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*Full Length Research Paper*

# Design and construction of fixed dome digester for biogas production using cow dung and water hyacinth

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**Engineered biological systems used for resource recovery often utilize anaerobic digestion to treat organic wastes by reclaiming the carbon as energy (methane gas) and a soil amendment (biosolids). This study explored the production of biogas from co-digestion of cow dung waste and water hyacinth (*Eichhornia crassipes*) using anaerobic biological conversion. Cow dung and water hyacinth biomass feedstock were collected from Abattoir and Ologbo River in Benin City, Nigeria. Samples were blended and substrate mixed in ratio 10:1 v/v due to balanced carbon/nitrogen (C: N) ratio of plant biomass and cattle rumen manure and charged into the fixed dome. Performance test was carried out after the biogas had been produced after twenty-one (21) days. The percentage composition of biogas produced shows that methane gas ($CH_4$) has 56.4%, carbon-dioxide ($CO_2$) is 35% and nitrogen ($N_2$) is 6.9%. Optimal production was found to be a function of temperature, hydraulic retention time, pH, concentration of bacterial population and overall design consideration of the digester. Scrubbers were fitted to rid the gas of hydrogen sulphide ($H_2S$), $CO_2$, ammonia ($NH_3$) and moisture. The gas was directed through a gas pipe to a burner for cooking in the staff canteen. This study is relevant for the implementation of Sustainable Development Goals (SDGs) and strengthening of the bio-based economy with respect to waste management. This can facilitate environmental and socio-economic sustainability leading to reduced carbon foot print and reduction in solid waste accumulation.**

**Key words:** Cow dung, water hyacinth, bio-digester, biogas.

## INTRODUCTION

Biomass waste in the form of plant and livestock residues such as crop leftovers and manures are some of the largest available bioenergy sources in both rural and agro-industrial areas (Avaci et al., 2013). It is estimated that nearly 1.3 billion tonnes of food including fresh vegetables, fruits, meat, bakery, and dairy products are lost along the food supply chain (FAO, 2012). Also, the carbon footprint of food waste is estimated to contribute to the greenhouse gas (GHG) emissions by accumulating approximately 3.3 billion tonnes of $CO_2$ into the

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atmosphere annually (Paritosh et al*.,* 2017). Therefore, exploring non-conventional and eco-friendly appropriate waste-to-energy technologies to mitigate the effects of climate change and reduce fossil fuel dependence has increased globally. Anaerobic digestion (AD) can be an alluring option for effective organic waste management leading towards a circular economy. It can help to foster the transition from fossil fuels dependence to more sustainable energy-producing scenarios while strengthening energy security and subsequently addressing waste management and nutrient recycling.

AD is a process in which microbial communities in the absence of oxygen convert biodegradable organic carbon (volatile solids (VS) or substrate) primarily into biogas containing the energy-rich compound methane. AD process involves four different stages (hydrolysis, acidogenesis, acetogenesis and methanogenesis) where methane is produced by methanogenic bacteria as shown in ure 1. AD is a versatile, effective and established method for the digestion of different organic wastes by the action of rumen-derived microorganisms (Verstraete et al*.,* 2005). Biogas can be used for producing heat, electric power and vehicle fuel and therefore can serve as a means of reducing energy poverty, which has been a serious clog in the wheel of economic development in Africa (Adaramola and Oyewola, 2011). The methane and energy content of the gas generated usually varies and is dependent on the physical and chemical properties of the substrate used (Chenxi et al., 2011).

Investment in AD technology has increased due to its environmental and economic benefits (Grisel et al., 2014; Fantozzi and Buratti, 2011; Abbasi and Abbasi 2010). Sustainable waste management (SWM) is highly beneficial in terms of greenhouse gas (GHG) emissions reduction. Most of the studies highlighting the anaerobic treatment of organic waste have made significant improvements to enhance the energy recovery as a factor of biogas production and digestate (Anjum et al*.,* 2018; Chen et al*.,* 2018).

The biogas industry has been identified to be uniquely positioned to address nine of the 17 sustainable development goals (SDGs) – perhaps conceivably more than any other sector (WBA, 2017) (Table 1). These nine SDGs pertain to food and energy security, well-being, gender equality, sustainable water management and sanitation, resilient regions and cities, sustainable industrialization and combating the effects of climate change (Figure 1).

Despite the use of AD across the world, the overall sustainability of this process as a source of an alternate fuel (biomethane) is intrinsically linked to the successful management of one of its major byproducts, the digestate. The digestate is increasingly used to refer to the digested effluent produced in anaerobic digesters (Magrí et al., 2017). Digestate can be used as a potential fertilizer and soil amendment to improve the physical, chemical, and biological attributes of soil for crop production (Albihn and Vinneås, 2007; Lantz et al*.,* 2007). This enables the recycling of plant nutrients, thus potentially reducing the need for fossil fuel-dependent mineral fertiliser (Holm-Nielsen et al*.,* 2009). Producing a safe anaerobic digestate suitable for agricultural land application has become as important as producing the maximum yield of biogas. The application of organic materials to agricultural soils is a widely recommended practice not only as a source of essential plant nutrients which can provide savings in inorganic fertilizer use (Defra, 2010), but also as a means of increasing soil organic carbon (SOC) levels with associated improvements in soil biological and physical functioning (Bhogal et al*.,* 2009).

The solutions of organic waste management should not only be environmentally sustainable but also cost-efficient and socially acceptable. There are several factors that influence this complex process (Table 2), which are largely intertwined. Despite the continually rising energy demands reported globally, millions of communities and households, particularly in developing countries, still lack access to basic energy services (Surendra et al*.,* 2014). As a result, over three billion people primarily in the rural areas of developing countries rely on traditional solid fuels such as firewood, cattle manure, and crop residues for meeting cooking and heating needs (Surendra et al*.,* 2014). Water hyacinth also known as *Eichhornia crassipes* is a rich lignocellosic biomass with other bioactive compounds that are favourable source of biofuels production (Shanab et al*.,* 2016). More so, it is well established that biomass of aquatic macrophyte can be used for biogas production to meet energy demand (Kumar et al., 2017). In addition, *E. crassipes* is highly enriched with carbohydrates and lignin content, its impressive growth rate makes it a suitable source of lignocellulosic matter for the generation of biogas (Kumar et al., 2018). However, *E. crassipes*, is an invasive water weed and thrives in fresh water bodies causing serious environmental problems (Njogu et al*.,* 2015). Despite a long history of research and innovation for the development and optimization of household digesters, little has been reported for the application of these in Nigeria. The aim of this study is to evaluate the co-digestion mixture of water hyacinth and livestock manures in order to boost the methane production for sustainable energy security.

## MATERIALS AND METHODS

### Sample collection and preparation

In this study, cattle whole rumen-derived content was obtained from evisceration unit of slaughterhouse located at Ikpoba (6°21'5.09'N, 5°38'34.49'N) in Ikpoba Okha Local Government Area of Edo State.

**Table 1.** Biogas and sustainable development goals.

| Sustainable development goal | Contribution of AD |
|---|---|
| Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture | Restoring soils through the recycling of nutrients, organic matter, and carbon Increasing crop yields through use of nutrient-rich digestate bio-fertilizer<br>Recirculating phosphorus, which is essential for the growth of plants but limited in supply |
| Goal 3: Ensure healthy lives and promote well-being for all at all ages | Reducing indoor air pollution by substituting solid biomass-based domestic fuels with biogas<br>Treating and recycling sewage and organic wastes to reduce odours and the spread of diseases |
| Goal 5: Achieve gender equality and empower all women and girls | Reducing the burden of collecting firewood to improve the quality of women's and children's lives, reducing household labour in cooking |
| Goal 6: Ensure availability and sustainable management of water and sanitation for all | Providing decentralized, local treatment of bio-solids in remote and rural communities to reduce odours and the spread of disease<br>Stabilizing and recycling bio-solids through AD to allow them to be applied back to land<br>Reducing the carbon loading of wastewater to reduce impact on water bodies. |
| Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all | Reducing dependence on fossil-fuel-based energy sources by replacing with biogas<br>Capturing waste heat from co-generating units linked to biogas plants<br>Utilizing locally produced wastes and crops to generate energy for rural and remote communities<br>Storing biogas to produce energy when required |
| Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation | Improving the self-sufficiency and sustainability of industries by extracting the energy from their own effluents and using it for the self-generation of electricity and/or heat<br>Collaboration between industries and agriculture for mutual benefit<br>Generating short-term construction employment and long-term equipment manufacturing and maintenance employment<br>Encouraging growth of micro-enterprises by providing reliable electricity that can be stored and used when needed, that is baseload energy |
| Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable | Preventing spread of diseases through collection and proper management of organic waste<br>Improving sanitation and hygiene through decentralized and local treatment of bio-solids<br>Stabilizing the sludge from wastewater treatment to protect the marine environment and urban air quality<br>Improving urban air quality by substituting fossil fuel with bio-methane in vehicles<br>Improving urban air quality by substituting solid fuel for domestic cooking and heating with biogas |
| Goal 13: take urgent action to combat climate change and its impacts | Reducing greenhouse gas emissions by using biogas-based renewable energy in buildings, homes and industry<br>Reducing carbon dioxide emissions by replacing fossil-fuel-based energy sources with biogas and commercial fertilizers with digestate bio-fertilizer<br>Reduction of methane and nitrous oxide emissions from livestock manures<br>Reduction of methane and generation of renewable energy from food and other organic wastes<br>Capturing emissions from landfills |
| Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss | Reducing deforestation by replacing solid-biomass-based domestic fuels with biogas<br>Recirculating nutrients and organic matter in organic wastes through AD and returning them to the soil in the form of digestate bio-fertilizer<br>Substituting firewood with biogas as a domestic fuel, reducing deforestation |

UN (2015).

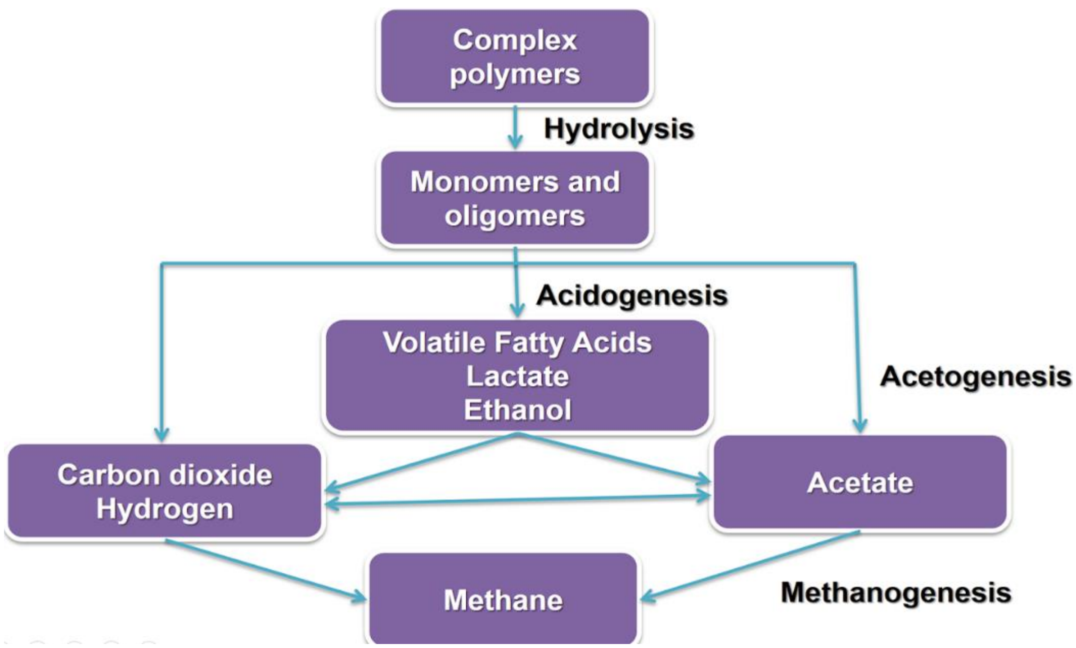


**Figure 1.** Simplified stages of anaerobic digestion pathways in organic waste degradation.

**Table 2.** Factors that influence waste management for anaerobic digestion.

| Factors of waste management | Influence |
|---|---|
| Political | Political will, multi-level governance, government regulations (taxes, subsidies), data collection and monitoring |
| Economic | Business model, cost-benefit analysis, availability of finance, collaboration, and transparency along the value chain |
| Environmental | Sustainability policy, human health impact |
| Social | Community perception; |
| Technological advances | Innovation, infrastructure |
| Educational | Research centres, cooperation projects |

Source: Malinauskaite et al. (2017).

Water hyacinth (*Eichhornia crassipes*) was harvested from Olobgo River (6°3'8.05'N, 5°39'50.48'E) also in Edo State. Sample of fresh water hyacinth (leaves, stem and root) was washed, chopped into small pieces of 2 to 5 cm pieces, and fresh rumen derived residue (10:1 ratio) was diluted and introduced into the digester. The rumen-derived microbial enriched (ME) inoculum was prepared by homogenizing water hyacinth with rumen contents using a blending machine.

The substrates respectively were mixed in the ratio of 2:1. The operational mode was the batch method using an operational mesophilic temperature. Biomethanation of these slurries was carried out for energy production in a fixed dome reactor and cumulative biogas production; slurry temperatures were monitored throughout the study. The digester was tightly corked with rubber stopper to create anaerobic condition and connected to a gasometrical chamber. The total biogas yields were determined by opening the outlet tap of the anaerobic digester and the inlet tap to the graduated burette. The biogas generated was released through the tube which then displaced the paraffin oil in the graduated burette downward. The volume of gas yield was determined by the volume of paraffin oil displaced that is gas yield was directly proportional to paraffin oil displaced. The schematic diagram of experimental laboratory set up is shown in Figure 2.

### Design of fixed dome digester

The design of the fixed dome digester also known as the Chinese dome digester (CDD) or Chinese model and hydro-pressure digester was based on low-cost, long life span, and low maintenance requirements. It consists of an underground reactor with a fixed cover where the gas and input slurry are stored and an effluent displacement tank with the outlet as shown in Plate 1. The system is typically loaded semi-continuously and as gas production increases inside the reactor, the digested slurry is pushed into the displacement tank, and likewise as the gas is used, the slurry in the digester tank flows back into the reactor, creating agitation. The volume ($V_D$) of the digester is derived from equation 1 in

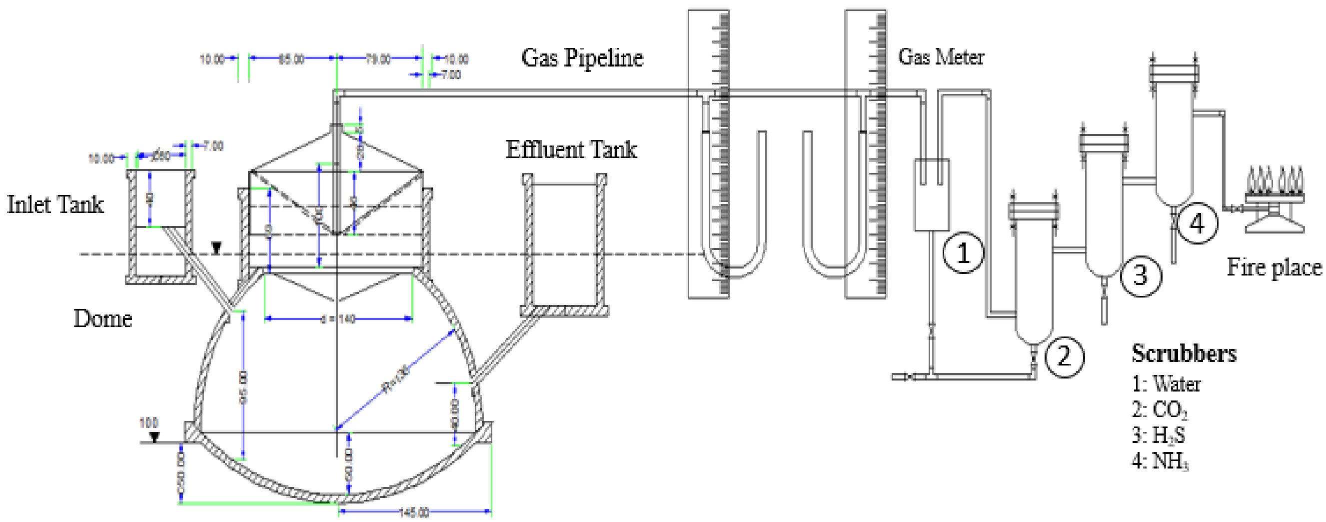


**Figure 2.** Conceptual diagram of a fixed dome system.

accordance with Sasse (1988) and Sasse et al. (1991), $S_d$ is the daily fermentation slurry supplied and HRT is the hydraulic residence time.

$$V_D(L) = S_d(\frac{L}{day}) \times HRT(day) \quad (1)$$

Considering the amount of fermentation $S_d(\frac{L}{day})$ slurry consisting of cattle rumen mixed with water hyacinth at ratio 10:1 and feedstock to water at ratio 1:2 in accordance with Pachaiyappan et al. (2014). The general reaction for methane formation is shown in Equation 2 as depicted in Serrano (2011):

$$C_cH_hO_oN_nS_s + yH_2O \rightarrow xCH_4 + nNH_3 + sH_2S + (c-x)CO_2 \quad (2)$$

Where $x = \frac{1}{8}.(4c+h-2o-3n-2s)$

$y = \frac{1}{4}.(4c+h-2o-3n-3s)$ and the reaction follows exponentially in Equation 3:

$$V_{BR} = C_1.(1-e^{-C_2.t_{BR}}) \quad (3)$$

$V_{BR}$ ($m^3$/d) is the biogas yield, $C_1$ and $C_2$ are constants and $t_{BR}$ is time. Jones and Salter (2013) noted that biogas yield as a function of other process parameters that is temperature and hydraulic retention time (HRT). The effects of temperature on the rate of reaction were compared with HRT in Njogu et al. (2015) in Table 3.

In this study, mesophilic condition was considered with an average temperature of 30°C and HRT of twenty-one (21) days.

The daily slurry is;

$S_d(\frac{L}{day})$ =93L (cattle rumen) + 9L (water hyacinth) + 203L (water) = $305\frac{L}{day}$. Therefore, substituting the variables into Equation 1

$$V_D = 305\frac{L}{day} \times 21day = 6405L = 6.4m^3$$

In accordance with Sasse (1988), 1 kg of fresh cattle rumen will yield 10L(0.01m$^3$) of biogas in HRT of 20 days. Assume that 1L of fermentation slurry is equivalent to 1Kg of water, daily gas production can be expressed as;

$$G = 0.01W \quad (4)$$

$$G = 0.01 \times 305 = 3.05m^3$$

The volume of the digester can be expressed in accordance with Kaur et al. (2017) as shown in Equation 5.

$$V_s = HRT \times \frac{2W}{1000} \quad (5)$$

$$V_s = 21 \times \frac{2 \times 305}{1000} = 12.81m^3$$

In other words, the height and diameter of the digester can be computed. The height is related with the diameter as $D = 2H$ and from the volume of a cylindrical shape,

$$V_s = \frac{\pi}{4} \times H \times D^2 \quad (6)$$

$H = \left(\frac{V_S}{\pi}\right)^{\frac{1}{3}} = 1.598\,m$ and $D = 3.196\,m$

In Nigeria, there is growing pressure on forest reserves as most of the rural and peri-urban settlement depends on fuel wood for cooking. In other words, biogas as an alternative has the potential of reducing forest pressure and emission occasioned by fossil fuel. Assume gas consumption during cooking with biogas from 0600 to 0800 h, 1200 to 1400 h and 1800 to 2000 h respectively each day. This means that cooking is achieved within 2 h and this is expected for three meals each day, hence the duration of gas consumption is 6 h. Therefore, gas consumption is expressed as:


**Plate 1.** Construction stages of the fixed dome digester.

$$\frac{3050L}{6hr} = 508.3\frac{L}{hr}$$

Since biogas is produced during consumption, it is important to know the difference between consumption and production. But hourly biogas production;

$$\frac{3050L}{24hr} = 127.1\frac{L}{hr}$$

$$D_G = 508.3 - 127.3 = 381.2\frac{L}{hr}$$

If cooking is done between 0600 to 0800 h (morning) and 1800 to 2000 h (evening), it implies that 4 h biogas consumption is compulsory for each day, it is therefore vital for gas production to exceed daily consumption.

$$V_G = 381.2\frac{L}{hr} \times 4hr = 1524.8L = 1.5m^3$$

**Table 3.** Effect of temperature on anaerobic bacteria.

| Anaerobic process | Operating temperature (°C) | HRT (days) | Microbial growth and digestion rates | Toxicity tolerance |
|---|---|---|---|---|
| Psychrophilic | 10 - 20 | >100 | Low | High |
| Mesophilic | 20 - 35 | >20 | Medium | Medium |
| Thermophilic | 50 - 60 | >8 | High | Low |

And, the required gasholder capacity C is 50%

The conceptual diagram of a fixed dome digester is as shown in Figure 2. The digester is linked with an inlet and effluent tank where feedstock is charged in and effluent discharged respectively. It is expected that biogas produced is measured using a pressure gauge and transferred through a water scrubber and furthermore, $CO_2$, $H_2S$ and $HN_3$ scrubbers depending on the composition of the biogas. This is significant in increasing the quality of combustion at the burner.

### Construction of fixed dome digester

The construction started with site investigations, which include location as well as the selection of component parts of the biogas digester. After site identification, the soil was excavated. The radius of excavation is a bit bigger than the digester radius to allow working space while at the same time ensuring that the space is not too much and result in more workload during excavation and backfilling. The system was typically made from mortar and poured concrete as sealant for the inside plastering. The biogas digester location implies proximity to the kitchen, open to atmosphere and direct sunlight, waste availability and clearance of any large tree which is similar to site selection procedure for biogas digester in (Jiang et al*.,* 2016, Samer, 2015; Rajput, 2011). The biogas digester will utilize cow dung as described in (Abarghaz et al*.,* 2011, Anaswara, 2015, Lebofa and Huba, 2011). The technical data for the biogas digester dome is as shown in Table 4. These are the data arrived at during the initial energy survey of the locality which aims at determining average household size, average household energy consumption per day and sources of energy for domestic hose connected from the digesters to the bottom of the gas collection systems. The biogas produced was channelled through moisture scrubber as shown Plat 1J to rid the biogas mixture of associated moisture. More so, $CO_2$ was scrubbed using activated carbon while $H_2S$ was stripped with iron fillings. Purification of biogas is of significant importance in limiting combustion inhibitors as well as prevention of corrosion. The biogas produced was a blue flame and primarily utilized for cooking food at the staff canteen of the National Centre for Energy and Environment as shown in Plate 1K.

Composition ($CH_4$ and $CO_2$ content) of generated biogas was determined using a Gas Chromatography (GC), (HP 5890II Series USA) coupled with a Hayesep Q column (13 m × 0.5 m × 1/800) and a Split Injector/flame ionization detector (FID) to determine the percentage composition. This was carried out two times a week in duplicate from the digester using a 100 µl gas tight syringe for taking biogas samples from the digester head space after releasing the gas and followed by injecting the biogas sample into the GC. The results of the sample analyses were computed and compared with standard operating procedures for biogas and the results obtained are as shown in Figure 3. Anaerobic decomposition of waste is also known as biomethanation process. It is one of the important and sustainable techniques for treatment of the biodegradable waste in subtropical climates. In this process, activities. These are essential for material costing and labour. Biogas digester is a rural based technology, therefore, local materials for construction gets priority to minimize cost. The plan and section drawing of the biogas digester are presented in Figure 2. However, commercial biogas digester will incorporate load and stress analysis for concrete structure sited in clay (Desal et al*.,* 2013). The construction process of the dome- shaped biogas digester is as shown in Plate 1 at the National Centre for Energy and Environment (Energy Commission of Nigeria), University of Benin (6°23’53.65’N, 5°37’35.65’E).

### Digester loading and biogas production

The feedstock water hyacinth and cattle rumen-derived content was prepared with water into slurry and introduced into the constructed fixed dome bio-digester at the National Centre for Energy and Environment. Initially, the fixed dome digester received the same type of feedstock in order to establish their baseline performance. The digester loading rate was increased progressively by adding greater volumes of water hyacinth and cattle rumen-derived content to eventually reach the maximum nominal COD loading. Samples were collected from the feed and the effluent tank for subsequent analysis. The slurry was allowed to occupy three quarter of the digester space leaving a clear height as space for the gas production.

Before feeding the reactors, the flexible hose connecting the gas outlet from the reactor to the gas holder was disconnected, such that the gas outlets from the reactors were left open. This was done to prevent negative pressure build up in the reactors. The gas was collected from the digesters through a 10 mm diameter flexible stabilization occurs, and biogas is liberated by the conversion of organic matter, which in turn can be used as energy.

## RESULTS AND DISCUSSION

### Fixed digester construction

The fixed dome digester is a semi batch reactor composed of a fermentation chamber for anaerobic digestion, feed and digestate pipes, and a fixed dome on the top for biogas storage. The reaction and biogas storage chambers are connected. The dome is built mainly with granite, sharp sand, iron rods and cement which is similar to fixed dome digester constructed in India. Some of the important design consideration includes local climate, amount of waste and water available to input into the anaerobic digester daily. The lower part of the digester contains a layer of biosolids and a layer of liquid above the biosolids. As the anaerobic microbial processes take place, volatile solids are

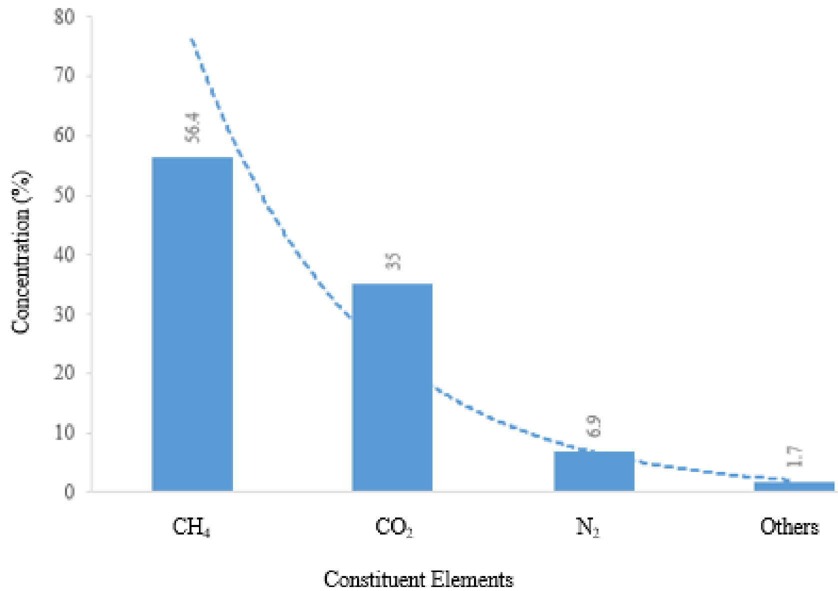


**Figure 3.** Percentage biogas composition.

**Table 4.** Technical specification for NCEE fixed dome biogas plant.

| S/N | Item | Description |
|---|---|---|
| 1 | Feedstock type | Faecal waste (Rumen content) from Ikboba Abattoir |
| 2 | Source of water | Functional borehole |
| 3 | Soil type | Hard clay, no rock, level land, low water table |
| 4 | Hydraulic Retention Time (HRT) | 21 days |
| 5 | Volume of digester ($V_D$) | 6.4 m$^3$ |
| 6 | Height of the digester (H) | 3.196 m |
| 7 | Volume of fermentable slurry ($V_s$) | 12.81 m$^3$ |
| 8 | Volume of gas consumption ($V_G$) | 1.5 m$^3$ |
| 9 | Gasholder capacity (C) | 50% |
| 10 | Gas production (G) | 3.05 m$^3$ |
| 11 | Faecal waste required per day | 93 kg |
| 12 | Water required per day | 203 L |
| 13 | Density of slurry | 1003 kg/m$^3$ |
| 14 | Digester shape | Cylindrical |
| 15 | Gasholder shape | Domed |
| 16 | Flame temperature | 870°C |
| 17 | Ignition temperature | 700°C |
| 18 | C:N Ratio | 29:1 |

consumed, and methane and carbon dioxide are produced. The fixed-dome digester was constructed inside a pit dug in the ground, which protects the structure, provide insulation, and provides open space for other uses above ground (GTZ/GIZ, 1999).

The construction was in accordance with key specifications as shown in Table 4. Essentially, the design considerations are in line with CAMARTEC model of biogas digester by GTZ as published by Sasse et al. (1991). The design computations were in consonance with Kaur et al. (2017) on the design and construction of 10m$^3$ scale fixed dome digester. Nonetheless, while they both examined a cylindrical based digester, this design adopted a flat based casted concrete. The result of performance shows 56.4% $CH_4$ as dominant compound amidst $CO_2$ (35%), $N_2$ (6.9%) and other trace elements as shown in Figure 3. This result corroborates that published by IRENA (2016) on the comparison of biogas to $CH_4$ equivalent. Produced biogas was purified using activated carbon and iron fillings to respectively remove $CO_2$ and $H_2S$ while the moisture was separated by scrubbing in consonance with Zhao et al. (2010).

Energy is an important indicator of socio-economic development of modern society (Surendra et al*.,* 2014) which has impacts on a wide range of development indicators, including health, education, food security, gender equality, livelihoods, and poverty reduction. It is an important factor in the economic, social and political development of any nation (Ojolo et al*.,* 2012). The use of biogas will reduce the workload for farmers, who would otherwise have to collect firewood for heating and cooking (Xiaohua et al*.,* 2007).

## Gas and methane production rates

AD technology is extensively acceptable as an efficient process to treat and utilize food waste because it has been proven to be promising method for waste reduction and energy recycling (Zhou et al., 2014). It has become popular and is widely used due to its ability to produce renewable energy from wastes. The gas production rate (GPR) and methane production rate (MPR) are two major performance indicators in the anaerobic process. The GPR and MPR, expressed as the volume of biogas or methane produced daily per unit reactor volume. The quantity of biogas produced from the co-digestion water hyacinth and cattle rumen-derived content over a period of 60 days SRT is shown in Figure 3. The result of performance shows 56.4 % $CH_4$ as dominant compound amidst $CO_2$ (35%), $N_2$ (6.9%) and other trace elements. Produced biogas was purified using activated carbon and iron fillings to respectively remove $CO_2$ and $H_2S$ while the moisture was separated by scrubbing in consonance with the results of Zhao et al*.* (2010).

The rate of biogas production was observed on the fifth day and increased gradually until the maximum values were recorded on the $30^{th}$. Apart from the 30th day when sudden increase was observed, biogas production dropped progressively after the day 40. It was observed that the digester temperature fluctuated between 28 and 36.7°C while the pH of the medium changed progressively from acidic to slightly alkaline fluctuating optimally between 6.5 and 7.8. The high biogas production could also be attributed to the high content of carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorous, potassium, calcium, magnesium and a number of trace elements in the water hyacinth feedstock. Also, the result shows that cattle rumen derived content could have attributed to multiplication of microbial organism within the methanogenesis stage. The biogas produced is a function of bacterial growth. The higher and faster biogas generation could be attributed to the faster rate of decomposition of water hyacinth and cattle rumen derived content which have already undergone a form of digestion in the digestive system of the cows. Therefore, the action of bacteria on this category of waste is fast relative to the water hyacinth which contains fibrous tissues like lignin, suberin, cutin etc. which may not have been completely degraded during the pre-fermentation stage prior to anaerobic digestion.

The fluctuations observed in the volume of biogas produced may be attributed to the change in metabolism of the bacteria in response to the fluctuations in the temperature and pH of the digestion medium. Thus, the drop observed after the $40^{th}$ day could be attributed to the progressive fall in both the digester and ambient temperatures observed during the second halve of the digestion period. Usually, biogas production rate in batch condition is directly equal to specific growth of methanogens (Nopharatana et al., 2007). This result corroborates IRENA (2016) on the comparison of biogas to $CH_4$ equivalent.

Despite the diverse applicability and rapid expansion of biogas globally, some factors including process complexity, poor stability, inefficient biodegradability, substrate complexity, and low productivity impede methane production from AD. Numerous ways to overcome operational shortcomings suppressing methane yield have been suggested in previous studies, where the innovative approaches like three-stage digester (Zhang et al., 2017), novel enzyme addition (Dollhofer et al., 2015) and continuous microbial growth analysis (Sasidharan et al., 2018) have been developed and implemented successfully. In parallel, optimization of the process performance by manipulating operational variables (Hublin et al., 2012) such as feedstock choice, pretreatment, co-digestion, reactor type, temperature, pH and HRT (Hydraulic retention time) (Ward et al., 2008) have been widely considered.

Dioha et al*.* (2012) examined different types of biogas digesters and their operability as well as financing potentials in Nigeria. In other words, it is of significant importance to match a range of physical parameters as shown in Table 4 with operating parameters, that is feedstock size, feeding rate, average household, cost of construction, maintenance cost etc. In the recent times, there exist biogas online calculators (Wu et al*.,* 2016) and other computational dynamics for calculating biogas yield. In this case, the designed volume of expected biogas was validated with measurement of the actual biogas produced. However, other variables which may not be completely defined by a model or online calculator exists e.g. the feedstock history and type, plant capacity, HRT and temperature as noted by IRENA (2016).

## Conclusion

A fixed dome digester was designed and constructed and charged with cow faecal and water hyacinth for biogas production. Daily gas production G is 3.05 $m^3$ with gasholder capacity of 50%. Biogas ($CH_4$) was produced from the blend of water hyacinth and cow faecal. Optimal production was found to be a function of temperature, HRT, pH, concentration and overall design consideration of the digester. Scrubbers were fitted to rid the gas of $H_2S$, $CO_2$, $NH_3$ and moisture. The gas was directed through a gas line to a burner for cooking in the staff canteen. Apart from the availability of biogas feedstock, biogas is cheaper than natural gas derived from fossils. This is because the plant uses cow dung as feed material. The production cost of 1 kg of bio-CNG (compressed natural gas) is about USD 0.23–0.24 which is much cheaper than the petro-based CNG (compressed natural gas) (The Hindu, 2016). In other words, it can be readily produced and deployed in individual/cluster homes for cooking and for power generation as stand – alone or grid. In addition, biogas production from abattoir waste, mainly cattle rumen potentially provides cleans up for the environment as most of the attendant waste is converted to useful energy. On the other hand, water hyacinth, a prolific sea weed commonly found in most of the rivers within the South-South Niger Delta can be curbed when utilized for energy production.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

## ABBREVIATIONS

**$CO_2$,** Carbon dioxide;**$CH_4$,** Methane; **$H_2S$,** Hydrogen Sulphide; **$NH_3$,** Ammonia; **G7,** Seven Advance Economies (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States); **G20,** International forum for the governments and central bank governors from 19 countries and the European Union (EU); **UN,**United Nation; **EU,** European Union; **REN21,** Renewable Energy Policy Network for the 21$^{st}$ Century; **AD,** Anaerobic digestión; **IRENA,** International Renewable Energy Agency; **NCEE,** National Centre for Energy and Environment; **ECN,** Energy Commission of Nigeria; **HRT,** Hydraulic Retention Time; **$V_D$,** Volume of Digester; **$S_d$**, Daily Fermentation Slurry; **G,** Gas; D, Diameter; **H,** Height; **$D_G$,** Daily Gas Production; **$V_G$,** Gas Volume; **C,** Gas Holder Capacity; **CAMARTEC,** Centre for Agricultural Mechanization and Rural Technology; **GTZ,** Deutsche Gesellschaft für Technische Zusammenarbeit.

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