

OPTIMIZATION OF BIOGAS YIELD FROM KITCHEN WASTE AND HUMAN WASTE USING TAGUCHI METHOD

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ABSTRACT

Biogas extraction from human excreta and kitchen waste was investigated. A biogas production system was developed locally, a tank filled with human feces and kitchen waste. Anaerobic treatment of excreta and kitchen waste was able to produce biogas which is a potential renewable energy source. Sixteen groups of sample were first produced containing different percentage composition the materials. The biogas produced, the PH Value, temperature and moisture content of the sixteen different samples mix were analyzed. All of the samples experienced its peak in day 14, which was in thermophilic condition. Taguchi method of design of experiment was used to determine the optimum design parameters, the levels used are, Temperature (29, 38, 48, 57 °C), PH value (7.0, 7.3, 7.6 7.9), and moisture content (45, 50, 55, 60. %). The L₁₆ (4³) full factorial design with a mixed orthogonal array was selected to conduct the experiments. Biogas produced was used as response while PH Scale, moisture content and temperature was used as control factors. Result showed that the optimum setting for the methane gas produced is: temperature of 38°C, PH value 7.0 and moisture content of 60 percent. Analysis of variance (ANOVA) was used to confirm the experiment that the most significant factor for the biogas produced is the temperature, as depicted in their signal to noise ratio using Minitab 2020 software. Sensitivity test was carried out for the biogas yield between the Taguchi method, and the Regression model. Confirmation test was carried out using the optimum test parameters and the regression model and experimental results showed a deviation of 6.5% which is agreeable.

Keywords: Biogas production, optimization, Taguchi method, kitchen waste and Human Excreta

1. INTRODUCTION

Biogas typically refers to a gas produced by the biological breakdown of organic matter in the absence of oxygen. Biogas originates from biogenic material and is a type of biofuel, (Ibikunle 2024). Biogas is produced by anaerobic digestion or fermentation of biodegradable materials such as biomass, manures, sewage, municipal waste, green waste, and plant material and energy crops. This type of biogas comprises primarily methane and carbon dioxide. Another type of gas generated by use of biomass is wood gas, which is created by gasification of wood or other biomass. This type of gas is also comprised primarily of nitrogen, hydrogen, and carbon monoxide, with trace amounts of methane. The gases methane, hydrogen and carbon monoxide can be combusted or oxidized with oxygen. Air contains 21 per cent oxygen. This energy release allows biogas to be used as a fuel. Biogas can be used as a low-cost fuel in any country for any heating purpose, such as cooking. It can also be used in modern waste management facilities where it can be used to run any type of heat engine, to generate either mechanical or electrical power. Biogas can be compressed, much like natural gas, and used to power motor vehicles and in the UK for example is estimated to have the potential to replace around 17 per cent of vehicle fuel. Biogas is a renewable fuel, so it qualifies for renewable energy subsidies in some parts of the world.

Biogas is often referred to as green energy, clean energy, and alternate energy source. This energy is obtained from natural resources that are not replenished or otherwise endless like the sun or the ocean. It is an alternative to most of the non-sustainable sources used widely today like coal, fossil fuel, etc. In many places, Biogas has been generated in both small- and large-scale plants for instance a house bio digester that provides cooking gas for an entire family and a large-scale biogas plant that can generate energy for a whole community.

1.2 Composition of Biogas

Biogas is composed of methane, carbon dioxide, and traces of other gases such as Nitrogen, hydrogen sulfide, hydrogen, and oxygen. The composition differs depending on the source of production, raw material used, organic matter loaded, and the feeding rate of the digester.

Biogas is carbon neutral hence the environmentally less damaging way of obtaining energy from organic waste matter by eliminating Methane emission into the atmosphere. The impact of biogas generation on the environment is much lesser than the impact of fossil fuels, and natural gas. Biogas is extensively used in some rural areas for electricity and cooking. Hence Biogas generation is one of the most effective ways to reduce the use of fossil fuel and greenhouse gas emissions.

1.3 Sources of Biogas

- **Livestock waste**

Livestock/ cattle and poultry waste comprise the most utilized substrate for biogas generation. Manure from poultry, dairy cattle, and pigs are largely genuine instances of this waste. This organic matter can be exposed to controlled deterioration to yield great amounts of bio-methane.

- **Landfill gas**

This energy generation technique utilizes aggregated wastes from domestic exercises to create biogas. Landfills are loaded up with appropriate organic materials that break down generating biogas that is modified and provided to various processes.

- **Activated Sludge from Waste Treatment Plants**

Sludge got from wastewater sanitization is generally composed of organic materials accordingly forming a rich substrate for biogas generation. Whenever wastewater has been filtered through, activated sludge buildup in the treatment plant can be diverted to particular disintegration chambers where they produce methane.

- **Industrial, Institutional and Commercial Wastes**

Numerous modern industrial manufacturing units utilize organic raw materials that are abundantly available in nature in their production. For instance, food product manufacturing industries use food materials that produce tremendous measures of organic waste matter. Biogas generating plants can outfit these materials, permitting controlled disintegration to yield environmentally friendly power through biogas.

1.4 Characteristics of biomass

Biogas stands out of other renewable having the following unique and outstanding characteristics

- **Biomass energy is a renewable resource**

Biomass energy can be regenerated through photosynthesis of plants, and is equivalent to wind energy and solar energy. It is a renewable energy source. It is rich in resources and can ensure the sustainable use of energy. Biomass energy is the only renewable energy that can be transported and stored.

- **Low pollution**

The biomass combustion process has little environmental pollution. The content of harmful substances in biomass is low, ash, nitrogen, sulfur and other harmful substances are far lower than mineral energy. The SOX and NOX generated in the combustion process are less, and the sulfur content of biomass is generally not higher than 0.2%; biomass is used as fuel At this time, since the carbon dioxide it needs for growth is equivalent to the amount of carbon dioxide it emits, its net carbon dioxide emissions to the atmosphere are close to zero, which can effectively reduce the greenhouse effect.

- **Widely distributed**

Biomass energy is universal and easy to take. Regardless of countries and regions, it is inexpensive, easy to obtain, and simple to process. In areas lacking coal, biomass energy can be fully utilized. The total amount of biomass fuel is very abundant

- **Biomass energy reserves are large and renewable.**

As long as there is sunlight, photosynthesis will not stop. Biomass energy is the fourth largest energy source in the world, second only to coal, oil and natural gas. According to estimates by biologists, the earth's land produces 100 to 125 billion tons of biomass annually, and the ocean produces 50 billion tons of biomass annually. The annual production of biomass energy far exceeds the world's total energy demand, which is equivalent to 10 times the current world's total energy consumption. The biomass resources that can be developed into energy in China will reach 300 million tons by 2010. With the development of agriculture and forestry, especially the promotion of charcoal forests, biomass resources will continue to increase.

- Biomass has high volatility and high carbon activity, which makes it easy to catch fire. There is little ash and slag after burning and it is not easy to stick.
- Biomass has low energy density, large volume, and difficult transportation.

The utilization of biomass energy mainly includes three ways: direct combustion (thermal energy-light energy), thermo chemical conversion (thermal energy-chemical energy) and biochemical (thermal energy-chemical energy) conversion.

The direct combustion of biomass will continue to be the main method of biomass energy utilization in China for a long time to come. At present, traditional wood-burning stoves with a thermal efficiency of only about 10% are renovated, and wood-saving stoves with an efficiency of 20%-30% are promoted. The simple technology and easy promotion of wood-saving stoves are energy-saving measures with obvious benefits, and they are listed as new rural areas by the

country. The thermo chemical conversion of biomass refers to the technology of vaporization, carbonization, pyrolysis and catalytic liquefaction of biomass under certain temperature and conditions to produce gaseous fuels, liquid fuels and chemical substances.

1.5 Aim and objectives

The aim of this work is to evaluate the biogas yield from a blend of human excreta and kitchen waste.

The objectives include to:

1. Develop the biogas extracting system and carry out ventilation test on the system produce.
2. Study its performance characteristics using the biogas wastes of human excreta and kitchen waste.
3. Optimization of the process conditions of the biogas gotten using Taguchi method of design of experiment and using ANOVA to confirm the results.

2. MATERIALS AND METHODS

2.1.1 Material selection

Most often Biogas digesters are designed and constructed using bricks, cement, metals, and reinforced concrete, while in some cases, the dome of the gas holder is made up of fiberglass. These biogas digesters encounter some challenges such as leakages at the edges of the brick structure after a short period of operation. There are some few biogas digester designs that utilize reinforced plastic; however, some of the reinforced plastic of the biogas digester deteriorates and creates holes due to the effect of ultraviolet (UV) radiations. Furthermore, the effect of corrosion that mostly occurs in biogas digesters built from metals results in their failure. In addition to the limitations aforementioned, the construction of the biogas digester using bricks or cement block is quite expensive due to high labor cost and materials.

To overcome these weaknesses and challenges associated with the various materials mentioned, an alternative construction material was investigated in this study. More so, to minimize the high cost of construction of these previous designs, a more cost-effective design is proposed. Thus, the study employed a high-density polyethylene (HDPE) plastic to fabricate the digestion chamber and galvanized pipes for the construction of inlet and outlet chambers. The choice of a plastic for the study is based on it being noncorrosive, a good insulator, cost-effective, and easy to maintain. This uniqueness of the present study stem from the use of composite materials (plastic). Another factor that made the present study different from previous design is the subjection to the ventilation test to ensure leak free, which will result to more biogas yield and production. These introduction and use of this technology involving composite materials will help to generate biogas for research purposes and serve as a perfect fertilizer used for farm work; all these motivated the need for this study. Therefore, the study fills this knowledge gaps existing in biogas digester designs, hence making it easier to consider a composite material for biogas digester design.

The aim of the study is to produce energy and also to design and fabricate a biogas digester using high-density polyethylene (HDPE) as an alternative material of construction/ fabrication. The detailed knowledge of the design equations and the nature of material used in the construction of the biogas digester will be helpful to the energy engineer, researcher, and academic contributions to the development of biogas technology. Hence, the objective of the study is to formulate a design equation used for the construction of the biogas digester and to carry out a ventilation test to certify the digester a leak free one, which is not usually common in previous studies.

Other materials used for the research include; the ph meter that was used to take the ph readings of the bio digesters, the thermometer for measuring the temperature of the bio digester. A tube, for collection of the produced biogas, a weigh balance, for measurement of the weight of the samples before pouring them into the digesters,

2.1.2 Design of the Bio Digester

Having considered the previous design and fabrication/construction of the biogas digester from selected authors, we designed ours thus considering the shape of the materials we are using.

$$\text{Volume of slurry chamber} = V = \pi r^2 h \quad 3.1$$

r = Radius of the slurry chamber is

h = Height of the slurry chamber

Therefore, the volume of the slurry chamber = Volume of 3/4 of the slurry chamber

$$\text{Volume of the gas holder} = V = \pi r^2 h^2 \quad 3.2$$

The materials for the work and the quantity used for the work are presented in the table below.

Table 2.1 parts of the digester

Item no	Parts name	Quantity
1	Digester chamber	1
2	Cover	1
3	Backnut assey	1
4	Slugde inlet pipe	2
5	Assem	2
6	Top assem	2
7	Backnut 2	1
8	Elbow	1
9	T – connector	1
10	H1	1
11	H2	1
12	H3	1
13	Tube	1

2.2 Experimental Procedures

16, 75-l laboratory-scale plastic anaerobic reactors, known as digesters in the work were fabricated locally for this research study. The digesters have four openings each, one serving as the inlet of the substrates, the second for the biogas outlet, while the third was for the removal of the slurry. The fourth opening was made on the cover through which a thermometer was permanently attached for temperature measurement. The process of generating energy from bio mass is illustrated in figure 3.1 below. After chosen the tank to use, two holes were made in the tank for the inlet and outlet using hot iron rod. Then the inlet and the outlet pipes were fixed. In furtherance a gas holder was made. A tube was used to make a gas holder; the tube held the gas produced. The tank was then overturned and fixed with a valve used for plumbing purpose.

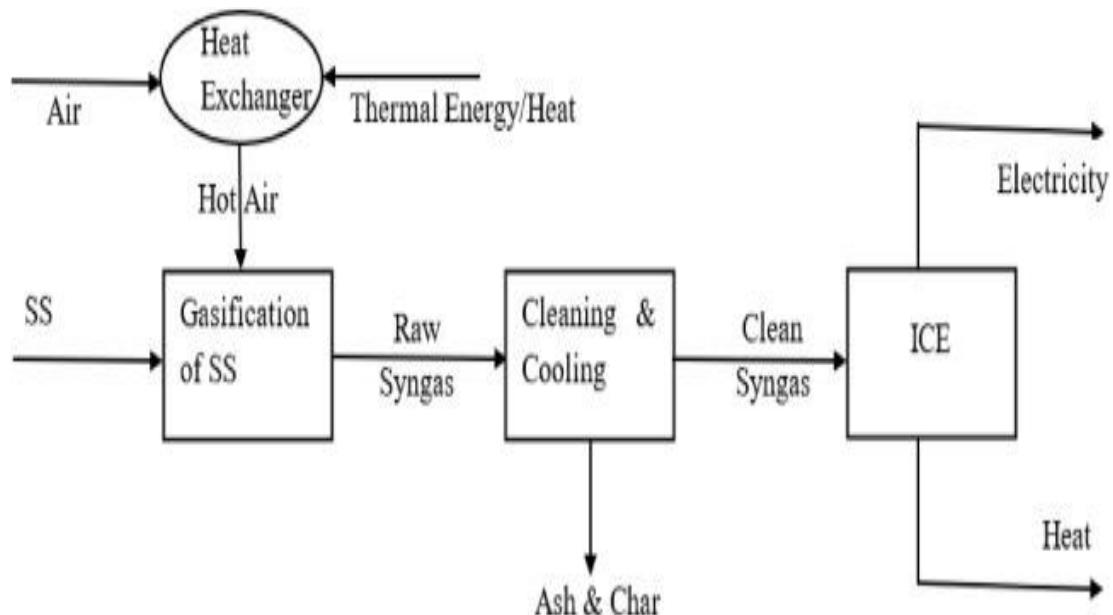


Fig. 2.1 Heat generation route from bio mass

The experiment was conducted into the developed digester with mixing system at $35\pm1^{\circ}\text{C}$. The capacity of the digester was 75L with 50 L effective volume (Fig.3.2). The produced biogas was escaped through a pipe into a tube. The samples for detecting various parameters were taken out from the side-ports. In the fermentation process, the substrate was fed into the airtight digester under specified environmental conditions for 35 days. The human feces were gotten from my septic tank at home. While the quantity of kitchen waste used was also gotten from the kitchen waste of a nearby restaurant. The kitchen waste consists of rice, beans, garri, soup etc, which are mostly left over from customers and

were thrown into a waste bin. This was followed by sorting of collected kitchen waste. Impurities and non-biodegradable municipal solid wastes (MSW) such broken bottles, plastics, metals, ashes, textiles, etc., were removed, and the KW was grinded with a grinding machine to achieve a homogeneous composition and also to improved microbial hydrolysis when fed into the anaerobic digester. The mixture was then inoculated with the 20% mesophilic digestate obtained from the previous investigation of dry anaerobic digestion of cow dung.

The dung was then mixed (ratio of 1kg for 10 liters of water). The mixture was stirred to make fine slurry. The slurry of both the human feces and the KW was poured into the digester tank in the ratio designed. Furthermore, the gas holder tank was overturned in the digester tank after adding the slurry, the valve was opened while putting the gas holder tube and the digester took about 7days for the first time to get output. The energy gotten from the system in terms of biogas was further evaluated to determine its yield according to each different composition of the blend of human excreta and kitchen waste. The research is focused on evaluating the biogas yield from the developed digesters and implementation of a cost-effective environmentally safe technology of waste recycling and utilization, including energy recovery, by means of thermal and biochemical conversion processes.

2.3 Experimental Design

In this research the design of experiment DOE adopted was the Taguchi method of experiment. Taguchi's approach is used for analysis and finding the responsible effective control factors or parameters. The model is developed for production performance based on responses. This method is good for investigating the effect of single parameters on output. In the biogas production process, the output biogas quantity depends on the different input parameters. This method was chosen because it is more versatile than other analytical techniques in determining the impact of each input parameter on the percentage of methane produced. The L16 Taguchi design of the experimental approach was considered because it decreases the cost and duration of the experiment (Prakash Babu Kanakavalli and Satish R More 2022.).

2.2 Design Summary

Taguchi Array	$L_{16}(4^3)$
Factors:	3
Runs:	16

Table 2.3 Full factorial design with orthogonal array of Taguchi $L_{16}(4^3)$

Experimental No	Parameter A	Parameter B	Parameter C
1	1	1	1
2	1	2	2
3	1	3	3
4	1	4	4
5	2	1	2
6	2	2	1
7	2	3	4
8	2	4	3
9	3	1	3
10	3	2	4
11	3	3	1
12	3	4	2
13	4	1	4
14	4	2	3
15	4	3	2
16	4	4	1

The system was test run for a period of eleven months between July 2022 and June 2023. The biogas gas produced was calculated using equation 3.3 below. The pilot installation of sewage sludge bioconversion was designed to achieve the production capacity of bio fuel per year. The designed capacity of the prototype installation allows 80% reduction of the currently generated volume of sewage sludge. The installation enables utilization as a qualified biomass in the energy sector. The process was fully pressurized and to a large extent, it reduced the environmental impact of the sewage plant by the elimination of land filling and the necessity of transporting the sludge to remote traditional utilization sites. The installation is characterized by the application of sewage sludge bioconversion consisting in the generation of bio fuel in the process of stimulated maturation of the mixture composed of sewage sludge, high carbohydrate content bio fuel as well as balanced amounts of reactive components and activated cultures of bacteria. During the process of maturation, microbiological oxidation of the mixture occurs, which leads to the conversion of microbes consisting in the cracking of their biochemical structure with the generation of biologically neutral decomposition elements.

The experiment were first done randomly to enable us get the possible design parameters. Table 3.2 shows the results characteristic of the experiments conducted toward identifying the optimum level setting for the manufacturing parameters within the experimental region.

Table 2.4 Biogas production testing setting parameters and their value at different level

Process parameters	Level 1	Level 2	Level 3	Level 4
Temperature	29	38	47	56
Ph value	7.0	7.3	7.6	7.9
Moisture content	45	50	55	60

Table 2.5 Composition of the mixture

S/N	Sewage(kg/l)	Kitchen waste (kg/l)
1	50	0
2	47.5	2.5
3	45	5
4	42.5	7.5
5	40	10
6	37.5	12.5
7	35	15
8	32.5	17.5
9	30	20
10	27.5	22.5
11	25	25
12	22.5	27.5
13	20	30
14	17.5	32.5
15	15	35
16	10	40

A weigh balance was used to measure the amount of gas produced, by subtracting the final mass of the tube after each circle by its initial mass before the experiment.

This is expressed mathematically as

$$M_i = m_2 - m_1 \quad 2.1$$

Where M_i is the methane gas produced, m_2 is the final weight of the tube and m_1 is the initial weight of the tube.

The biogas produced is measured in gram (g).

Temperature reading was taken on weekly basses, with a thermocouple placed inside the digester. The temperature of the system was measured with a well calibrated thermostat that was placed by the digester. At interval of every week a

sample of the digestate was released for us to be able to measure the Ph level as at that interval and the values recorded at the various intervals. The Ph level was measured with a digital ph meter. The moisture content samples produced for the study was determined using the formula

$$M = \frac{m_1 - m_2}{m_1} \times 100 \quad 2.2$$

Where M is the moisture content of the sample, %w.b; M_1 is the initial mass of the sample or wet mass, g; M_2 is the final mass of the sample or dry mass, g. For the purpose of determining the moisture content the weight of the sample was first measure before it was poured into the digester and after various intervals the same size was measure and weighed to ascertain the present weight of the sample, then applying formula 3.4 above to determine the moisture content at the various interval.

In this study, three parameters namely temperature, pH value and moisture content were considered in order to study biogas yield. Table 3.3 shows the testing settings and levels used in all of the trials. Table 3.4 shows the operating conditions for each test.

Table 2.6 Testing settings

Temperature	PH value	Moisture content
29	7.0	45
38	7.3	50
47	7.6	55
56	7.9	60

The results of the experiment were converted into a signal-to-noise (S/N) ratio. In general, There are different S/N ratios based on the sort of three characteristics; smaller the better, nominal the best, and larger the better (Budiyono, Aldi, Siswo, Bakti, & Iqbal 2021). For studying the maximal biogas generation with a higher percentage of methane gas, the larger the better characteristic of the S/N ratio was considered, as shown in equation 3.5 below.

The lager the better characteristic:

$$S/N = -10 \log_{10} 1/n \sum 1/y^2 \quad 3.5$$

Where n is the number of observations and y is the observed data i.e., biogas and methane percentage.

Table 2.7 Different design setting of the samples

Temperature	PH value	Moisture content
29	7.0	45
29	7.3	50
29	7.6	55
29	7.9	60
38	7.0	45
38	7.3	50
38	7.6	55
38	7.9	60
47	7.0	45
47	7.3	50
47	7.6	55
47	7.9	60
56	7.0	45
56	7.3	50
56	7.6	55
56	7.9	60

Taguchi method consists of three steps: design of experiments (DOE), signal-to-noise (S/N) ratio analysis, and optimization. In the DOE step, a set of experiments is designed to investigate the effects of various factors on the performance of the process.

Results of these experiments are used to analyze the data and predict the quality of components produced. Here, an attempt has been made to demonstrate the application of Taguchi's Method to improve the methane gas production process.

2.4. Sensitivity Test

Correlation between dependent and independent variables could be analyzed and predicted using regressions analysis (Budiyono, Aldi, Siswo, Bakti, & Iqbal 2021). In this study, the dependent variable was biogas yield (V_b), whereas the independent variables were temperature, Ph value and moisture content. By using regression model, equations was made to predict the biogas yield and shown in table 4.31 below. Regression equation will be developed and be used to determine the amount of biogas that can be produced. The developed model will also be used to predict the maximum biogas yield. Sensitivity text will be conducted between the experimental model, the regression model and the developed model. Furthermore, coefficient of performance will be carried out around all the models. The optimal test parameters of moisture content, temperature and pH value will be generated and used to perform the confirmation test. The result so obtained was compared with the initially generated result for biogas yield. Confirmation test about correlation between the parameters and biogas yield was made for the Taguchi method and regression equations at optimum and random levels. Confirmation test about correlation between the parameters and biogas yield was made for the Taguchi method, regression equations and the developed model at optimum and random levels.

3. RESULT AND DISCUSSION

The results obtained for the sixteen different mixture compositions done randomly to get the design parameters are presented in the tables below. The results obtain showed the relationship between the biogas produced with respect to the temperature at which there were produced, the Ph scale, the moisture content and number of days it took for the biogas to be produced. The results for the sixteen different sample mixes are presented below.

Table 3.1: Results for sample 1

No of days	Temperature (C)	PH value	Moisture content (%)	Biogas gas produced (g)
0	29	7.2	54	0
7	40	7.4	58	250
14	50	7.5	49	450
21	42	7.4	45	350
28	40	7.2	50	300
35	37	7.1	49	300

Table 3.2: Results for sample 2

No of days	Temperature (C)	PH value	Moisture content (%)	Biogas gas produced (g)
0	29	7.2	52	0
7	38	7.4	55	250
14	52	7.6	50	350
21	37	7.4	47	350
28	41	7.2	50	300
35	34	7.1	49	300

Table 3.3: Results for sample 3

No of days	Temperature (C)	PH value	Moisture content (%)	Biogas gas produced (g)
0	29	7.3	44	0
7	40	7.6	50	300
14	53	7.7	49	400

21	47	7.4	44	350
28	40	7.2	56	350
35	36	7.1	50	250

Table 3.4: Results for sample 4

No of days	Temperature (C)	PH value	Moisture content (%)	Biogas gas produced (g)
0	29	7.2	53	0
7	41	7.7	57	300
14	55	7.3	49	400
21	45	7.5	44	300
28	40	7.3	52	300
35	37	7.1	49	300

Table 3.5: Results for sample 5

No of days	Temperature (C)	PH value	Moisture content (%)	Biogas gas produced (g)
0	29	7.3	47	0
7	40	7.6	50	250
14	57	7.8	50	480
21	43	7.5	48	370
28	41	7.2	53	300
35	37	7.1	49	300

Table 3.6: Results for sample 6

No of days	Temperature (C)	PH value	Moisture content (%)	Biogas gas produced (g)
0	29	7.4	50	0
7	44	7.5	51	250
14	56	7.6	48	500
21	46	7.3	45	350
28	42	7.1	50	300
35	38	7.0	49	300

Table 3.7: Results for sample 7

No of days	Temperature (C)	PH value	Moisture content (%)	Biogas gas produced (g)
0	29	7.3	43	0
7	41	7.4	50	250
14	52	7.5	49	500
21	40	7.4	47	350
28	40	7.2	51	300
35	37	7.1	48	300

Table 3.8: Results for sample 8

No of days	Temperature (C)	PH value	Moisture content (%)	Biogas gas produced (g)
0	29	7.0	50	0
7	40	7.5	51	250
14	52	7.7	49	550

21	41	7.5	47	450
28	40	7.3	55	300
35	37	7.1	48	300

Table 3.9: Results for sample 9

No of days	Temperature (C)	PH value	Moisture content (%)	Biogas gas produced (g)
0	29	6.9	55	0
7	42	7.3	56	220
14	54	7.5	49	480
21	42	7.4	44	350
28	41	7.2	53	300
35	37	7.1	47	300

Table 3.10: Results for sample 10

No of days	Temperature (C)	PH value	Moisture content (%)	Biogas gas produced (g)
0	29	6.9	55	0
7	42	7.3	57	220
14	54	7.5	48	480
21	42	7.4	46	350
28	41	7.2	50	300
35	37	7.1	48	200

Table 3.11: Results for sample 11

No of days	Temperature (C)	PH value	Moisture content (%)	Biogas gas produced (g)
0	29	6.9	55	0
7	42	7.3	55	220
14	54	7.4	50	430
21	42	7.4	43	350
28	41	7.5	52	300
35	37	7.1	47	300

Table 3.12: Results for sample 12

No of days	Temperature (C)	PH value	Moisture content (%)	Biogas gas produced (g)
0	29	6.9	55	0
7	42	7.3	52	220
14	54	7.5	49	480
21	42	7.3	46	450
28	41	7.2	53	300
35	37	7.0	50	300

Table 3.13: Results for sample 13

No of days	Temperature (C)	PH value	Moisture content (%)	Biogas gas produced (g)
0	29	7.0	55	0
7	42	7.3	52	220
14	54	7.4	49	480

21	42	7.3	45	350
28	41	7.2	51	280
35	37	7.0	48	220

Table 3.14: Results for sample 14

No of days	Temperature (C)	PH value	Moisture content (%)	Biogas gas produced (g)
0	29	6.9	54	0
7	42	7.3	56	220
14	54	7.5	50	480
21	42	7.3	44	350
28	41	7.0	53	380
35	37	6.9	47	320

Table 3.15: Results for sample 15

No of days	Temperature (C)	PH value	Moisture content (%)	Biogas gas produced (g)
0	29	6.9	53	0
7	42	7.3	55	220
14	54	7.5	47	380
21	42	7.4	45	350
28	41	7.2	50	300
35	37	7.1	49	300

Table 3.16: Results for sample 16

No of days	Temperature (C)	PH value	Moisture content (%)	Biogas gas produced (g)
0	29	6.9	55	0
7	42	7.3	54	220
14	52	7.4	48	480
21	42	7.3	44	450
28	40	7.1	54	300
35	36	7.0	48	300

Table 3.17: Cumulative biogas yield

Samples	Cumulative biogas yield (g)
Sample 1	1650
Sample 2	1600
Sample 3	1550
Sample 4	1850
Sample 5	1750
Sample 6	1650
Sample 7	1850
Sample 8	1550
Sample 9	1650
Sample 10	1700
Sample 11	1600

Sample 12	1550
Sample 13	1600
Sample 14	1650
Sample 15	1600
Sample 16	1550

3.1.1. Biogas Produced

The biogas generated, experienced rise and fall during this study, which is seen in tables 1-16. The changes were in correspondent with the pattern of other parameters (moisture content, temperature, and pH value). This was because the metabolism process of methanogen bacteria in anaerobic condition produced methane gas. In the first 24 hours, the methane gas for all sample mix was measured to be zero which illustrated in day 0. It was maintained until the 7th day of which about 200g of biogas was measured in some days. .

The increment of biogas remained until it reached its peak in day 14 for samples 1-16, which ranged 300g and 450g. The biogas became decreased after thermophilic phase finished in day 21, with the concentration of 300g in average for all the samples, it gradually dropped until 35 days of the study as the bacterial activity decreased. The profile of biogas that produced in this study is coherent with the study by Elehinane, Okedere, Ayeni, & Ajewole, (2022).

3.1.2 Temperature Analysis

Another important factor that indicates the process of microbial activity and the types of bacteria that grow and develop during the composting process is the temperature of the sample. It also affects the greenhouse gas emissions. High temperature in composting process has the advantage to reduce the pathogen (Syafrudin 2019). The temperature change in this study is shown in figure 3.1- 3.16. The temperature in day 0 started in room temperature, which was about 29°C. The mesophilic bacteria grew until 7 days with the indication of the rise of temperature in the sixteen samples, which ranged between 40°C and 42°C. The temperature continued to increase in the second week and reached the peak temperature in day 14 that also caused the decrease of moisture content. In this state, the metabolism of the bacteria rapidly occurred. The thermophilic bacteria dominated this phase because the temperature reached 57°C for sample 5 being the highest temperature achieved at this stage and 38°C for sample 1 being the lowest temperature achieved at this stage. After the thermophilic phase occurred, the temperature dropped until it entered mesophilic phase in day 21, where the temperature decreased in around 40°C for all samples. The temperature still fell until it achieved the room temperature in day 35, which also indicated this study ended in the same day.

3.1.3 P.H Scale analysis

An important factor that affects the quality of compost produced beside moisture content is Ph value. The optimum condition can be achieved in Ph value around 6 – 8. Moreover, lower value in Ph leads to the inhibition of microbial development the reduction of degradation rate (Wang S P et al 2017). Meanwhile, higher Ph value that is still in optimum range will increase the length of thermophilic phase and the quality of the compost. All the digesters had Ph value of 6.9 and 7.9 in day 0. The optimum value had been achieved since the study began, which ensured that the composting process can be initiated.

The value of Ph was increasing in day 7, between with the amount of 7.3 and 7.6 for the entire digester. It gradually rose until reaching its peak in day 14 where all the Reactors had Ph value of 7.5 and above, before it started dropping for all samples.

3.1.4 Moisture content analysis

Moisture content is an important factor that determines the properties of compost. In optimal condition, which is ranged in 50 – 60%, biodegradation process will occur efficiently because the microbial activity is enhanced Figure 4.1 – 4.16 showed the fluctuations of moisture content in the anaerobic composting process during 35 days. Initial moisture content in each reactor was 43% and 53%, for all the digester which was originated from the existing moisture content of both waste of sewage sludge and kitchen waste.

The digester experienced a rise in 7 days, which reached 58% for sample A. The moisture content of the entire digester started to decrease until day 14, which was 50% to 48%. This condition indicated that the microbial activity was in condition, causing evaporation of water in the waste. After reaching its peak condition, the moisture content began to increase, indicating the metabolism activity of the microbes became slower and condensation of water occurred faster than the evaporation process. The rise of moisture content happened until the end of the study.

3.2 Optimization of result

Table 3.18 Design Summary

Taguchi	ArrayL ₁₆ (4 ³)
Factors:	3
Runs:	16

Table 3.19 3 factor 4 level

S/N	Level 1	Level 2	Level 3	Level 4
Temperature	29	38	47	56
PH Value	7.0	7.3	7.6	7.9
Moisture Content	45	50	55	60

Table 3.20 Taguchi L9 array with corresponding biogas yield

Temperature	PH	Moisture Content	Biogas Yield (g)
29	7.0	45	1450
29	7.3	50	1450
29	7.6	55	1650
29	7.9	60	1600
38	7.0	50	1600
38	7.3	45	1800
38	7.6	60	1900
38	7.9	55	1850
47	7.0	55	1900
47	7.3	60	1800
47	7.6	45	1600
47	7.9	50	1800
56	7.0	60	1400
56	7.3	55	1600
56	7.6	50	1400
56	7.9	45	1495

Total mean value of biogas yield $T_{vb} = \frac{1450 + 1450 + 1650 + 1600 + 1600 + 1800 + 1900 + 1850 + 1900 + 1800 + 1600 + 1800 + 1400 + 1600 + 1400 + 1495}{16}$

$$T_{vb} = 26295/16$$

$$T_{vb} = 1643.5 \text{g}$$

3.2.1 Analysis of signal to noise ratio

Tables 4.11 and 4.12 shows the computations for the quality characteristics (Biogas produced) with their respective signal-to-noise ratios which are targeted at reducing the variations due to uncontrollable parameters. The signal-to-noise ratios employed for the Biogas produced is THE LARGER THE BETTER. It is expressed mathematically as:

LARGER THE BETTER

$$S/N = -10 \log_{10} \frac{1}{n} \sum \frac{1}{y^2} \quad (2) \quad (4.1)$$

The evaluation of the signal-to-noise ratios and mean responses for the biogas produced is shown graphically in Figures 4.19-4.20 they indicate the factors that are statistically significant in the orthogonal array. Figure 4.19 indicates that Biogas produced under the S/N ratio of LARGER THE BETTER is best at the following settings: temperature of 38°C, PH value 7.0 and moisture content of 60 percent. The range (Delta) is the difference between the high and low response. A high delta value signifies the strength of the parameter on the response factor while a low delta value signifies the

least effect on the response factor. Therefore, Tables 4.14 and 4.15 shows that the most significant factors responsible for the biogas investigated are ranked as follows: the most significant factors are: Temperature > moisture content > PH scale. Analysis of the influence of each parameter (temperature, PH value, and moisture content) on biogas yield was performed with an “S/N response table” for V_b which is shown in Table 4.15, and then graphically it is appeared in Fig. 4.20. The optimal parameter combination for maximizing the biogas yield value in bold mode in Table 4.15. The levels and S/N ratio for the parameters resulting in the best V_b value were specified as parameter A (Level 2, S/N = 1738), parameter B (Level 1, S/N = 1633), parameter C (Level 4, S/N = 1688). That implies a maximum V_b was obtained by optimizing condition of temperature 38° (A₂), PH Value of 7.0 (B₁), and moisture content of 60% (C₄).

3.2.2 Analysis of variance (ANOVA)

Analysis of Variance (ANOVA) was conducted to examine the factors that significantly affect the response (Biogas produce). The percentage contribution, P reports the significance level. The Fisher test (F-Test) is used to determine statistically, the parameters that have significant effect on the quality characteristics. The lower the percentage value (P value), the more significant is the factor. Tables 4.19 shows the one-way ANOVA result for Biogas produce. The most significant factor for the biogas produced as depicted in Table 4.19 is the temperature. The result obtained from the ANOVA is in agreement with the analysis of the signal-to-noise ratios obtained in fig 4.15.

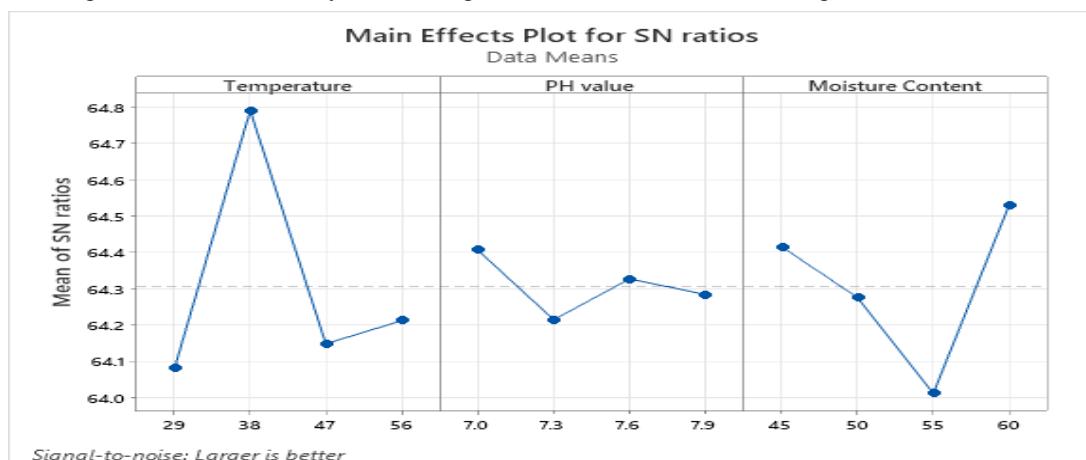


Fig 3.1: Mean effect plot for signal to noise ratio

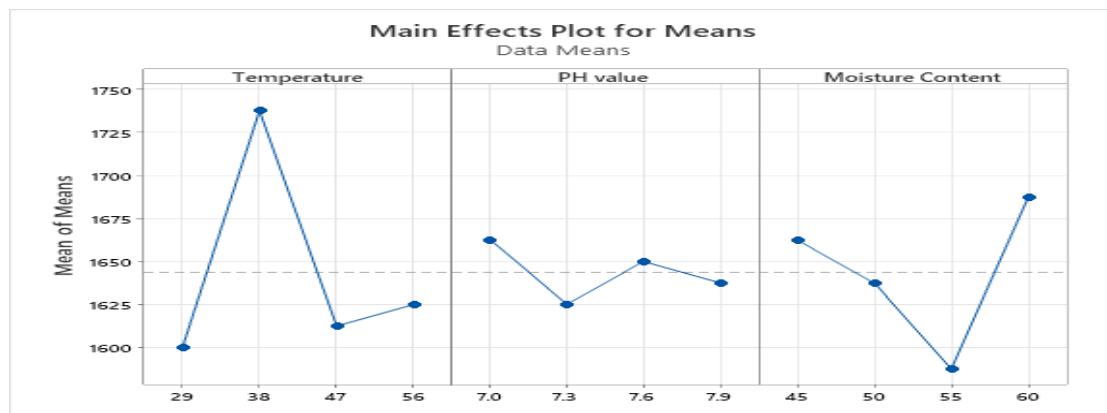


Fig 3.2: Main effect plot of the mean

Table 3.21: Response Table for Signal to noise ratios Larger is better

Level	Temperature	PH value	Moisture Content
1	64.08	64.41	64.41
2	64.79	64.21	64.27
3	64.15	64.33	64.01
4	64.21	64.28	64.53
Delta	0.71	0.19	0.52
Rank	1	3	2

Table 3.22: Response Table for Means

Level	Temperature	PH value	Moisture Content
1	1600	1663	1663
2	1738	1625	1638
3	1613	1650	1588
4	1625	1638	1688
Delta	138	38	100
Rank	1	3	2

Table 3.23 Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	1765	540	3.27	0.007	
Temperature	0.56	2.19	-0.25	0.804	1.00
PH value	16.7	65.7	-0.25	0.804	1.00
Moisture Content	0.50	3.94	0.13	0.901	1.00

Table 3.24 Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
88.1523	1.19%	0.00%	0.00%

Table 3.25 Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	1125.0	375.0	0.05	0.985
Temperature	1	500.0	500.0	0.06	0.804
PH value	1	500.0	500.0	0.06	0.804
Moisture Content	1	125.0	125.0	0.02	0.901
Error	12	93250.0	7770.8		
Total	15	94375.0			

Table 3.26: The results of the experiment with signal to noise ratio values

Temperature	PH	Moisture Content	Biogas Yield	SNRA1	MEAN1
29	7.0	45	1450	64.3497	1450
29	7.3	50	1450	64.0824	1450
29	7.6	55	1650	63.8066	1650
29	7.9	60	1600	64.0824	1600
38	7.0	50	1600	64.3497	1600
38	7.3	45	1800	64.8608	1800
38	7.6	60	1900	64.6090	1900
38	7.9	55	1850	65.3434	1850
47	7.0	55	1900	64.3497	1900
47	7.3	60	1800	63.8066	1800
47	7.6	45	1600	64.0824	1600
47	7.9	50	1800	64.3497	1800
56	7.0	60	1400	64.3497	1400
56	7.3	55	1600	64.6090	1600
56	7.6	50	1400	64.0824	1400

56

7.9

45

1495

63.8066 1495

Regression Equation

Biogas produced = $1.765 - 0.56\text{Temperature} + 16.7\text{PHvalue} + 0.50\text{ Moisture content}$.

Table 3.27 Settings

Variable	Setting
Temperature	38
PH value	7
Moisture Content	60

3.2.3 Regression model equation

Correlation between dependent and independent variables could be analyzed and predicted using regressions analysis. In this study, the dependent variable was biogas yield (V_b), whereas the independent variables were temperature, ph value and moisture content. By using linear regression models, equations were made to predict the biogas yield and shown in Eq. 4.2.

$$\text{Biogas produced} = 1.765 - 0.56\text{Temperature} + 16.7\text{PHvalue} + 0.50\text{ Moisture content} \quad (3.2)$$

V_{b1} indicates the predicted biogas yield based on the linear regression model. Fig. 4a) shows correlation between the measured and predicted V_b based on the experiment and Eq.3.2 respectively with correlation coefficient R² of 84.65%.

3.2.4 Estimation of maximum biogas yield using taguchi method

By using Taguchi method, a confirmation experiment was conducted for validating the optimization condition (Budiyono, Aldi, Siswo, Bakti,. & Iqbal 2021). The process conditions A₁, B₃, C₁ represented the optimum in the estimation of maximum biogas yield. These process conditions were used to generate biogas and 1900g biogas yield was gotten. Eq. 4.4 was used to estimate the maximum biogas yield. The value of V_{bmax} was calculated using data of A₂, B₁, C₄ shown in Table 4.20. Based on the calculations, the maximum biogas yield (V_{bmax}) from the optimum condition was estimated to become 1801.5g.

$$V_{b\max} = (A_2 - T_{Vb}) + (B_1 - T_{Vb}) + (C_4 - T_{Vb}) + T_{Vb} \quad (3.4)$$

$$V_{b\max} = (1738-1634.75)+(1663-1643.75)+(1688-1643.75)+1643.75$$

$$= 94.25 + 19.25 + 44.25 + 1643.75$$

$$= 1801.5g$$

$$V_{bA1B3C3} = (1600-1634.75)+(1650-1643.75)+(1588-1643.75)+1643.75$$

$$= -43.75 + 6.25 + (-55.75) + 1643.75$$

$$= 1550.5g$$

$$V_{bA3B3C2} = (1613-1634.75)+(1650-1643.75)+(1638-1643.75)+1643.75$$

$$= -30.75 + 6.25 + (-5) + 1643.75$$

$$= 1614.25g$$

$$V_{bA4B3C3} = (1625-1634.75)+(1650-1643.75)+(1588-1643.75)+1643.75$$

$$= -18.75 + 6.25 + 55.75 + 1643.75$$

$$= 1613g$$

3.2.5 Estimation of Maximum Biogas Yield Using Linear Regretion Model Method

Biogas produced = $1.765 - 0.56\text{Temperature} - 16.7\text{PHvalue} + 0.50\text{ Moisture content}$

The regression table shows that to create or calculate the biogas produced we calculate it as plus 1765 minus 0.56 Temperature minus 16.7 PH value plus 0.50 moisture content as shown in the regression equation above.

By using the regreational model developed for the biogas production which is

Biogas produced = $1.765 - 0.56\text{Temperature} + 16.7\text{PHvalue} + 0.50\text{ Moisture content}$, we can estimate and compare biogas yield for different factor levels to see the sensitivity of the model.

Optimum condition A₂B₁C₄

$$\text{Biogas yield}_{\max} = 1765 - 0.56(T) - 16.7(\text{PH}) + 0.50(M)$$

$$= 1765 - 0.56(38) - 16.7(7) + 0.50(60)$$

$$= 1765 - 21.28 - 116.9 + 30$$

= 1656.82g

Random condition A₁B₃C₃

Biogas yield_{max} = 1765-0.56(T) - 16.7 (PH) +0.50(M)

= 1765-056(29)-16.7(7.6) +0.50(55)

=1765-16.24-126.92+ 27.5

= 1640.34g

Random condition A₃B₃C₂

Biogas yield_{max} = 1765-0.56(T) - 16.7 (PH) +0.50(M)

= 1765-056(47)-16.7(7.3) +0.50(50)

=1765-26.32-121.91+ 25

= 1641.77g

Random condition A₄B₃C₃

Biogas yield_{max} = 1765-0.56(T) - 16.7 (PH) +0.50(M)

= 1765-056(56)-16.7(7.6s) +0.50(55)

=1765-31.36-126.92+ 27.5

= 1634.22g

Table 3.29 Predicted Biogas yield and sensitivity test results by Taguchi method, Regression equations and the Authors generated model.

levels	For Taguchi		For non linear regresion		
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Factor combination	Exp(g)	Pred(g)	Error (%)	Exp(g)	Pred(g)	Error(%)
A ₂ B ₁ C ₄ (Optimum)	1900	1801.5	5.2	1650	1656.82	0.4
A ₁ B ₃ C ₃ (Random)	1550	1550.5	0.03	1550	1640.34	5.83
A ₁ B ₃ C ₃ (Random)	1600	1614.25	0.89	1600	1641.77	2.61
A ₁ B ₃ C ₃ (Random)	1500	1613	7.53	1500	1634.22	8.95

Table 3.30 Summary of the biogas yield from the experimental data and combined factors for all the models

S/N	Experimental data yield	Taguchi data yield	Non Linear regresion data yield
1	1500	1613	1634.22
2	1550	1550.5	1640.34
3	1600	1614.25	1641.77
4	1900	1801.5	1656.82

3.3 Predictive equation

The biogas produced was predicted using the nonlinear regressive predictive equation. It is used for finding the association between the responsible parameters (Factors) and response. The regression was found by using Minitab 2020 software. The following form of the regression equation was obtained. Equation 4.2 is used for the prediction of biogas generation.

The regression equation is:

Biogas produced = 1.765 - 0.56Temperature -16.7PHvalue + 0.50 Moisture content

The value of the constant was calculated by using the Minitab 2020 software. The accuracy of calculated constants was confirmed because a high correlation coefficient (r²) of 0.091.

Table 3.31 Confirmation experimental results for mass of Biogas (g).

Moisture content (%)	Temperature (°C)	PH value	Biogas (g) by test	Biogas (g) by Taguchi	% Error
60	38	7.0	1900	1801.5	6.5

4. CONCLUSION

The design and fabrication of a biogas extracting system has been successfully carried out in this work. The biogas yield and optimization of the process parameters for different composition of human excreta and kitchen waste was also carried out. So many works done in this area of study were reviewed so as to see the possibilities of achieving the goal of this research work which gave birth to the knowledge gap of optimization of bio gas production process from sewage sludge and kitchen waste using Taguchi method of design of experiment. The said system was thus designed using relevant formula and computer aided tools (solid works). After the design of the system using solid works the system was developed. Ventilated test was carried out to ensure no leakage of air in and out of the system. The following performance characteristics using the biogas-wastes of human feces and kitchen waste were carried out which include number of days to decompose, the temperature difference, moisture content of the mixture, the PH value of the mixture on a weekly basis.

The system and its content started producing methane gas from the second day of each experimental circle though in very little quantity but then the highest methane gas produced was 1.85kg (1850g) and mostly recorded on the last day of all the experiment which is the 35th day that all the experiments terminated. The moisture content of the gas produced ranged between 42-60 percent. The temperature of the system during the experiment ranged from 35-55degree Celsius. While the PH scale of the system was between 7.0–7.9. Optimization of the process conditions of biogas gotten using Taguchi method of design of experiment was also done. From the optimization done we obtain that methane gas produced under the S/N ratio of LARGER THE BETTER is best at the following settings: temperature of 38°C, PH value 7.0 and moisture content of 60 percent. From the analysis of variance, it is clear that the three, moisture content, PH Value and temperature, have a significant effect on biogas production. In the one-way ANOVA result for methane gas produced the most significant factor for the methane gas produced as depicted in Table 3.19 is the moisture content. The result obtained from the ANOVA was in agreement with the analysis of the signal-to-noise ratios obtained.

Prediction of biogas yield was conducted through developed linear regression models which demonstrated a correlation coefficient (R²) of 0.04. Meanwhile, the Taguchi method could predict the biogas yield successfully with R² of 0.918. According to the confirmation test, The Taguchi method and regression equation resulted in error prediction below 10%. Hence, it is recommended to apply in the optimization of many parameters for various wastes. The confirmation test conducted for both the response result showed insignificant value of error between experimental and predictive models and it is in the acceptable range.

5. RECOMMENDATION

Alternative energy industry such as biogas is a fast growing one and where constant research is needed in other to maximize its efficiency especially now that Nigeria is experiencing serious crises in the energy sector. It is expedient that more energy experts be encouraged in biogas generation to serve as alternative energy source. Many other bio degradable substances can also be studied. In the light of the above, the following recommendations are relevant;

- Government should come up with a policy that will enable builder to channel their sewage system in such a way that it could go into a central reservoir so as to be used for energy generation.
- More funding should be put into research for biogas production to encourage more researchers go into research on better and easier way of generating biogas.
- More awareness should also be created on the use of biogas as an alternative source of energy

The present study has limitations related to the experimental setup because it is self-developed and in-house manufactured. Also, time constrain for experimentation for each experiment more time is required to produce biogas therefore L₁₆ set of experiments is considered.

In future work to overcome this limitation standard test rig and measuring instrument will be preferred. Also, try to conduct minimum L₃₂ experiments.

6. CONTRIBUTION TO KNOWLEDGE

Every new research tries to fill some gaps which has earlier been delineated or identified as a statement of problem or simply as problematic. This research work is no exception, after carrying out these experiments we were able to make the following contribute to knowledge

1. We got an optimum design mix and optimum design parameter for biogas gas production from a blend of human excreta and kitchen waste..
2. Generated a green energy that led to a lesser dependence on finite fossil fuel that is harmful to both human and plant.
3. The residual from the biogas production was used to produce organic fertilizer of high quality

4. The research will go a long way create employment, for many young people who will definitely venture into biogas production

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