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Experimental Determination of Production Rate of Cottage Scale Gas Treatment Plant from Landfill Waste

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***ABSTRACT** : This technical paper presents the study of gas production using solid waste collected from Niger Delta University dump site. Combined solid waste processing equipment having a gas treatment unit was designed, fabricated and installed for experimentation. The aim of the research is to determine daily gas production rate of the equipment. The plant consists of three gas production lines designated as "A", "B" and "C", each having one vessel of equal capacity of 0.1132 m^3. The equipment is designed to receive, treat and convert bio-degradable solid waste into biogas. Each of the three vessels, A, B and C was loaded with 200 kg of well mixed bio-degradable solid waste, then20 kg of cow dungs was added to vessel A, 20kg of poultry droppings was added to vessel B and 20kg of piggery faecal discharge was added to vessel C. Result show that; line "A" has daily peak gas production rate of 0.832, line "B" had a daily peak gas production volume of 0.388 litres, while Line "C" yielded a peak daily gas production of 0.823litres. Also, a cumulative daily total gas production volume of 5.182 litres, 3.239litres and 3.793 litreswere recorded for lines "A", "B" and "C" respectively. In addition, waste-to-gas production rate of 42.4kg/litre, 68 kg/litre and 58kg/litre were recorded for lines "A", "B" and "C. The determination of daily gas production rate and cumulative gas production volumes of a cottage gas processing equipment was successfully carried-out with the conclusion that; gas production line "A" is more attractive from the standpoint of gas production volume. The adoption and setting up of small-scale gas processing plant for the purpose of waste management and gas production in our communities is therefore recommended.*

***Keyword:** Bio-degradable, waste-treatment and Waste-to-gas production.*

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I. INTRODUCTION

According to Dickerson[1], Rapid urban development facing developing countries, including Nigeria has come with serious environmental challenges resulting from increased wastes production. Solid waste arising from domestic, social and industrial activities is continuously increasing in quantity and variety as a result of growing population in most African countries and the development of technology.

All forms of human activity result in the generation of wastes which can cause changes in the environment, harm to man &animals, plants and ecosystems if not properly handled [2]. However, only a careful management can reduce the damage done by such waste to the environment and conserve its scarce resources, Solid waste management (SWM) encompasses a wide variety of activities and practices of safe handling of unwanted residues**.**

The universal focus of efficient waste management has been on innovative recycling technologies, safe disposal options and the controversies surrounding disposal site selection for landfills & waste incineration in third world communities [3]. However, cost reduction and environmental health issues are the primary concerns in waste management.

In addition to waste management needs of this research, emphasis is also on the drive to generate gas being a renewable energy from landfill solid waste materials. Meeting the ever-growing demand for energy in a safe and environmentally friendly manner is a key global challenge, in this regard; renewable energy like biogas is a promising alternative solution[4]. A growing economy like ours in Nigeria requires massive energy supply to generate electricity for domestic and industrial uses [5]. Recent estimates 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 [6].

The challenges of solid waste management in most developing and underdeveloped countries, have increased in recent times due to increase in population, industrialization, urbanization and globalization [7 and 8]. In an attempt to accelerate the pace of its industrial development, an economically developing nation may fail to pay adequate attention to waste management. Most developing countries like Nigeria spend huge amounts of financial resources on waste management which do not necessarily lead to improvements in the quality of services rendered to citizens. This trend is as a result of the continuous growth in the amount of municipal solid waste (MSW) generated, which is one of the main consequences of urban lifestyle [9].

In various online surveys conducted since 2010, most Nigerian major cities which used to be tourist centers have been ranked as dirtiest and worst livable cities of the world. Ibadan and Lagos being commercial nerves in south west Nigeria, were described as the dirtiest cities in 2010 while Onitsha and Aba in the South East also joined the list in 2015 [10]. The story is similar in almost all the major cities in Nigeria where solid wastes are littered everywhere, along the roads, in drainages, and on most undeveloped plots of land. Furthermore, problems of waste disposal continue to contaminate rivers in Nigeria and have affected residents in most cities, like Port Harcourt, (the Nigeria's oil city) which used to be a tourist destination is now ranked as the 15th most polluted cities in the world [10]. Consequently, Lagos State, through the Lagos Waste Management Authority (LAWMA), is making effort to redeem her lost glory with the initiative for transformation in waste management and other related sectors in the state.

According to a researcher [11], efficient municipal solid waste management system (MSWMS) must involve waste reduction, recovery, recycling, application of safe waste treatment methods and environmentally friendly technology for final disposal. However, another researcher [12], stated that the ultimate goal of sustainable solid waste management is the recovery of valuable products from waste with positive environmental effect and efficient energy recovery.

One of the processes of waste management is the production of gas from the waste. Maintaining optimal temperature and other process variables for anaerobic digestion process is a quintessential aspect of generating gas from solid waste[13]. This is because varying temperatures can affect the overall rate of digestion process, the hydraulic retention time and the composition of the methanogenicbacteria[13]. Some other researchers [14], reported that anaerobic digestion should be maintained at psychrophilic (12˚C - 16˚C such in landfills), or mesophilic (35˚C - 37˚C such in animal rumen), or thermophilic environment (55˚C - 60˚C such in artificially made biodigester). In thermophilic conditions, the optimal temperature for maximum biogas production from animal manure was observed to be 39˚C - 43˚C.

Anaerobic microbiological decomposition is a process in which micro-organisms derive energy and grow by metabolizing organic material in an oxygen-free environment resulting in the production of methane gas. This is also supported with a report given by Noraini et al [15]; in order to ensure the maximum biogas yield; special attention should be given to certain factors like, the nature of the substrate, temperature, pH, loading rate, retention time and alkalinity of substrate.

II. OBJECTIVE

The objective of this researchis to design & fabricate a cottage scale biogas plant and to determine its daily gas production rate.

III. MATERIALS AND EQUIPMENT

Materials, equipment and tools used for the research work include: Landfill gas cleaning unit (designed and fabricated), landfill gas production unit (designed and fabricated), measuring scale, head pan, spade, digital gas flow meter, pressure gauge, wrenches, drilling machine, grinding machine, arc welding machine and wheelbarrow. Other materials and equipment include; Temperature gauge, hand trowel, tubing, pipes fittings, table vice, Microsoft excel (2010 edition), Microsoft Visio software and micro filters**.**

IV. RESEARCH METHOD

The study was carried out using a four-phase methodology; with each phase having several steps of research activities that are clearly described as follows:

Phase 1: Leak test of fabricated equipmentwas carried out to confirm that the vessels are air-tight prior to the experiment.

Phase 2: Experimentation/Gas Production;Solid waste materials were collected from a dump site and sorted out,Each of the three vessels, A, B and C was loaded with 200 kg of well mixed biodegradable solid waste, then 20 kg of cow dungs was added to vessel A, 20kg of poultry droppings was added to vessel B and 20kg of piggery faecal discharge to vessel C. The vessels were covered to ensure air-tightness and allowed for about sixty days. Experimental set-up is shown in figure 3.

Phase 3: experimental gas sample collection and Analysis. A total of 3 gas samples designated as; "A", "B", & "C", were collected using gas bottles which were stored under prescribed condition while in transit to laboratory for analysis using gas chromatograph.

Phase 4: Data analysis and interpretation was carried out using appropriate equations stated below in section 5.0 and Microsoft excel.

V. GOVERNING EQUATIONS

The Formulae and equations used for analysis of data of this research are;

$PV = \text{constant} = nRT$ [1]

Where;
P → Absolute pressure of the gas in in Pascal
n → number of particles of Gas in mol
V → the volume of the gas in m^3
R → universal gas constant = R= 8.314 J.K¯/mol
T → Absolute temperature of the gas in kelvin

$$V = \frac{nRT}{P} \quad [2]$$

T(K) = T (°C) + 273.15 [3]

Where;
T_A = Absolute temperature in K
T= Process pressure in °C

$P_{abs} = P_g + P_{atm}$ [4]

Where;
P_{abs} → Absolute pressure
P_g → Gauge pressure
P_{atm} → Atmospheric pressure in 101.325 *kPa*

$$n = \frac{\text{Mass of gas sample}}{\text{Molar mass of Gas}} \quad 5$$

Where ;Mass of gas sample
And Molar mass for Gas Sample

VI. METHOD OF DATA ANALYSIS

The data were analyzed using the formulae stated in section 5.0 in calculation to determine the following:

i. Daily Gas Production volume and cumulative gas production volume for production line "A",
ii. Daily Gas Production volume and cumulative gas production volume for production line "B".
iii. Daily Gas Production volume and cumulative gas production volume for production line "C".

VII.DETERMINATION OF DAILY GAS PRODUCTION VOLUME FOR PRODUCTION LINE "A",

In order to determine the production volume of gas production lines "A", the mass and molar mass were calculated below;
The Mass of gas sample = 25.156 kg/kmol (determined in laboratory). While the Molar mass for gas sample A-series is determined by adding up the atomic masses of all the element that are present in the gas sample as follows;
N_2 →(14 +14) = 28 kg/mol
O_2 → (16 +16) = 32 kg/mol
CO_2 → (12 + 16 +16) = 44 kg/mol
CH_4 → (12 + 1+1+1+1+1) = 16 kg/mol
C_2H_6 → (12*2 + 1*6) = 30 kg/mol
C_3H_8 → (12*3 + 1*8) = 44 kg/mol

$HC(CH_3)_3 \rightarrow (12*4 + 10) = 58$ kg/mol
$C_4H_{10} \rightarrow (12 * 4 + 1*10) = 58$ kg/mol
$C_5H_{12} \rightarrow (12*5 + 1*12) = 72$ kg/mol
$C_5H_{12} \rightarrow (12* 5 + 1*12) = 72$ kg/mol
$C_6H_{14} \rightarrow (12*6 + 1*14) = 86$ kg/mol
$C_7H_{16} \rightarrow (12 * 7 + 1*16) = 100$ kg/mol
$C_8H_{18} \rightarrow (12* 8 + 1* 18) = 114$ kg/mol
Total = 754 kg/mol

Hence, the number of particles for Gas Sample A-series; $n = \frac{25.156}{754}$ = 0.033kg/mol, then putting all parameters into equation 2 and solving same we have; daily gas production volumes and cumulative gas production volume for gas production lines "A" which is presented in Table 1 and Figure 1 and 2.

VIII. DETERMINATION OF DAILY GAS PRODUCTION VOLUME FOR PRODUCTION LINE "B",

In order to determine the production volume of gas production line "B", the mass and molar mass were calculated below;
The Mass of gas sample = 27.182 kg/kmol (Determined in Laboratory). While the Molar mass for Gas Sample B-series is determined by adding up the atomic masses of all the element/components that are present in the gas sample as follows;
$N_2 \rightarrow (14 +14) = 28$ kg/mol
$CO_2 \rightarrow (12 + 16 +16) = 44$ kg/mol
$CH_4 \rightarrow (12 + 1+1+1+1+1) = 16$ kg/mol
$C_2H_6 \rightarrow (12*2 + 1*6) = 30$ kg/mol
$C_2H_4 \rightarrow (12*2+ 1*4) = 28$ kg/mol
$C_3H_8 \rightarrow (12*3 + 1*8) = 44$ kg/mol
$HC(CH_3)_3 \rightarrow (12*4 + 10) = 58$ kg/mol
$C_4H_{10} \rightarrow (12 * 4 + 1*10) = 58$ kg/mol
$C_5H_{12} \rightarrow (12*5 + 1*12) = 72$ kg/mol
$C_5H_{12} \rightarrow (12* 5 + 1*12) = 72$ kg/mol
$C_6H_{14} \rightarrow (12*6 + 1*14) = 86$ kg/mol
$C_7H_{16} \rightarrow (12 * 7 + 1*16) = 100$ kg/mol
$C_8H_{18} \rightarrow (12* 8 + 1* 18) = 114$ kg/mol
$C_9H_{20} \rightarrow (12*9 + 1*20) = 128$ kg/mol

Total = 878 kg/mol
Hence, the number of particles of Gas; $n = \frac{27.182}{878}$ = 0.031 kg/mol
Then putting all parameters into equation 2 and solving same we have; daily gas production volumes and cumulative gas production volume for gas production line "B" which is presented in Table 1 and Figure 1 and 2.

IX. DETERMINATION OF DAILY GAS PRODUCTION VOLUME FOR PRODUCTION LINE "C",

In order to determine the production volume of gas production line "C", the mass and molar mass were calculated below;
The Mass of gas sample C-series = 28.71 kg/kmol (Determined in Laboratory). While the Molar mass for Gas Sample C-series is determined by adding up the atomic masses of all the element/components that are present in the gas sample as follows;
$N_2 \rightarrow (14 +14) = 28$ kg/mol
$O_2 \rightarrow (16 +16) = 32$ kg/mol
$CO_2 \rightarrow (12 + 16 +16) = 44$ kg/mol
$CH_4 \rightarrow (12 + 1+1+1+1+1) = 16$ kg/mol
$C_2H_6 \rightarrow (12*2 + 1*6) = 30$ kg/mol
$C_3H_8 \rightarrow (12*3 + 1*8) = 44$ kg/mol
$HC(CH_3)_3 \rightarrow (12*4 + 10) = 58$ kg/mol
$C_4H_{10} \rightarrow (12 * 4 + 1*10) = 58$ kg/mol
$C_5H_{12} \rightarrow (12*5 + 1*12) = 72$ kg/mol
$C_5H_{12} \rightarrow (12* 5 + 1*12) = 72$ kg/mol
$C_6H_{14} \rightarrow (12*6 + 1*14) = 86$ kg/mol

$C_7H_{16} \rightarrow (12 * 7 + 1*16) = 100$ kg/mol
$C_8H_{18} \rightarrow (12* 8 + 1* 18) = 114$ kg/mol
$C_9H_{20} \rightarrow (12*9 + 1*20) = 128$ kg/mol)
Total = 882 kg/mol

Hence, the number of particles of Gas; $n = \frac{28.71}{882}$ = 0.033 kg/mol

Then putting all parameters into equations 2 and solving same we have; daily gas production volumes and cumulative gas production volume for gas production line "C" sample which is presented in Table 1 and Figure 1 and 2.

Table 1. Daily Gas Production Volumes of Gas production Lines

Day of experiment	Line "A" Daily Gas production Volume in (litres	Cumulative gas production for Line "A" (litres)	Line "B" Daily Gas production Volume in (litres	Cumulative gas production for Line "B" (litres)	Line "C" Daily Gas production Volume in (litres	Cumulative gas production forLine "C" (litres)
1	0	0	0	0	0	0
2	0	0	0	0	0.823	0.823
3	0	0	0	0	0.411	1.234
4	0	0	0.387	0.387	0.274	1.508
5	0.83	0.83	0.388	0.775	0.207	1.715
6	0.832	1.662	0.26	1.035	0.165	1.88
7	0.278	1.94	0.195	1.23	0.137	2.017
8	0.279	2.219	0.13	1.36	0.119	2.136
9	0.208	2.427	0.112	1.472	0.103	2.239
10	0.209	2.636	0.112	1.584	0.092	2.331
11	0.209	2.845	0.111	1.695	0.083	2.414

Table 1.Contd. Daily Gas Production Volumes of Gas production Lines

Day of experiment	Line "A" Daily Gas production Volume in (litres	Cumulative gas production for Line "A" (litres)	Line "B" Daily Gas production Volume in (litres	Cumulative gas production for Line "B" (litres)	Line "C" Daily Gas production Volume in (litres	Cumulative gas production forLine "C" (litres)
12	0.166	3.011	0.098	1.793	0.075	2.489
13	0.166	3.177	0.087	1.88	0.069	2.558
14	0.166	3.343	0.078	1.958	0.064	2.622
15	0.167	3.51	0.071	2.029	0.059	2.681
16	0.167	3.677	0.065	2.094	0.055	2.736
17	0.138	3.815	0.056	2.15	0.052	2.788
18	0.119	3.934	0.049	2.199	0.049	2.837
19	0.104	4.038	0.049	2.248	0.046	2.883
20	0.084	4.122	0.044	2.292	0.044	2.927
21	0.069	4.191	0.041	2.333	0.041	2.968
22	0.064	4.255	0.039	2.372	0.04	3.008
23	0.052	4.307	0.039	2.411	0.038	3.046
24	0.049	4.356	0.039	2.45	0.036	3.082
25	0.046	4.402	0.039	2.489	0.035	3.117
26	0.044	4.446	0.039	2.528	0.033	3.15
27	0.042	4.488	0.037	2.565	0.032	3.182
28	0.038	4.526	0.043	2.608	0.03	3.212
29	0.036	4.562	0.035	2.643	0.029	3.241
30	0.036	4.598	0.035	2.678	0.028	3.269
31	0.033	4.631	0.034	2.712	0.028	3.297
32	0.032	4.663	0.034	2.746	0.027	3.324
33	0.032	4.695	0.033	2.779	0.026	3.35
34	0.03	4.725	0.032	2.811	0.025	3.375
35	0.029	4.754	0.032	2.843	0.024	3.399
36	0.027	4.781	0.028	2.871	0.024	3.423
37	0.025	4.806	0.025	2.896	0.023	3.446

38	0.025	4.831	0.024	2.92	0.022	3.468
39	0.025	4.856	0.023	2.943	0.022	3.49
40	0.023	4.879	0.021	2.964	0.021	3.511
41	0.023	4.902	0.02	2.984	0.021	3.532
42	0.023	4.925	0.02	3.004	0.02	3.552
43	0.023	4.948	0.019	3.023	0.02	3.572
44	0.022	4.97	0.018	3.041	0.019	3.591
45	0.021	4.991	0.019	3.06	0.019	3.61
46	0.021	5.012	0.018	3.078	0.018	3.628
47	0.021	5.033	0.019	3.097	0.018	3.646
48	0.021	5.054	0.018	3.115	0.018	3.664
49	0.019	5.073	0.017	3.132	0.017	3.681
50	0.017	5.09	0.016	3.148	0.017	3.698
51	0.017	5.107	0.016	3.164	0.017	3.715
52	0.016	5.123	0.016	3.18	0.016	3.731
53	0.015	5.138	0.016	3.196	0.016	3.747
54	0.015	5.153	0.015	3.211	0.016	3.763
55	0.015	5.168	0.014	3.225	0.015	3.778
56	0.014	5.182	0.014	3.239	0.015	3.793
Cum.Total	-	**5.182**	-	**3.239**	-	**3.793**

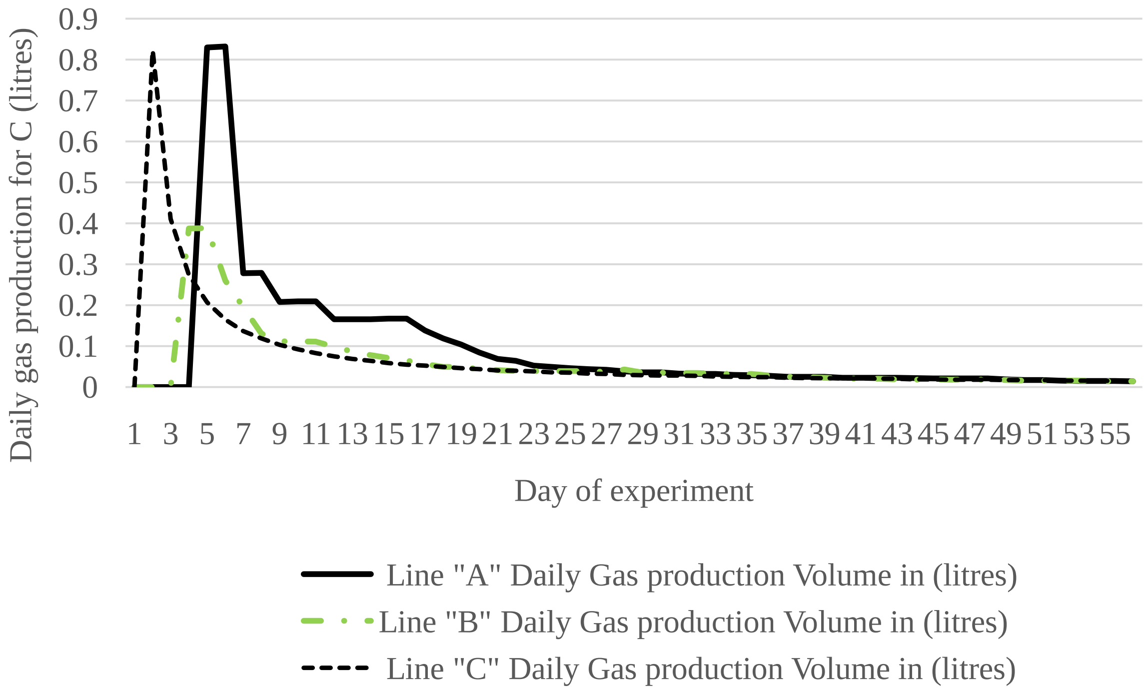

Figure 1: graph of Daily Gas Production Volumes of Gas production lines; “A”, “B” & “C”

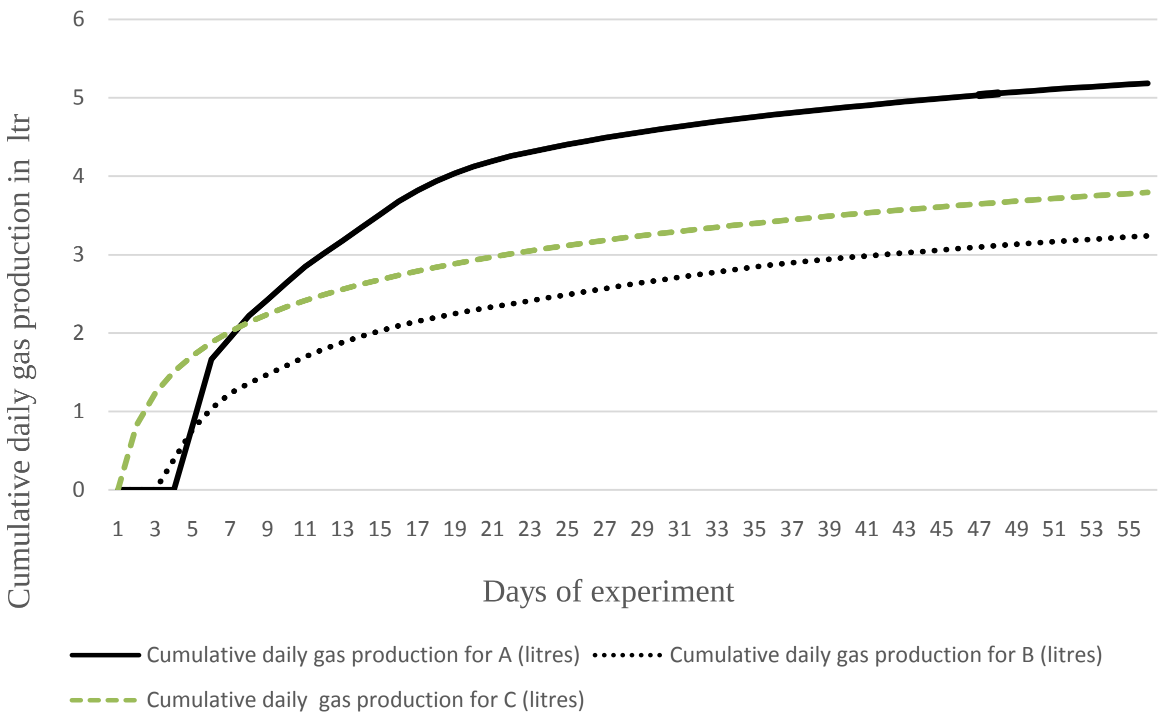

Figure 2: comparison of cumulative daily gas production Volumes

X. DISCUSSION OF RESULT

Daily gas production volumes and cumulative production volumes for production lines line “A”, “B” & “C” are presented in Table 1 and Figures 1. & 2. As it can be observed in Figure 1, gas production started at day four of the experiment for line “A”. The daily peak gas production volume of 0.832 Litre and a cumulative daily total of 5.182 litres were recorded for line “A”, which can conveniently meet the domestic gas need of a family of five members for three day.This can help reduce the living cost of low-income earners and rural residents in Nigeria. The use of gas produced with this equipment can also reduce the cutting down of forest tress for fire wood by our rural woman for cooking and other domestic heating operations. The use this equipment can also provide a safe means of recycling solid waste in line with the recommendations by [16].

It can be depicted from the slope of the graph in Figure 1 that between day 1 and day 3 of the experiment that there was no gas production for line “B”. This may be attributed to the fact that it takes some days for anaerobic decomposition of solid waste materials to commence. Gas production increased sharply from day 5 to day seven of the experiment after-which production started to decline. A daily peak gas production volume of 0.388 litres and a cumulative daily total of 3.239 litres were recorded for line “B”, which are lower than that recorded for line “A”. We can attribute this production pattern to prevailing process condition, which is supported by statement made by [17] that a certain degree of mixing is necessary to obtain a good contact between the substrate, the type of solid waste material used and the microorganisms.

Similarly, it can be depicted from the slope of the Figure 1 that line “C”gas production started from the day 1 of the experiment.A daily gas production volume of 0.823litres and a cumulative production volume of 3.793 litres were recorded for line “C”, which are lower than that recorded for line “A” but higher than that those recorded for line “B”. With this gas production rate line “C” can sufficiently provide gas for domestic needof family of four members for three days. The use of this equipment can safely convert garbages into useful energy resources thereby improving human health and quality of life for low-income earners in Nigeria. Conclusively, Waste-to-gas production rate of 42.4kg/litre, 68 kg/litre and 58kg/litre were recorded for lines “A”, “B” and “C respectively.

XI. CONCLUSION

The highest daily gas production rate of 0.832 and a cumulative daily total of 5.182 litreswas recorded for line “A”. Conclusively, daily and cumulative gas production volumes of a cottage scale landfill gas processing equipment was carried with the conclusion that; gas production line “A” is more attractive from gas production volumes observed in this research.

XII. RECOMMENDATIONS

From the findings of this research the following recommendations were made;

i. Landfill gas should be developed further and included in Nigeria energy mix.
ii. Privatization of waste management should be introduced in Nigeria as a means to solving problems posed by solid waste in our rural communities.

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Figure 3: Experimental set-up

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