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Research Paper

Improvement On The Design Of An Anaerobic Floating Drum Biogas Digester

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ABSTRACT
This project focuses on improving the design and fabrication of a bio-digester and generating Biogas using cow dung and rumen fluid as substrate. A biogas digester with a capacity of 1000litres was designed and fabricated. The substrate (cow dung and rumen fluid) was mixed in the ratio 3:2, and a water-substrate ratio of 2:1 was used. The digester was stirred thoroughly to avoid scum formation and allow for the easy escape of the gas produced. The retention time used for this experiment was 42 days. The daily internal temperature reading was taken to determine temperature variation and the effect of sunlight on the production rate. This study showed that methane has the highest percentage, and generally, cow dung with rumen fluid easily subjected them to anaerobic digestion. The project was carried out to improve the design and construction of the floating drum type biodigester (plastic). It was found out that the introduction of frames that prevent the gas holder from tilting, and the black plastic drum and gas collector with high heat absorption and retention have a significant effect on the production of the Biogas. It was found out that the initial PH value of the slurry is 8.5 and, with the help of the heat adsorption and retention in 21days, dropped the PH value to 6.5, which is acidic and combustible. Recent research suggested that 1kg of cow dung will produce 0.264m^3 of gas, but with the improvement made, 0.294m^3 per 1kg of cow dung and rumen fluid was obtained. Thus, it indicates that for a design capacity of 400kg cow dung and rumen fluid, it is expected that 117.6m^3 of gas would be made.
Keywords: *Biogas, digester, cow dung, rumen fluid, PH value*

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I. INTRODUCTION

The development and improvement of new techniques for the production and utilization of renewable energy in line with developing countries' economies and locations are paramount to solving the energy crisis and climate change problems. Climate change has been a source of international concern in recent periods. It is one of the leading problems that link the international community and receives much-desired attention. Fossil fuel resources used to be a source of concern in the recent past. However, climate change issues have since overtaken the centre stage. The trend has changed, and it is very timely for much attention to be shifted to renewable energy instead of energy from fossil sources.

In most developing countries such as Nigeria, Biogas could be an alternative for firewood and charcoal that can meet the energy needs of the urban, semi-urban and rural areas. Cooking was reported to stand for 90% of developing countries' domestic energy consumption, and access to electricity outside the urbanizations is very limited. (Rajendran et al. 2012)

According to a world bank report (2021), an estimated population of about 85 million Nigerians do not have access to grid electricity. This figure is equivalent to 43% of Nigeria's population and makes it the leading energy access deficit globally. The shortage of consistent power is a significant constraint for citizens and enterprises, causing annual economic losses projected at about $26.2 billion (₦10.1 trillion), equivalent to about 2 percent of GDP. As reported in the 2020 World Bank Doing Business report, Nigeria's rankings at 171 out of 190 countries in having electricity and electricity access is considered one of the main constraints for the private sector. (World Bank Report, 2021)

The anaerobic bio digestion process is not a new method of converting waste material into a usable product. However, there is the need for continuous improvement, particularly achieving sustainability in all ramifications. Traditionally, the Anaerobic Digestion (AD) process should be strictly in an anaerobic environment with no free oxygen available. The presence of oxygen (aerobic) undermines the performance of the digestive system, as reported by Hendrick (1991) as cited by Ramatsa (2014); therefore, the best suitable condition to produce Biogas is an oxygen-deficient environment. A recent survey by Rinkesh (2009) suggests that non-renewable energy sources in terms of fossil fuels are fast degrading. This has led to research on new energy sources like renewable energy sources such as solar energy, wind energy, thermal, hydro and biomass. Among these renewable energy sources, biomass is more advantageous because of its characteristics of using, controlling, and collecting organic waste to produce fuel and produce fertilizer for agricultural purposes. It does not have any geographical limitation, nor does it require any advanced technology for producing energy.

"biogas" is a renewable fuel provided by anaerobic digestion of organic material as a substrate for bio-methanation. The gas is flammable, obtained through the action of methanogenic bacteria, which work in the absence of oxygen through anaerobic digestion (Quaak *et al*., 2001). It contains 50-75% methane, carbon dioxide, hydrogen sulphide and hydrogen. It can be used as fuel in boilers and dual-fuel engines. It is made by fermenting organic wastes in biogas digesters.

The term **"Biogas digester"** is any structure that converts organic material (waste) into energy without oxygen. Various materials and geometric configurations have been used to design the biogas digester system. The geometric structure is horizontal, spherical, cylindrical and dome shapes. The materials commonly used for its fabrication include plastics, brick, cement, fibreglass for the dome shape and metal (stainless steel and mild steel). Biogas is a good source of renewable energy, composed of 50-70% methane and 30-50% carbon dioxide with other traces of gases. (Ranjeet *et al.* 2008)

"**Anaerobic digestion" (AD)** is an engineered methanogenic decomposition of organic matter under oxygen-free conditions. It involves a mixed consortium of different species of anaerobic micro-organisms that transform organic matter into Biogas. AD process is successfully used to treat municipal sludge, animal manure, industrial sludge, and industrial and municipal wastewaters. Applying anaerobic digestion for waste treatment produces significant benefits beyond simple waste removal. This benefit includes both energy production and energy conservation. In addition to waste removal, other environmental benefits result from anaerobic digestion, including odour reduction, pathogen control, minimizing sludge production, protection of nutrients, and reduction in greenhouse gas emissions. (Ranjeet *et al.* 2008) The replacement of fossil fuels also reduces atmospheric pollutants responsible for acid rain. Thus, anaerobic digestion is a waste treatment technology that enhances environmental quality and suitable energy-producing technology. With these in mind, the research intends to improve the design, construction, and testing of a biogas digester to enhance its performance for efficient domestic biogas production.

The scope and limitations of this research are to attempt to analyze and improve the existing biogas digester for their performance and recommend measures to reduce the moisture content in the gas produced, and obtain a systematic approach for implementation.

The problem with the existing plastic floating drum bio-digester is when the Biogas is produced, the floating gas holder tends to move up, which facilitates the collection of the gas, thereby making the gas holder tilt resulting in the escape of the gas produced and the material used usually not black which has less solar heat absorption, retention and has a high moisture content in the gas produced.

This paper aims to improve the design for functional production of Biogas by enhancing the existing structure of a bio-digester, minimizing the moisture content in the gas produced, and evaluating the performance of the digester.

Sagagi *et al.* (2009) presented the study results on biogas production from fruits and vegetables waste materials and their effects on plants when used as fertilizer (Using digested and undigested sludge). It has been observed that the highest weekly individual production rate is recorded for the cow dung (control) slurry with an average production of 1554 cm^3, followed by pineapple waste which had 965 cm^3 of Biogas. Orange waste, which had 612cm^3 of Biogas, lastly, pumpkin and spinach wastes had 373 cm^3 and 269 cm^3, respectively. The results obtained show that the difference in the production of Biogas largely depends on the substrate's nature. All the substrates used appeared to be suitable materials for biogas production, and their spent slurries can be used as a source of plant nutrients.

Bhumesh *et al.*(2011) reported biogas generation from dairy effluent and control of water pollution through dairy waste treatment. All parameters, however, showed statistically that gas generation fluctuated between 0.5m3 /day to a maximum of 4.5m3 /day with an average of 3m3 /day.

1.1 Anaerobic Digestion Technology and Environmental Sustainability

The concept of sustainable development is broad and can take on several meanings depending on the circumstances. According to one definition, sustainable development is a collection of local and global initiatives to promote a positive vision of a world in which basic human needs are addressed within planetary limitations. In this scenario, it's essential to look into how local efforts might help a community achieve a more sustainable future.

As an energy source, Biogas has enormous potential to contribute to sustainable energy. According to a study of household biogas digesters, houses with biogas plants emit 48 percent fewer greenhouse gases than households without biogas plants. Only 10% of households with biogas plants experienced methane leakage factored into their emission balance. The global warming mitigation potential of a three (3) meter cube household digester using cattle manure in India is projected to be 9.7 tones CO_2 equivalent per year. (Rajendran et al., 2012) Biogas combustion does not result in additional carbon dioxide emissions to the atmosphere because the biomass used for biogas production is derived from the photosynthetic fixation of carbon dioxide from the atmosphere. (Ahring et al., 2003)

Using Biogas instead of firewood for cooking reduces forest depletion and eliminates respiratory diseases caused by air pollutants produced when firewood is combusted inside homes. Compared to using electricity or liquefied gas as a source of energy for cooking, Biogas is also a more cost-effective option. Because of the bacterial action and the lack of oxygen, the leftover material formed in biogas generation is exceptionally high in nutrients. This wastewater can be utilized as an organic fertilizer, reducing chemical fertilizers. (Aguilar, 2001) The cycle from soil to crop, product, waste, and back to the ground is closed when the trash is upgraded into a valuable outcome (Da Costa Gomez, 2013). The wastewater is a better fertilizer than manure or synthetic fertilizers because digestion makes plant nutrients more readily available (The University of Adelaide, 2008). Small-scale AD technology is easy and inexpensive, and it can be used anywhere in tropical countries to improve life quality, save money, alter crops, and safeguard natural resources. (2001, Aguilar) Biogas is also a rapid, easy-to-control fuel that cleans up after itself (The University of Adelaide, 2008).

Animal and human feces can be fed to biogas plants, which helps to reduce the population of flies and mosquitoes while also reducing foul odours and harmful germs. (Aguilar, 2001) By reducing the number of inorganic plant nutrients in the trash, biogas systems limit the enrichment of bodies in freshwater resources. Another social benefit of biogas technology is that it decreases women's burden by eliminating the need to gather firewood for cooking. Biogas also minimizes the amount of imported fuel oil because it is made primarily from locally available raw materials. (Tumwesige and colleagues, 2014)

This biogas plant in Damaturu is intended to benefit the local population by providing educational opportunities and cooking gas for the few applications in the workshop environments of the Polytechnic. Estimating how much firewood is saved if the digester's gas can be utilized for cooking on a regular basis is one way to assess its ability to contribute to environmental betterment. Assuming 1kg of firewood is about equivalent to 200 litres of Biogas as suggested by (Eawag, 2014), If this system can be optimized to produce 300 litres of Biogas per day from 2 kg of food waste, which is adequate for 43 minutes of daily cooking time, it will save 1.5 kilogrammes of firewood per day and 30 kilogrammes of firewood per month if cooking is done during labour days. Another environmental benefit of the digester is that the slurry produced can be utilized instead of chemical fertilizers for the plants in Polytechnic farms or the nearby agricultural areas.

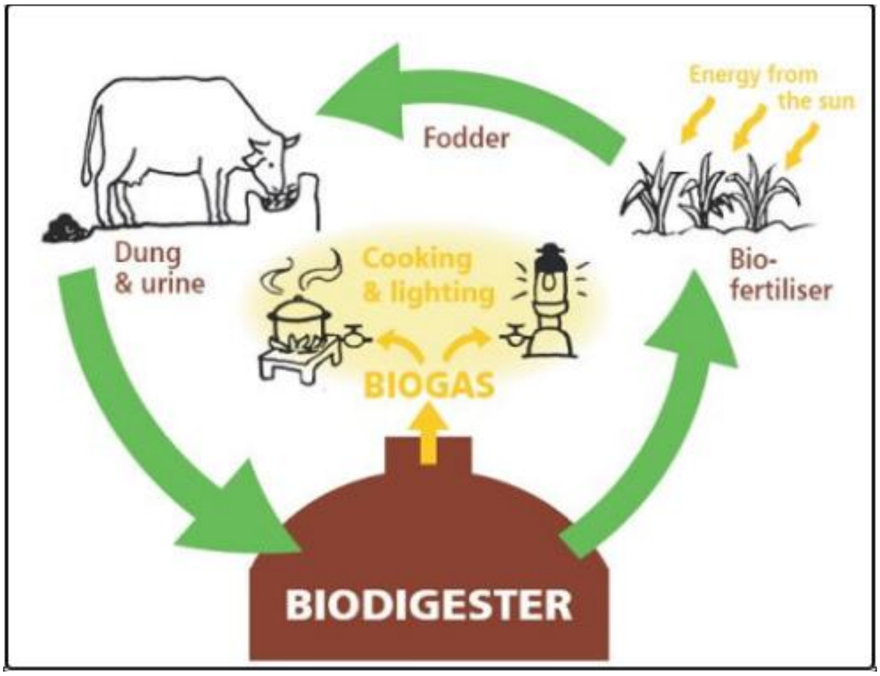

Figure 1: *Anaerobic Digester cycle*

II. Material and Method

2.1 Case Study

Damaturu has been a district headquarter since the then old Borno province. It was elevated to the status of local Government headquarters in 1976 with the creation of Damaturu Local Government, and in 1991 it became the headquarter of the newly created Yobe State, Northeastern Nigeria. Being the administrative nerve centre of the State, it is inhabited majorly by civil servants, farmers, and traders. It is located on latitude 11.743030^0 N and longitude 11.961980^0 E with corresponding GPS coordinates of 11^0 $44'$ 34.390″ N 11^0 $57'$ 43.128″ (Fig. 1) Damaturu city covers a land area of 2,378 Km^2 the population of Damaturu based on 2006 census was 87,706 and projected population of 124,500 as at 2016 with an annual population growth of 3.6 % (2006-2016), the population density of Damaturu is reported to be 52.37/Km^2.

The present study was carried out at the Mechanical Engineering Department on the coordinate 11 45 10 N and 11 59 05 in Federal Polytechnic Damaturu, located on A3 federal trunk A road along Kano-Maiduguri way, with postal zip code 620221.

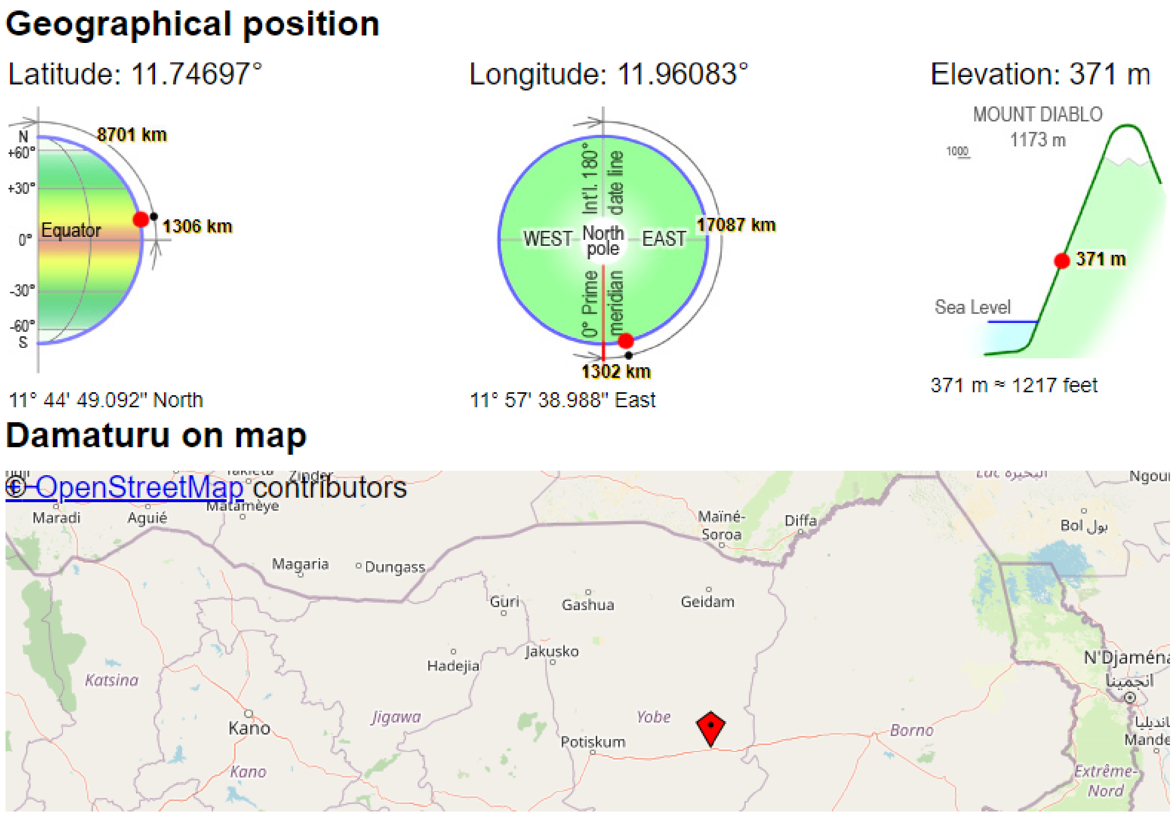

Figure 2: Geographical Position and Map of Damaturu

2.2 Climate of the study area:

The climate of Damaturu is referred to as a local steppe climate. There is little rainfall throughout the year. The average temperature is 25.0 ^{0}C, with about 741mm of precipitation falling annually. This climate classification is based on the Kőppen-Geiger system.

2.3 Choice of feedstock

Cow dung and rumen fluid were used as co-substrate due to the abundance of cattle in Nigeria and its numerous advantages. Cow dung is the ideal substrate for biodigester because of its non-toxicity, according to Onwuliri *e tal* (2013).

Factors affecting Anaerobic Digestion

Apart from the absence of oxygen, some other factors that need to be met to facilitate effective biogas production are constant temperature, optimal nutrient source, and optimal and consistent pH, as Da Costa Gomez (2013) opined. The optimal pH for the AD process is in the range of 6.0 to 8.5. Rates outside of this range can result in disturbances in the process. The pH value in the system is lowered by the effect of organic acids and carbon dioxide, while ammonia tends to increase it. (Ahring, 2003) More biogas is generated when the process temperature rises. The production rate is higher because this temperature range supports the survival of the participating bacteria organism in the process. AD is possible between a temperature range of 3°C and 70°C.

It was observed that, 35°C and 55°C are the two optimum temperatures of the substrate. The process and the bacteria involved in AD at different temperatures are incredibly distinct, and this has led to the classification of AD temperature range into three classes as follows: Psychrophilic (less than 20°C), Mesophilic (20°C - 40°C) and Thermophilic (above 40°C).

It has been observed by (Stoddard, 2010) that mesophilic digestion is predominant in small-scale polyethylene digesters mostly found in tropical regions. Given that the rate of digestion is quicker at thermophilic temperatures and little retention times and smaller reactor volumes are needed for processing the same quantity of waste. AD at thermophilic temperatures results in more efficient knocking down of pathogens. AD is susceptible to temperature change, but the significant effect is less on the process (Stoddard, 2010).

Another crucial factor affecting gas generation is the retention time (RT). Meaning the average number of days that a substrate unit remains in the digester. RT can be virtually any length for small-scale and continuously-fed digesters, up to 30 days or more. (House, 2010) More Biogas is produced when the retention time is extended. For several days, the daily production of Biogas will climb until it hits a peak, after which it will gradually decrease. Obtaining an optimal RT can be a complex process that requires a careful balance of all the components that control biogas output. (Stoddard, 2010; Stoddard, 2010). Another essential measure for comparing the outcomes of different investigations is the loading rate (LR). It is measured in kg total solids (TS) per day per liquid digester volume and is defined as the amount of substrate supplied daily (measured in m^3). (Stoddard,2010)

MATERIALS	USES
1000-liters tank	Used as the digestion chamber
500-liters tank	Used as the gas collector (floating drum)
9mm diameter rubber hose	Used for the collection of gas
PVC pipe	Used for inlet and outlet ports of the slurry
Weighing scale	Used to weigh the cow dung and the rumen fluid
Thermometer	Used for the measurement of the slurry temperature
Cow dung (raw material)	Used as the feedstock into the digester
Rumen fluid	Used as co-substrate
Silica	Used to absorb the moisture in the gas produced
Hack saw	Used to cut the digester tank
Meter rule	Used for measurement
90^0-elbow	Attached to the inlet pipe
PVC cap	Used to close the inlet pipe to avoid unwanted material getting into the digestion chamber
PVC adhesive	Used to seal the joints
Galvanized circular iron pipes	Used for the construction of the frame (guides)
Mass	Serve as a weight to avoid the floating drum from tilting.
Valve	Used for opening and closing of the outlet port
Cork	It is attached to the rubber hose, which is used for gas collection
Back note	Used as a sealer between the outlet pipe and the digester tank

Table 1. Materials and their uses

2.4 Methodology

The experimental setup includes the floating drum, which serves as the gas holder which was fabricated from a plastic tank having a capacity of 500 litters, a hole was drilled into the bottom of the gas holder, about 1.5cm diameter for the gas outlet and a hose was fitted into it, a one-way metallic valve was attached to the hose for opening and closing. The joint between the hose and the tank was sealed with PVC adhesives to avoid leakages. The digester was fabricated from a plastic tank having 1000 litters capacity, a hole was drilled on the side of the tank at its base, 10cm diameter and fit into it a PVC pipe of length 1m, and a 90^0 elbow, a line of 1m length 10cm diameter was included into the elbow and all the joints were sealed with PVC adhesive; This served as the inlet pipe. Also, another hole was drilled at the base of the digester opposite to the inlet pipe ø7cm and a pipe of 12cm was fitted into the hole together with a unidirectional valve; all the joints were also sealed with the PVC adhesive; this will serve as the outlet pipe (for discharge of the slurry). A base was cast with 9-inch blocks where the frame will be fitted, which is used as a guide for the floating drum where the digester rests on top, and some weights are used, which will help make the floating drum not tilt causes gas leakage.

Once the digester was operational for several cycles and several weeks after the initial filling, the pH value had reached the stable range of 6.5. It remained constant during the period of experimental processes. The temperature was also recorded and was constant between 35-43^0C during the day and 25-33^0C during the night. Therefore, these two parameters were considered the constants concerning the development. Those two parameters did not fluctuate significantly in Damaturu Climatic conditions based on the field data.

III. Experimental Details

Step I: Finding the amount of total solid (TS) in the slurry

$$TS = 8.5\% \text{ of slurry} = 0.085 \times 272kg = 23.12\ kg$$

Step II: Finding the amount of volatile solid (VS) in the slurry

$$VS = 0.8TS = 0.8 \times 23.12 = 18.496kg$$

Step III: Finding the biogas yield in terms of per kg of VS

The total amount of degradable materials present in the VS is about 50% only, therefore,

$$VS\ used = 0.5 \times 18.496 = 9.248\ kg$$

Now,

9.248 kg of VS gives 2.72 m^3 of Biogas

Therefore,

1.0 kg of VS will give 2.72/9.248 = 0.294 m^3 of Biogas

Thus, the biogas yield is **0.294 m^3/kg VS** from cow-dung and rumen fluid slurry

HYDRAULIC RETENTION TIME HRT (Weeks)	TEMPERATURE (^{O}C)
1	33.50
2	34.00
3	33.50
4	34.50
5	33.50
6	32.50
7	33.00
Average	33.50

Table 2: Average Weekly Temperature Readings for Biogas Production

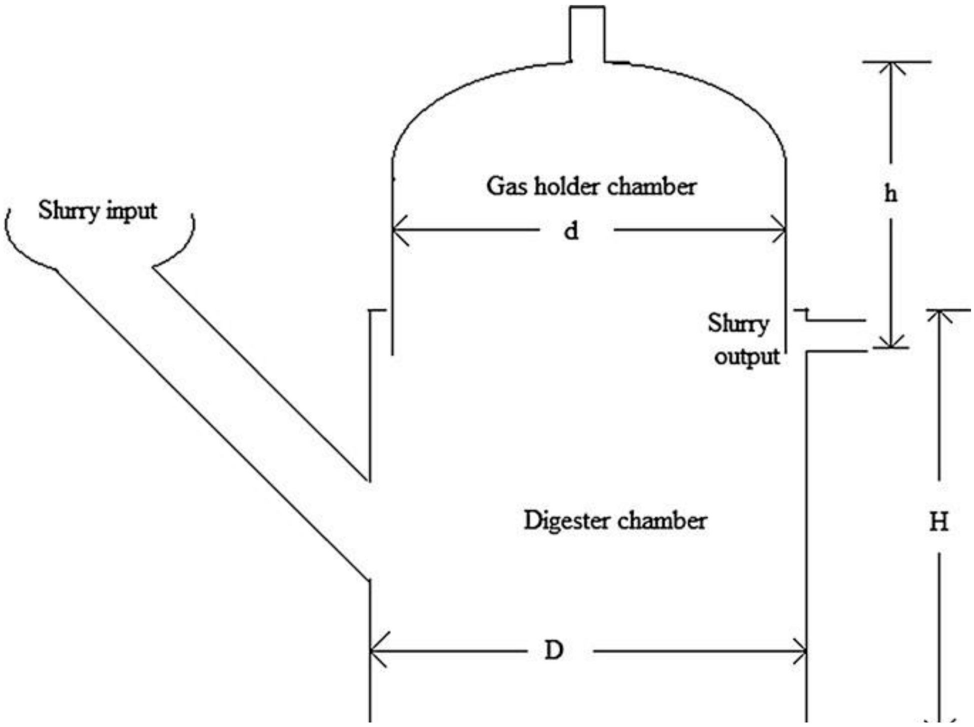

Figure 3:Block diagram of the Floating-drum type biogas digester
(http://www.kingdombio.com/ggcdraw.html)

Where;
D = the diameter of the digester.
H = the height of the digester/digester pit.
h = the height of the gas-holder.
d = the diameter of the gas-holder

IV. Conclusions

Based on the project carried out on the improvement on the design and construction of the floating drum type biodigester (plastic), it was found out that the introduction of steel frames which prevent the gas holder from tilting and the black plastic drum and gas collector which has high heat absorption and retention have a significant effect in the production of the Biogas. It was found out that the initial PH value of the slurry is 8.5 and, with the help of the heat adsorption and retention in 21days, dropped the PH value to 6.5, which is acidic and combustible.

According to Chinnappan (2012), 1kg of cow dung will produced $0.264m^3$ of gas, but with the improvement made, $0.294m^3$ per 1kg of cow dung and rumen fluid was produced. This means that for a design capacity of 272kg cow dung and rumen fluid, it is expected that $79.968m^3$ of gas would be produced.

This first small-scale biogas digester in Damaturu has the capacity to create enough Biogas to cook one meal or heat water for the few individuals who work in the Mechanical workshop in the Polytechnic daily. This necessitates the Polytechnic to establish gas production, deliver feedstock, and organize daily feeding. The digester can also be utilized for teaching and learning reasons as part of the Polytecninic's mandate. Biogas for light engines, cooling systems for the fish industry, latrines for suburban areas, and energy generation from a local anaerobic treatment plant are all viable biogas applications in the future, assuming adequate funding is available. Cooperation with governmental and non-governmental groups and other stakeholders within the country, as well as international agreements and grants

From the experiment, Biogas digester plants provide a sustainable way to meet hygiene concerns and meet the energy requirements in rural areas. Raw materials for the operation of biogas digester plants are found in abundance in villages, mainly cattle waste. Many biogas digester plants have already been set up in some towns across Nigeria. Still, the technology has not yet reached most parts because of the lack of initiatives and education. The installation cost of a biogas digester plant is also very high, which is another deterrent for a more extensive scale setup of plants. But there needs to be proper awareness among people. This presents a challenge for the government, academia and other non-governmental organizations.

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Appendix

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