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# Modeling composition of properties of biogas produced from the Co-digestion of cow-dung and organic kitchen waste

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## Abstract

Public concerns about climate change, air pollution, water quality and rising energy consumption have place pressure on producers and industry to reduce emissions and promote pollution-free sources of energy. One of the most generally available sources of renewable energy is biogas; hence, this study on kinetic modeling of the biogas composition was carried out at ambient condition for a period of 30 days to supplement energy requirements in farms and houses. The substrates, cow dung and organic kitchen waste were co-digested at different ratios for biogas production at laboratory scale. The digesters substrate had 3300g of feed each with varying ratios of 70:30 (Sample A), 50:50 (Sample B), 40:60 (Sample C), and 30:70 (Sample D) of cow dung to organic kitchen waste respectively. A biogas analyzer was used for the measurement of gas composition, biodigester operating parameter were measured using a multi-meter, while gas volume was obtained using calibrated floating drum. The model showed polynomial correlation as best fit using the $R^2$ method.

**Keywords:** Biogas; Biogas-analyzer; Co-Digestion; Cow-dung; Biodigesters; Correlation

## 1. Introduction

Nigeria is regarded as the giant of Africa because of her abundant potentials and the feat of having the largest population in Africa. As a country, Nigeria is endowed naturally with a lot of minerals such as coal, tin, columbite, iron ore, crude oil and gas, gold, lead, zinc, limestone. These minerals are natural substances which are obtained from the earth through mining. The harnessing of all the endowed natural resources for the generation of energy needed for both domestic and industrial use, and better utilization of all these minerals help to promote economic development such as creation of employment opportunities, aiding industrial development, promotion of economic and infrastructural development, help to improve the standard of living, earning of foreign exchange for Nigeria and so much more. The major sources of power in Nigeria are petroleum, water, Natural gas and Coal.

We can classify energy sources under two main parts which are the renewable and non-renewable sources of energy.

Renewable energy sources are those sources that are always naturally available in the environment, most times in excess, and can be replenished. They are "environment friendly" as they do not cause any natural imbalance. Renewable energy sources include Air (wind energy), water (hydro-electric energy), sun (solar energy), biomass (alternative fuels), hydrogen and inner earth layers (Geothermal energy).

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Non renewable energy sources are those sources that are limited in their availability. Globally, the most preferred and large scale energy harvesting is through the nonrenewable sources, this is because it is easier to harvest on a large scale. Its sources are coal, natural gas, nuclear energy and petroleum.

It is believed in science that matter occupies space and space is limited, as a result, this phenomenon in turn will show that the fixed factor like space (environment) will be affected when a continuous factor like population growth is put on it. The space in this case is the geographical area of Nigeria, which is by nature limited to 923,768 sq km. The population was estimated to be about 120 million in 2005. [1]. Facts to know about Nigeria is that the current population of Nigeria is 193,409,540 as of Thursday, January 4, 2018, based on the latest United Nations estimates, the Nigerian population is equivalent to 2.53% of the total world population. Nigeria ranks number 7 in the list of countries by population. The population density in Nigeria is 210 per $Km^2$ (543 people per mi2).

Public concerns about climate change, air pollution, water quality and rising energy consumption all place pressure on producers and industry to reduce emissions and promote pollution-free sources of energy. One of the most generally available sources of renewable energy is biogas. Recently, several commercial large scale anaerobic digestion facilities have come upstream due to dwindling natural gas supplies in most of the developed countries. Small scale units are also being implemented to supplement energy requirements in farms and houses.

## 2. Literature survey

There are ten main sources of energy that are used to generate power in the world today. All of these different sources of energy are used primarily to produce electricity. Solar energy is a promising and freely available energy source for managing long term issues in energy crisis [2]. It involves conversion of energy directly from the sun into electricity either directly using a photovoltaic (PV) cell or indirectly using a solar power or a combination. According to [3] Wind energy is indigenous and can help reduce dependency on fossil fuels. Wind is caused by differential heating of the earth's surface by the sun. Hence it is an indirect form of solar energy and is always being replenished by the sun. Geothermal energy refers to the heat contained within the Earth that generates geological phenomena on a planetary scale [4]. The biggest disadvantage with geothermal energy is that it can only be produced at selected sites throughout the world. The Earth's geothermal resources are theoretically more than adequate to supply humanity's energy needs, but only a very small fraction may be profitably exploited. Hydrogen is a very efficient and clean fuel. Its combustion will produce no greenhouse gases, no ozone layer depleting chemicals, little or no acid rain ingredients and pollution [5]. Hydrogen is available with water and is the most common element available on earth. Water contains two-thirds of hydrogen and can be found in combination with other elements. Once it is separated, it can be used as a fuel for generating electricity. Hydrogen is a tremendous source of energy and can be used as a source of fuel to power ships, vehicles, homes, industries and rockets. It is completely renewable, can be produced on demand and does not leave any toxic emissions in the atmosphere. Tidal energy has the potential to play a valuable part in a sustainable energy future [6] Tides are produced which rush back and forth in the ocean. Tidal energy uses rise and fall of tides to convert kinetic energy of incoming and outgoing tides into electrical energy. Tidal energy is one of the renewable sources of energy and produce large energy even when the tides are at low speed. According to [7], Ocean waves are a huge, largely untapped energy resource, and the potential from extracting energy from waste is considerable. Wave energy is produced from the waves that are produced in the oceans. Wave energy is renewable, environment friendly and causes no harm to atmosphere. Producing wave energy can damage marine ecosystem and can also be a source of disturbance to private and commercial vessels. [8] defined hydroelectricity as the term referring to electricity generated by hydro-power; the production of electrical power through the use of the gravitational force of falling or flowing water. It is the most widely used form of renewable energy as it accounts for 16 percent of global electricity generation-3,427 terawatt-hours of electricity production in 2010. What many people are not aware of is that most of the developing cities and towns in the world rely on hydro-power, and have for the past century. Every time you see a major dam, it is providing hydro-power to an electrical station somewhere. The power of the water is used to turn generators to produce the electricity that is then used. The problem faced with hydropower right now is the ageing of the dams. Many of them need major restoration work to remain functional and safe, and that costs enormous sums of money.

Nuclear power and renewable energy are the main options to bring down the carbon intensity of commercial energy supply .Nuclear power falls short of the sustainability criteria and its public acceptance is low [9]. Nuclear power is actually one of the major renewable sources of energy available to the world. The energy is created through a specific nuclear reaction, which is then collected and used to power generators.

Traditionally fossil fuels have been used as the main resource to obtain energy but its use has several negative impacts such as global warming and air pollution [10].When most people talk about the different sources of energy they list natural gas, coal and oil as the options, these are all considered to be just one source of energy from fossil fuels. Fossil fuels provide the power for most of the world, primarily using coal and oil. Oil is converted into many products, the most used of which is gasoline. The issue with fossil fuels is of two kinds. To get to the fossil fuel and convert it to use, there has to be a heavy destruction and pollution of the environment.

Biomass energy is produced from organic material and is commonly used throughout the world. Biomasses generally include crops, plants, trees, yard clippings, wood chips and animal wastes. Biomass energy is used for heating and cooking in homes and as a fuel in industrial production. This type of energy produces large amount of carbon dioxide into the atmosphere [11].

Many households in the world are facing the problem of inadequate supply of energy. The availability of other cooking fuel such as fuel wood, agricultural residues, dried dung and charcoal is also declining, while commercial fuel are mostly, too expensive. This simply means that the price of supplies of the fossil fuel will increase steadily. They will have great impact on developing countries that import energy. In this context, renewable energy source contributes to more secure energy supply. The renewable energy sources are better solution then fossil fuels [12].

The extensive depletion of non-renewable resources, particularly oil, along with a higher level of consumption will have a significant impact on the economic development of future generations. Development is limited by availability of natural resources and current development is approaching toward a near end due to nearby exhaustion of employed resources, because population is growing exponentially, whereas the resources and food supply is fixed [13] Pollution will further limit the availability of food. Another limiting factor is depletion of natural resources. As a result, raw material will become extremely expensive and the depletion of non-renewable resources will lead to sudden collapse of economic development.

Production of environment friendly energy from biogas, which is among the renewable energy sources, provides an environmentally less damaging way of obtaining energy by reducing $CO_2$ emission in environment. These renewable energy sources help in fighting against climate change and contribute to economic growth, job creation and increase in energy security. Even renewable energy technology has an impact on environment but their impact is much less than the impact of the fossil fuels and nuclear fuels. Global challenge of environment protection requires a modified and environment oriented energy system for the future, in order to slow down greenhouse gas emission. One of the ways must be massive effort to increase renewable energy sources such as biogas. [12].

According to [12] energy is the basis of human life, there is hardly any activity or moment that is independent of energy. Every moment of the day we are using energy. The early man used muscle power, then fire and animal power. Next, he learned to harness energy, convert it to useful form and put it to various uses. Energy sources are two types: they are conventional energy sources like coal, petroleum, natural gas etc. & non-conventional energy sources like solar cells, fuel cells, thermo-electric generator, thermal converter, solar power generation, wind power generation, geo-thermal energy generation, tidal power generation etc. Most of the energy consumption is from power generation, transportation, industry, and community sectors. Biogas, a clean and renewable form of energy, could very well be a substitute for conventional energy sources, such as fossil fuels (coal, crude oil, natural gas). Biogas comes as an efficient cost effecting method to generate power. Biogas production is clean, low carbon technology, useful for the efficient management and conservation of organic waste into clean renewable biogas and organic manure/fertilizer. Biogas obtained by anaerobic can be used as an energy source for various applications such as cooking, heating, space cooling and refrigeration, electricity generation and gaseous fuel for vehicle use. [14] In addition, biogas plant provides high quality organic manure with soil nutrient which in turn improve soil fertility.

Anaerobic digestion is a biological process that can convert organic substrates to biogas in the absence of oxygen. [15] One of the end products is biogas, which is used to create electricity and heat, or can be processed into renewable natural gas and fuels used in transportation., another end product is separated digested solids which can be applied directly to crop-land or converted into other products. Also, nutrients in the liquid stream are used in agriculture as bio-fertilizer.

The various interactions and reactions that take place among methanogens, non-methanogens and substrates fed into a digester are referred to as digestion. In the anaerobic digestion process, the organic matter is broken down by an association of microorganisms in the absence of oxygen and lead to the formation of digestate and biogas which mainly consist of methane and carbon dioxide. [16] Originally, anaerobic digestion was perceived as a two stage process involving the sequential action of acid forming and methane forming bacteria. Now, it is known to be a complex fermentation process brought about by the symbiotic association of different types of bacteria. [17][18][19] The products produced by one group of bacteria serve as the substrates for the next group.

The overall effects of this growth on the living standards, resources used and the environment will continue to change the Nigerian landscape for a very long period of time if nothing is done to checkmate the rapid population growth. These effects are presently felt most especially in energy consumption, carbon emissions, air pollution and human congestion.

Culture-independent methods for the identification and characterization of microbial communities involved in biogas production, have met considerable success in recent times [20][21]. Chouari et al.[22], detected the constituents of more than 20 bacterial phyla from anaerobic (mostly methanogenic) waste and wastewater sludge. Using the culture-independent methods of them, Proteobacteria, Chloroflexi, Firmicutes and Bacteroidetes are most prominent. Besides that, in a separate study, characterization of anaerobic microbial community related to biogas production has revealed the presence of Firmicutes, Proteo bacteria, Actonobacteria, Bacteroides, Acido bacteria, Spirochetes, [21]. Earlier studies have reported that the majority of the Archaeal community identified from anaerobic digesters are very similar to already identified methanogens such as Methano sarcinabarkeri, Methano sarcinafrisius, Methano bacterium formicicum, while the remaining are related to thermophilic microbes such as Crenarchaea or Thermoplasma sp. [23].

These bacteria feed upon the initial feedstock, which undergoes a number of different processes converting it to intermediate molecules including sugars, hydrogen & acetic acid before finally being converted to biogas. Different species of bacteria are able to survive at different temperature ranges. Bacteria living optimally at temperatures between 35-40°C are called mesophiles or mesophilic bacteria. Some of the bacteria can survive at the hotter and more hostile conditions of 55-60°C, these are called thermophiles or thermophilic bacteria. Methanogens includes species that can grow in the hostile conditions of hydro-thermal vents. These species are more resistant to heat and can therefore operate at thermophilic temperatures, a property that is unique to bacterial families.

### 2.1. Biogas chemistry

The Chemistry of the different stages for the conversion of the substate to biogas by the endogenous microorganism is shown in equations 1 to 6.

Biogas is a mixture of $CO_2$and $CH_4$:

$$C_6H_{12}O_6 \rightarrow 3CH_4 + 3CO_2 \text{.......} (1)$$

$$CH_4+2O_2 \rightarrow CO_2 + 2H_2O + \text{Energy} \text{.......} (2)$$

Methane is made of formate (HCOO-) or CO2:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2 \text{.......} (3)$$

Methane is also made of acetate ($CH_3COO$-) that is, acetic acid:

$$2CH_3CH_2OH + CO_2 \rightarrow 2CH_3COOH \text{.......} (4)$$

$$2CH_3COOH \rightarrow CH_4 + CO_2 \text{.......} (5)$$

Methane is made of alcohols like methanol:

$$CH_3OH + H_2 \rightarrow CH_4 + H_2 \text{.......} (6)$$

## 3. Material and methods

With respect to the scope of this research work, the biodigester considered for the production of the biogas using cow dung and kitchen waste is the “floating drum digester”.

The following factors are considered for the selecting the floating drum in the production of biogas using cow dung and kitchen waste;

- The operation of the plant is easy to understand and operate.
- The gas drum is air tight
- The digester has a constant gas pressure as a result of the weight of the drum
- Increase in gas-volume is easily recognized by the position of the drum.
- The designing and fabricating of the floating drum digester is cost effective.

- It is durable depending on the nature of material used in fabrication.

A total of four biodigesters were used in the course of this experiment. Their component parts are listed below;

- Biodigester (20litres)
- Gas holder (18liters)
- Gas Outlet Pipe
- Valve

Biogas holder: This holds the substrates (cow dung and kitchen waste).

Biodigester: This is a smaller drum which is called "the gas holder drum". It is a plastic bottle which is completely immersed into the paint bucket filled with the substrates in order to create an air-tight environment to create the anaerobic environment needed for biogas production.

Gas Outlet Pipe: This is a small pipe fitted on the top of the gas holder drum that allows the passage of gas to any external holding such as a burner for cooking or heating purposes.

Gas Valve: Regulates the flow of the biogas.

The gas holder drum was calibrated by making sure the valve is closed, water is poured in to fill the gas pipe after which the first 500ml of water from the measuring cylinder is poured into the gas holder drum and marked. This process is repeated until the gas holder is filled with water. The water is poured out of the gas holder drum and allowed to dry.

Four digesters were used for the experiment. The digesters held 3300g of feed each with varying ratios of 70:30 (Sample A), 50:50 (Sample B), 40:60 (Sample C), and 30:70 (Sample D) of cow dung to kitchen waste respectively. The dilution ratio was 1:3 of feed to water which follows Ojolo et al. [24] experiment.

A total of 9.9 litres was used to dilute the substrate in each paint bucket in other to achieve optimum slurry concentration. An agitator was used to agitate the mix. The slurry was covered with an inverted calibrated floating dome. A quick leak test was done. Gas valves were shut. The presence of water provides a favourable environment for microorganisms.

The pH, temperature and gas composition were measured every five (5) days using a multi-meter while the daily gas production volume was measured using the calibrated gas holder drum. This is achieved as the floating drum rises due to pressure in the paint bucket as gas produced increases. The value of gas produced is equal to the markings on the gas holder drum that coincident with the top of the paint bucket. Gas composition was also measured using a biogas analyzer. When the digester started producing gas, it was tested using a gas burner. Initially, it did not burn, but after some trials, it started burning producing a yellow flame and a clear blue flame later.

## 4. Results and discussion

The result of the gas produced by the different Cow-dung with Organic kitchen waste is presented in Table Fig. 1 to 4. The pH of sample A went from less acidic to more acidic (5.15 to 4.78) which agrees with Otun et al., [26] for sample B, C and D, the pH went from more acidic to less acidic which agrees with Dahunsi and Oranusi [27]. The pH variation most not be unconnected with the increasing concentration of $CO_2$ which is an acidic gas.

The temperature recorded an average of 26.65 $^{o}$C for sample A. Samples B, C and D had average temperatures of 26.55 $^{o}$C, 26.95 $^{o}$C, and 26.42 $^{o}$C respectively. All four samples' temperature where within same range hence, this experiment occurred under mesophilic temperature which agrees with Otun et al.,[26]

Sample A, Table 1, had its highest methane content (100%LEL) on the 10$^{th}$ day after which it started reducing steadily. From Table 2, sample B had a methane content of 46%LEL on the 8$^{th}$ day and then 17%LEL on the 30$^{th}$ day. Sample C and sample D had similar behavior. Both increased steadily with their first peak hitting 58%LEL and 48%LEL on the 17$^{th}$ respectively after which they both reduced and went as high as 99%LEL on day 30. The methane content produced conforms with literature one of which is; for biogas to be flammable the methane content must be ≥ 40% [28].

Subsequently, Sample B was not graphed due to inadequate data which was as a result of no production on the stipulated days for checking gas composition. According to Sorathia et al., [29]; "If not stirred, the slurry will tend to settle out and form a hard scum on the surface, which will prevent release of biogas. This problem is much greater with vegetable waste than with manure, which will tend to remain in suspension and have better contact with the bacteria as a result.

**Table 1** Biogas volume and composition for Sample A

| **Biodigester 1 (70:30) a** | | | | | | | | **Gas composition** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Days** | **Vi (ml)** | **Vo (ml)** | **Vo-Vi** | **Burnt off** | **Cumulative Volume (ml)** | **pH** | **Temp. ($^0$C)** | **$CH_4$** | **CO** | **$O_2$i** | **$O_2$o** | **$CO_2$** | **$H_2S$** |
| 1 | 4000 | 4000 | 0 | - | 4000 | 7 | - | | | | | | |
| 2 | 4000 | 5500 | 1500 | - | 5500 | - | - | | | | | | |
| 3 | 5500 | 6500 | 1000 | - | 6500 | - | - | | | | | | |
| 4 | 6500 | 6500 | 0 | - | 6500 | - | - | | | | | | |
| 5 | 6500 | 8500 | 2000 | 1000 | 8500 | 5.15 | 27.2 | 58 | 2000 | 21 | 15 | 5.5 | 0 |
| 6 | 7500 | 9500 | 2000 | - | 10500 | - | - | | | | | | |
| 7 | 9500 | 11000 | 1500 | | 12000 | | | | | | | | |
| 8 | 11000 | 13000 | 2000 | | 14000 | | | | | | | | |
| 9 | 13000 | 13500 | 500 | | 14500 | | | | | | | | |
| 10 | 13500 | 14000 | 500 | 7000 | 15000 | 5.25 | 27.5 | 100 | 2000 | 21 | 21 | | 147 |
| 11 | 7000 | 8000 | 1000 | | 16000 | | | | | | | | |
| 12 | 8000 | 8000 | 0 | | 16000 | | | | | | | | |
| 13 | 8000 | 8000 | 0 | | 16000 | | | | | | | | |
| 14 | 8000 | 8000 | 0 | | 16000 | | | | | | | | |
| 15 | 8000 | 8000 | 0 | 1000 | 16000 | 5.02 | 27 | 38 | 2000 | 21 | 12 | 8.4 | 0 |
| 16 | 7000 | 7000 | 0 | | 16000 | | | | | | | | |
| 17 | 7000 | 7000 | 0 | | 16000 | | | | | | | | |
| 18 | 7000 | 7000 | 0 | | 16000 | | | | | | | | |
| 19 | 7000 | 7000 | 0 | | 16000 | | | | | | | | |
| 20 | 7000 | 8000 | 1000 | 2000 | 17000 | 4.72 | 25.2 | 22 | 2000 | 21 | 14 | 6.8 | 54 |
| 21 | 6000 | 6000 | 0 | | 17000 | | | | | | | | |
| 22 | 6000 | 6000 | 0 | | 17000 | | | | | | | | |
| 23 | 6000 | 9000 | 3000 | | 20000 | | | | | | | | |
| 24 | 9000 | 11000 | 2000 | | 22000 | | | | | | | | |
| 25 | 11000 | 11000 | 0 | 7000 | 22000 | 4.71 | 26 | 32 | 2000 | 21 | 17 | 3.8 | 47 |
| 26 | 4000 | 4000 | 0 | | 22000 | | | | | | | | |
| 27 | 4000 | 4000 | 0 | | 22000 | | | | | | | | |
| 28 | 4000 | 4000 | 0 | | 22000 | | | | | | | | |
| 29 | 4000 | 4000 | 0 | | 22000 | | | | | | | | |
| 30 | 4000 | 4000 | 0 | | 22000 | 4.78 | 27 | 23 | 167 | 21 | 20 | 0.7 | 7 |

**Table 2** Biogas volume and composition for Sample B

| **Bio digester 2 (50:50) b** | | | | | | | | **Gas composition** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Days** | **Vi (ml)** | **Vo (ml)** | **Vo-Vi** | **Burnt off** | **Cumulative Volume(ml)** | **pH** | **Temp. ($^0C$)** | **$CH_4$** | **CO** | **$O_2i$** | **$O_2o$** | **$CO_2$** | **$H_2S$** |
| 1 | 2000 | 2000 | 0 | | 2000 | | | | | | | 0 | |
| 2 | 2000 | 2000 | 0 | | 2000 | | | | | | | | |
| 3 | 2000 | 2000 | 0 | | 2000 | | | | | | | | |
| 4 | 2000 | 2000 | 0 | | 2000 | | | | | | | | |
| 5 | 2000 | 2000 | 0 | | 2000 | | | | | | | | |
| 6 | 2000 | 2000 | 0 | | 2000 | | | | | | | | |
| 7 | 2000 | 10000 | 8000 | | 10000 | | | | | | | | |
| 8 | 10000 | 10000 | 0 | 3500 | 10000 | 5.21 | 26.5 | 46 | 2000 | 21 | 19 | 1.9 | 27 |
| 9 | 6500 | 6500 | 0 | | 10000 | | | | | | | | |
| 10 | 6500 | 6500 | 0 | | 10000 | | | | | | | | |
| 11 | 6500 | 6500 | 0 | 4500 | 10000 | | | | | | | | |
| 12 | 2000 | 2000 | 0 | | 10000 | | | | | | | | |
| 13 | 2000 | 2000 | 0 | | 10000 | 5.15 | 26.4 | | | | | | |
| 14 | 2000 | 2500 | 500 | | 10500 | | | | | | | | |
| 15 | 2500 | 2500 | 0 | | 10500 | | | | | | | | |
| 16 | 2500 | 2500 | 0 | | 10500 | | | | | | | | |
| 17 | 2500 | 2500 | 0 | 500 | 10500 | 4.9 | 26.9 | | | | | | |
| 18 | 2000 | 2000 | 0 | | 10500 | | | | | | | | |
| 19 | 2000 | 2000 | 0 | | 10500 | | | | | | | | |
| 20 | 2000 | 2000 | 0 | | 10500 | | | | | | | | |
| 21 | 2000 | 2000 | 0 | | 10500 | | | | | | | | |
| 22 | 2000 | 2000 | 0 | | 10500 | 5.1 | 26.8 | | | | | | |
| 23 | 2000 | 3500 | 1500 | | 12000 | | | | | | | | |
| 24 | 3500 | 3500 | 0 | | 12000 | | | | | | | | |
| 25 | 3500 | 4500 | 1000 | | 13000 | | | | | | | | |
| 26 | 4500 | 4500 | 0 | | 13000 | 5.53 | 26 | | | | | | |
| 27 | 4500 | 5750 | 1250 | | 14250 | | | | | | | | |
| 28 | 5750 | 5750 | 0 | | 14250 | | | | | | | | |
| 29 | 5750 | 5750 | 0 | | 14250 | | | | | | | | |
| 30 | 5750 | 6500 | 750 | 4500 | 15000 | 5.69 | 26.7 | 17 | 2000 | 21 | 20 | 0.6 | 0 |

**Table 3** Biogas volume and composition for Sample C

| **Biodigester 3 (40:60) c** | | | | | | | | **Gas composition** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Days** | **Vi (ml)** | **Vo (ml)** | **Vo-Vi** | **Burnt off** | **Cumulative Volume (ml)** | **pH** | **Temp. ($^0C$)** | **$CH_4$** | **CO** | **$O_2i$** | **$O_2o$** | **$CO_2$** | **$H_2S$** |
| 1 | 1500 | 1500 | 0 | | 1500 | | | | | | | 0 | |
| 2 | 1500 | 1500 | 0 | | 1500 | | | | | | | | |
| 3 | 1500 | 1500 | 0 | | 1500 | | | | | | | | |
| 4 | 1500 | 1500 | 0 | | 1500 | | | | | | | | |
| 5 | 1500 | 1500 | 0 | | 1500 | | | | | | | | |
| 6 | 1500 | 1500 | 0 | | 1500 | | | | | | | | |
| 7 | 1500 | 3000 | 1500 | | 3000 | | | | | | | | |
| 8 | 3000 | 9000 | 6000 | 500 | 9000 | 4.81 | 26.6 | 31 | 1982 | 21 | 19 | 1.8 | 11 |
| 9 | 8500 | 8500 | 0 | | 9000 | | | | | | | | |
| 10 | 8500 | 8500 | 0 | | 9000 | | | | | | | | |
| 11 | 8500 | 9000 | 500 | | 9500 | | | | | | | | |
| 12 | 9000 | 9000 | 0 | | 9500 | | | | | | | | |
| 13 | 9000 | 10750 | 1750 | 5750 | 11250 | 4.55 | 27.7 | 42 | 2000 | 21 | 17 | 4.1 | 6 |
| 14 | 5000 | 5000 | 0 | | 11250 | | | | | | | | |
| 15 | 5000 | 5500 | 500 | | 11750 | | | | | | | | |
| 16 | 5500 | 6000 | 500 | | 12250 | | | | | | | | |
| 17 | 6000 | 6500 | 500 | 1500 | 12750 | 4.65 | 28.6 | 58 | 1986 | 21 | 12 | 8.6 | 43 |
| 18 | 5000 | 5000 | 0 | | 12750 | | | | | | | | |
| 19 | 5000 | 5750 | 750 | | 13500 | | | | | | | | |
| 20 | 5750 | 6000 | 250 | | 13750 | | | | | | | | |
| 21 | 6000 | 6000 | 0 | | 13750 | | | | | | | | |
| 22 | 6000 | 6000 | 0 | 4000 | 13750 | 4.77 | 27.6 | 22 | 1777 | 21 | 18 | 2.4 | 18 |
| 23 | 2000 | 2500 | 500 | | 14250 | | | | | | | | |
| 24 | 2500 | 3000 | 500 | | 14750 | | | | | | | | |
| 25 | 2500 | 3000 | 500 | | 15250 | | | | | | | | |
| 26 | 3000 | 3000 | 0 | 500 | 15250 | 5.66 | 26.6 | 24 | 22 | 21 | 19 | 1.5 | 31 |
| 27 | 2500 | 5500 | 3000 | | 18250 | | | | | | | | |
| 28 | 5500 | 5500 | 0 | | 18250 | | | | | | | | |
| 29 | 5500 | 5500 | 0 | | 18250 | | | | | | | | |
| 30 | 5500 | 5500 | 0 | 3500 | 18250 | 5.66 | 24.6 | 99 | 1985 | 21 | 12 | 9.2 | 176 |

**Table 4** Biogas volume and composition for Sample D

| **Biodigester 4 (30:70) d** | | | | | | | | **Gas composition** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Days** | **Vi (ml)** | **Vo (ml)** | **Vo-Vi** | **Burnt off** | **Cumulative Volume (ml)** | **pH** | **Temp. ($^0C$)** | **$CH_4$** | **CO** | **$O_2i$** | **$O_2o$** | **$CO_2$** | **$H_2S$** |
| 1 | 1500 | 1500 | 0 | | 1500 | | | | | | | 0 | |
| 2 | 1500 | 1500 | 0 | | 1500 | | | | | | | | |
| 3 | 1500 | 1500 | 0 | | 1500 | | | | | | | | |
| 4 | 1500 | 1500 | 0 | | 1500 | | | | | | | | |
| 5 | 1500 | 1500 | 0 | | 1500 | | | | | | | | |
| 6 | 1500 | 1500 | 0 | | 1500 | | | | | | | | |
| 7 | 1500 | 2000 | 500 | | 2000 | | | | | | | | |
| 8 | 2000 | 2000 | 0 | 500 | 2000 | 3.55 | 25.7 | 0 | 76 | 21 | 21 | 0 | 0 |
| 9 | 2000 | 2000 | 0 | | 2000 | | | | | | | | |
| 10 | 2000 | 2000 | 0 | | 2000 | | | | | | | | |
| 11 | 2000 | 9000 | 7000 | | 9000 | | | | | | | | |
| 12 | 9000 | 9000 | 0 | | 9000 | | | | | | | | |
| 13 | 9000 | 11000 | 2000 | 3000 | 11000 | 4.74 | 27.6 | 14 | 1990 | 21 | 17 | 3.8 | 3 |
| 14 | 8000 | 8000 | 0 | | 11000 | | | | | | | | |
| 15 | 8000 | 8000 | 0 | | 11000 | | | | | | | | |
| 16 | 8000 | 8000 | 0 | | 11000 | | | | | | | | |
| 17 | 8000 | 8500 | 500 | 7000 | 11500 | 4.91 | 27.1 | 48 | 2000 | 21 | 16 | 5.3 | 66 |
| 18 | 1500 | 1500 | 0 | | 11500 | | | | | | | | |
| 19 | 1500 | 2000 | 500 | | 12000 | | | | | | | | |
| 20 | 2000 | 3500 | 1500 | | 13500 | | | | | | | | |
| 21 | 3500 | 5500 | 2000 | | 15500 | | | | | | | | |
| 22 | 5000 | 5500 | 500 | 2000 | 16000 | 5.5 | 26.1 | 11 | 1568 | 21 | 20 | 1.1 | 19 |
| 23 | 3500 | 3500 | 0 | | 16000 | | | | | | | | |
| 24 | 3500 | 4000 | 500 | | 16500 | | | | | | | | |
| 25 | 4000 | 5000 | 1000 | | 17500 | | | | | | | | |
| 26 | 5000 | 5000 | 0 | 3500 | 17500 | 5.64 | 27.4 | 17 | 2000 | 21 | 8.5 | 12 | 18 |
| 27 | 1500 | 1500 | 0 | | 17500 | | | | | | | | |
| 28 | 1500 | 1500 | 0 | | 17500 | | | | | | | | |
| 29 | 1500 | 1500 | 0 | | 17500 | | | | | | | | |
| 30 | 1500 | 4500 | 3000 | 5000 | 20500 | 5.67 | 24.6 | 99 | 1975 | 21 | 12 | 9.2 | 39 |

**Table 5** Cumulative Gas Volumes for All Samples

| Day | Gas Volume | | | |
|---|---|---|---|---|
| | **A** | **B** | **C** | **D** |
| 1 | 4000 | 2000 | 1500 | 1500 |
| 2 | 5500 | 2000 | 1500 | 1500 |
| 3 | 6500 | 2000 | 1500 | 1500 |
| 4 | 6500 | 2000 | 1500 | 1500 |
| 5 | 8500 | 2000 | 1500 | 1500 |
| 6 | 10500 | 2000 | 1500 | 1500 |
| 7 | 12000 | 10000 | 3000 | 2000 |
| 8 | 14000 | 10000 | 9000 | 2000 |
| 9 | 14500 | 10000 | 9000 | 2000 |
| 10 | 15000 | 10000 | 9000 | 2000 |
| 11 | 16000 | 10000 | 9500 | 9000 |
| 12 | 16000 | 10000 | 9500 | 9000 |
| 13 | 16000 | 10000 | 11250 | 11000 |
| 14 | 16000 | 10500 | 11250 | 11000 |
| 15 | 16000 | 10500 | 11750 | 11000 |
| 16 | 16000 | 10500 | 12250 | 11000 |
| 17 | 16000 | 10500 | 12750 | 11500 |
| 18 | 16000 | 10500 | 12750 | 11500 |
| 19 | 16000 | 10500 | 13500 | 12000 |
| 20 | 17000 | 10500 | 13750 | 13500 |
| 21 | 17000 | 10500 | 13750 | 15500 |
| 22 | 17000 | 10500 | 13750 | 16000 |
| 23 | 20000 | 12000 | 14250 | 16000 |
| 24 | 22000 | 12000 | 14750 | 16500 |
| 25 | 22000 | 13000 | 15250 | 17500 |
| 26 | 22000 | 13000 | 15250 | 17500 |
| 27 | 22000 | 14250 | 18250 | 17500 |
| 28 | 22000 | 14250 | 18250 | 17500 |
| 29 | 22000 | 14250 | 18250 | 17500 |
| 30 | 22000 | 15000 | 18250 | 20500 |

The CO content of sample A was 2000ppm until day 30 where it dropped to 167ppm, while, the CO content of sample C started higher than that sample D until day 13 through day 17 where both had the value. Both sample C and sample D experienced a drop in value from day 17 through day 22 with sample C still superseding sample D until a sudden downward slope occurred with sample C which in turn made sample D higher. At day 30, both sample C and sample D had the same value.

The $CO_2$ content of sample A, sample C and sample D followed a undulating pattern having their highest peaks at 8.4%Vol on day 15, 8.6%Vol on day 17 and 12.3%Vol on day 26 respectively. Both sample C and sample D had 9.2%Vol on day 30 which agrees with Kavuma [30]

The $O_2$ content of sample A, sample C and sample D followed undefined pattern having their highest peaks at 20.8%Vol on day 10, 19%Vol on day 8 and 20.8%Vol on day 8 respectively. Both sample C and sample D had 11.6%Vol on day 30.

The $H_2S$ content of sample A, sample C and sample D followed a zigzag pattern having their highest peaks at 147ppm on day 10, 176ppm on day 30 and 66ppm on day 17 respectively. Sample C and sample D didn't have same value on day 30. According to Suyog,[31], the $H_2S$ content should be between 20-20,000ppm

Cumulatively gas production Sample A (70:30) was more, as shown table 5. This is due to a higher amount of cow dung in Sample A. Sample D (30:70) was second highest. Sample B (50:50) had the least cumulative gas production with Sample C (40:60) as third highest.

### 4.1. Model of the Gas composition

**Table 6** Biogas composition correlation for Sample A

| | Linear Correlation | Polynomial |
|---|---|---|
| Time Vs CH4 | y = -2.5403x + 94.612 $R^2$ = 0.495 | y = -0.0113x4 + 0.908x3 - 25.69x2 + 296.65x - 1089 $R^2$ = 0.9789 |
| Time Vs CO2 | y = -0.2161x + 9.4911 $R^2$ = 0.3887 | y = 0.0002x4 - 0.0119x3 + 0.2662x2 - 1.9556x + 9.5198 $R^2$ = 1 |
| Time Vs CO | y = -57.619x + 2808.5 $R^2$ = 0.4024 | y = -0.1192x4 + 8.0703x3 - 194.45x2 + 1958.2x - 4871.6 $R^2$ = 0.9921 |
| Time Vs H2S | y = -1.1758x + 65.233 $R^2$ = 0.0294 | y = -0.0278x4 + 2.1811x3 - 60.753x2 + 701.66x - 2724.6 $R^2$ = 0.7481 |

**Table 7** Biogas composition correlation for Sample C

| | Linear Correlation | Polynomial |
|---|---|---|
| Time Vs CH4 | y = 1.5383x + 16.259 $R^2$ = 0.1888 | y = 0.0065x4 - 0.4326x3 + 9.8726x2 - 90.559x + 317.85 $R^2$ = 0.9756 |
| Time Vs CO2 | y = 0.1417x + 1.8595 $R^2$ = 0.1142 | y = 0.0011x4 - 0.078x3 + 1.8503x2 - 17.479x + 58.4 $R^2$ = 0.9148 |
| Time Vs CO | y = -40.387x + 2406.1 $R^2$ = 0.1774 | y = 0.3321x4 - 23.927x3 + 602.45x2 - 6254.2x + 24380 $R^2$ = 0.8812 |
| Time Vs H2S | y = 5.5079x - 58.985 $R^2$ = 0.4966 | y = 0.0131x4 - 0.9144x3 + 22.68x2 - 232.34x + 832.29 $R^2$ = 0.9947 |

**Table 8** Biogas composition correlation for Sample D

| | **Linear Correlation** | **Polynomial** |
|---|---|---|
| Time Vs CH4 | y = 2.9411x - 25.361 $R^2$ = 0.4344 | y = 0.0086x4 - 0.5933x3 + 14.145x2 - 135.47x + 446.05 $R^2$ = 0.9632 |
| Time Vs CO2 | y = 0.4321x - 3.071 $R^2$ = 0.5648 | y = -0.0015x4 + 0.1123x3 - 3.0531x2 + 34.532x - 132.64 $R^2$ = 0.7645 |
| Time Vs CO | y = 60.265x + 436.37 $R^2$ = 0.4197 | y = 1.1613x3 - 73.729x2 + 1491.9x - 7678.5 $R^2$ = 0.9248 |
| Time Vs H2S | y = 1.2191x + 0.5982 $R^2$ = 0.1644 | y = 0.0098x4 - 0.7195x3 + 18.403x2 - 188.97x + 660.83 $R^2$ = 0.7013 |

The correlation on the biogas constituents including, $CH_4$, $CO_2$, CO and $H_2S$ for the three samples A, C and D is presented in table 6, 7 and 8. All the models generated by the kinetics of the samples showed poor linear correlation, while the polynomial correlation of the 4th order had the best fit for the different ratios.

Sample B had a staggered correlation and was not presented.

## 5. Conclusion

The results obtained from the experiment carried out using cow dung and organic kitchen waste has been presented. In this study four (4) sample, labeled A, B, C, and D of different substrate ratio was experimented to understand the behavior of the various ratio based on the constitutes of the biogas produced. The kinetic model showed polynomial correlation as the best fit for all the samples. This project acts as sensitization to researchers on the efficient utilization of cow dung and organic kitchen waste using a low-cost bio digester which has low cost of construction, and maintenance ease to produce biogas for heat and electricity in farms and households. The results show that there is variation in the constituent biogas and the model that best fit in describing the different ratios.

## Compliance with ethical standards

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### *Disclosure of conflict of interest*

We wish to state that there is no conflict of interest and that this is the original work of the authors.

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