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Design and construct a biogas digester which uses human faeces as substrate

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ABSTRACT

The rapid increase in population has placed significant pressure on available resources globally. This is largely because energy serves as the foundation of any economy. Although Nigeria's dependence on fossil fuels continues to rise annually, access to electricity remains critically low. This has prompted the development of alternative energy sources, with recent attention focused on renewable energy. While biogas has gained notable attention, many existing biogas digester designs remain relatively expensive and are susceptible to corrosion and leakage. Therefore, this study aims to design and construct a biogas digester that utilizes human faeces as the primary substrate. To achieve this, design equations were developed to determine the volume of the digester, inlet and outlet pipes, gas holder, and digester cover plate, all based on the shape of the digester. The digestion chamber was fabricated using high-density polyethylene (HDPE) plastic. After fabrication, a ventilation test was conducted to ensure the system was leak-free. The results showed an average gas yield of **5.25 m^3** over a 30-day period, equivalent to **37.91 g**. The pH of the system decreased from **6.5 to 6.0**. After purification, the volume of gas obtained was **3 m^3**, indicating that methane accounted for **57%**, while carbon dioxide and other impurities made up the remaining **43%**. The performance of the biogas digester was found to be satisfactory. Furthermore, the use of human faeces as feedstock can significantly contribute to solving waste management challenges while simultaneously enhancing the energy sector.

Keywords and phrases:

Biogas, Fossil fuel, energy, digester.

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Introduction

The rapid increase in population has put more pressure on available resources globally. This is because the driver of any economy is energy. For sustainability, energy production and usage must be consistent with demand and the provision of affordable and clean energy is one of the problem facing sustainable development goal in the world (Oyedepo, 2014; Popoola and Adeleye, 2020; Udi et al, 2020; Vicent and Okowa, 2022). One of the major consideration in producing and using energy is the environment. Demand for energy increases as population increases and this also increases the chance of environmental issues. Recently, many environmental problems affecting mankind have been linked to energy production. Some of these associated problems includes carbon dioxide (CO_2) emissions, ocean acidification, deforestation, loss of biodiversity, seawater level rise, pollution and climate change (Adedoyin et al, 2019; U di et al, 2020; Vicent and Okowa, 2022). In most developed and developing countries, the primary sources of energy is fossil fuels. According to Vicent and Okowa (2022), fossil fuel is the most conventional energy source and major contributor of CO_2 and other greenhouse gases (GHG) which are responsible for global warming and climate change. As Abdulkarin (2023) stated that the world carbon emissions increases from 32.3 billion metric tons in 2012 to 35.6 billion metric tons in 2020 and is estimated to reach 43.2 billion metric tons by 2040 if cleaner source of energy is not development. The researchers also stated that more than 85% of gas flaring and venting associated with fossil fuel come developing countries with Nigeria, Iraq and Iran each contributing 10-20 billion cubic meters of gas per year.

While Nigeria dependent on fossil fuel increase yearly, access to electricity is still very low compare to their African counterparts. Energy poverty is still prevalence as approximately 45% of the population has access to electricity while about 94% who have access to electricity lack cleaner and functional energy source (Adedoyin et al, 2020; Popoola and Adeleye, 2020; World Bank, 2022). On average, Nigeria generate 4000 megawatts (MW) of electricity yearly which is unable to cater for the electricity demand of the population. Lack of access to electricity is more pronounced among the rural dweller as few connected to the grid received less than 4 hours of electricity per day on average (Milonia, 2022). The undersupply of electricity from national grid have increase the usage of fossil fuel because majority of household rely on firewood, charcoals, kerosene, diesel, petroleum and natural gas for heating, cooking and electricity. While some individuals who lack connections to the grid rely totally on petrol and fueled generator, few connected uses these generators as backup sources due to epileptic power supply and blackouts. Industries or commercial businesses also rely on generators to render their services (Adedoyin et al, 2020). The increasing use of fossil fuel has placed the country at 53rd most vulnerable country among the 182 countries in the Notre Dame Global Adaptation initiative (NO-GAIN) and 179th most ready country. Nigeria is also the 3rd highest carbon emitter in Africa after Egypt and Algeria in 2018 and 40th position in the world emitting 347 million tons CO_2-equivalent ($MtCO_2e$) with the energy sector contributing about 60% of this emissions (FGN, 2021; Milonia, 2022).

Aside the environmental issue with fossil fuel consumption, the cost of using fossil fuel generators is also highly. According to Yusuf (2014) and Chanchangi et al (2023), the running and maintenance of fossil-based generators consumes trillion of naira yearly due to power outages. An estimate of₦126 billion and ₦350 billion is spent annually on running and maintenance of fossil-based generators among residence and industries respectively. About ₦3.5 trillion is spent annually for the purchase of fossil fuel generators in the country. Nigeria is thus placed as the highest user and importer of generator in the world with about 600 million households having generators (Ayodele and Ogunjuyigbe, 2015; Akuru et al, 2017; Chanchangi et al, 2023). Telecommunications companies are not left out unaffected. mobile telephone network (MTN) which is the giant and largest telecommunications network is estimated to have about 6000 generators across the country operating for not less than 19h/day and requiring $5.5 million on fossil fuel consumption per month. This trend is also applied to other service providers such as Glo, Airtel and Etisalat (Oyedepo, 2012; Yusuf, 2014; Chanchangi et al, 2023).

The unreliability of electricity supply, increase in population, depletion fossil fuel, unsustainable economic growth, Supply risk and environmental issues with fossil fuel makes it imperative to search for alternative forms of energy to these conventional resources. Thus, countries tailored their energy plan towards renewable sources. Renewable energy resources are viable solution to the current energy crisis. The country is endowed with abundant renewable resources such as solar, wind, hydropower geothermal and biomass. Their potentials in Nigeria is about 1.5 times fossil fuel (Oyedepo, 2014; Shaaban and Petinrin, 2014; Osunmuyiwa and Kalfagianni, 2017; Vicent and Okowa, 2022; Chanchangi et al, 2023). Effort are made by the government to utilized biomass in the electricity sector. Biomass material are non-fossil fuel and can be categorised into bio-ethanol, bio-ethanol, biodiesel, bio-hydrogen and biogas (Adewuyi, 2020). Despite the potential of using biogas, available Waste-to-energy technologies needed for its uptake are lacking. In the midst of the various technologies, anaerobic digestion (AD) technologies proves to be effective.

Anaerobic digestion is a microbial process whereby organic carbon are converted into gaseous fuel by oxidation and reductions in the absence of oxygen. The process involves fermentation process where biodegradable organic carbon solid or substrate are converted into biogas containing energy-rich methane (CH_4). The methane and energy content of the gas generated have a varied composition depending on the physical and chemical composition of the substrate used (Mungwe et al, 2021; Ajieh et al 2020). Anaerobic digestion occur in a system called biogas digester. Biogas digester are mostly designed and constructed using bricks, cement, metal, reinforced concrete and reinforced plastic. In some cases, only the dome of the gas holder is made up of fiberglass. Human faeces contain organic waste which are detrimental to health and Society at large. Oloko-Oba et al (2018) asserted that animal waste especially those of human contain high concentration of phosphorus (P) and nitrogen (N) which can cause nutrient imbalance and Pollution to the environment. However, they also have great potential to be used as biogas providing dual solution as waste management control and renewable energy source. This source of biogas is also readily available as far as human existence is concerned. Such waste is therefore feasible considering it's availability.

Statement of the Problem

One of the greatest concerned to researcher recently is the issue of climate change and CO_2 emissions. These are causes by fossil fuels. The aftermath of using fossil fuels has resulted to looking for alternatives energy source with emphasis on renewable energy resources such as wind, solar, geothermal, hydropower and biomass. Considering cost and ease if technology, biomass become a focus among these renewable energy technologies. Various biomass are also available such as biofuel, bio-ethanol and biogas. The readily availability of biogas material stand a chance of using biogas for electricity generation. While many materials can be used as substrate for biogas, human faeces which is a waste considered to be toxic and offensive in ordour can be converted using biogas technology to generate electricity. The conversion process will also go a long ways to reduce the issue of waste management control as well.

On the other hand, various biogas there is the need to ensure the feasibility of its production process by optimization and technological modification. Factors such as biomass utilization, microbial treatment, enzyme addition, operating conditions and digester designs are known to enhance biogas production. Bio-digester design is a key feature in the techno-economic feasibility of process development among other enhancing factors. Biogas digester are mostly designed and constructed using bricks, cement, metals, and reinforced concrete, while in some cases, the dome of the gas holder is made up of fiberglass. &ese biogas digester encounter some challenges such as leakages at the edges of the brick structure after a short period of operation. There are some few biogas digester designs that utilize reinforced plastic; however, some of the reinforced plastic of the biogas digester deteriorates and creates holes due to the effect of ultraviolet (UV) radiations. Furthermore, the effect of corrosion that mostly occurs in biogas digester built from metals results in their failure. In addition to the limitations aforementioned, the construction of the biogas digester using bricks or cement block is quite expensive due to high labor cost and materials.

Aim and Objectives of the Study

The aim of this research is to design and construct an anaerobic biogas digester which uses human faeces as substrate. Specific objectives of the study includes to;

1. Obtain locally made material for the construction of the biogas plant.
2. Understand the principle and working structure of a biogas plant.
3. Construct the biogas digester using the sources material
4. Utilize the biogas digester for the digestion of human waste.
5. Analysis of the operational mode of a biogas plant

Literature Review

Biogas is a colourless combustible gas produced through the biological breakdown of organic matter in the absence of air. It is anaerobic decomposition of biogenic materials which leads to the release of gas. Biogas is an output obtained from AD through the metabolic process of breaking down organic matter by various organism. Biogas is a cheap source of energy which can be used for heating, cooking and generation of electricity (Oloko-Oba et al, 2017; Sayerr et al, 2019; Chavan et al, 2021). The process involves four distinct stages which are hydrolysis, acidogenesis, acetogenesis and methanogenesis. During hydrolysis, fats, protein and complex carbohydrates are hydrolyzed to their monomeric form catalyse by enzymes. In the second stage which is acidogenesis, the monomers are further converted into short chain acids. These acids are then converted into carbon dioxide, hydrogen and acetate in the third stage (acetogenesis) and then to methane and carbon dioxide in the final stage which is methanogenesis (Ramatsa et al, 2014; Badiyya, 2018; Sayerr et al, 2019; Ajieh et al, 2020; Issahaku, Derki and Kemausuor, 2024).

Several research has been conducted on the various biogenic materials which can be utilised in production of biogas. They includes agricultural waste, animal waste, municipal and industrial waste. The transformation of various animal wastes such as cow dung and chicken droppings has been explored for biogas production and found to provide dual solution as waste management control and renewable energy source. Moreover, biomass materials have also been exploited for biogas production. They have been singly used as substrate or co-substrate with animal waste(s) for biogas production. Some of these biomass materials include maize hybrids, organic wastes, sawdust, sugarcane, cassava, lemon grass, pawpaw peels, fluted pumpkin peels, banana stems, banana leaves, potato waste and aquatic weed (Jakayinfa et al, 2014; Oyedepo, 2014; Anaswara, 2015; Ahmed et al, 2017; Kara et al, 2018; Akubude et al, 2019; Adewuyi, 2020; Obileke et al, 2020). On design consideration researchers has delve into the use of different materials for the design of biogas digester. Some researchers constructed the biogas digester using metal, brick and concrete, plastic, ceramics and a blend of two or more of these materials (Jakayinfa et al, 2014; Agu and Igwe, 2016; Bello and Alamu, 2016; Nwankwo, Eze and Okoyeuzu, 2017, Oloko-Oba et al , 2018; Obileke et al, 2020, Ajieh et al, 2020; Agbede et al, 2020).

Several research on design and construction of anaerobic digestion estimated the performance of these digester. For instance, Oloko-Oba et al (2018) conducted a performance evaluation of three different shapes bio-digester for biogas production and optimisation by artificial neutral network integrated with genetic algorithm. The three shape selected were cylindrical, cubical and conical Biogas digester of $15dm^3$ each. Their performance were assessed using poultry dropping, cow dung and piggery waste and we're modelled using co-digester plantain peels with animal waste. The average daily production obtained were 0.58, 0.46 and $0.36dm^3$/day for cylindrical, cubical and conical shaped bio-digester respectively. The average daily production of biogas of cow dung, poultry dropping and piggery waste using the cylindrical digester were 0.40, 0.23 and $0.01dm^3$/day respectively. On using the developed model coupled with genetic algorithm, the optimal biogas production was $13.65dm^3$ with substrate combination of 0.7kg of poultry dropping, 0.6kg piggery waste, 0.2kg plantain peels and 0.0004kg cow dungs.

Badiyya (2018) investigated comparative study of biogas production using sugarcane bagasse and cow dung as substrate. Three bio-reactors labelled A, B and C were used. A for sugarcane, B for cow dung and C for the mixture of sugarcane bagasses and cow dung. The researchers found that higher volume of gas was obtained from the combine mixture of cow dung and sugarcane bagasses. Sthembiso (2018) also conductor three sets of twelve independent batch laboratory experiment on the production of biogas using sugarcane. The experiment was maintained at a temperature of 35^0C and retention time 14 days using 500ml bottles as a digester. The result shows that the maximum biogas production generated by bagasses, leaves and molasses of sugarcane are 305.87ml, 522.66ml and 719.24ml respectively. It was also found that the volume of biogas produced is influenced by feed ratio, pH of media and digester moisture

Obileke et al (2020) designed and constructed a plastic biogas digester for the production of biogas from cow dung. The digestion chamber of the biogas was fabricated using high density polyethylene (HDPE) plastic while the inlet and outlet chamber were constructed using bricks and cement. They finds that the digester was leak free and produce a methane volume of 2.18m^3 and carbon dioxide of 1.77m^3. The concentration of methane and carbon dioxide were also found to be 60% and 30% respectively.

Ajieh et al (2020) carried out the design and construction of fixed dome digester for biogas production using cow dung and water hyacinth. Scrubber were fitted to the digester to get rid of hydrogen sulphide (H_2S), ammonia (NH_3) and other trace elements. The sample were collected from collected from abattoir and Ologbo River in Benin city and blended in the ratio of 10:1 (cow dung:water hyacinth) and charge into the fixed dome. Performance test was carried out after 21 days. Results shows that the biogas produced compose of 56.4% of methane, 35% of carbon dioxide and 6.9% of nitrogen. The gas were directed through a pipe to a burner for cooking. Optimal production was influenced by temperature, retention time, pH concentration, and the designed consideration of the digester .

Gausi et al (2020) conducted a study on design and construction of a low-cost tubular biogas digester for rural households in Malawi. The study consisted of three pairs of locally constructed tubular polyethylene digester (same design) that were fed with pig dung, goat stomach waste and kitchen food wastes. One digester in each pair was enclosed in a greenhouse structure made from transparent polyethylene. Gas production onset was quickest in digester containing pig dung (1 day) followed by those containing goat stomach wastes (3-4 days) and lastly kitchen food wastes (14 days). Average daily gas production from digester was 35.7 L/day and the average percentage of methane content in the biogas was 62.1 %. The study concluded that the overall performance of the tubular polyethylene digester that were feed with goat stomach waste and pig dung was superior compared to other studies done at similar ambient temperatures. The flame was sustainable and usable for home and industrial purposes as the methane content was above 52%.

Bicks (2020) conducted an investigation of biogas energy yield from local food waste and integration of biogas digester and baking stove for Injera preparation. Computational fluid dynamics (CFD) was used to investigate the performance and heat distribution of baking mitad. In the study, the measured average daily biodegradable food waste and kitchen waste generation rate in the campus was found to be around 863 kg/day. The conversion of this food waste using the anaerobic digestion system yields 43.2 m3 biogas per day. Utilizing the daily biogas generated for baking injera improves the overall food making process and reduces firewood consumption by 5.4%. This biogas energy yield is considered to be utilized for baking injera in the kitchen. The designed biogas mitad (stove) does not generate smoke due to the type of fuel used and configuration of baking mitad. Furthermore, the stove has an insulation mechanism considered to conserve the heat loss to the surrounding.

Agbede et al (2020) designed and fabricated of electric jacketed anaerobic digester. The jacketed bio-digester system which incorporates a heater, an agitator and a pH probe was designed, fabricated and successfully utilized for the anaerobic co-digestion of kitchen waste and cow dung. The digester was operated at a constant volume of 12 kg, temperature of 400C, agitation speed of 30 rpm, a total solid content of 8% and pH of 7.5 for a period of 70 days. The pH, agitation and temperature of the substrate were introduced, monitored and controlled in the reaction. The biogas yield showed a good performance of the bio-digester system.

Ihara et al (2020) carried out a field testing of a small-scale anaerobic digester with liquid dairy manure and other organic wastes at an urban dairy farm. The study uses an 8 m3 commercial portable bio-digester which was modified by installing a mixing device and a heating element coil wire, and fed with liquid dairy manure, dairy by-products and food wastes. The results showed that the mixing device and heating element were effective to keep bio-digester temperature around 37.7 °C at an ambient temperature between − 8 and + 25 °C. Higher temperature and longer hydraulic retention time (HRT) were related to higher digestion performance, while the opposite was observed with organic loading rate (OLR). Bio-digester performance was not influenced by temperature and HRT, while it was increased with the increase of OLR. The highest biogas yield was observed during the co-digestion of liquid manure with waste milk and food waste, while the highest volumetric production of biogas was observed with liquid dairy manure co-digested with camembert cheese waste and food wastes.

Ukwu et al (2020) design and developed a bio-digester for production of biogas from dual waste. The design consideration is a batch horizontal 267 L digester made from cast iron with centrally positioned four-impeller shaft to enhance mixing. The system operated with a retention time of 63 days and a substrate (cow dung and poultry waste) ratio of 1:2 and water substrate ratio of 1:0.5 in the gas holder system. The purification, compression and performance evaluation of the generated biogas were also conducted. The findings showed that the total volume of gas produced for each substrate compositions designed over 14 days ranges between 49.34 and 52.91 mL/day. The optimal value of 52.45 ml using cow dung and poultry waste (w/w) 20:80 was obtained. The average ambient temperatures during the study were within the mesophilic range of 20-40°C. The pH values were stable and always in the optimal range of 6.5-8.0. The reductions in moisture content, ash content, total solids and volatile solids were from 80.50-0.20 per cent, 39.60-14 per cent, 18.50-5.90 per cent and 11.60-4.90 per cent, respectively.

From the reviewed literature, there is a dearth of literature on the use of human faeces in biogas digester as many researchers focus on other animals waste and agricultural Residues. More so, biogas digester are mostly designed and constructed using bricks, cement, metals, and reinforced concrete, while in some cases, the dome of the gas holder is made up of fiberglass. These biogas digester encounter some challenges such as leakage, corrosion and some deteriorates and creates holes due to the effect of ultraviolet (UV) radiations. The metal type aside their corrosion tendency are also relatively expensive. To overcome these weaknesses and challenges associated with the various materials mentioned, an alternative construction material was investigated in this study. Therefore, to minimize the high cost of construction of these previous designs, a more cost-effective design is proposed. Thus, the study employed a high-density polyethylene (HDPE) plastic to fabricate the digestion chamber and bricks/cement for the construction of inlet and outlet chambers. The choice of a plastic for the study is based on it being noncorrosive, a good insulator, cost-effective, and easy to maintain. The uniqueness of the present study stem from the use of composite materials (bricks/cement and plastic).

Materials and Methods

The biogas plant that was constructed consists of a rectangular tank made of plastic. It has the following components:

1. Inlet pipe (Feed entrance)
2. Slurry outlet
3. Gas outlet
4. Stirrer (Manual)
5. Cover and
6. Digestion chamber (Plastic tank)

Before the construction, all the components parts were also prepared. The manufacturing process used were dimensioning follow by cutting and gluing or joining.. the designed volume of the digester was sized according to the dimensions and calculations made. The primary structure consist of a plastic digestion tank which is strong enough to withstand the weight and pressure of the contained slurry. The plastic tank is air tight and place above the ground level and outside where it is exposed to sunlight. Human waste was introduce into the digester for a period of 31 days during the study. The slurry was allowed to occupy three quarter of the digester space flowing from the top to the bottom to occupied the bottom space. After digestion took place, they were removed and feed into the reactor. This is done by removing the flexible plastic pipe connecting the gas outlet of the reactor to the gas holder such that the outlet from the reactor is left open. This is to ensure that there is no negative pressure builds up in the reactor. The gas was collected using a flexible hose connected through the digester to the storage tank. The biogas produced was pass through the organic scrubber to remove hydrogen sulphide and carbon dioxide.

The operating volume of the digester is determined using equation (1) on the basis of the chosen retention time and the daily substrate input quantity, and is given according to Agbede et al (2020)

$V_0 = S_i \times R_t$ -- (1)

Where V_0= operating volume of digester (m^3), S_i= Substrate input (m^3/day) and R_t = Retention time

The retention time is the interval of time during which the biomass is allowed to decompose in the digester. The retention time is determined by the chosen digester temperature and the amount of biomass resource available. The substrate input is obtained using equation (2) as given by Obileke et al (2020)

$Si = B + W$ -- (2)

Where W = Water input (m^3/day) and B = Biomass input (m^3/day)

The total operating volume of the digester should be greater than the operating volume. This is to give room for the biogas produced and the rise of the slurry during fermentation. The operating volume of the digester must not exceed 90% of the total volume of the digester (Mungwe et al, 2021). For this research, 80% (0.8) was used. Equation (3) is used to obtained the total volume

$V_t = V_0 / 0.8$--(3)

The digester is rectangular in shape. For a rectangular digester, the chosen geometry for this work,

$V_d = LxWxH$--(4)

Where, V_d = total volume of digester (m^3), L = length of digester (m), W = width of digester(m) and H = height of digester(m)

In designing the gas holder, the volume of the gas holder is considered. Since this is cylindrical in shape, equation (5) is used according to Mungwe et al (2021) and Ajieh et al (2020)

$Vg = \pi r_g^2 h_g$ -- (5)

Where V_g is volume of the gas holder (m^3), r_g is radius of the gas holder(m) and and h_g is the height of the gas holder (m).

The size of the gas holder, i.e. the gas holder volume depends on the relative rates of gas generation and gas consumption. The gas holder should be designed to cover the peak consumption rate for the period of maximum consumption and hold the gas produced during the longest Zero consumption period (Anaswara, 2015).

The inlet and outlet Gas holder volume are obtained using equation (6) and (7). For 5 he purpose of safety, the volume at outlet is design to be highest

$V_{g1} = g_{max} \times t_{max}$ --- (7)

$V_{g2} = G_h \times t_{zmax}$ --(8)

Where $V_{g1}$is Inlet gas holder volume, V_{g2} is Outlet gas holder volume, g_{max} is maximum hourly gas consumption (m^3/hr), t_{max} is time of maximum consumption (hr), G_h is hourly gas production (m^3/hr), t_{zmax} is maximum zero consumption time (hr)

Table 1: Summary of design parameters

Parameters	Units	Value
Length of of digester	m	1.2
Width of digester	m	0.8
Height of digester	m	1.1
Total volume of digester	m^3	1.056
Radius of gas holder	m	0.124
Height of gas holder	m	0.248
Volume of gas holder	m^3	0.0121
maximum hourly gas consumption	m^3/hr	0.2
time of maximum consumption	hr	0.055
hourly gas production	m^3/hr	0.000222
maximum zero consumption time	hr	10
Inlet gas holder volume	m^3	0.011
Outlet gas holder volume	m^3	0.0195

Results and Discussion

The anaerobic digester was designed and constructed for the digestion of toilet waste in this study. The experiment at all results obtained during the monitoring period in the study were analysed using statistical methods such as table, chart and graph.

Table 2: Gas Produced at various day of digestion

Time (days)	Pressure (bars)	Volume (cm^3)	Mass(g)	Moles(mol)
10	0.1	0.0043	1.083	0.0414
11	0.2	0.0170	2.167	0.0830
12	0.5	0.1070	5.416	0.2070
13	0.8	0.2740	8.670	0.3310
14	1.0	0.4290	10.83	0.4140
15	1.4	0.8400	15.17	0.5790
16	1.8	1.3890	19.50	0.7450

17	2.2	2.0740	23.83	0.9100
18	2.8	3.3610	30.33	1.1590
19	3.0	3.8580	32.50	1.2410
20	3.5	5.2510	37.91	1.4480

From the table above, the daily gas produced increases as the retention time increases. Thus, the minimum gas produced occur at a retention time of 10 days while it is maximum at 20 days with volume of $0.0043m^3$ and $5.2510m^3$ respectively.

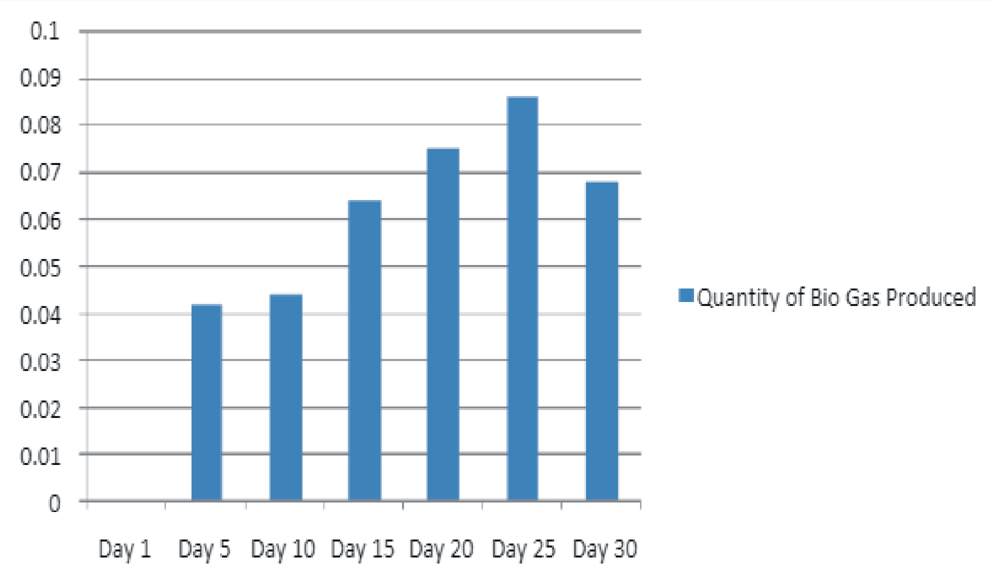

Fig 1:Quantity of biogas produced

From Figure 1 above, no gas was produced initially in the digester. The yield of biogas started in the middle of the first week and was peak in the fourth week before decline set in. This implies that the maximum biogas production occur between 20-28 days.

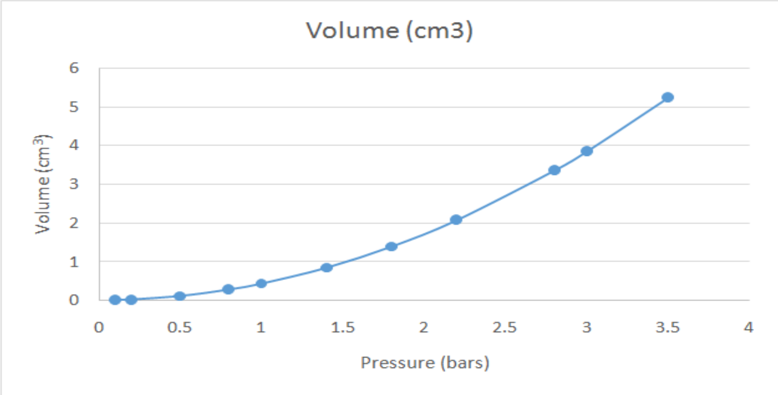

Fig 2: graph of volume plotted against pressure

Fig 2 above shows that as the pressure inside the digestion chamber increases, the gas produces also increases. This is due to the different properties of methane and carbon dioxide. Methane has a very low solubility in water and mainly remains in the gaseous phase regardless of pressure conditions in the digester. Carbon dioxide is characterised by greater solubility that significantly grows with increasing pressure. Consequently, the pressure rise causes a greater solubilization of carbon dioxide in liquid phase 2hich result in a biogas of higher methane fraction and a greater lower heating value than generated under atmospheric conditions.

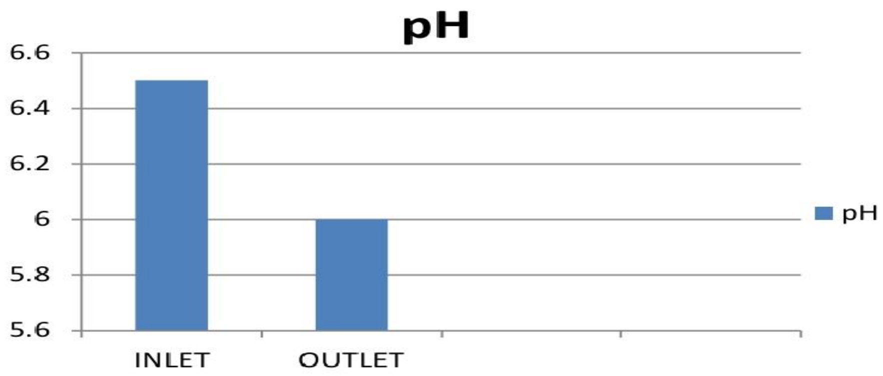

Fig 3: Inlet and outlet pH of materials

Fig 3 above shows the pH of the substrate before and after digestion as measured using the pH meter. It was observed that the inlet pH was 6.5 and 6.0 at the outlet. Human faeces show a general decrease in pH with minimal fluctuation. The decrease in pH could account for the unsteady rate of gas production. Badiyya (2018) and Obileke et al (2020) suggested that pH is a limiting factor for biogas production during methanogenesis. Agbede et al (2020) also finds that bacterial are very sensitive to pH during methanogenesis and do not thrive below 6.0 pH values.

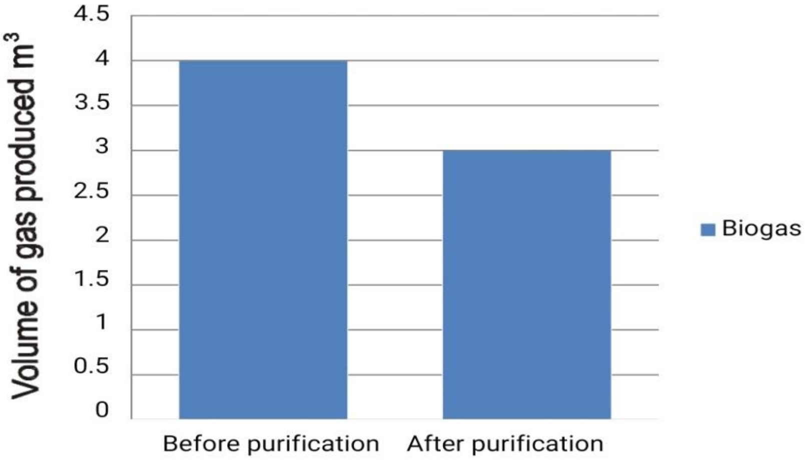

Fig 4: comparison of gas volume before and after purification

Fig 4 above shows that there was reduction in the volume of gas obtained after purification. The purification was necessary in order to remove carbon dioxide, hydrogen sulphide, nitrogen, joist urea and other impurities from the gas. The result shows that about 3m^3 or methane was obtained. This represents about 57% of methane while other impurities make up the remaining 43%. According to Gausi et al (2020), Bicks (2020) and Ajieh et al (2020), a good biogas digester should be able to produce about 50-70% of pure methane. Thus the performance of the digester was satisfactory.

Budget

Table 3: Bill of Engineering Measurementand Evaluation (BEME)

S/N	Description	Qty	Unit	Rate (₦)	Amount (₦)
1	Digester Body: 1000 liters IBC tank	1	Unit	75,000	75,000
2	Slurry Inlet Pipe: 2" Niger pipe	1	Unit	2,500	2,500
3	Slurry Outlet Pipe: 1" Niger pipe	1	Unit	2,500	2,500
4	500L Biogas Storage Bag	1	Unit	45,000	45,000
5	Biogas Scrubber	1	Unit	25,000	25,000
6	Gas Hole Nipple with Valve	12	Pieces	1,000	12,000
7	Bushing	2	Pieces	1,200	2,400
8	Hose	–	–	5,500	5,500

S/N	Description	Qty	Unit	Rate (₦)	Amount (₦)
9	3" Pipe Adapter	1	Piece	4,400	4,400
10	45° Y Tee	1	Piece	1,800	1,800
11	Ball Gage Valve	2	Pieces	2,800	5,600
12	1½" Cor Rubber	2	Pieces	2,700	5,400
13	3" Uniseals	6	Pieces	6,500	39,000
14	Clip	10	Pieces	50	500
15	Tee Joint	2	Pieces	1,800	3,600
16	2" 90° Elbow	4	Pieces	1,800	7,200
17	Biogas Burner	1	Unit	18,000	18,000
18	Silicon Gum	1	Tube	1,800	1,800
19	Abro Gum	1	Tube	1,400	1,400
20	Gas Regulator	1	Unit	6,000	6,000
21	Thread Tape	2	Rolls	300	600
22	Measurement Tape	1	Unit	800	800
23	2" Uniseals	4	Pieces	5,500	22,000
24	Electric Hand Drill	1	Unit	16,000	16,000
25	Reducer Accessories	8	Set	–	14,000
26	Waste Cost	–	–	–	8,000
27	Workmanship	–	–	–	30,000
28	Transportation	–	–	–	40,000
29	Gas Stand	1	Unit	8,000	8,000
30	Thermometer	1	Unit	1,000	1,000
31	pH Meter	1	Unit	7,500	7,500

S/N	Description	Qty	Unit	Rate (₦)	Amount (₦)
32	Miscellaneous	–	–	–	3,000
	Total				**₦415,500.00**

From table 3 above, the total cost of the bio-digester is four hundred and fifteen thousand naira ₦415,500.00.

Conclusion

A biogas digester was successfully designed, constructed, and charged with human faeces to facilitate biogas production. Based on the results obtained, the digester was fabricated using locally available materials and tested under the prevailing weather conditions in Otefe-Oghara.

The constructed digester effectively processed toilet waste through anaerobic digestion, demonstrating that biogas can indeed be produced from human faeces. Over a 30-day operational period, a total of **5.25 m³** of biogas was generated, containing approximately **57% methane**, with the remainder comprising carbon dioxide, hydrogen sulphide, and other impurities.

Optimal gas production was influenced by several key parameters, including **temperature**, **retention time**, **pH**, **substrate concentration**, and the **overall design** of the digester. Gas purification was achieved using scrubbers, which effectively removed hydrogen sulphide, carbon dioxide, nitrogen, and other impurities, thereby enhancing the heating efficiency of the biogas.

Biogas offers a cost-effective and environmentally friendly alternative to fossil-based natural gas, especially since human faeces is a readily available and sustainable resource. It is produced through microbial digestion of organic matter in the absence of oxygen, with potential feedstocks including toilet waste, kitchen waste, animal manure, and crop residues.

Throughout the experiment, the **pH values remained stable**, ranging between **6.0 and 6.5**, which falls within the optimal range for anaerobic digestion. Although the specific energy output was not quantitatively measured, the gas produced was sufficient to boil potable water in a time comparable to that of kerosene and electric stoves.

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