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Low Cost, Energy Efficient Production of Bio-Methane from Landfill Gas

Ohwofadjeke Paul Ogheneochuko
Graduate Research Fellow, Department of Mechanical Engineering,
Niger Delta University, Nigeria

Abstract:
As the world is currently moving fast towards globalization, industrial and technological advancement; sufficient generation and utilization of energy sources have become important issues. Presently, the main energy source is fossil fuel which is non-renewable. However, Renewable energy sources (RES) supply about 14% of the total world energy demand. The aim of this research work is to generate and study the quality of gases produced from municipal solid waste. Landfill simulating vessels, with associated piping, fitting and treatment unit, were to generate the required gas samples for the study. The test rig is intended to receive, treat and convert bio-degradable non-hazardous solid waste into pure bio-methane which is a useful renewable energy resource. The objectives of this study are to;(1) To ensure maintenance of high sanitary standards for the disposal of waste in Niger Delta University and its environs;(2) To develop waste prevention scheme via recycling and conversion of waste into bio-methane;(3) To reduce cost for the disposal of waste. A total of three gas samples were simulated; one gas sample in each of the three vessels and subjected to five different treatment resulting to fifteen gas samples (5 treatment by 3 replication experiment =15 samples) which were collected using 0.5L capacity Swagelok gas bottles and stored in large plastic coolers containing iced blocks so as to retain the quality & composition of gas samples, while in transit to laboratory for analysis. The experimental gas samples were designated as samples; A_1, A_2, A_3, A_4, A_5, B_1, B_2, B_3, B_4, B_5, C_1, C_2, C_3, C_4 and C_5 respectively. Analysis of collected gas samples was carried out at Niger Delta University central Research laboratory with support from Geospectra Engineering services & consultancy laboratory, using gas chromatograph and other hi-tech equipment. Results show that; sample A1 had the highest methane content of 78.87 %. The methane contents got here are higher than those reported in some past researches. For example Polprasert (1996), reported that landfills gas is basically composed of methane (CH_4, 55 to 65%). While, Larry (2011), Reported in his research on landfills gas that he recorded Methane content of between 45 – 60%. Sample A5 had the highest amount of carbon dioxide of 10.53%. While sample C2 yielded the smallest amount of CO_2 of 3.94% out of the 15 gas samples that were used for this experiment. Sample A1 had the lowest moisture content of 0.5 ppm. Sample A1 also yielded the highest Gross heating value of 48.67 KJ/kg and Net heating value of 44.16 KJ/kg. From the findings of this research the following recommendations were made; That the renewable energy solutions got in this research should be commercialized by the Niger Delta University management, the federal government of Nigeria and agencies of government like; Petroleum Technology Development Fund, Tertiary Education Trust fund & Nigeria content Development Board.

Keywords: *Advancement, Bio-degradable, commercialized, Non-hazardous, partnership Simulating, treatment, replication, renewable, technological, chromatograph*

1. Introduction

Energy is a critical enabler and an indispensable commodity in our day-to-day living that is required for the economic growth and development of any nation which accounts largely for human existence. It is an asset and resources for mankind without which human survival will be impossible. The industrial growth of any country is determined by the availability and utilization of energy in that country (Ebotion, 1996). Energy is also an essential input to the growth and development of the various sectors of every country's economy. However, in any industry, the three top operating expenses components are often found to be energy (both electrical and thermal), labor and materials. If one were to relate to the manageability of the cost or cost savings potential in each of the above components, energy would will invariably emerge as a top ranker thus energy production and management constitutes a strategic area for cost reduction, (Cape and Kennedy, 1997).

In Nigeria for example; in spite of recent reforms, the challenges ahead are tremendous. A growing economy like ours requires massive energy for domestic and industrial uses. Recent es¬timates have shown that; to achieve the Vision 2030 goal of making Nigeria one of the twenty largest economies in the world; energy must be available and affordable to all its citizens.

As the world is currently moving fast towards globalization, industrial and technological advancement; sufficient generation and utilization of energy sources that are clean and eco-friendly has become an important issue.

However, most of these energy sources are non-renewable and are getting fast depleted. Finding fossil fuel now involves deep sea exploration, as most oil shores are already being depleted, which has resulted in geometric increase in drilling cost. Eventually, the scarcity of the raw sources has led to geometric increase in the price of fossil fuels in the market over the years. The combustion of the fossil fuels also contributes high percentage to the emission of the largest greenhouse gases like carbon dioxide into the atmosphere which is increasing global warming. Many countries are now moving towards generation and use of cleaner energy resources as an alternative energy source.

One example of green energy that could be used is landfill gas. Landfill gas is preferred over fossil fuels as it is much cheaper and environmentally friendly, Demirbaş, (2001). The sources for landfill gas production could be from readily available raw materials like cow manure, fruit and vegetable waste, food processing industries, poultry as well as municipal solid waste (MSW), Steffen et al (1998). Landfill gas emits less nitrogen oxide, hydrocarbon and carbon monoxide than gasoline or diesel, Rasi et al (2007).

The energy released, which is about ~22 MJ/kg, allows landfill gas to be used as fuel for heating purposes such as cooking or to power motor vehicles, McKendry, (2002). Landfill gas also may be made transportable via pipelines, or can compressed in gas cylinders like natural gas.

Landfill gas could also be used for electricity generation. However, before the landfill gas can be supplied for energy application, it needs to be cleaned and purified as there is the presence of undesirable entities like CO2 and H2S which can affect the calorific value, quality, quantity and also the performance of the whole system for landfill gas production. Upgrading landfill gas to near natural gas quality is a multiple step procedure. Various technologies are available in order to remove contaminants or trace elements from landfill gas being produced, leaving more methane per unit volume of gas, Ryckebosch et al., (2011).

Renewable energy are energy resources that are naturally replenished within human timescale and these include; sunlight, wind, rain, tides, waves, and geothermal heat, Tester et al (2012). Renewable energy often provides energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services, Edenhofer et al (2011). Power generation through hydroelectric energy which provides about 16.3% of the world's electricity. When hydroelectric is combined with other renewable such as wind, geothermal, solar, biomass and waste: together they constituted 21.7% of total electricity generation worldwide in year 2013.

Biogas produced from wastes in landfill can reduce the dependence on fossil fuels, beyond finding solutions that are environmentally friendly and sustainable to contribute to the energy matrix of local communities in Nigeria. The use of bio-methane, as a supplement to natural gas, is capable of bringing about substantial reductions in greenhouse gases, while creating flexibility in gas supplies across the universe. The intensification of human and industrial activities in the last few decades has generated increase in the production of municipal solid wastes (MSW), hence becoming a serious problem for the society. Consequently, the uses of large landfills in urban centers are still common, which causes sanitary problems in most states of Nigeria.

Another important area of interest of bio-methane is that it can serve as a source for renewable hydrogen. Although methane can be derived from numerous sources, environmental benefits are gained using renewable feedstock in its production from such waste dumps sites. Continuous improvement of renewable energy and technological diversification of energy sources would result in significant energy security and economic benefits. It would also reduce environmental pollution such as air pollution caused by burning of fossil fuels and improve public health, reduce premature death due to pollution and save associated health costs that amounts to several billion of naira annually in Nigeria.

Renewable energy production from biomass and subsequent purification into more useful products such as bio-methane is currently a very costly and capital intensive process, which is often due to the dispersed nature of biogas sources and economies of scale. The quest to provide solution to these problems highlighted necessitated this research.

1.1. Objectives of the Study

The main objective of this research is to produce and upgrade Low cost, energy efficient bio-methane from landfill gas. The specific objectives are;

To investigate optimal condition for the production and treatment of landfill gas to yield pure Bio-methane from Niger Delta University solid waste dump site.

To undertake gas quality test of bio-methane produced in step (i) above, in order to establish its following composition; methane content, heating value, specific gravity, hydrocarbons, water vapor, hydrogen sulfide, carbon dioxide, nitrogen, oxygen and other trace constituents of the experiment gas samples.

2. Research Materials

The materials, equipment/tools used for this research work include:

- Scale
- Head pan
- Spade
- Digital gas flow meter
- Pressure gauge
- Landfill gas treatment unit
- Landfill gas simulating unit containing three vessels
- Sets of mechanical hand tools

- Wheelbarrow
- Temperature gauge
- Hand trowel
- Spanners of different sizes and configurations
- Pipe fittings
- Table vice
- Microsoft Excel & Microsoft Visio
- Micros-filters

3. Research Methods

Fundamentally, waste management in Landfill system is that of sustainability which is intended to meet the needs of the present generation without compromising the chances of future generations meeting their own needs. For the purpose of this research; three metallic Landfill simulating vessels were used to produce the required gas samples for the study. The test rig is intended to receive, treat and convert bio-degradable non-hazardous solid waste into pure bio-methane which is a useful renewable energy resource.

This research work was carried out using a six step methodology as follows;

- Step 1: the experimental set up consist of three vessels tagged "A" "B" and "C" respectively as shown in fig.1. Each vessel was made to create conditions needed to produce landfill gas samples which are required for this research work. The vessels were fitted with thermometer and pressure gages to continuously measure & monitor the process variables of the system. The charging and discharging hopper-flanges of each of the vessels was fitted with gaskets and appropriate mechanical fasteners to ensure complete air and gas tightness of the system.

Figure 1: Experimental Set Up

- Step 2: 4450kg of Municipal solid waste was collected from refuse dump site used by Niger Delta University waste disposal contractor. The initial mass of the solid waste collected was recorded before sorting them out into their respective category as presented in tab.1. 600 kg was then collected from the bio-degradable components of the sorted waste, comprising; food/Kitchen waste + Plant wastes + animal wastes, thoroughly commingled and buried in a dug pit and then covered up for 7 days to allow large concentration of methanognic bacterial attack on the waste, after which the waste were brought out of the pit. The partially decomposed bio-degradable waste materials were properly mixed together to achieve homogeneity and divided into three equal parts of 200kg for the vessels shown in fig.1.

Figure 2: Dump Site from Where Experimental Waste Was Collected

Type/Component	Weight (kg)	% by Mass
food/Kitchen waste	1700	38.202
paper	40	0.899
Rubber & plastics	400	8.989
Textiles	300	6.741
Leather (used bags +shoes)	68	1.528
wood	150	3.37
Metals	127	2.854
Glass	100	2.247
Tin cans	350	7.865
Plant wastes	700	15.73
Animal Wastes	515	11.573
Total	4450	100

Table 1: Amassoma Solid Waste Characteristics Data

- Step 3:Vessel “A” was charged with 200Kg of partially decomposed bio-degradable landfill waste mixed with, 20 kg of yam peelings + 20kg of plantain peelings + 20kg of cow dung as additive. All the components were properly mixed using spade to turn the materials so as to ensure homogeneity of materials inside the vessel.

Vessel “B” was charged with 200 Kg of partially decomposed bio-degradable landfill waste mixed with 20kg of yam peelings + 20kg of plantain peelings + 20kg of poultry droppings as additive. All the components were properly mixed using spade to turn the materials so as to ensure homogeneity of materials inside the vessel.

Vessel “C” was charged with 200Kg of partially decomposed bio-degradable landfill waste mixed with 20 kg of yam peelings + 20kg of plantain peelings + 20kg of piggery faecal discharge as additive. All the components were properly mixed using spade to turn the materials so as to ensure homogeneity of materials inside the vessel.

- Step 4: After feeding mixed landfill materials into each vessel as stated in step 3 above, the three vessels were closed and allowed for a period of about 90 days to allow anaerobic decomposition of materials into landfill gas. The process temperature and pressure were taken and recorded three times daily (at 6:00am, 12:00 Noon and 6:00pm).
- Step 5: The generated landfill gas was passed through the treatment/purification unit of the test rig (landfill gas processing equipment) that was used for this research as shown in fig.1. The treatment unit has five trains which are designated as trains; 1,2 3,4 & 5 respectively. Each of the five trains treats the gas differently from others. See fig. 3. for details of the treatment unit.

Train 1: the landfill gas from each of the vessels was passed through train 1 which had a combined filters system of; Synthetic filter + Metallic filter + bio-filter, one at a time by opening valve BV7 and closing every other valve on the treatment unit. Here drying of the gas samples was done as follows; The first three gas samples from vessel “A”, “B” & “C” individually was passed through the drying compartment which contained calcium oxide + silica gel to remove moisture and then collected via LGDV1 valve into gas bottles designated as; sample A1, B1 & C1 using ¼ fitting + turbing connection into 0.5L capacity Swagelok gas sampling bottle. The samples were stored in large plastic coolers that were filled with iced block in order to preserve the integrity of gas samples while in transit to laboratory for analysis.

Train 2: the landfill gas from each of the vessels was passed through train 2 which had only synthetic filter system, one at a time by opening valve BV8 and closing every other valve on the treatment unit. Drying of the gas samples was done as follows; The second gas samples from vessel “A”, “B” & “C” individually was passed through drying compartment which contained calcium oxide + silica gel to remove moisture and then collected via LGDV2 valve into gas bottles designated as; sample A2, B2 & C3 using ¼ fitting + turbing connection into 0.5L capacity Swagelok gas sampling bottle. The samples were stored in large plastic cooler that was filled with iced block in order to preserve the integrity of gas samples while in transit to laboratory for analysis.

Train 3: the landfill gas from each of the vessels was passed through train 3 which had only metalic filter system, one at a time by opening valve BV9 and closing every other valve on the treatment unit. Here drying of the gas samples was done as follows; The third gas samples from vessels “A”, “B” & “C” individually was passed through the drying compartment which contained calcium oxide + silica gel to remove moisture and then collected via LGDV3 valve into gas bottles designated as; sample A3, B3 & C3 using ¼ fitting + turbing connection into 0.5L capacity Swagelok gas sampling bottle. The samples were stored in large plastic coolers that were filled with iced block in order to preserve the integrity of gas samples while in transit to laboratory for analysis.

Train 4: the landfill gas from each of the vessels was passed through train 4 which had only Bio-filter filter system, one at a time by opening valve BV10 and closing every other valve on the treatment unit. Here; drying of the gas samples was done as follows; The fourth gas samples from vessel “A”, “B” & “C” individually was passed through the drying compartment which contained calcium oxide + silica gel to remove moisture and then collected via LGDV4 valve into gas bottles designated as; sample A4, B4 & C4 using ¼ fitting + turbing connection into 0.5L capacity Swagelok gas sampling bottle. The samples were stored in large plastic coolers that were filled with iced block in order to preserve the integrity of gas samples while in transit to laboratory for analysis.

Train 5: the last landfill gas from each of the vessels was passed through train 5 of the treatment which had no filter (zero treatment), no drying compartment one gas sample at a time by opening valve BV11 and closing every other valve on the treatment unit. The gas samples were then collected via LGDV5 into gas Swagelok gas sample bottles. These samples were designated as; A5, B5 & C5 respectively and each can be referred to as base samples for three vessels.

Volumes of landfill gas generated in each vessel were measured separately using clamp on gas flow meter as shown in tab.2. A total of 15 gas samples were collected from gas collection valves (LGDVs 1-5); 3 material base samples and 5 process base samples using gas bottles which were stored under prescribed condition. Experimental gas samples were collected and sent to laboratory for analysis on the 10th day of December 2019. The samples are designated as; A1,A2,A3,A4,A5,B1,B2,B3,B4,B5,C1,C2,C3,C4 and C5 respectively.

Step 6: The 15 gas samples collected in Step 5 above were analyzed at Niger Delta University Central Research Equipment laboratory using gas chromatograph and other state of the art analytical equipment to determine components and quality of the sampled gases. The analysis results were interpreted and applied to make research decisions. Analysis results of experimental gas samples are given in tables 3, 4 and 5 respectively.

KEY:
LGDV→ Landfill gas dispensing valve
BV → Ball valve
See fig.3 for details of valve label/numbers

4. Data Collection and Analysis

The primary data for this study were obtained from direct measurement of relevant parameters and laboratory analysis results of experimental gas samples.

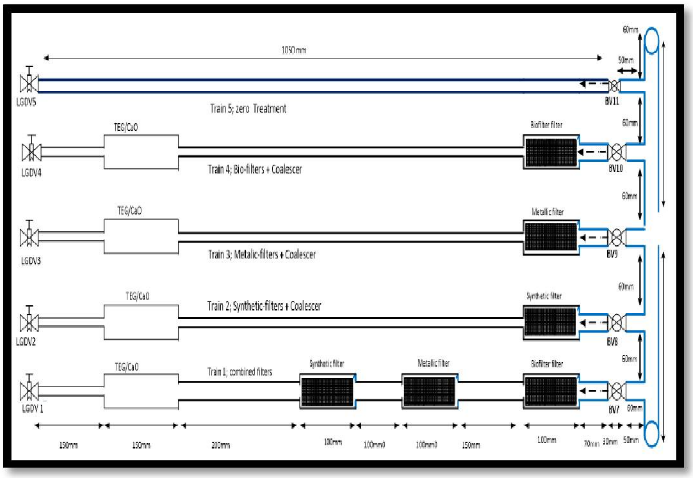

Figure 3: Treatment Unit of the Test Rig

5. Results

Vessel	Volume of Landfill Gas Measured In Litres
A	15
B	22
C	19

Table 2: Volume of Landfill Gas Simulated in Each Vessel

Gas Sample ID	A1 (%)	A2 (%)	A3 (%)	A4 (%)	A5 (%)
Nitrogen	0.166	0.20	0.23	0.27	3.00
Oxygen	0.01	0.03	0.03	0.04	0.04
Hydrogen Sulphide	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	4.51	7.22	8.50	9.71	10.53
Methane	78.87	71.28	64.10	55.78	52.92
Ethane	6.73	8.76	12.38	14.14	15.33
Ethylene	0.00	0.00	0.00	0.00	0.00
Propane	5.76	7.49	8.82	12.91	7.00
i-Butane	1.20	1.58	1.86	2.84	3.08
n-Butane	1.53	2.00	2.36	2.60	2.82
i-Pentane	0.53	0.56	0.66	0.60	2.44
n-Pentane	0.40	0.52	0.61	0.65	2.35
Hexane	0.22	0.27	0.32	0.33	0.37
Heptane	0.04	0.06	0.07	0.07	0.08
Octane	0.02	0.03	0.04	0.05	0.08
Nonane	0.00	0.00	0.00	0.00	0.00

Gas Sample ID	A1 (%)	A2 (%)	A3 (%)	A4 (%)	A5 (%)
Decane	0.00	0.00	0.00	0.00	0.00
Total Composition	100	100	100	100	100
Molecular Weight (kg/mol)	21.54	23.53	25.15	27.4	28.16
Specific Gravity	0.74	0.81	0.87	0.95	0.97
Gross Heating Value (kJ/kg)	48.67	45.99	44.93	4414	42.16
Net Heating Value (kJ/kg)	44.16	41.80	40.90	40.27	38.48
Moisture Content (ppm)	0.50	0.90	1.00	25.00	43.00

Table 3: Quality Compositions of Samples; A1, A2, A3, A4 & A5

Gas Sample ID	B1 (%)	B2 (%)	B3 (%)	B4 (%)	B5 (%)
Nitrogen	0.26	0.86	1.54	1.68	1.61
Oxygen	0.00	0.00	0.00	0.00	0.00
Hydrogen Sulphide	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	7.18	6.24	6.81	8.44	8.08
Methane	67.06	59.96	49.62	46.12	44.12
Ethane	10.18	12.72	18.04	17.20	17.28
Ethylene	0.13	0.08	0.09	0.08	0.08
Propane	9.91	12.78	13.95	14.73	15.79
i-Butane	1.65	1.65	1.80	2.59	3.38
n-Butane	2.05	2.04	2.23	3.64	4.40
i-Pentane	0.57	1.35	2.06	1.92	1.83
n-Pentane	0.53	1.76	2.94	2.74	2.61
Gas Sample ID	B1 (%)	B2 (%)	B3 (%)	B4 (%)	B5 (%)
Hexane	0.34	0.4	0.75	0.69	0.66
Heptane	0.09	0.09	0.09	0.09	0.09
Octane	0.09	0.09	0.09	0.09	0.09
Nonane	0.01	0.02	0.02	0.02	0.01
Decane	0.00	0.00	0.00	0.00	0.00
Total Composition	100	100	100	100	100
Molecular Weight (kg/mol)	24.53	26.95	23.48	30.1	30.85
Specific Gravity	0.85	0.93	0.81	1.00	1.10
Gross Heating Value (kJ/kg)	46.06	46.67	44.88	44.68	45.04
Net Heating Value (kJ/kg)	41.92	42.56	40.93	40.85	41.21
Moisture Content(ppm)	0.6	0.8	22.5	40.00	45.20

Table 4: Quality Compositions of Samples; B1, B2, B3, B4 & B5

Gas Sample ID	C1 (%)	C2 (%)	C3 (%)	C4 (%)	C5 (%)
Nitrogen	0.19	3.58	3.50	3.48	3.40
Oxygen	0.03	0.04	0.04	0.04	0.04
Hydrogen Sulphide	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	7.23	3.94	5.99	5.82	5.69
Methane	71.28	56.98	52.12	46.07	43.42
Ethane	8.76	14.44	16.44	16.90	17.39
Ethylene	0.00	0.01	0.01	0.01	0.01
Propane	7.48	8.88	9.66	12.19	14.89
i-Butane	1.58	1.81	2.83	3.80	3.75
n-Butane	2.00	2.59	1.85	2.50	2.45
i-Pentane	0.56	3.03	2.99	4.25	4.15
n-Pentane	0.52	3.55	3.46	3.89	3.81
Hexane	0.27	0.47	0.46	0.43	0.42
Heptane	0.06	0.12	0.13	0.12	0.11
Octane	0.06	0.12	0.12	0.11	0.11
Nonane	0.00	0.11	0.10	0.10	0.09
Decane	0.00	0.00	0.00	0.00	0.00
Total Composition	100	100	100	100	100
Molecular Weight (kg/mol)	27.18	26.66	28.29	30.39	31.03
Specific Gravity	0.94	0.92	0.98	1.00	1.10
Gross Heating Value (kJ/kg)	47.03	47.62	45.48	45.74	45.91
Net Heating Value (kJ/kg)	42.93	43.46	41.54	41.84	42.02
Moisture Content (ppm)	1.00	2.50	3.00	23.50	35.00

Table 5: Quality Compositions of Samples; C1, C2, C3, C4 & C5

6. Discussion of Results

6.1. Methane Content Graph of Experimental Gas Samples

The methane contents of experimental gas samples given in tables 3, 4 & 5 and fig.4. in all 15 gas samples; A1 had the highest methane content of 78.87 %, while sample C5 had the lowest methane content of 43.43%. Methane content of samples decreased across the five trains from 1 to 5 as can be seen in fig.4. For A-series samples; A1 yielded bio-methane of 78.87 % which is more than that of other the four members of the group with designations A2, A3, A4 & A5. For B-series samples; B1 yielded 67.064% of bio-methane which is more than other four members of the group with designations B2, B3, B4 & B5. Similarly, in the C-series; sample C1 yielded 71.279 % bio-methane content which is highest in the group. The high methane contents of samples A1, B1 and C1 might be due to the fact that each of these samples was subjected to multi-stage filter treatment using; bio-filter, metallic filter, synthetic filter and two stage drying process using silica gel & calcium oxide as can be seen in train 1 of fig. 3. From observations during this research, further cleaning and drying of these gas samples could yield more bio-methane. Hence, train 1 of the experimental rig can be developed further; to increase its size and commercialized to produce large scale bio-methane for gas turbines used in power generation in Nigeria rural communities. Bio-methane is an emerging source of combined heat and power (CHP) in our modern day world. An Excerpt of chromatograms of these experimental samples are given in fig.8.

The methane contents got are higher than those reported by past resaerchers. For example; Polprasert (1996), reported that; landfills gas is basically composed of methane (CH_4, 55 to 65%). While, Larry (2011), reported in his research on landfills gas that he recorded Methane content of between 45–60%. This is an indication that the treatment process applied in this research yield a good result which is an improvement.

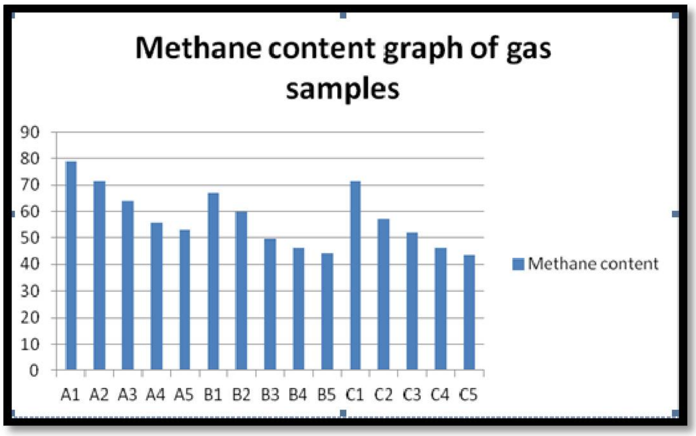

Figure 4: Methane Content Graph of Experimental Gas Samples

6.2. Carbon Dioxide Content of Experimental Gas Samples

Fig.5. shows the carbon dioxide (CO_2) contents of experimental gas samples. Sample A5 had the highest amount of carbon dioxide of 10.53%. while sample C2 yielded the smallest amount of CO_2 of 3.94 % out of the 15 gas samples that were used for this experiment. However, for the A-series gas samples, the CO_2 contents increased across the trains from A1 through A5. But for the B-series and C-series gas samples the CO_2 contents did not increase or decrease in any definite order. Carbon dioxide being a greenhouse gas that impacts our environment negatively should always be a factor of consideration in deciding the choice of gas to be used as fuel or other purposes. To this end those experimental gas samples with very high CO_2 contents like in the case of samples A4 and A5 might require further treatment to eliminate or reduce their CO_2 contents to as low as possible in order to protect man and his environment from the harmful effects of global warming due greenhouse gases. Use of fuel with low CO_2 contents is part of the vision of sustainable development which enables mankind to provide for his immediate needs using natural resources without compromising the chances of future generation meeting their own need.

The carbon dioxide gotten in the samples used for this experiment are far lower than those reported by earlier researches. Polprasert (1996), reported; carbon dioxide (CO_2, 35 to 45%) in his analysis of landfill gas sample. Larry (2011). Reported in his research on landfills gas that he recorded Methane content of between 45 – 60%.
From the foregoing, the contents got from this experiment are low when compared to those recorded by past researchers on landfill gas.

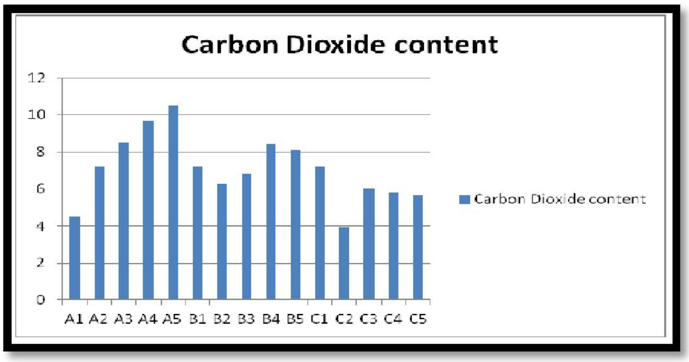

Figure 5: Carbon Dioxide Content Graph of Experimental Gas Samples

6.3. Gross Heating Value and Net Heating Value of Experimental Gas Samples

Calorific value represents the amount of heat or energy in a given volume of gas when combusted. Gross calorific value (GCV) is the amount of heat released by the complete combustion of a unit of natural gas. It is also known as Higher Heating Value (HCV).While, Net Calorific Value (NCV) also known as lower heating value (LHV) or lower calorific value (LCV) is determined by subtracting the heat of vaporization of water vapor from the higher heating value of substance.

The heating value of gas is a major determining factor of consideration in fixing its selling price in both local and international market. Fig.6. and tables 3, 4 & 5 show that out of the 15 experimental gas samples; sample A1 has the highest GHV of 48.67 KJ/kg and NHV of 44.16 KJ/kg. It could be recalled that sample A1 also had the highest methane content of 78.87%. Hence, one could infer that there is a strong relationship between GHV, NHV and methane contents of experimental gas sample.

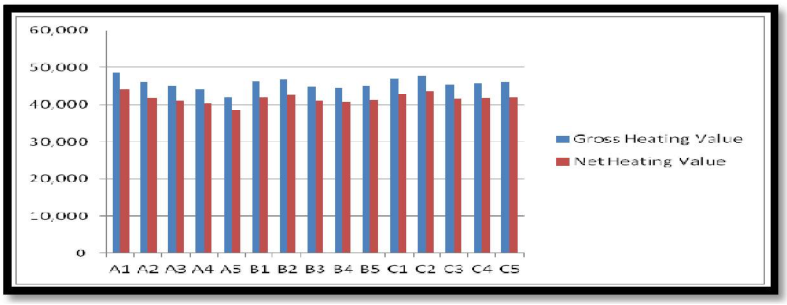

Figure 6: Gross Heating Value and Net Heating Value Graph of Experimental Gas Samples

Fig.7. shows moisture contents of all 15 Experimental gas samples using a histogram. Samples; A1, A2, B1 & B2 had low moisture contents of less than 1.00ppm, with sample A1 having the lowest moisture content of 0.5 ppm. However, other samples like; A3, C1, C2 & C3 had moisture contents of between 1.00ppm and 3. 0ppm.While, samples; A4, A5, B3, B4, B5, C4 & C5 had high moisture contents ranging between 22.5 and 45.2 ppm. Moisture content is another very vital characteristic that determines the suitability of a given gas for specific application. The main disadvantage in using gas that has large molecule of moisture is that it causes corrosion of metallic parts of the equipment which makes such gas unfit for purpose. This is why gas engines, gas turbines and other gas powered hi-tech equipment always have efficient desiccator as part of their fuel system, which functions primarily to remove and eliminate all traces of moisture from the fuel gas supply.

Larry (2011). Reported in his research on landfills gas that he recorded Moisture content of 80 ppm, which is much higher than 45.2 ppm recorded for sample B5.

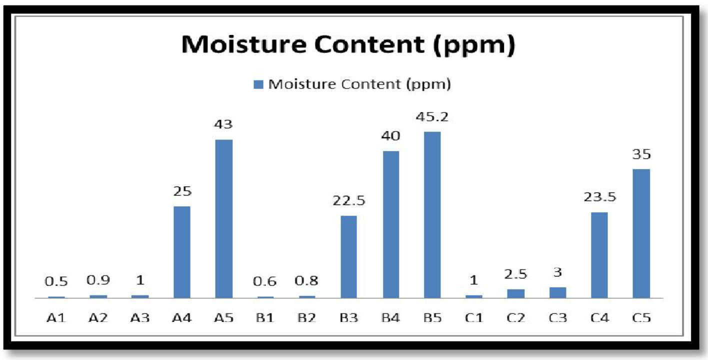

Figure 7: Moisture Content Graph of Experimental Gas Samples

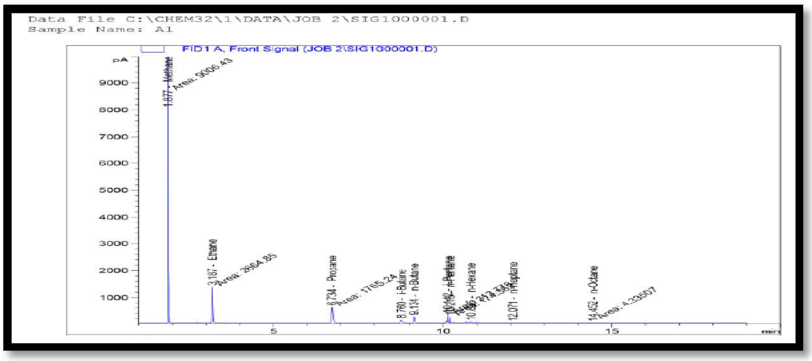

Figure 8: Chromatogram of Sample A1

7. Conclusion

That sample A1 had the highest methane content of 78.87 %, while sample C5 had the lowest methane content of 43.426%. For A-series samples; A1 yielded bio-methane of 78.87% which is more than other four members of the group with designations A2, A3, A4 & A5.

Sample A1 had the lowest ethane content of 6.73 %, while sample B3 had 18.04 % which is the highest in all 15 gas samples analyzed. For three the gas samples series; A-series, B-series and C-series, ethane contents of samples increased across the trains from 1 to 5 which is in reversed order of methane composition increase of experimental gas samples.

In A-series, sample A4 had the highest propane content of 12.91% in the group. For B-series, sample B5 had the highest propane content of 13.95% in this group. In C-series, sample C5 had the highest propane content of 14.89% in this group. Whereas sample B5 had the highest propane content out of the 15 gas samples analyzed.

Sample C2 had the highest nitrogen contents of 3.585%. Gas samples under C-series yielded much higher nitrogen contents than gas samples under A-series & B-series. Samples A1, A2, A3 and A4 yielded only a very minimal level of nitrogen in the range of 0.16 to 0.27%.

Sample A5 had the highest amount of carbon dioxide of 10.53%. while sample C2 yielded the smallest amount of CO2 of 3.94 % out of the 15 gas samples that were used for this experiment.

The results got show that; that sample A1 had the lowest molecular weight of 21.54kg/mol and specific gravity of 0.74. While, sample C5 had the highest molecular weight 31.03kg/mol and specific gravity of 1.1.

Sample A1 has the highest GHV of 48,67 KJ/kg and NHV of 44,16 KJ/kg. It could be recalled that sample A1 also had the highest methane content of 78.87%. Hence, one could infer that there is a strong relationship between GHV, NHV and methane contents of experimental gas sample.

Other components of the Experimental gas samples which were found in trace quantity include; pentane, hexane, heptane, octane and Nonane. However, Decane and Hydrogen Sulphide were not found in any of the 15 experimental samples used for the Research.

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