas collection as shown in Figure 3. The gas that comes out from digester would be checked whether it burns and the color of the flame also checked [14].



Figure 3: Flammability Test

3.4 Quantity of Biogas Potential

The quantity of biogas produced in volume will be obtained using the U-tube manometer as shown in figure 4. The pressure of the biogas is first obtained and converted to volume using the expressions below:

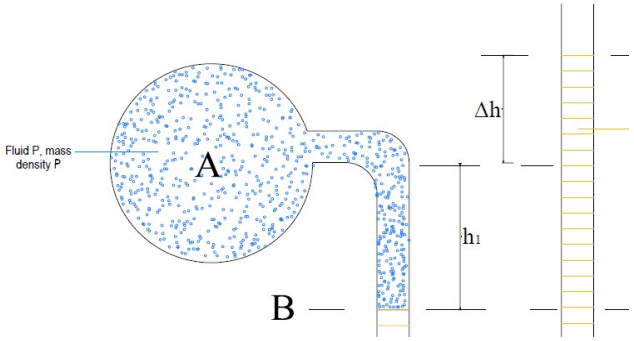


Figure 4: U-tube manometer [15][16]

$Pressureinacontinuousstaticfluidisthesameatanyhorizontallevelso$:

$PressureatB = PressureatC$

$P_B = P_C$ (1)

$PressureatB = PressureatA + Pressureduetoheighth_1offluidbeingmeasured$

$P_B = P_A + \rho g h_1$ (2)

$PressureatC = PressureatD + Pressureduetoheighth_2ofmanometerfluid$

$P_C = P_D \mid \rho_{man} g h_1$ (3)

But; $P_D = Atmoshericpressure = Zerogaugepressure$

$P_C = 0 + P_{man} g h_2$ (4)

$P_A + \rho g h_1 = \rho_{man} g h_2$ (5)

$P_A = (\rho_{man} g h_2 - \rho g h_1) kPa$ (6)

Since $h_2 - h_1 = \Delta h$

$P_A = g \Delta h (\rho_{man} - \rho_{bio}) kPa$ (7)

Where P_A the pressure of the fluid is in kPa, g is acceleration due to gravity, Δh is the change in height, ρ_{man} is the density of manometer liquid and ρ is the density of the fluid [15].

Boyle's law is an experimental gas law that describes how the pressure of a gas tends to increase as the volume of the container decreases. Boyle's law states that the absolute pressure exerted by a given mass of an ideal gas is inversely proportional to the volume it occupies if the temperature and amount of gas remain unchanged within a closed system [14].

Mathematically, Boyle's law can be stated as:

$P \propto 1/V$ Pressure is inversely proportional to the volume (8)

Or

$PV = k$ Pressure multiplied by volume equals some constant k (9)

Where P is the pressure of the gas, V is the volume of the gas, and k is a constant.

The equation states that the product of pressure and volume is a constant for a given mass of confined gas and this holds as long as the temperature is constant [14]. For comparing the same substance under two different sets of conditions, the law can be usefully expressed as:

$P_1V_1 = P_2V_2$ (10)

Therefore, $P_{bio} = g\Delta h(\rho_{man} - \rho_{bio})kPa$ (11)

The volume of the biogas produced is obtained using equation 10;

$P_{bio}V_{bio} = P_{atm}V_{sew}$

Therefore, $V_{bio} = \frac{(P_{atm}V_{sew})}{P_{bio}}$ (12)

A margin of error (MoE) is to be applied on the V_{bio} as shown in equation 13;

$MoE = 1.98\frac{\sigma}{\sqrt{n}}$ (13)

Where σ is the standard deviation and n is the sample size [17]

3.5 Calorific Value of Biogas Produced

For the purpose of calorific value determination, a large digester of 30l capacity is fabricated with locally sourced materials and a motor cycle tube is used to collect the gas. The experimental procedure for biogas production is repeated with the setup as shown in Figure 5.



Figure 5: Gas collection for calorific value determination

The experiment for the calorific value determination is performed with a Junker's gas calorimeter at the thermodynamics laboratory of Ramat Polytechnic, Maiduguri, Nigeria as shown in Figure 6. The calorific value of the biogas produced is obtained using Equation 14 as presented by [18].

$$CV = \frac{m_w C_w (T_o - T_i) + m h_{fg}}{m_g} \quad (14)$$

Where, T_i is cooling water inlet temperature, T_o is cooling water outlet temperature, C_w is specific heat capacity of water, m_w is mass flow rate of cooling water, m is rate of mass of condensate collected in a pot, h_{fg} is latent heat of water at atmospheric pressure, m_g is mass of gas



Figure 6: Calorific value measurement using Junker's gas calorimeter

4.0 RESULTS AND DISCUSSION

4.1 Flammability Test

The testing for the presence of biogas started on day 1 after setup. It is observed that the gas coming out of the digester will turn off the burning flame when brought close to the burner. All the samples sustained the burning flame on the 6th day when a colorless burning flame was obtained.

4.2 Design of Experimental Digester

The experimental digester is designed in accordance with the design characteristics as reported by [18] and basic design considerations for digester construction by [19].

The experimental digester for this study is fabricated using locally sourced materials. A 500ml glass container with a cork sealed with glue is used as the digester as shown in Figure 6.



Figure 7: Experimental digester for the study

4.3 Setting up of Apparatus

The U-tube manometer used to measure the pressure of the gas produced is also fabricated from locally sourced materials. The digester is connected directly to the U-tube with a drip giving set which allows the produced gas pressure to enter the U-tube manometer as shown in Figure 8.

A total of 15 samples are collected in the digesters labelled A1-A5, B1-B5 and C1-C5. Each of the digester is fed with 406.25ml sewage and the initial pH values checked. The samples are placed on a table under ambient temperature and the evolvement of biogas monitored. After biogas is detected, each of the digester is connected to a U-tube manometer and placed on a flat surfaced table (Figure 8). The results are taken on daily basis with a retention time of 30 days for the study.

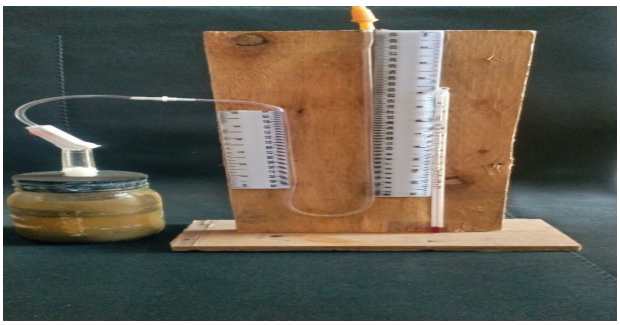


Figure 8: Setting up of Apparatus

The experimental results from the setup are presented in Figure 9

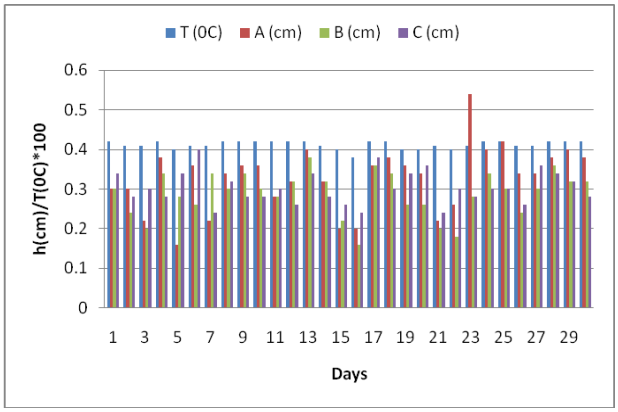


Figure 9: Average values of Δh of samples A, B and C in cm and temperature in $^{\circ}$C

The values of Δh (change in height on the U-tube manometer) in cm and T (temperature) in ^{0}C are recorded as shown in Table 1. The reading is taken for the retention period of 30days. Rainfall is recorded on days 15 and 21. The actual values of change in h on the U-tube manometer in cm and temperature are also recorded as shown in Figure 9 which is the relationship between chance in h and temperature.

It is observed that temperature which is in the range of mesophilic and thermophilic is an important parameter in anaerobic digestion process as it affects the rate of gas generation as stated by [14]. The highest height of 0.38cm was achieved at 42^{0}C while the lowest height of 0.16cm was at 38^{0}C. It is also observed that sample A3 on days 3, 15 and 23 gave unusual reading of 0, 0 and 1.3cm respectfully and samples A1, A5 and B4 gave no yield on days 5 and 16 despite the temperature, Sample A showed a very high yield on day 23 as a result of the unusually reading recorded on sample A3 at temperature of 41^{0}C and also lowest yield by sample B on day 16 at temperature 38^{0}C which was after a rainy day on day 15 (Figure 9).

4.4 Determination of the quantity of biogas potential

The gas pressure P_{bio} and volume V_{bio} are estimated using the parameters in Table 1. The results are presented in Tables 2, Tables 3 and Figure 4.

Table 1: Parameters for the calculation of pressure and volume of biogas

Parameters	Symbol	Value	Unit	Source
Density of manometer fluid	ρ_{man}	1000	kg/m^3	[20]
Density of biogas	ρ_{bio}	1.15	kg/m^3	[21]
Acceleration due to gravity	G	9.81	m/s^2	[22]
Atmospheric pressure	P_{atm}	101325	Pa	[20]
Volume of sewage used	V_{sew}	0.00041	m^3	Present study
Total volume of sewage	TV_{sew}	235870.38	L	Present study

Table 2: Estimation of the gas pressure and the volume of biogas

Sample	h(cm)	h(m)	P_{bio}(kPa)	P_{bio}(Pa)	$V_{bio}(m^3)$	$V_{bio}(m^3)$/day	$TV_{bio}(m^3)$
A	0.328	0.00033	3.21398	3213.98	0.012808	0.03152634	7436.128639
B	0.288	0.00029	2.822031	2822.031	0.014586	0.03590499	8468.924283
C	0.30333	0.0003	2.972278	2972.278	0.013849	0.03409002	8040.824814
Average	**0.30644**	**0.00031**	**3.002763**	**3002.763**	**0.013748**	**0.03384045**	**7981.959245**

Table 3: Estimation of the margin of error of volume of biogas

Samples	TVbio(m^3) (x)	x-μ	(x-μ)^2	SD (σ)	MoE
A	7436.128639	-545.830606	297931.0504	423.687	**479.433**
B	8468.924283	486.965038	237134.9482		
C	8040.824814	58.865569	3465.155214		
Mean value μ	**7981.959245**		**538531.1539**		

Since biogas production is usually measured or estimated in cubic metres over a period of time, converted and reported in energy units (MJ), results in Table 4 is converted and reported as stated by [20].

The experimental 0.00041m^3 sewage sample produced 0.13748m^3 biogas with 0.0089362m^3 of methane and 0.3038308MJ energy. 0.03384045m^3/L of biogas is produced with 21.9962912m^3 methane and 747.8739008 MJ of energy. Total quantity of biogas potential daily from 235870.38L of sewage is 7981.959245m^3 with total daily methane potential of 5188.2735m^3, total daily energy potential of 175603.103MJ and a yearly energy potential of 64334.59MJ is projected. Statistically, the quantity of daily biogas potential is 7981.959245±479.433m^3.

4.5 Determination of Calorific Value of Gas Produced

Table 4: Experimental results from Junker's gas calorimeter

S/NO	Parameters	Symbol	Value	Unit
1	Water inlet temperature	T_{in}	29	^{0}C
2	Water outlet temperature	T_{out}	64	^{0}C
3	Initial mass of biogas	$m_{initial}$	377.3	g
4	Final mass of biogas	m_{final}	364.8	g
5	Volume of heated water	V_w	1200	ml
6	Time taken for the water collection	t	60	Sec
7	Mass of condensed steam	m_s	0.03	g

Table 5: Parameters for the calorific value of biogas calculation

S/NO	Parameters	Symbol	Value	Unit	Source
1	Temperature change (T_{out} - T_{in})	ΔT	35	^{0}C	Present Study
2	Mass of biogas used (m_{final} - $m_{initial}$)	m_{gas}	12.5	g	Present Study
3	Volume of heated water	V_w	1200	ml	Present Study
4	Mass of condensed steam	m_s	0.03	g	Present Study
5	Specific heat capacity of water	C_w	4.182	kJ/kg^{0}C	[23]
6	Latent heat of vaporization of water	h_{fg}	2260	kJ/kg	[24]
7	Density of water	ρ_w	1000	kg/m^3	[20]

The calorific value of the biogas produced is 19475.52 kJ/kg (19.5MJ/kg) or 4657.19 kcal/m^3 which is obtained using parameters in Table 5 and table 6. .

5.0 CONCLUSIONS

The 500ml digester was fabricated using locally sourced materials and a U-tube manometer was used in the determination of the quantity of biogas produced. The total biogas potential daily from 235870.38L of sewage is 7981.959245±479.433m^3 while its calorific value is 19475.52 kJ/kg (19.5MJ/kg).

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