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Development of Gas Processing Equipment using Locally Sourced Materials

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ABSTRACT

The aim of this research was to develop equipment for producing bio-methane from solid waste. Gas processing equipment was designed and fabricated for experimentation. The equipment had three production lines designated as A, B and C, each having a vessel of equal capacity of 0.1132m^3 and fives gas treatment trains designated as; 1, 2, 3, 4 and 5. Fifteen gas samples bearing tags; 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 were produced using the fabricated equipment. Gas samples were collected using gas sampling bottles. Samples were analyzed in the laboratory using gas chromatograph. Results showed that; gas sample A_1 which was scrubbed in a three-stage filter system and dried using calcium oxide and silica gel, had the highest methane content of 78.87 %. Waste-to-gas production rate of 42.4kg/litre, 68 kg/litre and 58kg/litre were recorded for lines “A”, “B” and “C”. The total project cost was ₦ 592,960. The adoption and setting up of Small scale bio-methane processing plant for waste management and gas production in our local communities.

Key words: chromatograph, experimentation, bio-methane, oxide and silica gel

1. INTRODUCTION

Globally every country’s economy requires access to modern energy resources to secure its development and growing prosperity. While many developed countries may focus their attention on domestic energy security and decarburizing their energy mix, several other countries are still seeking to secure enough energy to meet the basic needs of their citizens. In developing countries, access to affordable and reliable energy is fundamental to reducing poverty, improving health, increasing productivity, enhancing competitiveness and promotes economic growth, (International Energy Agency, 2001).

The survival of human beings depends largely on availability and utilization of energy. It plays a vital role in the economic, social and political development of a nation. Inadequate supply of energy restricts socio-economic activities, limits economic growth and adversely affects the quality of life of a people, (Ogbonnaya *et al*, 2012). Energy efficiency has alot benefits to both the energy user and provider. The benefits to an energy user include reducing operational costs, reduction in local air pollution and increasing competitiveness. Whereas, the benefits to an energy provider include reducing the need for investment in additional energy infrastructure, offering low cost on greenhouse gas (GHG) abatement and decreasing dependence on imported energy sources, (Hyslop, 2012).

Renewable energy resources are natural energy resources that have inherent ability for regeneration naturally within a reasonable time limit; examples include; wind, water, tides, waves, geothermal heat and solar energy which can be regenerated in a relatively short period of time; they are unlimited in quantity, (Blaine, 2009). 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 provides about 16.3% of the world’s electricity. When hydroelectric is combined with other renewable energy sources such as wind, geothermal, solar, biomass and solid waste together contributed about 21.7% of global electricity generation in year 2013.

Landfill gas is one good example of green energy source that can be used in order to prevent greenhouse gas emission and protect man’s natural environment. Landfill gas is preferred over fossil fuels as it is much cheaper and

environmentally friendly, Demirbaş, (2001). The sources for landfill gas production are readily available materials like; cow manure, fruit and vegetable waste, food processing industries wastes, poultry waste as well as municipal solid waste (MSW), Steffen et al (1998). Landfill gas emits less nitrogen oxide and hydrocarbon than gasoline or diesel fuel, Rasi *et al* (2007). The energy released, which is about 22 kJ/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 landfill gas can be compressed the same way like compressed natural gas (CNG).
Landfill gas can also be used for electricity generation. However, before landfill gas can be supplied for energy application, it needs to be cleaned and purified to get rid of entities like CO_2 and H_2S which can affect the calorific value, quality, quantity and also the performance of the whole system being powered by landfill gas. 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).
Pressure vessels used in industry are leak-tight pressure containers, usually cylindrical or spherical in shape, with different head configurations. They are usually made from carbon or stainless steel and assembled by welding.
Pressure vessels are design based on the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1: Pressure Vessels.
The ASME Code [1994] is included as a standard by the American National Standards Institute (ANSI). The American Petroleum Institute (API) has also developed codes for low-pressure storage tanks, and these are also part of the ANSI standards. The ASME Boiler and Pressure Vessel Code have been used worldwide, but many other industrialized countries have also developed boiler and pressure vessel codes. Differences in these codes sometimes cause difficulty in international trade.

2. METHODS AND MATERIAL

Materials, equipment and tools used for this 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, gas sampling bottles, Microsoft excel (2010 edition), Microsoft Visio software and micro filters**.**
The research was carried out using a Three-phase methodology; each phase having several steps of research activities as follows:
Phase 1: Engineering design, analysis and fabrication of required equipment. The engineering factors of consideration applied in designing the equipment include:

i. The equipment should be cheap to buy, operate and maintain (cost-effective).
ii. The equipment should require minimal energy consumption for its operations.
iii. The equipment should provide adequate condition for optimal conversion of solid waste into useful gas.
iv. The equipment design should provide minimum of ten years of service life.
v. The equipment should be safe and easy to operate such that an averagely educated person can use it without difficulty.
vi. Materials for construction should be corrosion resistant and durable.
vii. Materials to be used for construction should be able to retain their strength when subjected to load and withstand the designed pressure.
viii. The equipment should be environmentally friendly and should not cause pollution to the environment.

In the course of this study; an equipment consisting of gas production unit and treatment unit was designed and fabricated in compliance with American society of Mechanical Engineer (ASME) Code Sec VIII Div.1. The design aspect is divided into;

i. Design of gas production vessels and accessories.

Design of Gas cleaning/up-grading equipment (bio-methane treatment unit). Here the design methods, standards and operational systems adopted are based on best current practices which reflect progress in solid waste management and containment standards. This design process is consistent with the need to protect the Niger Delta University environment, human health and generate bio-methane gas as source of clean renewable energy.

Details of Step-by-step design process are given as follows;

a. Design Calculation of Volumetric Carrying Capacity of Gas Production Vessels

The calculation of volumetric capacity is required to determine the carrying capacity of vessels. The design of gas production vessels is in accordance with American society of Mechanical Engineer Code Sec VIII Div. 1. The physical dimensions of the vessel were taken as:

i. Diameter of vessel = 600 mm $\equiv$ 0.6 m, radius = 300 mm ≡ 0.3 m.
ii. Height h = 1200 mm ≡ 1.2 m.

Recall that: diameter = 2 x radius

$$r = \frac{\text{diameter}}{2} \quad (1.1)$$

Also, circumference $C = \pi d \equiv 2\pi r$ (1.2)

$$A = \pi r^2 \quad (1.3)$$

Volumetric carrying capacity of vessels was calculated by applying Equation 1.4

$$V = \frac{4}{3} \times \pi\, r_3 \quad (1.4)$$

Where; V = capacity of vessel in m^3,
r = radius of the shell = ½ diameter of the shell in m,

Putting values into Equation (1.4) and solving it, we have:

Volume of vessels = $\frac{4}{3} \times 3.142 \times 0.3 \times 0.3 \times 0.3$ = 0.1132 m^3

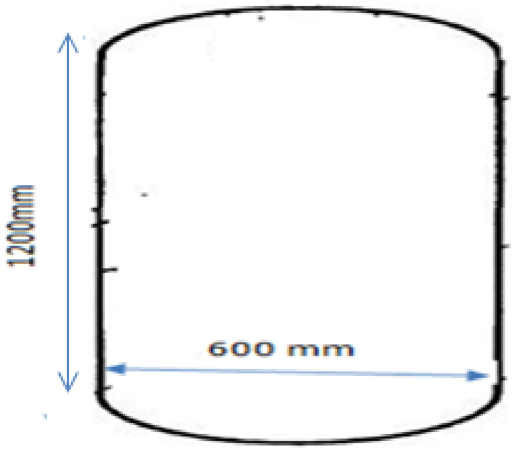

Fig. 3.1 Schematic Diagram of Vessel

b. The operating pressure P was calculated using ASME Sec VIII Div. 1 code equation for operating pressure of vessel as follows;

$$P = Pd + \left(\frac{pg_o h}{100} - 0.03Pd\right) \quad (1.5)$$

Where, P = operating pressure in kN/m^2.
ρ = Density of fluid (landfill gas in this case) 1.15 kg/m^3.
g_o = Standard acceleration due to gravity = 9.8 m/s^2.
Design Load = 100 kg of landfill waste $\equiv$ 1,470 N.
h = Vertical distance from the load point to top of the pressure vessel 700 mm $\equiv 0.7m$.
pd = Design pressure = 5 bar $\equiv$ 500 kN/m^2.
Then, putting values into inserting Equation (1.5) and solving same, we have:
Operating pressure P

$$= 500 + \left(\frac{1.15x9.8x0.7}{100} - 0.03x500\right) = 485.0789\ kN/m^2$$

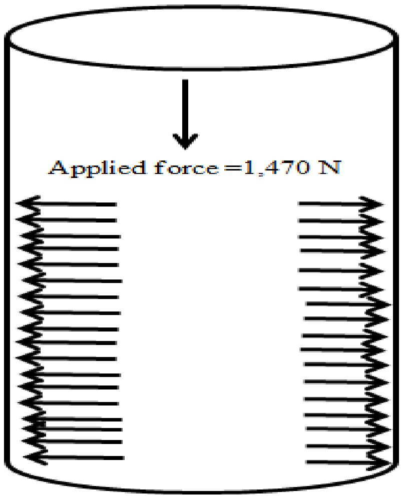

Fig. 2 Force Diagram on Vessel

c. Design of shell thickness of Vessel

Force which tends to rupture the shell along the centre was determined using Equation (1.6).

Pressure × Area = $P \times \frac{\pi}{4} \times d^2$ (1.6)

Resisting force on the shell of vessel = stress x resisting area = $\delta_t x d.t$ (1.7)

equating Equations (1.6) and (1.7), we have: $P \, x \, \frac{\pi}{4} x \, d^2 = \sigma_t x d.t$ (1.8)

Hence, $t = \frac{P.d}{4\sigma_t}$ (1.9)

t = thickness of the shell in m or mm.

δ_t = permissible tensile stress for the shell material $\equiv 6.894 \ Mpa$ (according to ASME division 1 standard for pressure vessel).

P = intensity of internal pressure = 485078.9 N/mm^2 calculated from Equation (1.5) above. Then, putting the required parameters into Equation (1.9) and solving same, we have:

$t = \frac{485078.9 x 600}{4x \, 68947572.9} = 2.055$ mm

Then, applying factor of safety of 1.5; we have effective thickness (t_e) = thickness × factor of safety.

Hence, effective thickness (t_e) of vessel = 2.055 x 1.5 = 3.0825 mm,

Use 4 mm standard steel plate.

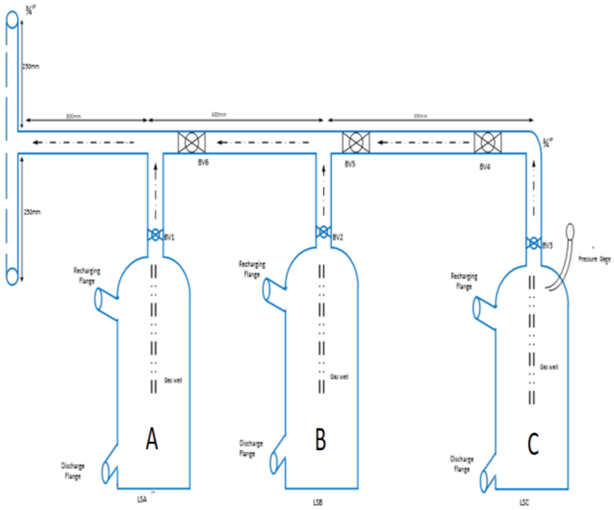

Fig. 3 Drawing of Landfill Gas Processing Equipment

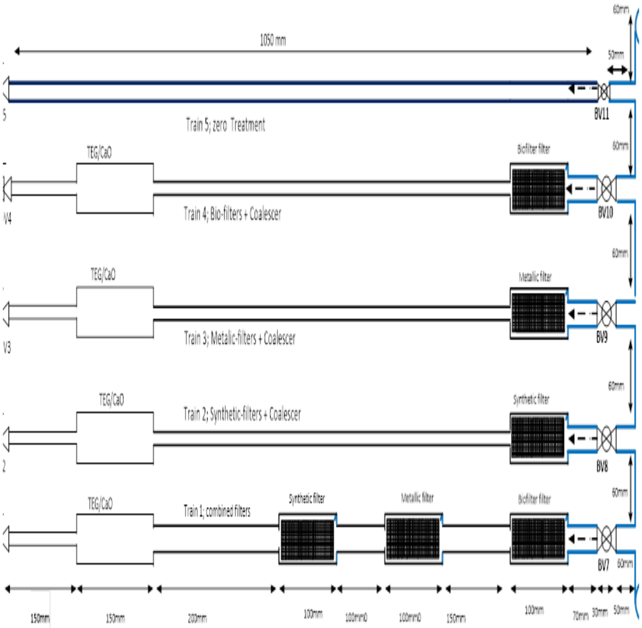

Fig. 4 Drawing of Gas Treatment Unit.

Fig. 5 Picture of Gas Processing Equipment

Phase 2: Fabrication of Equipment

This section discusses fabrication of designed equipment. The main activities here include:

i. Purchase of construction materials from mile 3 metal market in Port Harcourt. Table 1. (Engineering Bill of Measurement and Evaluation, BEME) gives full details of procured constructional materials.
ii. Marking out and cutting of construction materials as per design specifications determined earlier in chapter three of this dissertation.
iii. Joining of fabricated and purchased components.
iv. Purchase of bio-filters, metallic filters, synthetic filters and gaskets.
v. Welding and use of mechanical fasteners (bolt and nuts) were used to join construction materials/parts together.
vi. Use of multiple pipe fitting, elbow, plugs, union, socket, Tee joint, Reducer to achieve connections and simplification in maintenance.
vii. Surface finishing.
viii. Painting/Spray painting/Coating/ Metal treatment.
ix. Testing, evaluation, installation and marketing of product.

Table 1: Bill of Engineering Measurement and Evaluation

S/N	Item description	Qty	Unit price (₦)	Amount (₦)
1	4mm thick stainless-steel plate	3 full length	25,000	75,000
2	6-inch steel pipe	1 full length	20,000	20,000
3	¾ pipe galvanized steel pipe	2 full length	2,750	5,500
4	½ galvanized steel pipe	1 full length	4,200	4,200
5	3/4-inch ball valve	10 pcs	950	9,500
6	½ inch ball valve	5 pcs	750	3,750
7	Washer	200 pcs	10	2,000
8	¾ union	12 pcs	650	7,800
9	½ union	8 pcs	480	3,840
10	1½ inch pipe	1 foot	670	670
11	Bolt and nuts	96 pcs	100	9,600
12	6” Gasket	12	1,000	12,000
13	Temperature gage	3 pcs	10,000	30,000
14	Pressure gage	3 pcs	10,000	30,000
15	Electrode	3 packets	3,000	6,000
16	Hack saw blade	10 pcs	150	1,500
17	Cutting disk	**5**	500	2,500
18	Cost laboratory analysis of gas samples	15	20,000	200,000
19	Costing of folding plate into cylindrical shape	3 pcs	3,000	9,000
20	Tread tape	12 pcs	300	3,600
21	Painting of equipment	**-**	-	15,000
22	Labour cost for welders	4-man days	5000 per man day	20,000
23	Renting of gas bottles	15	1,000 per bottle for 2 days	30,000
24	Piggery waste	25 kg	20	500
25	Poultry waste	25 kg	20	500
26	Cow dugs	25 kg	20	500
27	Solid waste material	20 bags (1 ton)	250	5,000
28	Silica gel	2 kg	1,000	2,000
29	Calcium oxide	2 kg	1,500	3,000
30	Metallic filter	5 pcs	2,000	10,000
31	Bio filter	5 pcs	2,000	10,000
32	Synthetic filter	5 pcs	2,000	10,000
33	Transportation	-	-	20,000
34	Miscellaneous	-	-	30,000
	Total			**592,960**

3. RESULTS AND DISCUSSION

The design, fabrication and testing of Landfill Gas Processing Equipment cost a total of ₦ 592,960. Equipment has three gas production lines (designated as “A”, “B” & “C” and five treatment trains (designated as trains; “1”, “2”, “3”, “4” & “5” respectively) was developed using locally sourced materials. Results of testing of the developed equipment and quality analysis of the gases samples produced show the following;

i. Gas production Line “A”, yielded daily peak production volume of 0.832 litres (0.43 kg). Line “B” had daily peak production volume of 0.388 litres (0.2 kg). While gas production line “C” gave daily peak production of 0.823 litres (0.35 kg).
ii. Gas production Line “A” gave waste-to-gas production rate of 42.4 kg/litre. Line “B” had waste-to-gas production rate of 68 kg/litre. While, 58 kg/litre waste-to-gas production rate was recorded for production “C”.
iii. Sample A_1 had the highest methane content of 78.87 %. While Sample C_5 had lowest methane content of 43.43%.
iv. Sample A_1 had the highest gross heating value (GHV) of 48.67 kJ/kg and net heating value (NHV) of 44.16KJ/kg.

Sample A_1 had the lowest molecular weight of 21.54 kg/mol and the lowest specific gravity of 0.74. While, Sample C_5 had the highest molecular weight 31.03 kg/mol and specific gravity of 1.1.

4. CONCLUSIONS

Landfill gas processing equipment was designed, fabricated, tested and evaluated using locally sourced materials. In addition, quality analysis of experimental gas samples produced was successfully carried-out.

RECOMMENDATIONS

- The adoption and setting up of Small scale bio-methane processing plant for waste management and gas production in our local communities.
- The equipment developed in this research should be patented, mass produced and commercialized to make gas available for domestic use and provide income for the researcher.
- Bio-methane produced from solid waste in landfill should be developed further and added to the energy mix.

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REFERENCES

[1]. American Society of Mechanical Engineers. 1994. ASME Boiler and Pressure Vessel Code, Section VIII Division 1, Pressure Vessels. ASME, New York.
[2]. Blaine E. Z., (2009). Methods for Bibliometric Analysis of Research: Renewable Energy Case Study. A Thesis of Master of Engineering in Electrical Engineering and Computer Science at the Massachusetts Institute of Technology.
[3]. Demirbaş, A. (2001). Biomass resource facilities and biomass conversion processing for fuels and chemicals. *Energy conversion and Management*, *42*(11), 1357-1378.
[4]. Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Kadner, S., Zwickel, T. & Matschoss, P. (Eds.). (2011). *Renewable* energy sources and climate change mitigation: Special report of the intergovernmental panel on climate change. Cambridge University Press.
[5]. Hyslop P., (2012) An Energy Audit of The Canmore Nordic centre.
[6]. International Energy Agency, IEA (2001) World Energy Outlook 2011; Energy for All, Financing Access for the Poor. Special early excerpt of the World Energy Outlook 2011.
[7]. McKendry, P. (2002). Energy production from biomass (part 3): gasification technologies. Bio-resource technology, 83(1), 55-63. Processing. resources, conservation and recycling, 16(1-4), 213-226.
[8]. Ogbonnaya, E. A. Ugwu, H. U., Nwankwojike, B. N., & Ekoi, E. J. (2012). Energy and Economic losses due to constant power outages in Nigeria. Nigerian Journal of Technology, 31(2), 181-188.Policy vol 24, pg 447-453.
[9]. Steffen, R., O. Szolar, and R. Braun, (1998)."Feedstocks for anaerobic digestion." *Institute of Agrobiotechnology Tulin, University of Agricultural Sciences, Vienna* (1998).
[10]. Rasi, S., Veijanen, A., & Rintala, J. (2007). Trace compounds of biogas from different biogas production plants. *Energy*,*32*(8), 1375-1380.
[11]. Ryckebosch, E., Vervaeren, H. & Drouillon, M., (2011). Techniques for transformation of biogas to bio-methane. Bio-mass and Bioenergy, 35(5), pp. 1633–1645. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0961953411001085 [Accessed November 18, 2013].