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Production of 1.2kg of Biogas per Day from the Designed and Constructed Mini Plant

Tsado[1], D. G., Yakatun[1], A. A. And Owolabi[2], E.O.
1. Chemical Engineering Department, the Federal Polytechnic, P.M.B 55, Bida. Nigeria.
2. Mechanical Engineering Department, the Federal Polytechnic, P.M.B 55, Bida. Nigeria.
Corresponding Author; Tsado

Abstract: *Renewable energy sources are a vital area to look into in the quest for alternatives for fossil-based raw materials and energy. As such, a 14 litres capacity of a digester was designed and constructed and produced 1.2kg per batch of biogas from a mixture of pig dung and cow dung in a ratio of 60 : 40 respectively. The experiment was batch operated and the gas yield after 30 days of retention time was monitored. The digester was charged with the substrate and water forming slurry in a ratio of 1: 1.5 respectively. The mesophilic ambient temperature range attained within the testing period were 30 – 40 ^oC at retention time of 30days. The result obtained from the gas production shows that the use of pig and cow dung as a substrate for biogas production yield 1.2 kg and 0.81 kg of methane before and after scrubbing of the gas with was achieved by passing the gas through a solution of slake lime which absorbs a reasonable amount of the CO_2 from the gas. The mechanical design involved the operating volume, the total volume, the digester dimension, and the guide frame. The temperature is designed to operate within the mesophilic temperature range (20 - 40 ^0C). The materials selection for the construction of the digester and piping are selected based on some factors which includes; the water/gas tightness, good tensile strength, ability to withstand high pressure of the biogas, rigid and non-corrosive.*

Key Words: *Anaerobic digestion, Biogas, Digester, Design, Methane production,*

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I. Introduction

Biogas is a mixture of methane and carbon dioxide, produced by the breakdown of organic waste by bacteria without oxygen (anaerobic digestion). Biogas is a mixture of methane (60-70%), carbon dioxide (30-40%) and traces of other gases like hydrogen sulphide and hydrogen (Thakur, 2006).

Bio-gas plants are generally made from stain less steel, zinc, best quality rubber, mild steel, aluminium etc. The use of construction material to construct the wall of the digester of bio-gas plant was limited to a specific period of time. Nowadays, the body of biogas plant is commonly manufactured through casting process.

Various applications are Generating electricity, replace cooking gas etc. For example in India, the biogas plants are widely used to generate electricity and use as a substitute for cooking gas. Methane in biogas provides a source of fuel without smoke.

Anaerobic digestion (AD) is the process by which plant and animal material is converted into useful product by micro-organisms in the absence of air. Biomass is put inside a sealed tank and naturally occurring micro-organisms digest it, releasing methane that can be used to provide heat and power. The material left over at the end of the process, known as bio-slurry, is very rich in nutrients so it can be used as fertilizer. This means that generation of biogas is carried out by using waste materials of plant or animal origin which can be capacity source of environmental pollution if disposed of without conversion (Adaramola and Oyewola, 2011). Most importantly, it provides an alternate source of renewable energy and thus reduces the burden on use of fossil fuel as a source of energy. The bio-slurry provides organic fertilizer which, unlike synthetic fertilizers imparts no catastrophic effect on soil as well as environment (Parawira, 2009). Various different factors such as bio-gas capacity of feedstock, design of digester, nature of substrate, pH, temperature, load rating, hydraulic retention time for bio-gasplant (HRT), C: N ratio, volatile fatty acids (VFA), etc. influence the biogas production.

Biogas technology is extremely appropriate to the ecological and economic demands of the future. Biogas technology is progressive. However, a biogas plant seldom meets the owner's need for status and recognition.

Biogas technology has a poor image ("Biogas plants are built by dreamers for poor people"), If you do not want to see one of the poor, you do not buy a biogas plant. The image of the biogas plant must be improved. The designer makes his contribution by supplying a good design. The biogas plant must be a symbol of social advancement. The economic benefit of a biogas plant is greater than that of most competing investments.

Kerosene and other oil based sources of fuel are scarce and costly to be easily available for small marginal and medium farmers residing in rural areas. Furthermore, frequent alarming hike in prices of imported oil and chemical fertilizer have serious economic threat to therural poor. In this context, to reach the self-sufficiency in energy and fertilizer and to minimize the pressure on traditional biomass fuel, biogas technology has been the best alternative energy solution, which could be achieved through the active mobilization and economic utilization of local indigenous resources available in the country.

Therefore, there is urgent need of methane for heating source and also is the process of conversion of animal waste and agricultural waste into a useful substance (biogas).

Bio production of methane is a renewable and sustainable means, as compared with petroleum source and the production of the methane using natural resource is more environmental friendly.

Therefore this work is aimed to design and construct a mini biogas production plant that can produce 1.2 kg of biogas per month.

II. Methodology

1. Material Balance

Digester Unit

For pig and cow dung in a ratio for 60:40 used as substrate, 65 % methane and 35% CO_2 is produced (Fry 2011).

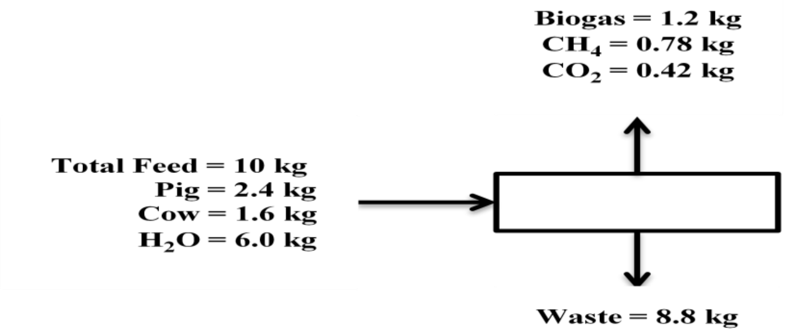


Figure 1: Material balance around the digester

Overall material balance

F = G + W

10 kg = G + 8.8 kg

G = 1.2 kg (Before scrubbing)

Scrubbing Unit

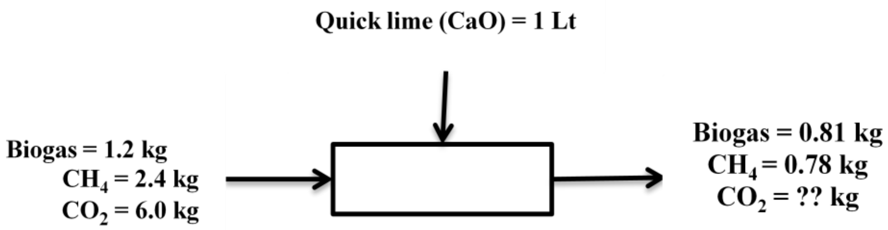


Figure 2: material balance around the scrubbing unit.

Bottle Reaction: $CH_4 + CO_2 + CaO \longrightarrow CH_{4\,(g)} + CaCO_3$

Accumulation = Input - Output

Overall material balance

Accumulation = 1.2 kg - 0.81 kg

Accumulation = 0.39 kg

At the exit of the bottle

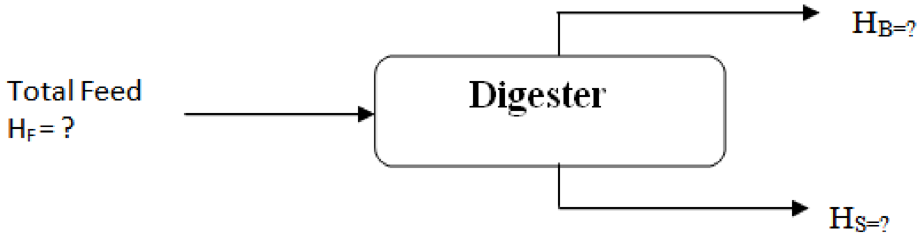
Gass = $CH_4 + CO_2$

0.81 kg = 0.78 + CO_2

CO_2 = 0.03 kg (negligible)

2. Energy Balance

Specific heat capacity of biogas (C_B) = C_{CO2} + C_{CH4}
C_{CO2}= 0.88 kJ/kg K
C_{CH4}= 2.2 kJ/kg K
C_B= 0.88 kJ/kg K + 2.2 kJ/kg K = 3.064 kJ/kg K
Specific heat capacity of water Cw= 4.2kg/kg
Specific heat capacity of pig dung Cp= 0.00812kg/kg k
Specific heat capacity of cow dung Cc= 1.9925kg/kg ^{0}C = 0.00727kg/kg k
r



Fi**gure 3:** Energy balance across the digester

Energy input: $H_{f=} H_w + H_p + H_c$
H_f=MwCw(T2 – T1) + MpCp(T2 – T1) + McCc(T2 – T1)
Assuming the substrate and water enter into the digester at 28^{0}C (301k) and 25^{0}C (273k).
Mass of pig dung(Mp) = 2.4kg
Mass of cow dung (Mc) = 1.6kg
Mass of water (Mw) = 6.0kg
Cw = 4.2kJ/kg k, Cp = 0.00812 kJ/kg k, Cc = 0.00727 kJ/kg k
H_f = [6.0 x 7.2 (301 - 273)] + [2.4 x 0.00812 (301 – 273)] + [1.6 x 0.00727 (301 - 273)]
H_f = 705.6 + 0.546 + 0.326, H_f = 706.472KJ
$H_B = M_BC_B$ (T2 – T1), $H_{B\,=}$ 1.2 X 3.064 (301 - 273) = 102.950KJ
But $H_f = H_B + H_S$
$H_S = H_f – H_B$ = 706.472 – 102.950, Hs = 603.52KJ.

3. Design of Mini Scale Anaerobic Digesters

A digester should be watertight and the gasholder must be gastight, for this reason it must have no cracks. The cylindrical shaped digester was adopted to enhance better mixing. A round shape is always a good shape, because a round shape has no corners, its load pattern is more favourable and it uses less material. The separate gas holder system was incorporated into this design to allow for ease of measurement of gas volume at atmospheric pressure. The succeeding sections give details of the principles and design consideration for the digester type adopted.

The main constituents of this gas, methane and CO_2 are only sparingly soluble in water, thus the gas is collected and transferred to a cylinder where it is stored for further usage.

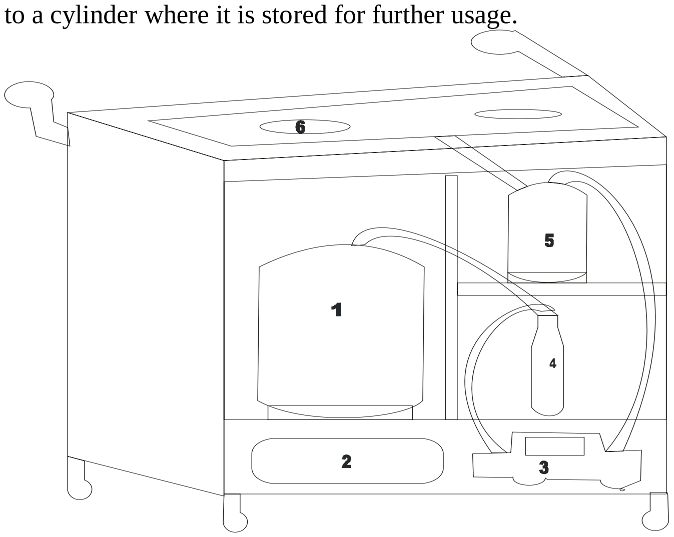


Figure 4: Schematic View of the Plant set up

Legends:
1. Digester
2. Electric Motor
3. Compressor
4. Quick Lime solution bottle
5. Gas storage cylinder
6. Burner

4. Mechanical Design
Digester sizing

The Anaerobic reactor adopted for this study is the batch type. 6kg of waste was used for all substrates digested during the study. This waste was mixed with water to form slurry in a ratio of one part of waste to one part of water by volume to arrive at the substrate input of $0.02m^3$/reactor.
From equation (3.2), Sd, = Biomass (B) + Water (W) m^3/ batch
= 0.01 + 0.01 = $0.02m^3$/ batch
Where; Sd= Substrate input (for batch type digester)
A retention time of 30 days is chosen for this study.
For a batch type digester, the daily substrate input (batch input) equals the operating volume of the digester (V0) (Kossmann et al., 2001) therefore V0 = Sdx RT = $0.02m^3$
Where, V0 = Operating volume of the digester
Sd= Daily substrate input, which is the net slurry input in the case of batch digester.

Gas holder sizing
- About 45kg dung produces close to $0.03m^3$gas/day (Mathew, 1982). Thus, 4kg ofdung would produce about $\frac{0.03X4}{45}$ = 0.00267 m^3 gas/day. This implies about $\frac{0.00267}{24}$ m^3/hr = 1.11 x $10^{-4}m^3$ gas/hr
Let this be the hourly gas production (Gh) = 1.11 x $10^{-4}m^3$ gas/hr
- A biogas stove requires 0.2 – 0.4m3gas/hr (Ahmadu, 2009)
For this work, let this values be the maximum hourly gas consumption. Thus, gc_{max} = $0.2m^3$/hr.
For the purpose of this work, we take the time of maximum consumption (tc_{max}) = 0.055hrs.
Also, the time of maximum zero consumption (tz_{max}) is taken as the interval between the last use of the day (night) to the first use next day (morning).For this work thus, tz_{max} = 10hrs.

i. Operating Volume:
The operating volume of the digester is simply the volume of slurry in the digester (Ahmadu, 2009).
The operating volume of the digester (Vo) is determined on the basis of the chosen retention time (RT) and the daily substrate input quantity (Sd), and is given as (Ahmadu, 2009):
Vo = Sd x RT [m^3= m^3/day x number of days]

The retention time is the interval of time during which the biomass is allowed to decompose in the digester. The retention time, in turn, is determined by the chosen digester temperature and the amount of biomass resource available. Kossmann et al, 2001 noted that for a plant of simple design, retention time should amount to at least 30 days.
Substrate input (Sd) = Biomass (B) + Water (W) (m^3/day)
In most agricultural plants, mixing ratio of dung to water varies from between 1:1 to 2:1.

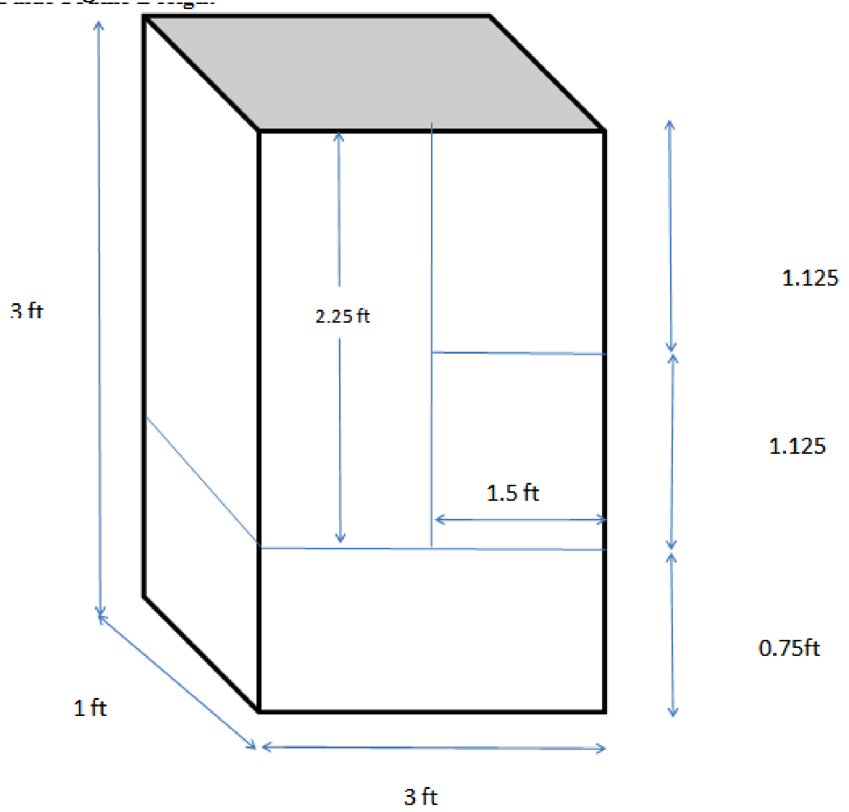
ii. Total Volume:
The total volume of the digester (VT) should be greater than the operating volume. This is to give room for the biogas produced and the rise of the slurry during fermentation. The operating volume of the digester must not exceed 90% of the total volume of the digester
(Ahmadu, 2009). The total volume is thus given as:

$$V_T = Vo/0.8$$

iii. Digester dimensions:
Having determined the total volume of the digester, a ratio for the dimensions can be adopted, depending on the chosen geometric shape of the digester. For a cylindrical digester, the chosen geometry for this work,
$V_T = \pi r_d^2 h_d$
Where V_T = Total volume of digester
r_d = radius of digester

h_d = height of digester

iv. Guide Frame Design:



The guide frame is to guide the digester, gas holder and all the other components in its upward displacement and prevent it from tilting. It's also to provide a maximum displacement position for the gas holder. It consists of two rods mounted on opposite sides of the gas holder, sliding through corresponding slides ways.

Length of the rods should be a little less than height of gas holder to give allowance for welding onto the gas holder. Any convenient length can be taken for this allowance, let this be denoted c, thus

Length of guide frame (Lf) . Lf = hg – c

Where hg = height of gas holder, C = allowance

On the guide frame is a maximum displacement point at a distance Lf – dmax

Where dmax is a distance taken from the bottom tip of the frame, with a hole drilled at this point and a pin inserted. With this, at maximum displacement of the gas holder, a portion of it is still submerged in the water seal, thereby providing rigidity and safety.

The guide frame merely guides the gas holder in its upward displacement, thus it's not under the action of any load or force. Therefore, any convenient safe diameter can be adopted (Ahmadu, 2009).

vi. Gas Pipe Diameter:

The gas pipe diameter is selected based on the flow rate of biogas through the pipe and the distance between the digester and gas holder. (i.e. length of pipe required). The values can be checked from standard tables to determine the required pipe diameter (Ahmadu, 2009).

5. Construction of Biogas Digestion plant.

Biogas digester was constructed to digest the mixture of two substrates for the study biogas generation for a particular retention time.

Material Selection

As a general rule, the selection of all the materials would be based on: Cost-effectiveness, availability and durability.

Materials for Digester Construction: The material used for the digester is a mild-steel cylinder meeting the calculated dimensions. It was selected to meet the following requirements:

- Water/gas tightness: Water tightness in order to prevent seepage of the slurry. Gas tightness to ensure proper containment of the entire biogas yield and prevent air entering into the digester.
- Good tensile strength.
- Relatively cheap.
- Ability to withstand high pressure of the biogas
- Non corrosive
- Rigid

Materials for gas pipe: The materials used for the gas pipe are two flexible plastic pipe of different diameter which was used to link the digester outlet to the various stages of production. Galvanized steel pipe was selected based on its resistance tocorrosion and rigidity, flexible plastic pipe was selected based on its resistance to corrosionand flexibility.

Fabrication of Parts

Having selected the materials to be used, machining of component parts was carried out using the appropriate machine tools and hand tools.

6. Materials for Biogas Production

The following materials (equipment, glassware, Reagents etc.) were used in this study

i. pH meter model pHS-2S, (SHANGHAI JINYKE REX, CHINA) was used to measure the pH of sslurry every week day throughout the retention period.

ii. Gallenhamph Weight balance, Mettler P160N was used for measuring the weight of evaporating dish and sample for Total Solid analysis.

iii. Thermometers: (2/1 ^{0}C made in England): was used to obtain daily temperature of the digester as well as the ambient temperatures for Bida, Niger.

iv. A 25-liter Plastic bucket: Was used for measuring equal volume of waste to water to form slurry.

v. Shovels: was used to ensure proper mixing and packing of dung.

vi. Waterproof sacks: was used to convey dung to place of mixing.

vii. Funnel: was used to feed the slurry into the digester so as to minimize spillage of slurry.

7. Process Description for Anaerobic Digestion of Mixture Cow Dung and Pig Dung

Method of Biomass Collection, Slurry Preparation and Digester Loading The design volume of the identical anaerobic digesters was sized according to the amount of volatile solids that must be treated daily and the period of time the material will remain in the digesters (Retention time). The primary structure consists of a Mild steel digestion cylinder which is strong enough to withstand the weight and pressures of the contained slurry, and painted to prevent corrosion. The cylinder is air tight and is clearly placed above the ground level and outside the shed where it is exposed to the sunlight for partial heating. A gas holder cylinder of similar property was also provided and used to temporarily store the biogas until it was used to replace or supplement the supply of cooking gas.

Two kinds of waste were introduced simultaneously into the digester for a period of thirty days during the study, these wastes include;

i. Cow dung from Bida

ii. Pig dung from kuchiworo

Cow dung and pig dung were the biomass resources used as feed materials for this work. Cow dung was obtained (fresh and free from impurities) while the pig dung was gotten (fresh and free from impurities). They were both transported to the research site.

6kg of the wastes (0.6:0.4 of pig dung to cow dung respectively) was mixed with water to form slurry in the ratio 1:1.5 by volume and introduced into the digester through an inlet pipe of 50mm at the top of the digester tank. The slurry is allowed to occupy three quarter of the digester space leaving a clear height of about 0.1875m as space for the gas production. The inflow was directed downward to cause the solids to accumulate at the bottom of the tank where after digestion they were easily removed. Before feeding the reactors, the flexible plastic pipe connecting to the gas outlet from the reactor to the gas holder was disconnected, such that the gas outlet from the digester was left open. This was done to prevent negative pressure build up in the reactor. The gas was collected from the digester through a 10mm diameter flexible host connected from the digester to the bottom of the gas collection system. The collected gas is allowed to pass through slaked lime as scrubber.

8. Evaluation of the Technical Performance of the Anaerobic Digestion of the Substrates.

The evaluation of the technical performance of the anaerobic digestion process was carried out with respect to the gas production and the treatment efficiency of the digester systems. The reactor was monitored for the 30- day's retention time in the following areas.

i. Measurement of gas production,

ii. Analysis of feedstock and effluent to evaluate the treatment efficiency of each digestion process.

9. Daily Monitoring of Operational Parameters

In order to study and determine the most feasible local environmental conditions to optimally operate the developed biogas facilities, various physical and chemical parameters were monitored to check the status of the digester. Monitoring of the digester was carried out every day between 0800 and 1800 hours. Readings were taken to record digester and ambient temperatures and pH. Discussed below are the physic-chemical parameters monitored, reasons why and the instruments used for the monitoring.

1. Temperature

This gives the kinetic energy of atoms or molecules. It was measured to determine the feedstock influence on the temperature and consequently, the metabolism of the bacteria.

2/1 ^{0}C Thermometers (made in England) were used to measure the temperature of the digester and that of Bida. The digester temperatures were taken three times daily.

3. pH

This gives the intensity of acidic or basic character at a given temperature. It was measured to determine the feedstock influence on the acidity/alkalinity and consequently, the metabolism of the bacteria. Samples were analysed at ambient temperature with a pH meter model pHS-2S, (SHANGHAI JINYKE REX, CHINA). Analysis was carried out immediately after sampling to avoid loss of carbon dioxide from the sample. The pH analysis was carried out once a week throughout the period of study.

10. Upgrading of Biogas Produced

The biogas produced was in turn passed through slaked lime to remove carbon dioxide and the volume of gas produced was noted.

III. Results and Discussion

Mini scale anaerobic digesters were designed and fabricated for the digestion of the mixture of two substrates in this study. The details of the design and fabrication are presented in the tables below. More so, the experimental results obtained during the monitoring period in the study were analyzed using statistical methods.

Table 1: Summary of Dimensions for Anaerobic Digester and Gas collection System

Digester	Gas holder	Gas pipe	guide frame
Operating volume $V_o = 2.0 \times 10^{-3} m^3$ Total volume, VT = 2.5 x 10-3m3 Digester height, hd = 0.50m = 50cm Digester diameter, dd = 0.25m =25cm	Total gas holder volume, $V_g = 1.21 \times 10\text{-}3m^3$ Gas holder height, hg = 0.25m =25cm Gas holder diameter, dg = 0.20m = 20cm	Length of 10mm diameter pipe = 0.72m Length of 30mm diameter pipe = 1.2m	Length of frame = 3m Height of frame = 3m Width of frame =1m

IV. Discussions

14-litres biogas digester plant was designed and fabricated using locally available materials and tested under the existing weather condition in Bida and the biogas digester plants constructed in this study used cow and pig dung mixture as substrates. The methane contents for all the substrates digested were within the range given in literature (Fry, 2011).The pH values in all the plants were very stable and always in the optimal range between 6.5-8.0, and also the temperature inside the digesters were stable fluctuating around 29±1°C which is within the mesophilic range.

A good productivity of methane for mixture of 60%pig and 40% cow dung was found to be 64.5 % by volume and the substrates were anaerobically digested, maximum methane production was harnessed between the 15th to 25th days of digestion. Mixture of 60% pig dung and 40% cow dung produced more methane than the rest of the treatments (prototype) on the 20th day of digestion. Even if co-digestion is reported to increase biogas production, as stated by several researchers (Kasisira, 2009; World Energy Council, 2004), the percentage of methane and CO_2 largely depend on the feedstock. The production of methane was hindered by the presence of some trace gases such as hydrogen sulphide which limited the methane producing bacteria. The scrubbing of the produced gases to remove carbon dioxide improve the heating efficiency of the gas. Although the energy outputsof the gases were not determined.

The fast rates of production relative to previous studies (Ojolo, 2007, Ahmadu, 2009) could beattributed to the extended pre-fermentation periods. The mixture of the substrate was seen to have the highest average daily gas production of 0.00703m^3/day (0.00434m^3/day after scrubbing) compared to cowdung and lemon grass produced 0.191m^3 (0.032 m^3/kg, 0.340 m^3/m^3 of slurry day), 0.125m^3 (0.021 m^3/kg, 0.222 m^3/m^3 of slurry day) and lemon grass respectively produced 0.00635m^3 (0.00417m^3 after scrubbing) and 0.00416m^3(0.00299m^3 after scrubbing) of biogas daily.

The higher and faster biogas generation in the digester cow dung and pig dung could be attributed to the faster rate of decomposition of animal intestinal wastes which have already undergone a form of digestion in the digestive system of the cow and pig dung. Therefore, the action of bacteria on this category of waste is fast relative to the lemon grass that was undergoing the first form of decomposition since it has not undergone one prior to digestion. The relative biogas yield from the substrates could be attributed also to the organic matter content of the wastes which confirms the submissions of earlier studies carried out on cow and pig dung (Ojolo, 2007 and Ahmadu, 2009, Igboro, 2011). The drops in levels of gas production and subsequent peak could be associated to microbial succession digester.

Daily Monitoring of Operational Parameters

In order to determine the most feasible local environmental conditions to optimally operate the developed biogas facilities the pH and the temperatures were adequately monitored as operational parameters. The following results were obtained.

It was observed that in the beginning, the pH values of the media in the substrates digested was slightly neutral and its co-digestion was acidic. They gradually increased until they remained buffered around 7.5 to 8.0 when gas production was stabilized in all the reactors. In other words, all the feedstock showed a general increase in pH with minimal fluctuation. This progressive increase in pH could account for steady rate of gas production which is in agreement with the studies carried out previously by Ahmadu (2009) and Igboro (2011), which suggest low pH as a limiting factor for biogas production. Methanogenic bacteria are very sensitive to pH and do not thrive below a value of 6.0 (Karki, 2005).

V. Conclusions

A 14-litres biogas digester was successfully designed and fabricated using locally available material (steel cylinder) and was used for the anaerobic digestion of cow and pig dung mixture in a ratio of 60 – 40% respectively and 1 – 1.5 of waste to water respectively . The study has shown that biogas can be produced from cow and pig dung (as observed in previous studies). The methane contents for all the substrates digested were within the range given in literature. The co-digestion of the cow dung and pig dung improved the quality and quantity of methane produced and hence, the heating efficiency. Mixture of 60% pig dung and 40% cow dung produced more methane than the rest of the treatments (prototype) on the 20th day of digestion.

Also it can be concluded that, the percentage of methane and CO_2 produced largely depend on the feedstock or substrate used. The production of pure methane was hindered by the presence of some trace gases such as CO_2 which limited the methane production thus the need for scrubbing which was achieved by passing the gas through a solution of slake lime which absorb higher percentage of the CO_2 from the gas thereby improving the heating efficiency of the gas. Although the energy outputs of the gases were not determined.

VI. Recommendations

1. The co-digestion of the substrate and its synergy will produce biogas of very high quality (64.53%) and high cooking rate and should be preferred.
2. A comparative study of the use of spent digester slurry from differentsubstrates digested singly and synergistically should be carried out so as to establish the optimum use of compost produced from the slurry.
3. Biogas users need to understand the process of methanogenesis. This allows manipulation, which can serve to maximize gas production in the field. Since the temperatures in the digester become reduced during the rainy season. It is better for biogas users to insulate their digesters in order to maintain themesophilic temperatures.
4. Users should also make sure that the pH of the substrates within the digester is between 6 and 8. This is because above a pH of 8, free-ammonia becomes toxic to methane forming bacteria and below 6, free-volatile fatty acids become toxic for the methane forming bacteria.

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Figure A1: designed and constructed digester

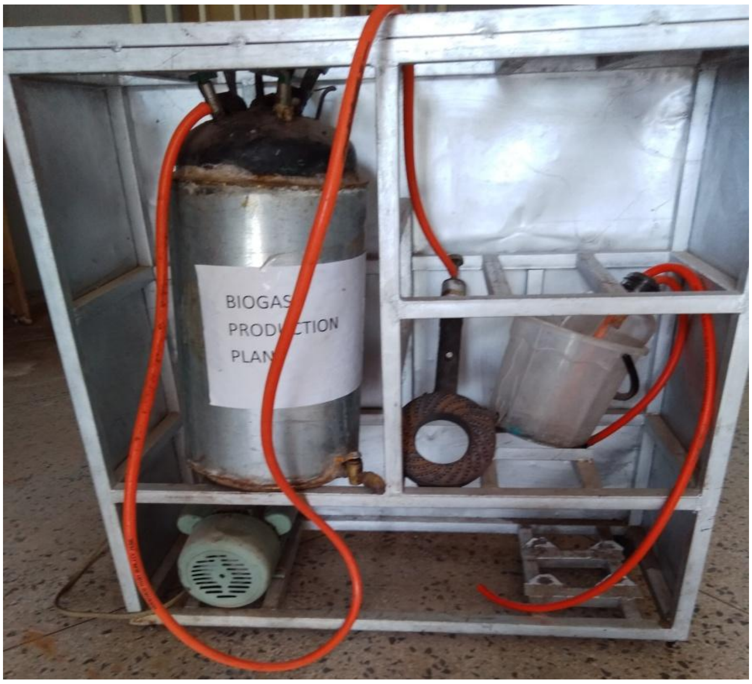

Figure A2: Designed and Constructed Biogas Mini Plant