IMPROVEMENT OF THE THERMAL EFFICIENCY OF BIOGAS PRODUCED FROM NEEM LITTER

Y. M. Ngulde and Yerima I.
Department of Biological Sciences
University of Maiduguri, Nigeria
E-mail: yunusanguldemaina@yahoo.com

ABSTRACT

Cooking gas has today become highly essential but unaffordable commodity in many homes institutions and industries in Nigeria. Efforts are being made towards sourcing for alternative cheaper and more affordable energy sources especially those that impact less pressure on our already fragile environment one of which is biogas. The constituents of cumulative biogas generated from neemlitter was determined by passing the biogas through a gas chromatography and the result revealed the percentage ratio of the elements that constitutes the composition of neemlitter biogas as methane (CH_4) – 54%, carbon dioxide (CO_2) – 38.5%, oxygen (O_2) - 0.05%, Ammonia (NH_4) – 1, Hydrogen (H_2) – 0.6%, Hydrogen sulphide (H_2S) – 0.8%, Nitrogen (N_2) – 3.35%, Water vapour, (H_2O) – 0.8% and others 0.17%. The study also subjected the cumulative biogas to refinement processes by passing the biogas through chambers of acidified potassium permanganate solution ($Kmno_4$), concentrated potassium hydroxide solution (KOH) and hygroscopic substance (CaO) with the view to find out the possible variations of the values of each elements of the biogas after the refinement processes and the results showed that there were variations which were noted as follows methane (CH_4) – 58.08% carbon dioxide (CO_2) – 30.2%, oxygen (O_2) - 0.02%, Water vapour, (H_2O) – 0.3% and others 0.25%. The unrefined and refined biogas were subjected to heating processes to determined their thermal efficiency and the result revealed that there was an increase in temperature in the heating process carried out by the refined biogas while no increase in temperature was noted by the unrefined biogas. The volume of gases utilized in the heating process also varies in both cases.

Keywords: *Cumulative Biogas, Energy and Elements ratio.*

INTRODUCTION

Energy is indispensable to socio-economic and industrial development of any nation, yet the strategic role energy and energy policy play in the economic development has not been appreciated in Nigeria (Iwu, 1993). All forms of life including that of man are dependent on energy and its level of industrial development. Energy consumption patterns in the world today shows that Nigeria and indeed African countries have the lowest. Nevertheless, Nigeria suffers from inadequate supply of usable energy due to rapidly increasing demand which is typical of a developing economy (Ayodele, 1991). Nigeria is rich in conventional energy resource which includes oil, national gas, lignite and coal. It is also well endowed with renewable energy source like wood, solar, hydropower and wind. Rather than harness these abundant energy resources, fuel wood constitute the major source of household fuel. For instance about 80% of the country's populace that dwell in the rural areas uses firewood as energy source (Baliya, 1991). The inability to harness cost effective alternative fuel for both industrial and household usage in the various parts of the country has resulted in the nationwide domestic energy crisis and a

consequent deterioration of the industrial and economic sectors (Badamose, 1991). This paper examines cumulative Biogas generated from Neemlitter as alternative to domestic energy source and how its quality/thermal efficiency can be improved for effective usage as domestic energy source. Biogas primarily composed of methane (CH_4) and carbondioxide (CO_2) with smaller amounts of hydrogen sulphide (H_2S) and ammonia (NH_3) and trace amounts of hydrogen (H_2), Nitrogen (N_2), Carbon monoxide (CO). saturated or halogenated carbonhydrates and oxygen (O_2) are occasionally present in the biogas. Usually the mixed gas is saturated with water vapour and many contain dust particles and siloxanes. For many applications the quality of biogas has to be improved, and main parameters that may require removal in an upgrading system are hydrogen sulphide (H_2S), water vapour (H_2O), carbondioxide (CO_2) and halogenated compounds (Biogas supply project 2001).

MATEREIALS AND METHODS
Experimental Procedures:- Location of study site (Maiduguri)
Maiduguri lies within latitudes $11^o48^{/--}$ $11^o55^{/}$ and longitude $13^o4^{/--}13^o14^{/.}$ The geology of the area is that of Chad Basin formation, a lake with the largest area of inland drainage in Africa. It is estimated to have an area of about 1.6million $km^{2.}$ Maiduguri is directly underlain by the Chad formation of which the exposed section is through the river cut of the Ngada complex. Maiduguri is boarded by Shehuri in the south west, custom in the east and AbbaGanaram low-cost in the south-east (Beacon Services ltd 1972).

Sources of Neemlitter:
Neemlitter, from the tree of Azadirchta indica or Neemtree represents organic wastes that is generated annually in large quantity in Northern Nigeria where it is very abundant (Keay, et al.1964).This wastes which does not have any competing demand and is a threat to environmental sanitation was collected and used as raw material for biogas generation.

Source of Anaerobic Digester
Floating fed batch type of anaerobic digester constructed with metal oil drum with a capacity of 375litres was used for this research.

Determination of Moisture Content of Neemlitter Samples
3g of Neemlitter samples was distributed evenly over the entire heating aluminium pan of the mettler LP 16 and LJ 16 moisture analyzer. The heating aluminium pan was covered completely to avoid any possible heat exchange between the uncovered heating aluminium pan thus causing samples under analysis to lose thermal energy which may result to sluggish long drying time which possibly can also lead to incomplete drying thus resulting to wrong moisture value of samples at the end of the analysis. However, the calculation mode selected on the moisture analyzer was $0 - 100\%$, in this calculation mode the moisture content of the samples was calculated/analyzed in percentages referred to as the wet weight of the samples in 100% which the equipment displayed at the end of the operation and was recorded as the value of moisture content of the Neemlitter samples in percentages (%).(Mettler infrared Dryer,s Method,1992).

Determination of Total solids (Ts) in percentage(%)

50g of Neemlitter samples were placed in heating oven for 24 hrs at $105^{o}C$. The oven was put off and the samples were retrieved after 12hrs and cooled in a dessicator and weighed. The weights obtained at $105^{o}C$ after the heating in the oven corresponds to the total solids (TS) in percentages (%)(Dioha et al,1989).

Determination of Ash content (AC) in percentages (%)

The samples of total solids obtained above were heated in muffle furnance at $540^{o}C$ for 3hrs. The weights obtained after heating and cooling in the dessicator represent the ash content (AC) in percentages (%).(Dioha et al, 1989).

Determination of volatile solids (VS) in percentage (%)

The difference in weight of the ash content and total solids gave volatile solids in percentages (VS) %.(Dioha et al, 1989).

Determination of daily pH values of anaerobic digester content

This parameter was determined by using HANNA microprocessor based bench $pH/MV/^{oC}$ meter (1999) method. The instrument i.e HANNA pH210 was calibrated by deeping the pH electrode into the standard calibration buffer solutions of pH 4.01, 6.86, 7.01, 9.18 and 10.01. Two point calibration methods were adopted for this analysis.

Determination of slurry temperature (%) under which biogas set was operated.

Mercury bulb thermometer $(0\text{-}100^{o}C)$ was used for the determination of daily slurry temperature in degrees Celsius $(^{oC})$.

Pretreatment of Neemlitter

328.2kg of the Neemlitter was weight and pretreated by soaking in 150 litres of tap water in a plastic bowl and was allowed to remain in the water for four days to undergo a partial aerobic hydrolysis.

Feeding of Anaerobic digester

328.2kg of the pretreated Neemlitter was mixed with water in a ratio 1:0.5 to form the slurry of the Neemlitter, which was fed into the anaerobic digester and 2 litres of innoculum from a previously slurry of used digester was added into the content of the digester and the whole setup was allowed to attain its fermentation period. At the end of the fermentation period, cumulative biogas was generated and the gas generation was allowed up to the end of the retention period.

Refinement Process

The cumulative biogas generated was subjected to refinement processes by passing the biogas through chambers of concentrated potassium hydroxide (KOH) solution, acidified potassium permanganate ($KMNO_4$) solution and quicklime (CaO), which tend to reduces the concentrations of carbondioxide (CO_2), hydrogen sulphide (H_2S) and water vapour (H_2O) respectively with the view to purify/refined the biogas status which will tend to improve the quality of the cumulative biogas generated.

The cumulative biogas generated under both refined and unrefined status were subjected to combustibility test with the view to find their thermal capabilities by using the cumulative biogas generated (refined and unrefined) to cook 1.2kg of raw-par boiled rice (expected to feed a family size of 4), and also taken note of the following parameters, time taken to cook (mins), degree of heating temperature (^oC) and volume of biogas utilized in cubic meters (M^3).

RESULTS

Table 1:   Proximate composition of Neemlitter before and after Anaerobic fermentation in percentages (%)

Composition	Before	After
Total solids (TS)	20	4.4
Volatile solids (VS)	13	2.2
Moisture content (MC)	20.3	0.5
Ash content (AC)	7.0	2.0

Source: Lab work 2012.

Table 2. Daily production of biogas and its Physiochemical characteristics

Time in days		pH value	Slurry tempt (^oC)	Cumulative biogas generated (M^3)
Fermentation period	Gas generation period			
1	-	6.30	38	0.00
2	-	6.35	38	0.00
3	-	6.50	37	0.00
4	-	6.57	36	0.00
5	-	6.56	40	0.00
6	-	6.50	40	0.00
7	-	6.60	41	0.00
8	-	6.70	41	0.00
9	1	6.80	38	0.1219
10	2	6.80	38	0.1219
11	3	6.80	38	0.1828
12	4	7.50	40	0.1828
13	5	7.50	40	0.1828
14	6	7.50	41	0.3657
15	7	7.30	40	0.3657
16	8	7.30	38	0.3657
17	9	7.50	39	0.3657
18	10	7.50	40	0.3657
19	11	7.50	40	0.3657
20	12	7.50	41	0.3657
21	13	7.50	42	0.3002
22	14	6.50	40	0.3002
23	15	6.30	40	0.3002
24	16	6.32	40	0.282
25	17	6.30	45	0.282
26	18	6.30	46	0.1912
27	19	6.20	42	0.1912
28	20	6.30	42	0.1585

| 29 | 21 | 6.30 | 40 | 0.082 |
| 30 | 22 | 6.30 | 40 | 0.082 |

Source: Lab work 2012

Table 3:   Analyzed Biogas Status before and after Refinement

Source of gas	Composition of gas mixture in percentage (%)	
Neemlitter	Before	After
Methane (CH_4)	54	54.07
Carbondioxde (CO_2)	38.5	30.2
Oxygen (O_2)	0.05	0.02
Ammonia (NH_3)	1	0.05
Hydrogen sulphide (H_2S)	0.8	0.01
Hydrogen (H_2)	0.6	0.5
Nitrogen (N_2)	3.35	2.05
Water vapour (H_2O)	0.5	0.3
Others	0.17	0.25

Source: Lab work 2012

Table 4:   Combustibility Test of Neemlitter biogas before and after refinement

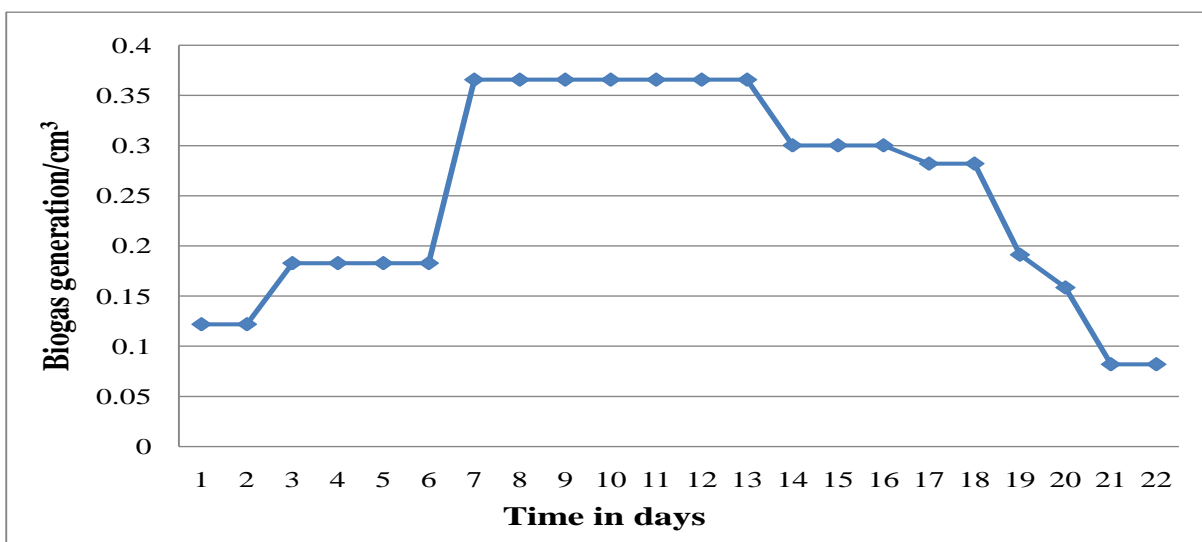| Raw food source	Parameters	Before	After
Rice par boiled	Quantity boiled (kg)	1.2	1.2
	Family size to be feed	5	5
	Volume of gas utilized (M^3)	0.7314	0.3657
	Time taken to cook (mins)	45	30
	Tempt (^oC) attained	60	95

Source: Lab work 2012

Fig.1: Changes in cumulative biogas generation over time in days
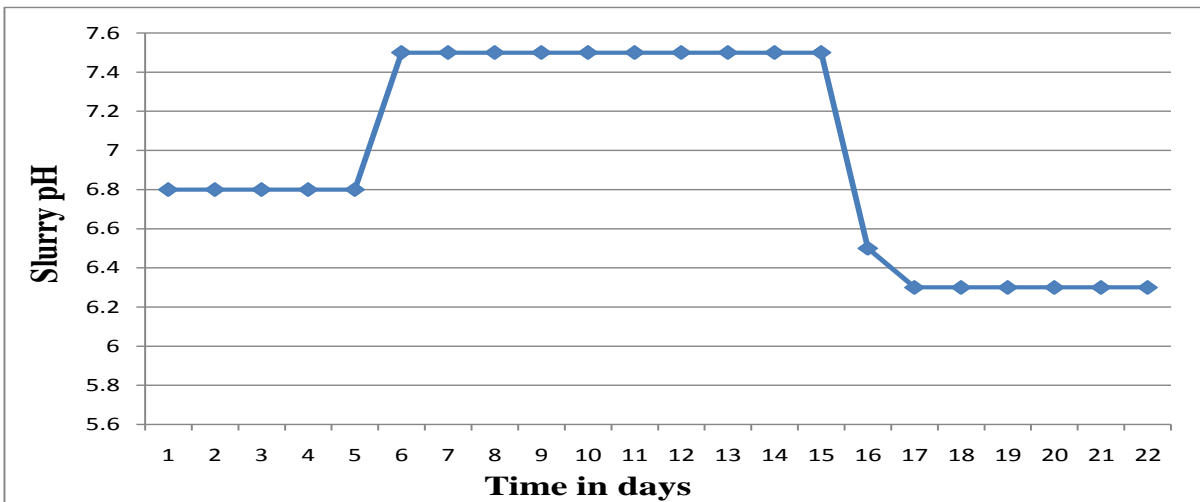
Fig.2: Changes in slurry pH over time in days
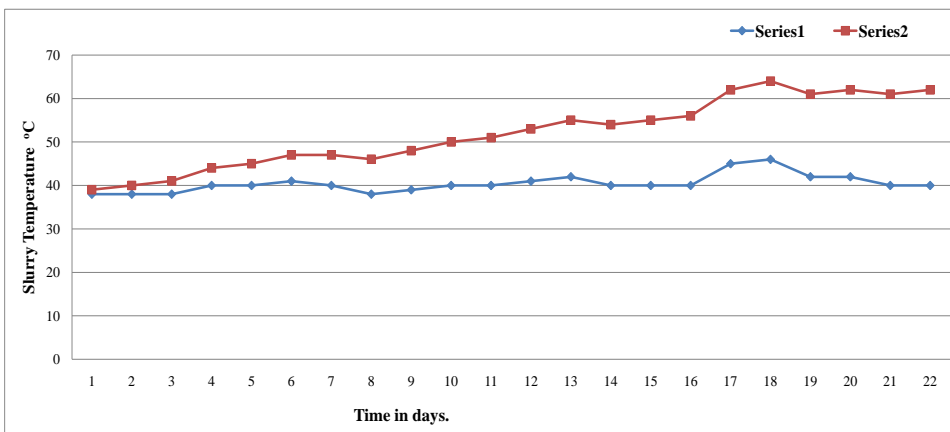

Fig. 3: Changes in slurry temperature over time in days

DISCUSSION
Proximate composition of Neemlitter

Proximate composition of Neemlitter was determined before and after anaerobic fermentation. The study shows that the percentage (%) values of total solids, volatile solids, moisture content and ash content referred to as the raw material before anaerobic fermentation were 20%, 13%, 20.3% and 7% respectively see table 1. These values disclosed the richness of inorganic content of the raw material and the richer the inorganic content of raw material the higher the chances of yielding higher volumes of gas. This finding reflects the earlier work by Meynell (1982) who said that the reduction in total solids and volatile solids content through microbial digestion is a useful preliminary index of the efficiency of the digester at reducing the organic matter within the anaerobic digester which can lead to decline in the gas production.

Changes in Total Solids and Volatile Solids during the Anaerobic Fermentation

The study noted that after anaerobic fermentation the microbial activities of the anaerobic organism reduced the organic content of the raw material and the study noted that the initial values noted earlier in the before anaerobic fermentation status changes to 4.4%, 2.2%, 0.5% and 2% respectively see table 1. This might be unconnected to the viability of anaerobes broken down the raw material within the content of the anaerobic digester from their complex to simpler forms. This stage involved complex physio-chemical and biological processes involved different factors and stages of changes (Karki, 1984).

Changes in pH during anaerobic fermentation

Immediately after charging the anaerobic digester with Neemlitter slurry, the pH of the digester was 6.30 (day one of the fermentation period), as anaerobic fermentation takes place the pH value of the Neemlitter slurry rose from 6.30 which was slightly acidic to 6.35 2nd day to 6.50, 6.57, 6.56, 6.60, 6.70 and 6.80 in the 3rd, 4th, 5th, 6th, 7th, 8th and 9th day respectively of the fermentation period see table 2, which shows that the content of the anaerobic digester remains acidic during anaerobic fermentation from the 1st to 9th day of the fermentation period. The reason for this acidic pH within the 1st to the 9th day of fermentation period which was attributed to the fact that initially, the acidogens were breaking down the inorganic matter (neemlitter) and producing volatile fatty acids. As a result, the acidity of the medium increased and the pH fell below neutrality and as fermentation continues, the acidogens were most probably displaced by the methanogens, which resulted for the breakdown of acids by the methanogens to methane i.e. biogas and the gradual rise in values from acidity to neutrality.

From table 2, it was noted that the pH of the Neemlitter slurry was acidic (6.80) on the first day of gas generation period that is after the 9th day of feeding the anaerobic digester, which means the Neemlitter took 8th days to undergo fermentation and on the 9th day gas generation began and the volume of gas generated on the 1st day of gas generation was $0.1219m^3$, the pH value noted against the first day of gas generation was 6.80 while the temperature at which gas was produced was $38^{o}C$, it was also noted that on the 4th day of gas generation the pH value increase from 6.80 to 7.50 and the study noted that the pH value of 7.50 was maintained from the 4th day up to the 13th day of gas production see fig. 2, where the volume of gas produced against these pH value of 7.50 were very substantial which fluctuates between $0.3657m^3$ to $0.3002m^3$ see fig.1 and also the study noted that temperature values also fluctuates between $39^{o}C$, $40^{o}C$ and $41^{o}C$ during these temperature period higher volume of gas generation was noted see fig. 3. The temperature values within the range of $39^{o}C$ to $41^{o}C$ tend to favour the activities of anaerobes which also in turn favours gas generation, this shows that pH and temperature simultaneously influence biogas generation.(Chittendea et al, 1980).

Furthermore, it was also noted that after the 13th day of gas generation, the pH value started falling again from 7.50 to 6.30 respectively see fig. 2 and also gas generation declined see fig. 2. The drop in pH value was an indication that the acidogens once more displaced the methanogens, which resulted to inhibiting methanogensis and this has adversely affected biogas generation, at this stage the organic content of the raw materials has also been reduced, this has conform with the research findings of Meynell (1982), disclosed that the reduction in the total solids and volatile content through

digestion of organic waste is a useful preliminary index of the efficiency of the digester at reducing the organic matter within the anaerobic digester which can lead to decline in the gas generation.

Analysis of biogas status before and after refinement

The gases that is hydrogen sulphide (H_2S) and carbondioxide (CO_2) produced along with the biogas need to be removed as it affects the quality of the biogas or its thermal efficiency (Yader and Hesse, 1996). From table 1 it could be observed from the results of the analysis that the percentage compositions of methane (CH_4), carbon dioxide (CO_2) and hydrogen sulphide (H_2S) before refinement are 54, 38.5 and 0.8 mole % dry gas respectively. These values conform to the literature values of 50-70, 30-40 and 0.1-1 mole% dry gas for methane (CH_4), carbon dioxide (CO_2) and hydrogen sulphide (H_2S) respectively (Yadav and Hesse, 1996). The gases, hydrogen sulphide (H_2S) and carbon dioxide (CO_2) produced along with the methane were removed as it affects the quality of the cooking gas. However, the study revealed that the results of gas analysis after refinement shows serious reduction in the carbon dioxide (CO_2) and hydrogen sulphide (H_2S) present in the gas produced. The percentage compositions of the product after refinement are 54.07, 0.02 and 0.01 mole % dry for methane (CH_4), carbon dioxide (CO_2) and hydrogen (H_2S) respectively. The carbon dioxide was absorbed by concentrated potassium hydroxide solution forming the soluble carbonate as shown in the below equation:

$$2KOH + CO_2 \rightarrow K_2CO_3 + H_2O \ \ldots\ldots\ldots\ldots (1)$$

Furthermore, it could be observed in the table of results that percentage composition of hydrogen sulphide is quite low, see table 3. But despite its low concentration still impact negatively to the thermal performance of the biogas. It is absorbed by the acidified potassium permanganate solution as shown in equation (2) below:

$$5H_2S + 2KMnO_4 + 3H_2SO_4 \rightarrow K_2SO_4 + 2MnSO_4 + 8H_2O + 5S\uparrow \ldots\ldots (2)$$

Having reduced the concentration of carbon dioxide and hydrogen sulphide from the gas the gas still has some proportions of moisture which also tend to impact negatively to the thermal performance of biogas and this was also reduced by passing the biogas through a third chamber of calcium oxide (CaO) quicklime and the moisture being produced along with the biogas reacts with the quicklime resulting to formation of calcium hydroxide as a hydrated compound formed and thus oxygen is given off resulting to emission of moisture into the atmosphere which tend to reduced the concentration of water vapour mixed along with the biogas as shown in the below equation:

$$2CaO + {_2}H_2O \rightarrow {_2}CaOH_2 + O_2\uparrow \ \ldots\ldots\ldots\ldots\ldots (3)$$
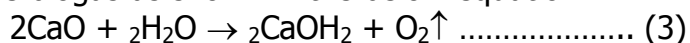
Test for Combustibility of Biogas before Refinement

The study noted that in the unrefined biogas the composition of hydrogen sulphide (H_2S) was 0.8%, carbondioxide (CO_2) was 38.5%, and water vapour, moisture (H_2O) was 0.5% respectively, the thermal performance of this unrefined gas was tested by subjecting the gas to heating processes by boiling 1.2kg of raw rice which is expected to feed a family size of five (5) and the study noted that $0.7314m^3$ of gas was utilized to boil the rice to cook and it took 45mins to cook and heating temperature attained was 60^oC see table 4.

Test for Combustibility of Biogas after Refinement

The study noted that after passing the biogas through chambers of concentrated potassium permanganate solution, potassium hydroxide solution and calcium oxide respectively, the values of hydrogen sulphide, carbon dioxide and water vapour/moisture in the unrefined biogas reduces to 0.01%, 30.2% and 0.3% mole% dry gas respectively, this was an indication that the quality of the biogas has been improved from unrefined to refined status. The gas was subjected to heating processes by boiling 1.2kg of raw rice expected to feed a family size of five (5) and the result showed that $0.3657m^3$ of biogas was utilized to boil the rice to cook and it took 30 minutes only to cook and the cooking temperature attained was 95^oC. Based on the results of the combustibility test of unrefined and refined biogas, the study revealed that there was a reduction in the amount of volume of gas utilized from $0.7314m^3$ in the unrefined gas to $0.3657m^3$ in the refined gas, which means that half the volume of gas used in the unrefined gas was utilized in the refined gas to cook a similar volume of 1.2kg of the par boiled raw rice. The study also revealed that heating temperature (^oC) drastically increased from 60^oC in the unrefined gas status to 95^oC in the refined gas status, which means an increment of temperature of 35^oC was achieved which was an indication that the quality of biogas has been improved. The study also noted that there was a variation in the cooking timings from 45 mins in the unrefined gas to 30 mins in the refined gas as cooking time for cooking 1.2kg of par boiled rice. Based on these results from table 4 , it can be deduced that the quality of biogas produced is improved by reduced the hydrogen sulphide, carbon dioxide, and water vapour content of the biogas to a considerably low concentration through refinement processes.

The study further revealed that in the unrefined biogas status, $2.2m^3$ of gas need to be utilized to be able to cook three meals a day for a family size of five. While in the refined biogas status, the study revealed that $1.1m^3$ of biogas is required to cook three meals a day for a family size of five, this slightly conforms with the research findings of Charlie Forst (2002), who disclosed that as a general rule a cubic meter (M^3) of biogas will cook three meals a day for a family size of 4 – 5.

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