EXPERIMENTAL STUDY OF POWER GENERATION UTILIZING HUMAN EXCRETA

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Abstract: This study examines the potential of generating electricity from human excreta using biogas technology 1 m^3 biogas plant was implemented and experiment upon with human excreta collected from DELSUTH, to evaluate its performance. Anaerobic process was employed in biodegradation of excreta in digester within 30 days. The Biogas produced was scrubbed to eliminate CO_2, H_2S, and stored in gas holder. Methane yield was used to fuel modified generator to determine its output power. The results indicate 0.450 m^3 daily of biogas produced runs 3 KVA generator for 47 minutes with 1.8 KW load. The biogas generator worked perfectly without knocking during experiment period.

Keywords: biogas, human excreta, anaerobic digestion, methane, hybrid carburetor, renewable energy

1. INTRODUCTION

Nigeria faces increasing difficulty in meeting its energy demands due to rapid urbanization, population growth, and limited infrastructure [1]. Demand for electricity and other energy services continues to expand across residential, commercial, and industrial sectors [2]. However, access to reliable and affordable energy remains inadequate, slowing socioeconomic development and limiting industrial growth [3]. Concerns about the sustainability of fossil fuels have led to growing interest in renewable and alternative energy sources such as solar, hydropower, wind, and biomass. Biomass energy is derived from organic resources, including agricultural residues, animal manure, and human waste [4]. Through anaerobic digestion, such feedstock can be converted into biogas, a combustible mixture mainly composed of methane and carbon dioxide [5].

Biogas is generally made up of 50–70% methane, with smaller fractions of CO_2, H_2S, nitrogen, hydrogen, and water vapor [5]. While cattle manure and crop residues have been extensively used in biogas plants, human excreta remains largely untapped despite its abundance and suitable chemical characteristics [6]. Human waste typically consists of about 78% water, while the solid fraction account for 22% includes bacteria, proteins, salts, fats, and undigested fibers [7-8]. On average, one person could produces 0. 5kg of feces per day which is capable of yielding around 0.03 m^3 of methane gas [9]. Additionally, human excreta has near neutral pH value (7) favors microbial activity during anaerobic digestion [8-10]. Table 1 outlines the typical composition of human feces, while Table 2 shows human waste biogas related parameters. The energy potential of Nigeria's human excreta is estimated at about 8.8×10^2 MJ annually [10] which indicate that the country is hub of bioenergy potential.

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Table 1. The content of human faces [8].

S/N	Component	Amount
1.	Dry mass [at excretion]	216 g/kg
2.	Total nitrogen	11 g/kg
3.	Potassium	8 g/kg
4.	Moisture content percentage	78 %
5.	Dry matter content[at excretion] percentage	22 %

Table 2. Human waste biogas parameter [9].

S/N	DESCRIPTION OF HUMAN WASTE	VALUE	UNIT
1.	Average human waste produced per person	0.5	kg
2.	Faeces	0.02-0.028	M^3/persons/day
3.	Density of Methane	0.668	Kg/m^3 at NTP
4.	Calorific value of Biomethane	36	MJ/M^3

Besides, the numerous human waste potential, the work of [11] perceived that human excreta cannot produced enough biogas suitable for electricity generation comparable to other waste like cow dung. This perception could limit its application to cooking and heating, whereas human waste based biogas can be harness for electricity production, which is multipurpose offering greater versatility [13-14]. This research therefore focuses on designing, constructing, and experimentally testing a biogas-based electricity generation system powered by human waste, to validate its operation.

2. EXPERIMENTAL SETUP

The procedures adopted in this study are as follows: Design conceptualization of proposed model, sizing of component parts, material selection, construction, installation and testing. The design considerations for human waste biogas plant include simplicity of installation, operator's safety, material availability, quality of working life, and functional need.

2.1. Materials

Materials deployed for Human waste based Biogas Power plant (HWBP) are; Bioflex digester and gas holder is ethylene propylene. 1 m^3 Bioflex digester, 0.5 m^3 Gasholder, Hybrid carburetor, 3 KVA generator, 4" PVC pipe, 10 L bucket, 10 W pressure pump, water and human excreta.

2.2. Method used

In this section method adopted for efficient implementation of Human waste based Biogas Power plant (HWBP) are discussed. Anaerobic digestion technique was used to digest human excreta collected from individual through toilet facility. The system process involved production of biogas, purification and utilization for power generation.

2.2.1. Digester sizing

A bio digester is system or device that breaks down organic matter, such as human waste or sewage sludge in absence of oxygen. The process involve microorganism such as bacterial, it consists of inlet, digestion tank, effluent outlet and biogas outlet. According [9, 15, 16] the volumes of the digesters were calculated using equation (1).

$$VD = (TDHW + VW)\,RT \tag{1}$$

where, VD is volume of the digester in cubic meters, TDHW i amount of substrate per person in kilograms, VW is Volume of water, and RT is Retention time in days.

$$VD = (11.2 + 22.4)30$$

Volume of Digester (VD) = 1m^3

The working volume = 20% the total volume = 0.2 m^3

2.2.2. Gas storage bag sizing

The gas holder is design to accommodate biogas produced for storage and capable of delivery to utilizing device efficiently. The gas holder size is determined using the modify equation (2) as stated in [9, 16].

$$VG = \quad (BP\text{x } 0.2) \tag{2}$$

where,VG is volume of the gas holder in cubic meters.

$$VG = \quad 1 - (1\text{x } 0.2)$$

Volume of gas holder = 0.8 m^3

2.2.3. Construction of HWBPP

The construction and installation of HWBPP was carried out at the Delta State University Teaching Hospital, Oghara Delta state. The fabrication process involves marking out of required lengths, cutting and shaping out flexible membrane to desired size and shape, joining each members through sealing with gum. The construction work started with careful mapping and pegging out dimension of the digester, thereafter excavation of the digester trench which is dimension (3 x 2 x 1.5) m. The shape of the trench was done slightly bigger to the volume of the balloon to facilitate ease of installation. Furthermore, two holes of 80 cm long, 25 cm width and 70 cm deep shown in the were dig for the inlet and outlet pipes on each part. The first step consists of assembly the inlet and outlet pipe and the gas outlet to the reactor. Installation of the digester start with mounting the digester in the trench followed by connection of the inlet pipe to toilet chamber that linked to the toilet setter as shown in Figure 2. Indeed, the vertical PVC pipe was connected to the reactor through an "L" junction shape. And to ensure that there is no leakage all the parts were sealed with pipe glue and PVC sealant on all the junctions. This action requires few minutes and it is recommended to wait for at least two hours to be sure that the glue is dry. The same procedure is carried out for the gas pipe outlet. The outlet pipe was connected to a valve and all the pieces and the valve are sealed together with PVC glue. The outlet pipe was connected with 3 inches pipe and valve to the septic tank, while the gas out was connected to scrubbers with aid of 1/2ines pipe and vales. The digester was buried half way to thermally insulated and minimize the heat loss.

2.2.4. Modification of generator

A dual-fuel hybrid carburetor as shown in Figure 1, was integrated into the generator's air–fuel intake system, allowing operation on both petrol and biogas. The carburetor ensured safe and steady gas delivery at low pressure. This modification required minimal changes to the spark ignition engine.

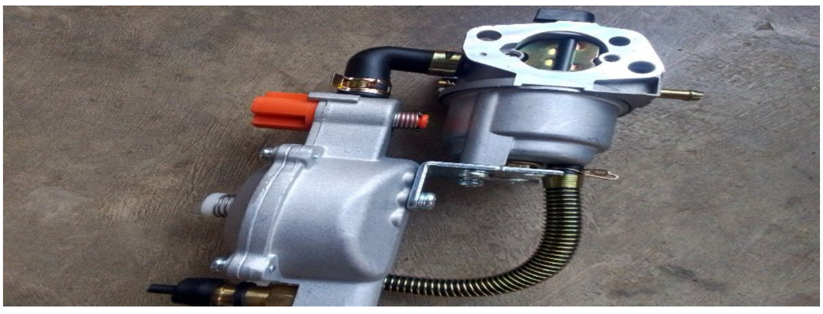

Fig. 1. Hybrid carburetor.

2.2.5. Experimental configuration

Figure 2 present the pictorial view of experimental configuration of human waste biogas production for power generation. The digester was inoculated with fresh cow dung to stimulate microbial activity. It was then fed daily with approximately 2.5 kg of human waste collected from individual using the hospital toilet facility. Produced gas was purified through two scrubbing chambers: one containing $Ca(OH)_2$ solution to absorb CO_2, and another filled with silica gel, iron filings, and steel wool to remove H_2S and moisture. The purified methane-rich gas was stored in the gas bag and supplied to the 3kva generator through a pressure pump and hybrid carburetor. The generator was connected to a distribution board supplying a constant load of 1.8 kW, including fans, lighting, and refrigeration equipment. Voltage and current outputs were monitored using a digital multimeter.

Fig. 2. Pictorial view of experimental configuration of human waste biogas production for power generation: 1-Modified generator; 2-Gas pressure regulator; 3-Inlet Valve; 4-Control Valve; 5-Bio-flex digester; 6-purification Unit; 7-gasholder; 8-hybrid Carburetor; 9-Gas host.

2.2.6. Operation of HWBPP

The process of biogas production started with inoculation of the developed biodigester with 20kg of fresh cow dung to produce bacteria that are responsible for biodegradation (BD) of organic waste. The inoculated Bioflex digester inlet was open for fresh human faeces of (2.5kg) produced from average of five (5) persons that used the hospital toilet facility daily. The Human faeces enter into the digester (bioflex balloon type) through toilet chamber connected to the toilet setter. The outlet valve was closed to allow 30% space reserved for accumulation of biogas. The substrate input channel (inlet) of the digester was sealed with rubber cover to guarantee the anaerobic condition was maintained. The digester inlet was open for continue feeding with human faeces from the toilet daily users and the accumulated sewage was retained, until biogas production is noticed. The raw biogas produced inflated the bioflex digester (balloon) as shown in Figure 3. To acertain the biogas produced from human excreta contain / or carrier of energy, (flambility) test was carried out as shown in Figure 4.

However, since raw biogas is not suitable for power plant utilization, to improve the methane level of the biogas obtained or generated, it was dehumidify to remove (CO_2), (H_2S), and small traces of other gases. The water (H_2O) scrubbing method was adopted to filter gas produced. Within the chamber, calcium hydroxide ($Ca(OH)_2$) containing water was prepared to a concentration of (40%) of exothermic reaction at a very high amount of heat produced (HP). The gas is run through upper top of the chamber with solution $Ca(OH)_2$, thereby removing carbon-dioxide. And it flow into the second into the flittering chamber unit; silica gel, steel wool and iron feelings and flow out, removing (water vapour, hydrogen sulphide) and entered gas holder. The average daily biomethane produced is as presented in Table 3. The scrubbed gas (biomethane) stored in the gas bag flow through a pressure pump to boost supply of gas to the generator via the coupled hybrid carburetor. The hybrid carburetor was switched to gas fuel mode and started running. The engine was run for about 5 minutes on (no-load) state to stabilize its operation. The output of the generator was connected to power distribution system (PDS) feeding a constant load of 1800W, which comprises of ceiling fans, refrigerator and lightings system in the waste treatment plant, to evaluate it performance. The generator parameters; current (A) and voltage (V) were ascertained with the aid of a digital multimeter (DM) as shown in Table 4. This was done to evaluate the generator's performance and efficiency at full load condition (FLC) while running on biogas fuel.

3. RESULTS AND DISCUSSION

This section presents the performance result of implementation of prototype model of human waste biogas plant power plant (HWBPP). The Pilot scale anaerobic digesters were designed and fabricated for the digestion of the human waste substrates in this study. The daily volume of biogas produced was recorded as presented in Table 3 and illustrated graphically as depicted in Figure 5. The generator performance results obtained during the monitoring period in the study are presented in Table 4.

3.1. Measurement of gas production

Table 3 show the daily and cumulative gas production from human waste substrates digested in this study.

Table 3. Result for biomethane produced from pilot scheme of human waste biogas plant.

Retention times [days]	Volume of biogas (liters)	Volume of biomethane produced (liters)
1 -8	0	0
9	90.60	58.89
10	100.10	65.07
11	126.0	81.9
12	145.25	94.41
13	156.42	100
14	174.90	113.69
15	188.23	122.34
16	196.44	127.68
17	224.76	143.84
18	246.12	160.00
19	258.67	168.14
20	266.76	173.32
21	278.43	180.97
22	301.50	195.97
22	305.41	198.52
23	295.45	192.04
24	303.98	197.56
25	303.65	197.30
26	289.00	187.85
27	307.10	200.00
28	294.62	191.50
29	303.31	197.15
30	302.59	196.68
Total	5459.29	3544.82

From Table 3, it was observed that there was no biogas production from first week of inoculation. Production of biogas from human waste started on the 9th day with a value of 90.60 liters. Data collected from this experiment indicate that biogas production was actually slow at the start period. This was due to the slow activity level of the methanogenic bacteria, as gas production rate is directly equal to the specific growth of methanogenic bacteria. Also, the percentage reduction in volume of biomethane could account for the removal of impurities such as carbon dioxide, hydrogen sulfide and water it can be observed that the volume increase steady from 9th day till end of the hydrogen retention time. This progress is due to constant feeding the digester with human excreta under normal temperature condition. The daily biogas production was average of 250 L with peak value of 304litres at 24th day at a retention period of 30 days.

Table 4. Current and Voltage output of modified 3KVA Bio generator.

Load (W)	Load Type	Phase Voltage (V)	Phase Current (A)
600	Lighting	220	2.83
1000	Lighting /Electric motor	218	4.58
1200	Lighting / Ceiling fan	215	5.34
1600	Lighting /Fridge	210	7.68
1800	Lighting /Fridge/Ceiling fan	200	10.28

Fig. 3. Pictorial view of human waste based biogas production system.

It can be observed from Figure 4, that the digester (balloon) has expanded compared to before the inoculation, which is an indication of the presence biogas production from human waste.

3.2. Flammability test

A test based on human excreta biogas flammability was carried out utilizing hallow pipe (1/2inches). The pipe was connected to bioflex-digester (BD) gas outlet duct at one end and the other end fixed to a burner. The gas outlet valve turned to open position and the burner was ignited with a fire (lighter device) to examine the presence of (methane gas) in the biogas produced. From the result, it can ascertained or observed that the human waste biogas burnt with a pale blue flame as shown in Figure 4. This ascertain that result obtained conform as well corroborates in line with the work of [17].

Fig. 4. Flammability test result of human waste biogas produce.

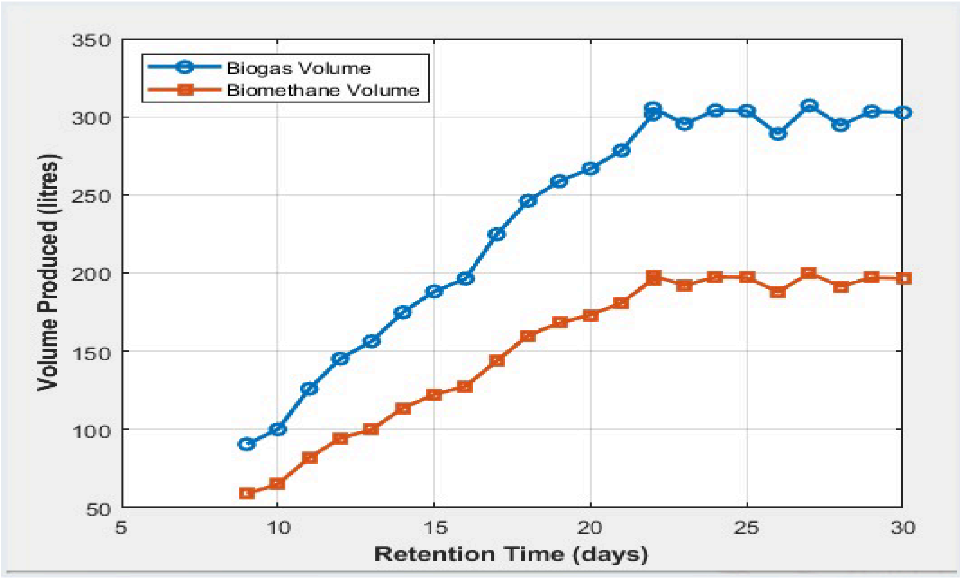

Fig. 5. Biogas Production vs. Retention Time.

Figure 5 shows Pilot scale (HWBP) volume of biogas produced after purification and corresponding hydrogen retention time. The plot shows a linear increases of HRT with both volume of biogas and methane but not in same proportional. The percentage reduction in volume of biomethane could account for the removal of impurities such as carbon dioxide, hydrogen sulphide and water. It can be observed that volume increase steady from the 9th day till end of the hydrogen retention time. This progress is due to constant feeding the digester with human waste under normal temperature condition.

3.3. Analysis of power generated utilizing human excreta biomethane

The HW biogas produced and subjected to purification technique yield a total of 3544.82 m^3 gas (biomethane). To estimate the electric power production rate of the biomethane generated, volume of biogas was converted into mega joules (MJ) mega and to kilowatt hour (KWh) then multiplied by assumed percentage (%) of energy carrier [17-19].

Therefore, $3544.83\ cubic\ meter\ of\ biogas\ =\ 67351.5$ MJ

$$\text{Power (kW)} = \frac{Biogas\ produced}{3.6\ MJ} \tag{3}$$

where, 3.6 MJ is the energy conversion equivalent of biogas produced.

$$\text{Gross electrical power generated} = \frac{67351.5MJ}{3.6\ MJ} = 18708\ \text{kWh}$$

Assumed 65% of the energy lost as heat and useful energy of 35% of the rated kilowatt-hour [15].

Therefore, 35% of 18708 kWh = 6548 kWh

From the analysis of the result above, the useful electrical power generated from 3544.82 m^3 of biomethane is approximately 6548 kWh.

3.4. Analysis of biogas consumption with load

Analysis of biogas consumption was conducted with load input on the power generation system. Biogas consumption rate was observed with respect to duration. The collated gas measured as (0.450m^3), and used on the 3KVA power generating system to power 2200 watt load. Biogas run on the plant for a duration of (47) minutes, and shut down due to low (biofuel) gas level. The above results implies that 0.450m^3 of biomethane run the generator for 47minutes. It can deduced that 1m^3 of biomethane run the 3KVA bio generator for one hour forty four minutes 1hr 44 minutes.

3.5. Performance characteristics of bio-generator

The bio generator (modified internal combustion engine) operation was smooth, with no engine knocking or stalling observed. Measurements indicated stable voltage and current outputs, confirming the suitability of human-waste-derived biogas for electricity production at small scale. The observed favorable characteristic ascertain the successful modification technique applied and anti-knocking properties demonstrated by biofuel component in biogas. At variable loading (600W-1800W), generator current and voltage responded to increase in load.

4. CONCLUSION

The study of development and performance evaluation of 1m^3 human waste biogas power plant at DELSUTH was successful. This experimental study demonstrated that human excreta can be effectively harnessed for small-scale electricity generation through biogas technology. A 1 m^3 digester produced an average of 0.45 m^3/day of methane-rich biogas, which reliably fueled a 3 kVA generator to supply a constant 1.8 kW load. The system proved technically feasible, safe, and adaptable for decentralized applications. Synergistically, it will provide a sustainable technique to attain energy self-sufficiency that encourage techno-economic development and as well curbat waste management in Nigeria. The findings suggest that human-waste-to-energy systems could supplement in Nigeria's energy supply, particularly in institutions and communities with concentrated waste generation. Wider adoption would also contribute to improved sanitation and environmental sustainability. The following are recommendation and future direction from the study:

- Scale-up studies should be carried out to evaluate long-term performance under higher loads.
- Cost–benefit analysis is required to assess economic viability compared with other renewable technologies.
- Further purification techniques may be applied to enhance methane quality for improved generator efficiency.
- Policies should encourage integration of human-waste-based biogas systems into municipal waste management and rural electrification schemes.

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Data Availability Statement: *We The data generated or analyzed during the current study are available from the corresponding author and could source from Bioenergy website; www.bloenergy.com.ng.*

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Conflicts of Interest*: The authors declare no conflicts of interest.*

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