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ORIGINAL RESEARCH ARTICLE

PERFORMANCE OF A SIMPLIFIED MODEL INNER-TUBE BIODIGESTER FOR BIOMETHANE PRODUCTION FOR HOUSEHOLD USE IN NIGERIA

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ABSTRACT

In the developing countries, methane capture from manures has been encouraged by using biogas plants which are predominantly household anaerobic digesters handling manure of livestock held by an average-sized family. This paper aims to assess the performance of a simplified model inner tube biodigester for biomethane production for household use in Nigeria. This paper also evaluates the biomass conversion technologies tested in the REEF (Renewable Energy Engineering Facility) Lab at the University of Exeter, the UK and the technology readiness level and implementation in Nigeria. Cow slurry and Inoculum were used to evaluate the operational efficiency and feasibility of the model Inner tube digester, with the aim of encouraging its use and adoption in Nigeria and Africa in general to help impact on the Sustainable Development Goals (SDG) on Climate Change and Energy Efficiency targets. The model digester as an option against the use of firewood, Kerosene or Liquid Petroleum Gas (LPG) system could increase the renewable energy potential in Nigeria while retaining organic matter and nutrients for soil replenishment for agricultural purposes. The 12-litre scale Biodigester showed a characteristic pattern of optimum biogas production efficiency and performance when mixed with inoculum, which indicates its prospect for future evaluation and use.

1.0 Introduction

1.1 Bioenergy Technology Development Worldwide

Access to affordable, clean energy is a major driver of Nigeria's and the Globe's actualization of the Sustainable Development Goals (SDGs). It also underpins other SDGs since energy access facilitates economic development, food security, health, education and other related objectives (Röder, Thornley, Campbell, & Bows-Larkin, 2014). Nigeria and other African Countries have a wide range of bioenergy feedstocks, which can be combined with a vast array of conversion technologies at a variety of scales to deliver sustainable bioenergy solutions from liquid fuels to cooking gas, and electricity (Andrew, 2014; Mirjam Röder, 2018). Bioenergy systems are already playing a key role in many countries towards achieving their climate change, emission reduction and renewable energy

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contribution targets (Andrew W, 2017). The term biomass is often referred to as the biodegradable fraction of products, waste and residues from the biological origin; agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of the industrial and municipal waste (Ben-Iwo*et al.*, 2016). Biomass contributes to the supply of energy approximately to 12% of the global status of the renewable energy inputs ranging from 40% to 50% in some developing countries (Ben-Iwo *et al.*, 2016; Tauseef*et al.*, 2013). Despite this enormous and potential opportunity in bioenergy, Nigeria still lags in biofuel production amongst other African Countries such as Ghana, Kenya and South Africa(Ben-Iwo *et al.*, 2016).This paper aims to explore the prospects of a Simplified Model Inner-Tube Biodigester for Biomethane Production for Household Use in Nigeria.

In the last decade, a major part of the globe has witnessed consistent growth in bioenergy, a renewable and environmentally friendly energy source, owing to its usefulness and advances in biodigesters development globally allowing for this technology to become more readily available in different applications worldwide (Thornley*et al.*, 2014). Precisely, the success stories of bioenergy are mainly due to the efforts of developed continents like South and North America, Asia, and European nations (Brazil, USA, China, India, Malaysia, the UK, etc.). See Figure 1, the Global trend of methane emissions from the management of livestock manure (Tauseef *et al.*, 2013).

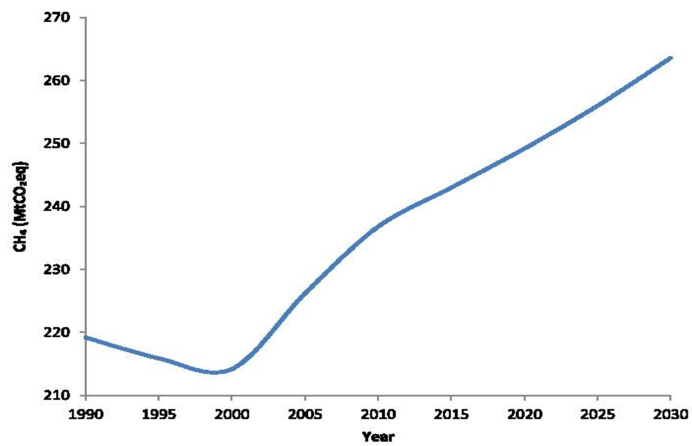

Figure 1. The global trend of methane emissions from the management of livestock manure (Tauseef *et al.*, 2013).

1.2 Energy Crisis in Africa and Nigeria

Energy plays a very significant role in the socio-economic development of a region and its people. Over the years, Africa has not only been the poorest continent in the world, but also the only major developing region with negative growth in income per capita between 1980–2000 and till date (Ben-Iwo *et al.*, 2016). In the rural communities, fuelwood and charcoal which is sourced from wood biomass is the predominant energy source used in Africa, resulting to about 74% of the total energy consumption for cooking and heating homes, when compared to 37% in Asia and 25% in Latin America (Ben-Iwo*et al.*, 2016; Kevin, 2015). Most of the people living in Sub-Saharan Africa (SSA) region lack access to clean, affordable, and environmentally-friendly energy and depend on solid biomass (usually referred to as firewood in Nigeria) to meet their basic needs for cooking (Kumar and Bai, 2005). This has been a major contributor to poverty and a hindrance to the development of the African Continent. Even in recent times, nothing significant has really changed or improved on the biofuel production capacity in Nigeria (Galadima *et al.*, 2011). Those living in the rural areas constitute the highest number of users of firewood because of their proximity to the biomass source and fewer regulations and monitoring on deforestation from the Government(Sunset, 2015).

Those in the urban and sub-urban areas who use modern cooking devices like gas cookers, burners, or stoves find it difficult to cope with the rising costs of the energy required to run those devices or systems. Over the year, the rising cost of Liquid Petroleum Gas (LPG) and Dual-Purpose Kerosene (DPK) have made most people living in these mentioned areas to abandon the use of gas cookers or stoves to cheaper alternatives such asfirewood and some locally made charcoal powered stoves(Ben-Iwo *et al.*, 2016; Sunset, 2015.). For those who persist in using LPG powered gas cookers, most of them buy on credit and pay at the end of the month when they receive their wages from employers. These set of people are usually the credit-worthy Civil Servants who project in Public Service institutions, or private industries where they get paid at month end. The LPG retailers know they are creditworthy and hence could afford to sell on ''buy now pay later'', as it is often referred to in most part of Africa.

In Nigeria more specifically, the case is no different.Despite its rich source of crude oil, it has experienced a slow pace of growth in the bioenergy industry because it is historically plagued by civil unrest and poor government policies on energy supply and security, which are among the main contributor for its poor economic performance in the past and even recently(Ben-Iwo *et al.*, 2016).Nigeria has four petroleum refineries with combined crude distillation capacity of 10.7 million barrels per day (bbl./d), an amount that far exceeds the national demand, the country still imports most refined petroleum products because the refineries are moribund(Ben-Iwo *et al.*, 2016). This is due largely to the low capacity utilization of existing refineries and the poor government policies as mentioned earlier.

The growing number of oil discoveries in the African continent has had a questionable negative impact on the economies of Nigeria(Ben-Iwo *et al.*, 2016). With the growing tensions in Niger Delta oil-rich regions because of the environmental impact of operations of major oil and gas companies (Shell, Agip, Mobil, Total, ADDAX and NNPC), have not helped in making the much-needed progress in the energy sector. Electricity supply from gas-powered turbine has suffered more due to the incessant crisis between the youths and gas companies in the region where the gas is produced. The availability of Dual Purpose Kerosene (DPK) for cooking and used as jet fuel have equally suffered a setback. Oil Companies and suppliers would rather sell to aviation industries or airline operators in the bid to make more money than those who simply use the kerosene to power their stove for cooking and heating purposes.

Biomass is the main energy resource in Nigeria owing to the huge reliance on the energy source for cooking and heating purposes by most of the Nigerian people(Ben-Iwo *et al.*, 2016; Thornley *et al.*, 2014). According to the global initiative on available, clean and efficient energy - Sustainable Energy for All (SE4ALL), not much progress has been made in providing access to non-solid cooking fuels (like firewood) since 1990. As visible in figure2, below, in 2010, only 26% of the population had access to non-solid cooking fuels with a big difference between urban and rural areas(Ben-Iwo *et al.*, 2016; López-Bellido, 2014). The government of Nigeria have made little or no efforts in trying to remedy these situations because it makes more money through oil exports.

Regardless, the profits from oil exports could mean that the government in Nigeria can invest in domestic businesses (like the development of the bioenergy technology) and infrastructure, consequently promoting economic growth and attracting foreign investments(Ben-Iwo *et al*., 2016). However, with the growing concerns of Climate Change and demand to cut down on Green House Gases (GHGs) emissions, Nigeria is making efforts like other countries towards Research and Development(R&D) of alternatives to fossil fuels but these efforts have resulted in little or no major impact or results(Sunset *et al*.,2015).

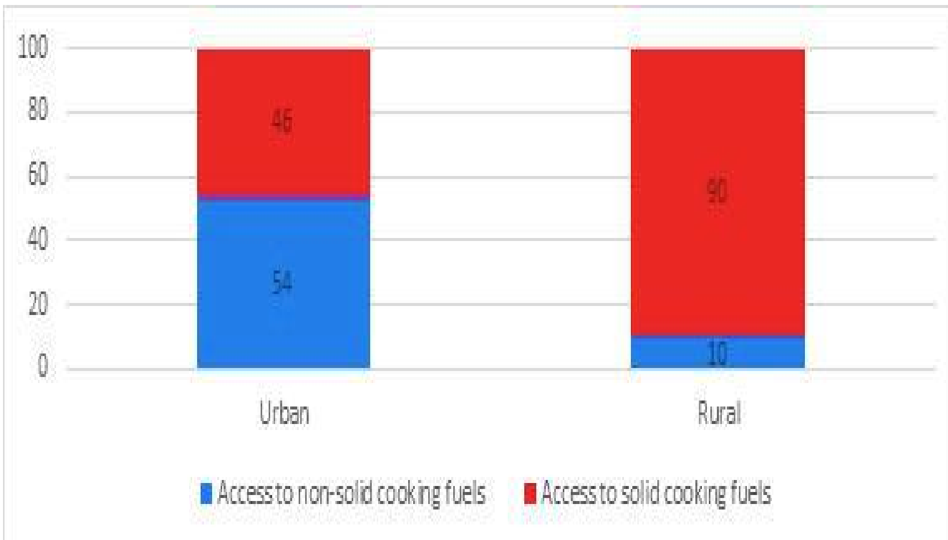

Figure 2. Access cooking fuels in rural and urban areas in 2010 (in %) (Ben-Iwo *et al*., 2016)

The argument is that the government must seek help from international corporations just like it has done with the crude oil (petroleum) industry. But this is equally not yielding the much-anticipated result like we see in developed countries (Ben-Iwo *et al*., 2016; Nand, *et al* 1991). Hence, in the bid to draw more attention from Government and the people both in the urban and most especially the rural areas, there is a need to design and construct a low cost and small-scale tailor-made bioenergy system that can be used to produce gas (Methane) for cooking, heating purposes thereby creating the much-needed awareness and attention on the feasibility of harnessing renewable energy from solid wastes (renewable energy), and improve on the energy security of the Country.

1.3 Biomethane from Biomass and Solid Waste in Nigeria

Globally, research and development on laboratory and field trials for biofuel systems has significantly increased over the last two decades and has become attractive as the right substitute for fossil fuels (Ben-Iwo *et al*., 2016; Liu & Wu, 2016). This is because of the increasing demand for clean energy, global climate change targets and policies towards reducing dependence on crude oil (Ben-Iwo *et al*., 2016). The processing of biomass into biofuel and its co-products has important effects on international policy and economy, and on rural development. It helps in reducing the over-dependence on oil-producing countries and supports rural economies through job creation and an additional source of income (Ben-Iwo *et al*., 2016; Welfle, 2017). The solid biomass(wood) account for about 80% of the total primary energy consumed in rural and suburban communities in Nigeria (Ben-Iwo *et al.*, 2016; Simonyan and Fasina, 2013). The Northern Part of Nigeria has the highest number of cattle husbandry and about 95% of these cattle graze in the open with the dungs disperse without proper collection (Ben-Iwo *et al.*, 2016; Galadima *et al.*, 2011). In the Southern part of the country where we have slaughterhouses (abattoirs) or sites where animals such as cows, goats or sheep (often referred to as Zongo) are sold, this waste is properly collected and could be used as fertilizer or dumped in the open.

Despite the difficulty of Ranching Cattles in Nigeria, cow slurry still holds a lot of prospects to help curb the energy crises in Nigeria (Galadima *et al.*, 2011; Tauseef *et al.*, 2013). Most especially in the production of biofuel for domestic purposes. It has been estimated that slurry from animal husbandry produces about 240 million metric tons of carbon dioxide equivalent of methane to the atmosphere and this represents one of the highest anthropogenic sources of biomethane (Simonyan and Fasina, 2013). Since methane is the second highest contributor to global warming after carbon dioxide (Tauseef *et al.*, 2013; Zheng *et al.*, 2015), it is necessary to explore ways in developing systems to capture as much of the anthropogenic methane as possible and convert them into use. There is a lot of advantage in the capture and utilization of methane: it is clean as a source of energy when compared to natural gas (Tauseef *et al.*, 2013), which is predominant in Nigeria and creates major pollution crises in Niger Delta Regions.

The aim of this research project is to explore the prospects of using the inner tube digester to produce biomethane from cow slurry which can be used in developing countries for providing energy to the rural poor. The effect of inoculating the cow slurry in the digester to produce more biomethane was equally investigated. The materials and ease of construction of the digester from locally sourced materials and how the methane can be captured for domestic purposes, in this case, was highlighted.

1.4 Anaerobic Digestion: Steps associated with the generation of methane

Anaerobic digestion is the bacterial fermentation of organic substances in the absence of oxygen. The process leads to the decomposition of complex biodegradable organics in a four-step process (Kevin, 2015) (Fig. 1). The anaerobic digestion of organic material in municipal solid waste or from cow slurry provides renewable energy in the form of biogas (Mata Alvarez, 2003; Kevin 2015) and can also create a means of recycling valued mineral nutrients back to agricultural land (Lukehurst *et al.*, 2010). To optimize the latter requires source separation of targeted organics, as the material arising from mechanical pre-treatment, has a high level of contamination, with heavy metal concentrations above the recognized values for agricultural land used in food crop production (Zhang, 2012).

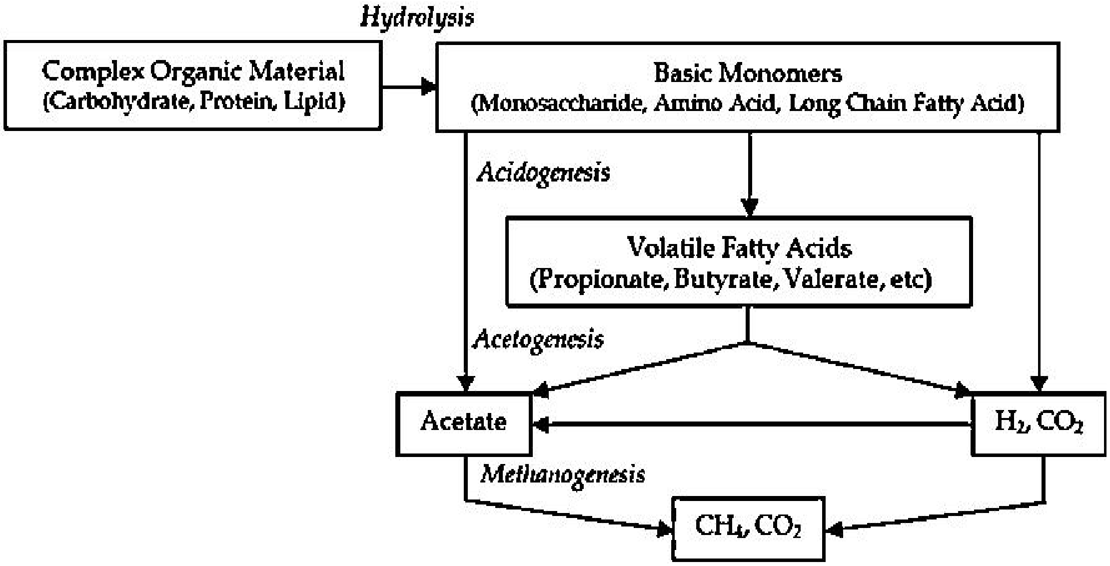

Figure 3. Steps of the Anaerobic Digestion Process (Tauseef *et al*., 2013)

Food waste from both domestic and commercial sources have been a major source of feedstock for biogas production due to its high biochemical methane potential (Zhang, 2012), though its high moisture content makes energy recovery through thermal treatment unappealing (Ahring, 2003).

2.0 Methodology

2.1 Materials

The research was conducted in laboratory using three lab-scale manually mixed mesophilic inner tube digesters which were fed on a daily basis for 30 day period. The results presented here were for the first 10-days trial. The laboratory-scale digesters each had a 6-litre substrate volume as content but with a total capacity of 12-litres and were constructed using the innertubes of automobile car tyres, acrylic tubes with gas-tight top and runner bungs as stoppers for the openings in the tubes.

2.1.1 Conventional Components of Biodigesters

There are several types of biodigester used in producing biogas from organic wastes that have been introduced and applied to various areas of use like in domestic and industrial applications. The most predominant being the large-scale communal type, e.g. Fixed dome and floating dome types(Tauseef *et al*., 2013). China and India were among the first countries which methodically developed biogas technology for rural communities. They equally experienced that large-scale biodigester frequently showed some glitches for rural application and use. Some of the reasons adduced were the high production cost and difficulty in maintenance by the households (Liu and Wu, 2016; Tauseef *et al*., 2013). As an alternative to the common types of large-scale biodigester, an inner tube (for automobile tyres) biodigester has been conceptualized and constructed for small-scale household purposes in Nigerian rural areas. The original idea was from John L Fry, Innertube Methane Digesters for Fuel Gas and Fertilizer, developed in 1973 for households. Some globally recognized biogas digesters used in places like India, China, and other developing countries for producing biogas from animal manure normally have the following features:

- Digester: The slurry which is usually animal wastes mixed with water or other solid wastes is fermented inside the digester and biogas is produced through bacterial action(Tauseef et al., 2013). This research adopted this type of digester concept given the ease of construction, the availability of the materials for construction and the low-cost of the entire biodigester.

- Gas holder or gas storage dome: The biogas here is collected in the gas holder, which holds the gas until the time of consumption (Tauseef, *et al*, 2013).

- Outlet pipe: In the outlet pipe the digested slurry is discharged into the outlet tank either through the outlet pipe or the vent provided in the digester.

- Mixing tank: The feedstock material (dung) is collected in the mixing tank. Enough water is added, and the material is thoroughly mixed until a homogeneous slurry is formed for the anaerobic digestion process.

- Inlet pipe: In the inlet pipe type, the feedstock is emptied into the digester through the inlet pipe/tank for the process.

- Gas pipeline/hose: The gas hose transports the gas to the point of application, such as a heating or cooking stove or a lamp. Cow slurry is the most common feedstock for biogas digesters, but substantial amounts of manure produced by buffalos, poultry, and pigs, are used, too (Table 1).

Table 1. Biogas Potential of Livestock Manure (Tauseef *et al.*, 2013)

Animal fresh	Total manure (kg/head/day)	Total solid (TS) (kg/head/day)	Biogas yield factor (m^3/kg of dry matter)	CN	VS (% of manure)
Cow	20	4.0	0.20 – 0.50	18 – 25	13
Buffalo	25	4.5	0.15 – 0.32	18 – 25	-
Pigs	1 – 5	0.6	0.56 – 0.65	13	12
Sheep	1.8	0.6	0.37 – 0.61	29	-
Goats					
Poultry	0.1	0.03	0.31 – 0.54	-	17
Horses	2.4	7.1	0.20 – 0.30	24 – 25	-
Rabbits	0.2	0.1	0.36	-	

2.1.2 Experimental Procedure of the biodigester

The research project was conducted using a lab-scale manually mixed mesophilic biodigesters, which was constructed and fed daily. The lab-scale biodigesters each had a 12-litre capacity but 6-litres projecting volume (for headspace considerations) and were constructed of acrylic (Perspex) tubes with air-tight, and waterproof tyre tubes. The innertubes of car tyres were locally sourced from tyre shops around the community. The top part of the digester was fitted with a gas outlet tube made from acrylic, an inlet feed port sealed with a rubber bung, and an effluent port sealed with a rubber bung where the digestate is released. The figures 5 and 6 shows the complete draft and layout of the inner tube digesters as it was designed and setup. Given the prevailing weather condition, the temperature of the system was raised at 36 ± 1°C by concentrating two 1000 watts halogen lamps on the biodigesters at a height of about 1.5 metres to keep the temperature of the biodigesters at the optimum gas production level. The lamps provided the much-needed thermal energy required to keep the biodigesters at an optimum temperature level for 7 hours daily and the thick blanket was used to cover the digesters through the night, to maintain or retain most of the heat generated from the lamp. The values from the temperature probes showed that part of the heat was retained at night when the halogen was put out to reduce the energy billings. The artificial heating (parasitic energy)(Kevin, 2015) was equally necessary to simulate the average Nigerian type of temperature from a solar source, where the ambient temperature is usually higher than the ambient temperature of the lab where the research was carried out.

2.1.3 Household Continuous- Feed Methane Biodigester

There are several types of biodigester used in producing biogas from organic wastes that have been introduced and applied to various areas of use like in domestic and industrial applications. The most predominant type being the large-scale communal type, e.g. fixed dome and floating dome types (Tauseef *et al*., 2013). China and India were among the first countries which methodically developed biogas technology for rural communities. They equally experienced that large-scale biodigester frequently showed some glitches for rural application and use. Some of the reasons adduced were the high production cost and difficulty in maintenance by the households (Liu and Wu, 2016; Tauseef *et al*., 2013). As an alternative to the common types of large-scale biodigester, an innertube (for automobile tyres) biodigester has been conceptualized and constructed for small-scale household purposes in Nigerian rural areas. The original idea was from John L Fry, Innertube Methane Digesters for Fuel Gas and Fertilizer, developed in 1973 for households. The biodigester was made from tractor scrap innertubes, acrylic (Perspex), bicycle innertubes, PVC Pipes, shown in Figure 4, below. The small-scale biodigester was suitable for the household purpose and quite affordable to be installed individually in each household with access to solid waste like cow slurry.

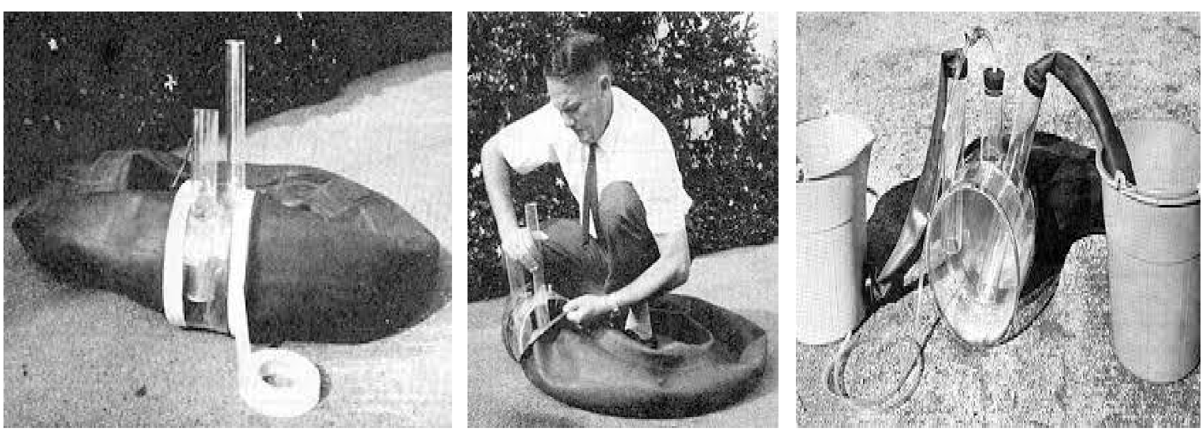

Figure 4. Innertube Digester; Methane Digesters for Fuel Gas and Fertilizer (Fry *et al*., 1973)

The newly conceptualized digester was designed and constructed from similar materials like automobile car tyre innertubes (butyl rubber), acrylic (usually referred to as Perspex in Nigeria). See Figures5,6, for the array of the design and construction of the simplified model of a low-cost innertube digester. The biodigester was constructed taking into consideration the availability and low costs of the materials rural communities in Nigeria. The Biodigester can be fed continuously using food wastes and other semi-solid waste or biodegradable biomass,unlike John L Fry's digester that was strictly used for cow slurry. Household users can take the effluent as ready-to-use biofertilizer in addition to the biomethane gas for their daily cooking and heating purposes.

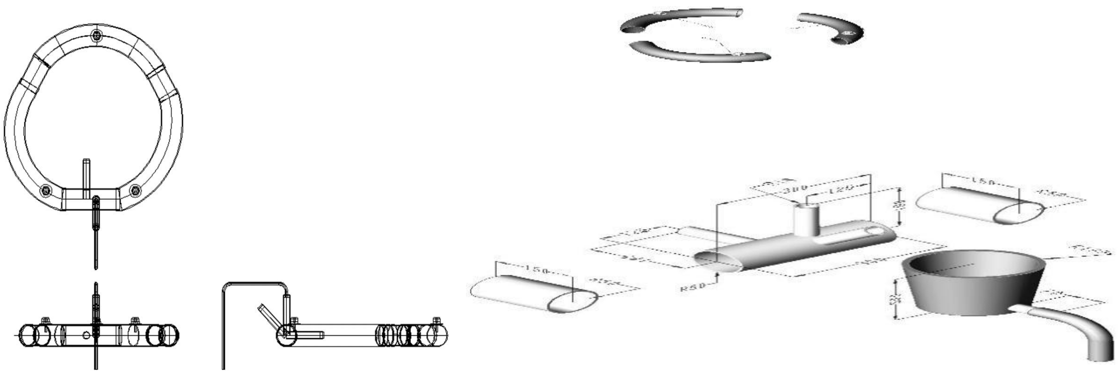

Figure 5. Arrays of the AutoCAD Design of the 12 litres Innertube Digester

Figure 6. Arrays of the 12 litres innertube digesters been tested

2.1.4 Feeding Regime

A continuous feeding operation was realized by daily removal of digestate through an outlet tube in the other section of each digester, followed by substrate addition through the inlet tube. The lab-scale digesters were of the same design and the same mixing regime and Hydraulic Retention Time (HRT) was to be observed for a 30-day period(Kevin, 2015). In all the cases biogas production was measured using tipping-bucket gas counters with continuous data logging (Y Zhang, Walker, Banks, & Environment, 2010) using the Rasberry Pi kit and phyton coding.

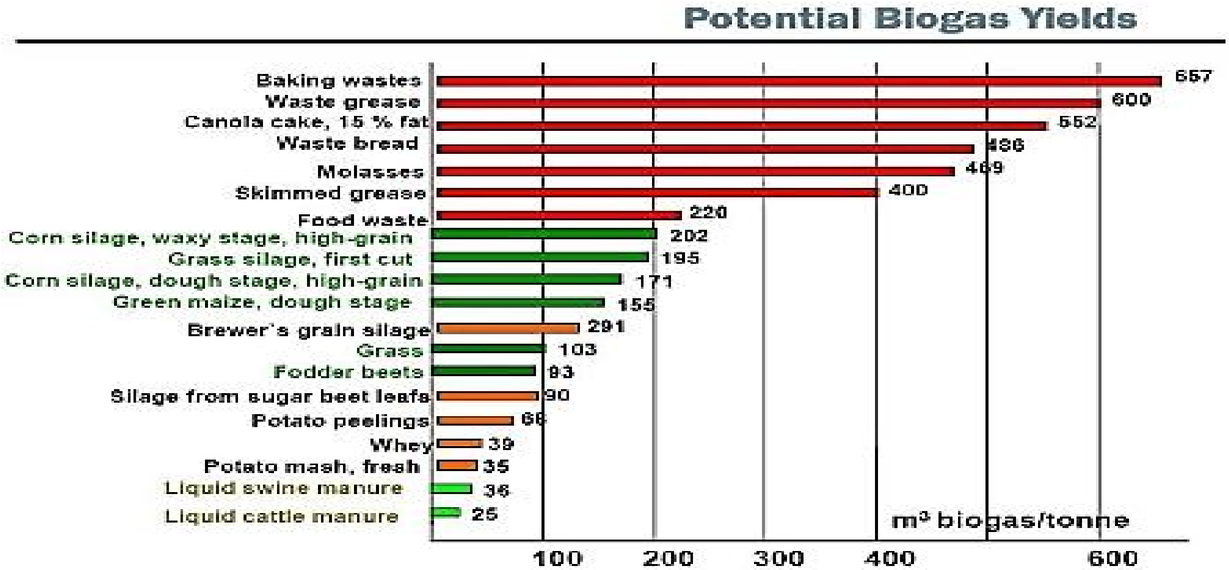

Figure 7. Potential Biogas Yield (Tauseef *et al.*, 2013)

2.1.5 Mixing Mechanism: Parasitic Energy Demand

The major requirements of the anaerobic digestion process are thermal energy to maintain temperature (as in the case of using the halogen lamps) and pumping/mixing energy to distribute and homogenise substrate(Kevin, 2015). In the case of these digesters, the manual mixing by hand was adopted looking at the prevailing energy crisis in Nigeria and rural communities globally. Most rural homes lack access to constant electricity and it became obvious that these digesters may not get the required parasitic mixing energy from electricity. Hence, manual mixing is adopted given the fact that the materials of construction of the digesters are flexible (butyl rubber) and elastic. Since most anaerobic digestion systems are used to generate electricity using a Combined Heat and Power (CHP) unit(Kevin, 2015), excess heat is often readily available in most sophisticated systems, so the parasitic energy required to heat will not be considered further as far this project is concerned.

2.1.6 Data Logging of The Bioprocess: Using Raspberry Pi and Sensors

Operative monitoring and control are important to ensure process stability while optimizing process performance and the economics of the system (Kevin, 2015), particularly if the organic loading rate is high (Latif, *et al*, 2011). Certainly, there is a need for effective monitoring and control if the mixing system is to be optimized for biogas production. As a general case, monitoring and control systems vary depending on the application or use (Ounnar, *et al*, 2012). Research and Development require adaptable process instrumentation whereas on-site system needs robust and automated process instrumentation solutions (Kevin, 2015). In a more complex biodigester, a more sensitive, comprehensive and reliable approach for data logging is adopted, whereas a small single-feedstock rural AD plant may survive with simple titration augmented by the occasional visit by a consultant (Zhang *et al.*, 2010). Though the cost of monitoring equipment is becoming cheaper thereby improving the affordability of monitoring and control for smaller operations, the robustness and simplicity will always be key requirements when deployed in the potentially harsh environment of a farm. To save cost and ensure a simple data logging process is achieved to evaluate the performance efficiency of the lab-scale digesters, the biogas production was measured using tipping-bucket gas counters with continuous data logging (Zhang *et al.*, 2010) connected to the Raspberry Pi kit and phyton coding used to interpret the readings of the temperature probes (inserted into the digesters) and gas volumes. The simple codes used was effective in reading the volumes of gas produced and the temperature from the sensor probes. See figure 8, for the set up used for the bioprocess data logging. Many sensors produce pulsed outputs with a switching action. This circuit and code combination for gas production as shown below are very useful;

GPIO.cleanup() #reset GPIO port GPIO.setmode(GPIO.bcm)#Broadcom pin notation GPIO.setup(17,GPIO.IN)#setup GPIO 17 as input pinstate=GPIO.input(17)#read the pin

A Simple circuit diagram for the connection used on the raspberry pi breadboard for the DS18B20 temperature probes is shown in figure 8.

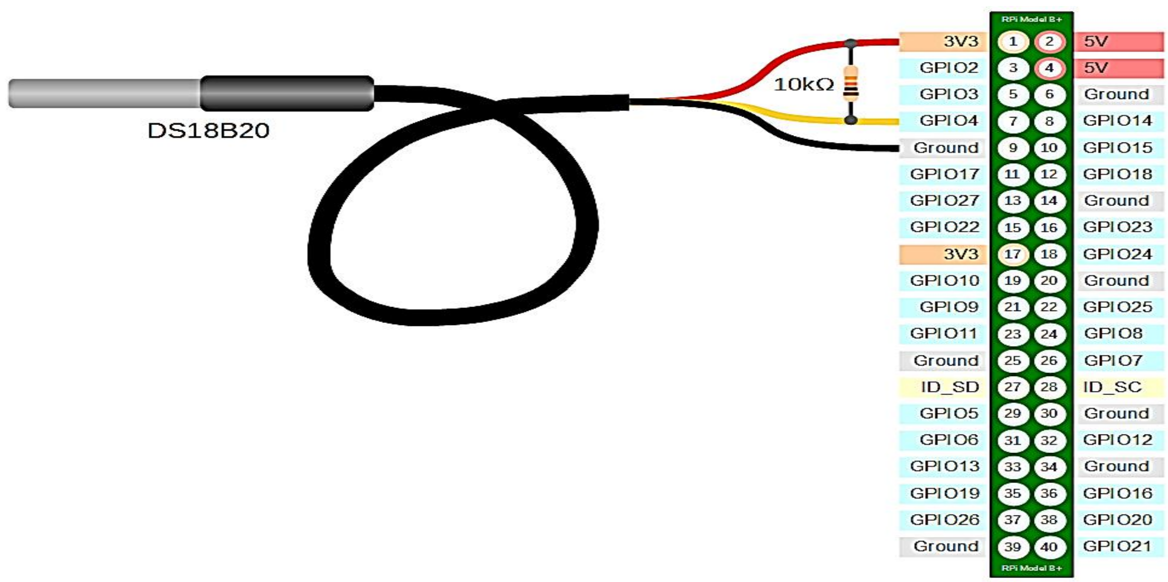

Figure 8. Circuit Diagram for the typical DS18B20 Temperature Probe(DS18B20, 2018)

The temperature sensor circuit diagram for the lab-scale biodigesters was built as outlined in figure8, and the codes written, run on the Python script.

2.1.7 Other Bioprocess Optimization Metrics Used

The practicality of the different metrics that can be measured varies(Catron, *et al*, 2013) but key values are usually the pH, alkalinity, Volatile Fatty Acid (VFA) concentration and biogas flow rate and composition of the substrate(Budhijanto, *et al*, 2012). Biogas production is an easy way to measure reactor performance but does not indicate the chemical stress experienced by the digester (Kevin, 2015). The biogas production of the digester was measured using tipping-bucket gas counters with continuous data logging (Zhang *et al.*, 2010) connected to the Raspberry Pi kit and phyton coding used to interpret the pulse readings and gas volumes. The pH of the substrate was also relatively easy to monitor using a standardized and calibrated double junction pH meter (pHTestr 30).

2.1.8 Cattle slurry

Over the period of this research two 60litres, drums of cattle slurry were obtained from Chynoweth Dairy Farm, Truro, the United Kingdom. It was then homogenised and stored in the bioresource refrigerator under the cold chain. Table 1 shows the typical characteristics of the cow slurry material and the biogas potential. To determine the moisture content and total solids of the cow slurry before mixing with deionized water (1:1), there was a need to oven drying and desiccation.

2.1.9 Inoculum

The inoculum for the 12-litre laboratory-scale trial digesters was taken from a 30-litre drum that is equally used at the farm at Truro, the UK. The inoculum was free from any large particles and easy to use in mixing with the cow slurry (1:1) to form the digestate. One of the 12-litre digesters were inoculated with the combination of 6-litres digestate (inoculum and cow slurry) to give a composition of 1:1, under a mesophilic condition at the Renewable Energy Engineering Facility, at the University of Exeter, the UK. The inoculum was provided by Chynoweth Dairy Farm at Truro in Cornwall. A digested dairy manure inoculum was selected due to the high levels of biomass it contained, the reliability of the source and the instantaneous digester start-up that the inoculum enabled (Yue Zhang, *et al*, 2012).

2.2 Digester Operation and Monitoring

The model laboratory-scale digesters were fed in parts with a mixture of inoculum and Cow Slurry, at a ratio 1:1 on a Volatile Solid basis (Yue Zhang *et al.*, 2012). Two more digesters were fed with cow slurry (the same ratio as the first digester) and Inoculum only in the proportion of 1:1 on a fresh weight basis as calculated based on the moisture content and total solids (TS) content with respect to their relative quantities in the UK waste stream(Kevin, 2015; Yue Zhang *et al.*, 2012). To ensure homogeneity the substrates in the digesters were thoroughly mixed manually by hand-agitation which reduced the total solids content from 94% to around 20%. The choice of manual mixing was to reduce the cost of parasitic energy (Kevin, 2015) required for mixing and to simulate the mixing technique that is predominantly available in Nigeria or Africa where the model digester is originally designed to be used. The third digester which was fed only on inoculum and acted as a control, for the evaluation of the entire process. The total Organic Loading Rate (OLR) for all digesters was 6 kg VS m−3 day−1 throughout the trial. The solids and liquid retention times were coupled and hydraulic retention time (HRT) of 30 days and maintained. The digestates were removed with the aid of calibrated syringes through the effluent tube after which they are discarded or used as biofertilizer when needed. Fresh substrates were fed to the digester in the same quantity as the effluent taken out. See figure 9, for part of the bioprocess carried out.

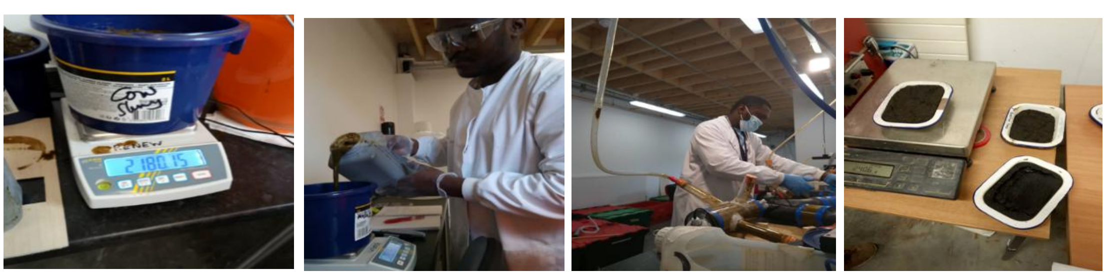

Figure 9. Bioprocess: Loading the biodigester with the feedstock

The operating regime of the entire system was maintained for 30 days with the possibility of extending to measure another parameter which is not under study in this paper. All digesters (namely Alpha, Beta, Cappa) were monitored daily for biogas production, temperature and pH. All gas volumes reported are corrected to Standard Temperature and Pressure (STP) of 0 ^{0}C, 101.325 kPa.

3.0 Results and Discussions

3.1 Carbon and Nitrogen content

The Carbon to Nitrogen (C/N) ratio plays an important role in the AD and biogas production process. A C/N ratio that is either too high or too low will inhibit biogas production(Tauseef *et al.*, 2013). The C/N ratio of the substrate after inoculation was calculated and found to be 24.7 for the dairy manure. The suitable range of the C/N ratio was 20–30 for anaerobic digestion processes, and the optimal C/N ratio suggested for gas production is 25(Tauseef *et al.*, 2013; Yue Zhang *et al.*, 2012).

Table 3. The Volume of Biogas Produced from the Tipping Counter (Pulse/ml)

Time (Days)	Alpha biogas production Pulse/130mL	Beta biogas production Pulse/120 mL	Cappa biogas production Pulse/104mL
1	4	31	5
2	2	69	4
3	1	53	0
4	0	45	0
5	4	59	9
6	7	67	4
7	6	52	5
8	6	63	10
9	7	64	9
10	3	1	2

Table 4. The Volume of Biogas Produced (mL)

Time (Days)	Daily Alpha biogas production (mL)	Daily Beta biogas production (mL)	Daily Cappa biogas production (mL)
1	520	3720	520
2	260	8280	416
3	130	6360	0
4	0	5400	0
5	520	7080	936
6	910	8040	416
7	780	6240	520
8	780	7560	1040
9	910	7680	936
10	390	9720	208

3.1 The Effect of Inoculating the Innertube Digester

A suitable nutrient content in the inner tube biodigester is very important for the AD process of cow slurry. The essence of using inoculum in one of the digesters (Beta Digester) was not only to provide active microorganisms but also to serve as an active source of nutrients. The inoculum satisfies the demand for macronutrients, micronutrients and nitrogen for the anaerobic digestion process without the addition of chemicals (Kevin, 2015; Yue Zhang *et al*., 2012). These nutrients essential for cell growth and the methanogens require special micronutrients for optimum gas production(Kevin, 2015). The macronutrient (Na, K, Ca and Mg) content in the inoculums was enough for the metabolic activities of the microorganisms(Yue Zhang *et al*., 2012).The results from the bioprocess show that the concentrations of K and Ca in the Beta digester were higher than in non-inoculated digester containing only cow slurry (Cappa Digester).

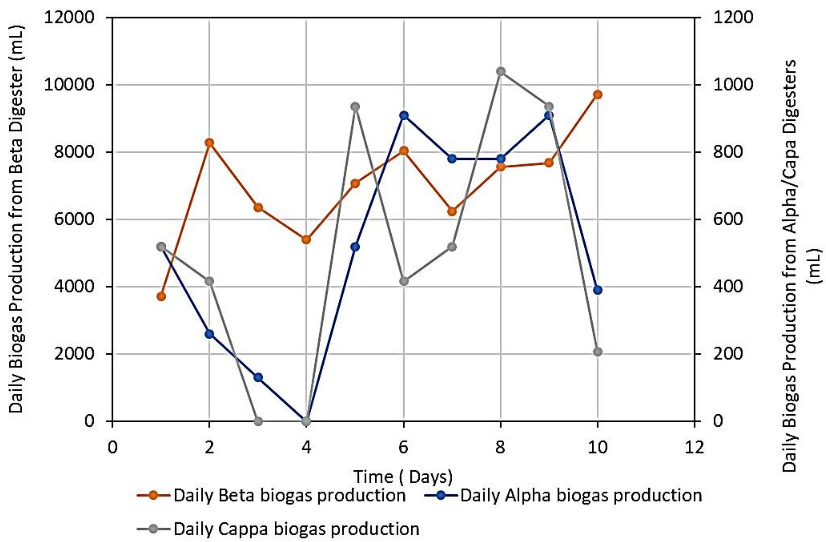

Figure 10. Daily biogas production(mL)

According to Zhang *et al*., 2011, the micronutrients contained in bioreactors were the key factors for improving anaerobic digestion. The results from the volume of gas produced and the charts buttress these points (See figure 10 & 11). After inoculation for the first 10 days, the digested cow slurry in the Beta Digesterclearly shows from the charts in figures 10 & 11 and results shows that it had a higher concentration of micronutrients than when it is not mixed with the inoculum, the Cappa Digester (without inoculum). The biogas production rate and volume from the inoculated Dairy Manure (Beta Digester) were the highest of the three digesters (Alpha, Beta Cappa). The Alpha Digester (Inoculum only) like the Cappa Digester, did not produce a substantial amount of biogas like the inoculated digester. The chart shows that under the same set of conditions (Temperature, Insulation, Volume, Hydraulic Retention Time, feeding regime) the inner tube digester containing the inoculated cow slurry (Beta-Digester) had the most effective and consistent methane gas production level among all the digesters. The higher concentration of micronutrients contained in the Beta Digester because of inoculation resulted in an improved performance than seen with the other digesters (Gu, *et al*, 2014).

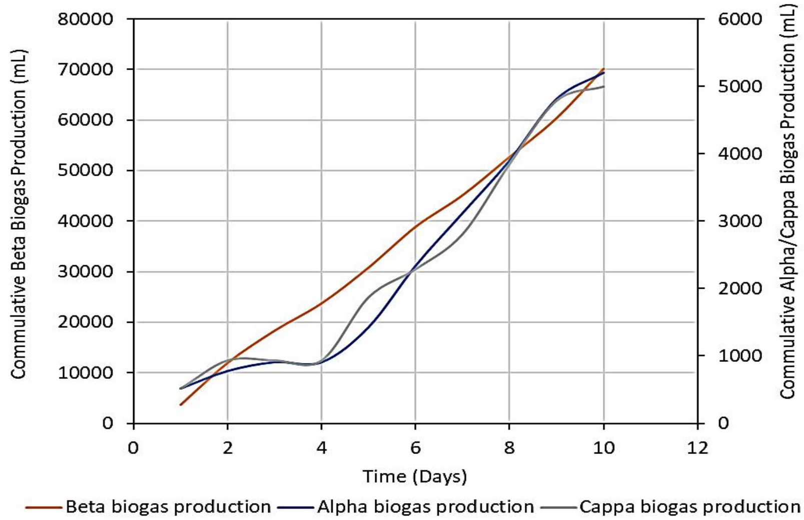

Figure 11. Cumulative Biogas Production (mL)

3.3 Methane Gas from the Inoculated Digester

The gas produced from the inoculated Beta digester can be scrubbed to produce pure methane which could be used for the purposes under studys. Looking at the chart for the cumulative biogas production rate, it is obvious that the Beta-Digester can be upgraded by the capacity to produce more gas (methane) for household use.

4.0 Conclusion

Biogas production takes a considerably long time to be stable.In developing countries, especially India, Nigeria, Ghana, and other Southeast Asian countries methane capture from manure has been encouraged by using biogas plants which are predominantly household anaerobic digesters handling manure of livestock held by an average-sized family. While this project is exploring the possibility of direct application on the field or households, it is important for it to be subjected to conventional trial and error experiments as seen in the lab-scale digester. This research project at this level only concerns itself with developing an innertube biodigester from automobile car tyre tubes for the quantitative optimization of continuous biodigester performance from an inoculated cow slurry. The purposes of the optimization efforts in biogas production using the tipping counter and raspberry pi are not only to obtain the highest conversion of the cow slurry but also to achieve the highest possible selectivity in simple materials for biodigesters construction. Improvements on this model and the bioprocess optimization of the digesters will be presented in another publication of this project.The common feature of this digester, described in figure5&6, is that they employ no heating or continuous or excessive mixing due to which anaerobic digestion proceeds at a very slow rate. But this model adopted keeps the costs of the system down and makes them net energy producers, thereby making them a source of much-needed energy in the villages. The simplicity also makes their operation easy, enabling even illiterate farmers to use them effectively. There is a need to promote this form of bioenergy capture system throughout the developing world.

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