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Design and Construction of an Energy Specific Landfill Gas Production System for use in Nigeria

Aniekan Essienubong Ikpe[a]*, Namnsowo Edet Akpan[b], Michael Okon Bassey[c]

[a] Department of Mechanical Engineering, Akwa Ibom State Polytechnic, Ikot Osurua, PMB 1200, Nigeria.
[b] Department of Electriccal/Electronics Engineering, Akwa Ibom State Polytechnic, Ikot Osurua, PMB 1200, Nigeria.
[c]Department of Mechatronics Engineering, Akwa Ibom State Polytechnic, Ikot Osurua, PMB 1200, Nigeria.
*Corresponding Author: aniekan.ikpe@eng.uniben.edu

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ABSTRACT

In this study, an engineered landfill prototype was designed and constructed as an alternative system for landfill gas production which can offset Nigeria's increasing demand for energy and dependence on fossil fuels. To design a landfill system for landfill gas production which is the primary aim of this study, Computer Aided Design (CAD) model of 1.2m depth, base area of 1.44m^2, top area of 5.06m^2, volume of 3.68m^3 (3680 litres) with side walls slope of 45^o was developed. The modelled design was practically replicated in the field, with the field construction consisting of prepared subgrade, compacted clay, geomembrane liner, geotextile mat, leachate collection system, gas extraction system, landfill cover etc. Food-based organic waste of about 1763kg was measured and deposited in the system prior to closure, and landfill gas evolved after six months of intense chemical reaction and biological degradation within the anaerobically confined system. Raw and purified landfill gas samples of 1kg were collected and analyzed to determine their percentage compositions. CH_4, CO_2, O_2, H_2, N_2 and H_2O (moisture) were the primary constituents in the raw landfill gas. However, CH_4 and CO_2 were dominant in both samples with 55.40% CH_4 and 43.60% CO_2 contents in the raw landfill gas and 99.60% CH_4 and 0.20% CO_2 contents in the purified landfill gas. O_2, H_2, N_2 and H_2O in the purified landfill gas were observed in trace quantities. While the raw landfill gas during combustion burned with yellow flame due to impurities, the purified landfill gas was observed to burn with blue flame that was odorless, indicating high concentration of methane gas.

1. Introduction

Solid waste management through open dumping and open burning is the prevalent practices in most developing countries such as Nigeria, and this has led to severe ecological, environmental and health problems in recent times [1, 2]. Open dumpsites are the third largest anthropogenic source of Green House Gas (GHG) emissions, accounting for about 13-20% of global methane (CH_4) emissions or over 223 million Metric Tons of Carbon dioxide (CO_2) [3], of which CH_4 is 21 times more potent than CO_2 when released into the atmosphere. However, the quantity of methane emitted from dumpsites can be useful if harnessed and processed adequately in reasonable quantities through engineered landfill systems. According to Jimenez and Oakley [4], engineered landfill is a system of solid waste management that involves carefully engineered excavation of the ground into which waste materials are buried in layers without posing any threat to the surrounding environment. In other words, its primary function is to minimize any hydraulic connection and emission between the waste materials and the surrounding environment, unlike open dumpsites which is characterized by indiscriminate disposal of waste materials including hazardous and non-hazardous content at the detriment of the environs [5].

Considering the utilization of landfill gas in some parts of the world such as Canada, Finland, etc. where the cold climate condition is not quite favorable for decomposition of organic matter in landfills systems, landfill gas production rate may be higher in countries like Nigeria where large amount of organic waste is generated by approximately 218,000,000 people. With about 5-7 hours of daily sunlight in Southern Nigeria and about 9-11 hours of sunlight in Northern Nigeria, an average daily temperature of 28^{o}C is experienced in Nigeria [6], and such temperature offers mesophilic condition ideal for landfill gas production.

Jozefek [7] reported that carbonate fuel cell powered by landfill gas has been deployed in Canada, and this has led to the demonstration of a 300kW tri-generation stationary fuel cell plant at a landfill near Vancouver, Canada. The project uses landfill gas as fuel source to generate heat and electricity for export to the grid.

Kuang-Ling [8] carried out a comparative analysis for two distinct landfills in South Sweden managed by Sysav Company in Malmo and Nordvastra Skanes Renhallning (NSR) Company in Filborna. Landfill gas production in Filborna which operates with leachate recirculation was reported to be around 150-200m^3 per tonne of waste which is higher than landfill gas production in Malmo of about 100m^3 per tonne of waste operated without leachate recirculation. This is in agreement with the findings of Warith [9] who reported that leachate recirculation can improve the moisture content of the landfill waste which in turn increases the rate of landfill gas recovery as well as biological degradation and stability of in the landfill.

However, landfill leachate which can impact negatively on the soil surface and adjacent soil areas, percolating through the soil while undergoing various processes such as physiochemical process, ion exchange reactions, chemical alterations, oxidation and hydrolysis, is a highly toxic liquid effluent that contains dissolved organic matter and inorganic compounds classified as water-based solution of four groups of pollutant i.e. dissolved organic matter, inorganic macro components, heavy metals and xenobiotic organic [10].

Prior to commencement of landfill projects, it is important that site selection, construction materials, geotechnical tests, structural designs, type of waste and other factors be considered in order to protect the environment against the effect of leachate [5]. This is because quite a number of landfill systems has failed catastrophically, claiming lives and properties due to negligence to standards and the use of substandard materials for landfill development. For example, a large landslide occurred on December 20, 2015, at a waste landfill in Hong'ao Village, Guangming New District of Shenzhen, Guangdong, China. Over 77 people lost their lives in the incident and about 33 houses within an industrial zone of Shenzhen were destroyed [11].

One of the effective methods of producing a sustainable and affordable energy in Nigeria could be looking inwards at harnessing the bioenergy (biogas) contents from organic fraction of Municipal Solid Waste (MSW) which is readily available in households, residential, commercial and industrial areas of Nigeria [12, 13]. Organic materials such as food waste, green waste, animal excreta and other biodegradable materials are known for their energy potentials in terms of biogas which evolves through microbial breakdown of organic materials in the absence of oxygen. Engineered landfill technology as a result of its capacity to accommodate and prevent organic wastes from the negative effects they have on the environment after decomposition is economically viability and environmentally sustainable for harnessing of biogas, provided it is properly designed and constructed. It is gradually gaining popularity in many countries of the world, but there is no single engineered landfill system in Nigeria designed for energy recovery from organic waste.

The present study aimed at designing and construction of a prototype landfill gas production system that can serve as alternative energy resource in Nigeria. Based on organic materials deposited in the system which were properly selected and segregated, flame quality as well as burning duration was examined before and after purification and evacuation of biogas produced from the landfill system. The motivation behind this study was the increasing cost of importing Liquefied Petroleum Gas (LPG) which could be offset through designing, implementation and adoption of alternative energy system that can proffer a cost-effective solution to the energy crisis in Nigeria, with little or zero impact on the ecosystem.

2. Materials and Methods

Detailed description of materials considered for the landfill design is presented in Table 1. The landfill design is based on the method of operation, ergonomics and how it can appropriately contribute to Nigeria's energy needs without compromising our environment and the ecosystem at large. Figure 1 represents the adopted design for the prototype landfill system designed with vertical and horizontal gas extraction well.

Table 1: Description of individual layer of a landfill system

S/N	Materials	Description	Specification
1.	Landfill cover	A typical landfill system comprising a number of earth layers to prevent erosion, gas diffusion, rain water percolation etc. Concrete slab was employed in this design in which a man hole was provided for easy access, loading and offloading of organic feedstocks.	Concrete slab
2.	Gas extraction system	This is a system of gas collection (known as well) designed with perforated pipes surrounded by granular materials. The pipes were connected in series and parallel to allow gas intrusion and possible extraction through gas compressors.	1½ inches pipe
3.	Organic waste	This is majorly a variety of biodegradable waste materials that were collected, sorted, measured and compacted in layers within a small area to reduce the volume consumed within the landfill. The method of compacting the waste also helped in the reduction of odour, prevented littering and deterred scavengers.	Rice, bean, garri, fufu, plantain, pineapple, orange, banana, water melon, cucumber etc.
4.	Leachate Collection System	Also known as drainage layer consisted of granular materials which served as filtration medium between liquid and solid particles present in the landfill system. It also provided a flow path (funnel) for leachate to drain into the perforated	Hydraulic conductivity $K = 1x10^{-3}$cm/sec

		pipes where it was transported to specially designed low point called sump.	
5.	Leachate collection pipe	Perforated pipes were buried within a bed of gravel at the bottom of the landfill system. Surface pump was connected to the leachate collection pipes to removes the leachate from the landfill and transported it to leachate management facilities for treatment.	1 inch pipe
6.	Geotextile mat	This is a non-woven polypropylene fabric similar in appearance to felt, mechanically bonded through needle-punching to obtain a sturdy and flexible fabric with optimum pore sizes and high permeability. It was installed on top and underneath the drainage layer system to provide additional separation of solid particles from liquid. This prevented clogging of the pipe system and as well as the drainage layer.	1.5mm-2.5mm, Hydraulic conductivity K = $1x10^{-3}$cm/sec
7.	Geomembrane liner	A thick impermeable plastic layer (liner) that prevented leachate from percolating through the landfill and contaminating the soil and ground water. Geomembrane is typically constructed with special type of plastic called high-density polyethylene or HDPE. HDPE is tough, impermeable and extremely resistant to attack by chemical compounds present in leachate. This layer also helped prevent the escape of landfill gas.	1.5mm
8.	Compacted Clay	Was placed below the subgrade, which formed an additional barrier to prevent leachate from percolating through the bottom of the landfill into the environment. The clay layer also helped prevent the escape of landfill gas.	Hydraulic conductivity K = $1x10^{-7}$cm/sec
9.	Prepared Subgrade	These are native soils underneath the landfill system, prepared as required prior to commencement of the landfill construction.	

The adopted design showing the various layers and functional parts of the landfill system is presented in Figure 1. The primary advantage of combining both gas extraction wells in one design is that gas ingress into the gas wells is allowed in several arms of the landfill system, particularly areas with extension of the gas wells in both horizontal and vertical direction within the landfill system.

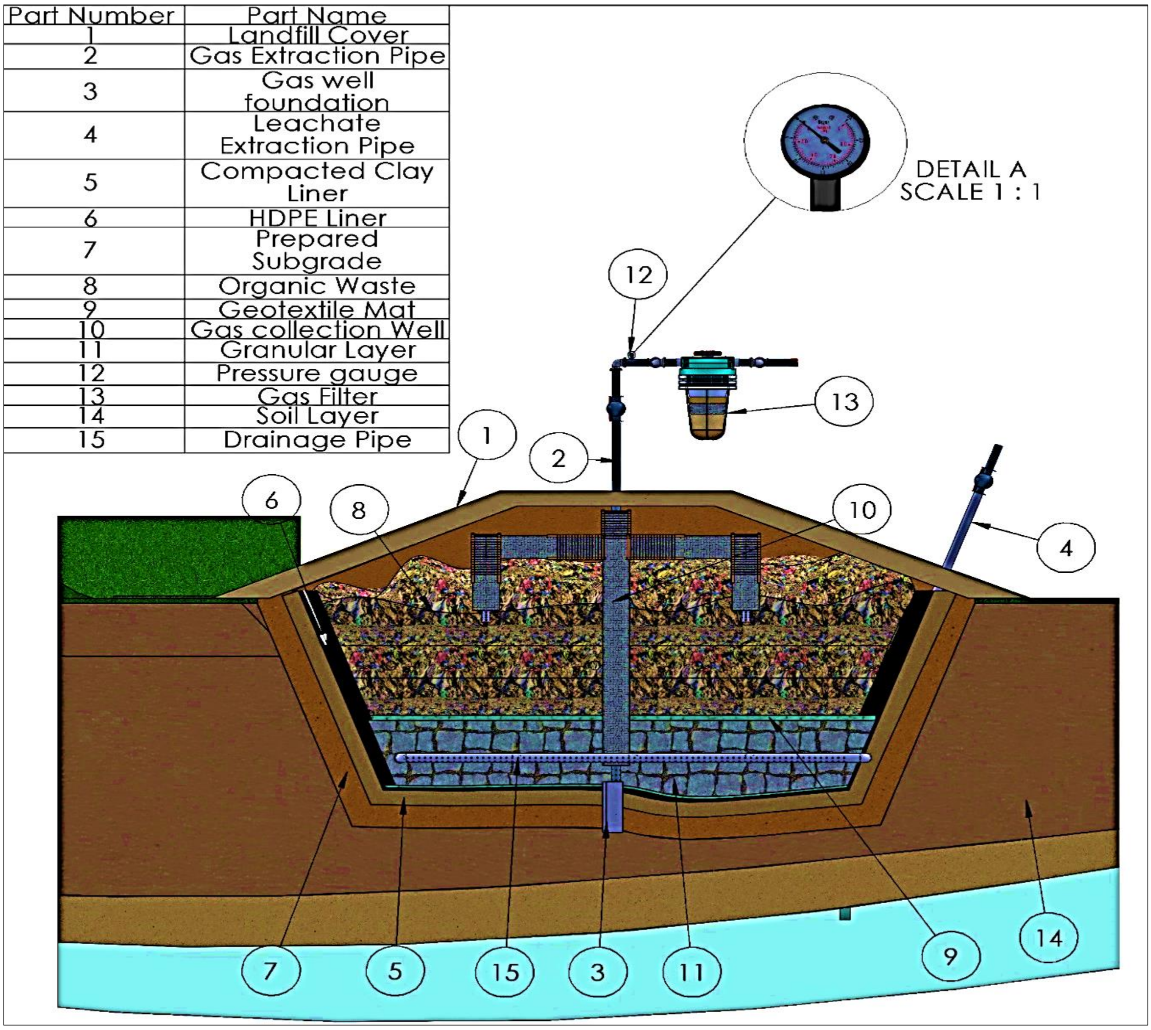


Figure 1: Landfill design with vertical and horizontal gas extraction system

The gas extraction well is designed with four (4) cornered steel rods binned together with copper wire, with the annulus packed granular materials (such as non-cancerous stone) with perforated pipes install at the middle to allow gas intrusion during waste decomposition. The minimum borehole diameter for the gas extraction well is 0.20m, whereas, the minimum gas extraction pipe diameter is 0.10m. Perforated pipes with minimum diameter of 0.10m and 0.40-0.50m spacing are buried within the granular layer for leachate extraction to storage area on the surface. Side walls of the system are sloped at an angle of 45^o to allow accelerated movement of leachate into the drainage layer, thereby, preventing clogging.

The base of the landfill system after prepared subgrade is designed with compacted clay liner of approximately $1x10^{-7}$ cm/s while another liner specifically High Polyethylene liner is spread across the entire base and side walls of the landfill system and anchored on the surface before preparing the drainage layer. The drainage layer is designed with granular materials such as non-calcareous stones or granite with a network of perforated pipes buried within its layer to collect and transport leachate to a collection sump. Dimension of the empty trench without liners and waste is about 6 feet (1.5m) with the side slopes inclined at an angle of 45^o.

In the design, the drainage layer is covered with a geotextile filter with hydraulic conductivity of $1x10^{-2}$ cm/s to separate solid particles from liquid as a result of organic waste decomposition.

Having achieved and incorporated the aforementioned task and component in the design, the trench is covered with further layers indicated in Figure 2 and described in Table 1, to minimise the escape of landfill gas and entry of rain water through the cover, and maximizing the total landfill gas output.

PART NO.	1	2	3	4	5	6	7	8	9
SOIL LAYERS	CONCRETE COVER	ORGANIC WASTE LAYER	GEOTEXTILE MAT	GRANULAR LAYER	HDPE LINER	CLAY LINER	PREPARED SUBGRADE	EARTH	WATER TABLE

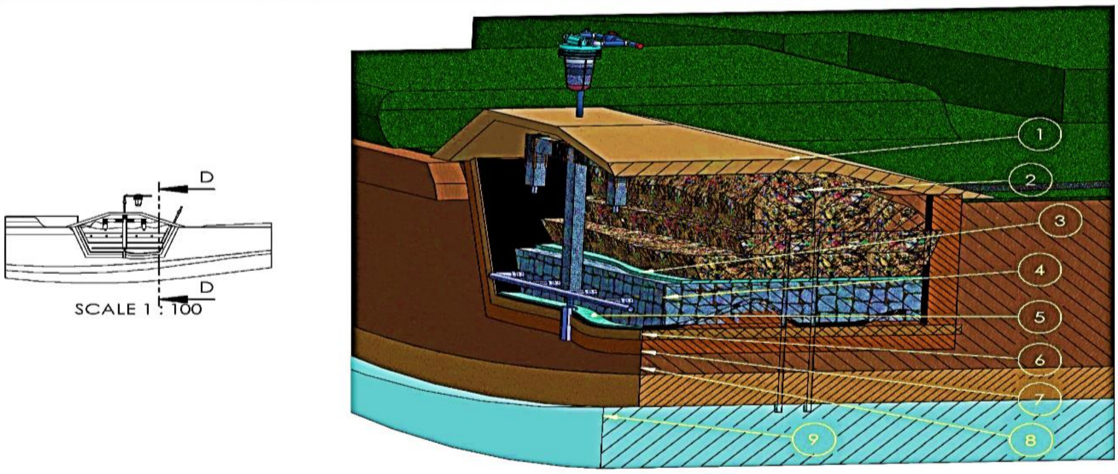


Figure 2: Cross sectional view of the landfill layers

2.1. Design Calculations

In this section, existing mathematical formulae was employed to determine some physical factors for the landfill system. As shown in Figure 3, the adopted landfill system has the shape of a truncated pyramid with unknown volume that must be determined for understanding of settlement area;

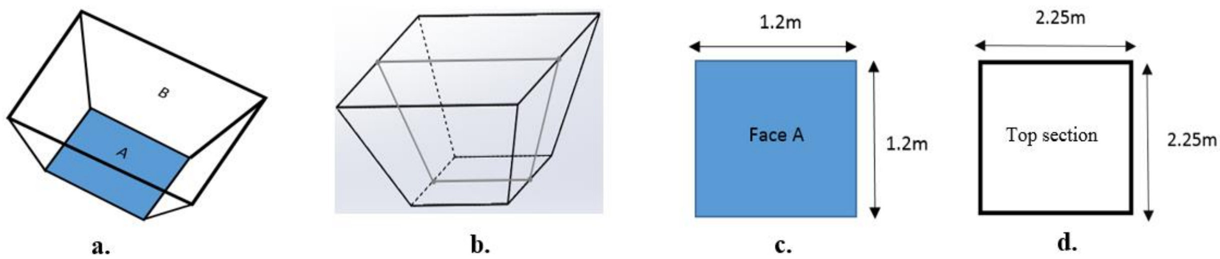


Figure 3: Truncated Pyramid Shape of the Landfill System

Considering that Face A of the truncated pyramid is a square of 1.2m x 1.2m, the base area is calculated as;

$$\text{Base Area} = 1.2 \times 1.2 = 1.44\text{m}^2$$

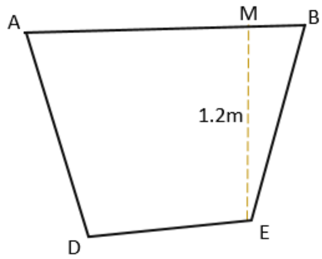
Considering that the Top section of the truncated pyramid is a square of 2.25m x 2.25m, the base area is calculated as;

$$\text{Top Area} = 2.25 \times 2.25 = 5.06\text{m}^2$$

The volume of the truncated prism is given by Equation 1

$$Volume = \frac{1}{3} \times (a^2 + ab + b^2) \times h \quad (1)$$

To obtain the slant height, we extract the trapezium at the mid plane



$$V = \frac{1}{3} \times (1.44 + 2.7 + 5.06) \times 1.2$$

$$V = \frac{9.2}{3} = 3.68m^3$$

V = 3680 litres

2.2. Vertical Pipe Load

Equation 2 was employed to calculate the vertical earth load pressure of fill on the pipe leachate collection pipes;

$$P_{vu} = P_v - 2c\, {}^{C}/_{D} \quad (2)$$

Where,

P_{vu} is the vertical dead load pressure on bottom pipe, P_v is the vertical dead load pressure on landfill, γ is the unit weight of waste fill, c is the Cohesion between pipe and granular materials, D is the outer diameter of pipe, C is the height of fill above top of pipe.

γ was found to be 1763 kg/m^3, c = 600, D = 1.1 inches = 27.94mm = 0.02794, C = 400 mm = 0.4 m, $P_v = \gamma C = 1763 * 0.4$, P_v = 705.2 N/m^2.

Therefore P_{vu}

$$P_{vu} = 705.2 - (2 \times 600 \times \frac{0.4}{0.02794})$$

P_{vu} = 705.2 – 17179

P_{vu} = -16473.8 Pa

The negative value (-16473.8 Pa) is as a result of the backfill (organic waste materials) not producing sufficient opposing force to resist the granular layer underneath the perforated leachate collection pipes in the landfill system. Due to the slurry nature of organic waste materials deposited in the system, the level of friction and cohesion between the leachate collection pipes, granular layer and the backfill is less, thereby, significantly reduce the vertical dead load pressure acting on the leachate collection pipes installed at the bottom of the landfill system.

2.3. Maximum Pressure of the Gas Extraction Pipe

From the guideline by American Society of Civil Engineers (ASCE) [14] for the design of buried pipes, the maximum internal gas pressure (P) that the gas extraction pipe can withstand before failure is determined by Equation 3;

$$P = \frac{2tS}{D-2t} \quad (3)$$

where P is allowable internal gas pressure through the gas extraction pipe, t is thickness of pipe = 0.05in, D is outside diameter = 1.1in, S is HDS value = 2960 X 0.5. Design factor from ASME [15].

$$\mathrm{P} = \frac{2 \times 0.05 \times 1480}{1.1 - 2 \times 0.05}$$

P = 148psi = 1.02042Mpa

2.4. Ovality of the Pipe

Ovality is the degree of deviation of a pipe from perfect circularity. Ovality of the pipes (buried within the landfill layer) due to external forces may be given by Equation 4 [16, 17].

$$Ovality = \frac{\Delta y}{D} = \frac{D_1 KP}{\frac{(EI)eq}{R^3} + 0.061E'} \quad (4)$$

where D is the pipe outside diameter, Δy is the vertical deflection of pipe inches, D_1 is deflection lag factor (~ 1.0-1.5), K is the bedding constant (~0.1), P is the pressure on the pipe due to vertical earth load (P_C) plus live load (P_P), R is the radius of the pipe, $(EI)_{eq}$ is the equivalent pipe wall stiffness per meter of pipe length, E' is the modulus of soil reaction given as 1000psi ≈ 6.8MPa [14]. The pipe wall stiffness, is the sum of the stiffness of the bare pipe, lining, and coating given by Equation 5;

$$(EI)_{eq} = E_P I_P + E_L I_L + E_C I_C \quad (5)$$

Where I is the moment of inertia of the pipe walls given by Equation 6;

$$I = \frac{t^3}{12} \quad (6)$$

t is the wall thickness of pipe, lining or coating given as 0.05 in

The pipe ovality was calculated as 0.001942 using Equation 7,

$$Ovality = \frac{\triangle y}{D} = \frac{D_1 KP}{\frac{(EI)eq}{R^3} + 0.061E'} \quad (7)$$

Were D is pipe outside diameter, Δy is vertical deflection of pipe, $D_1$is deflection lag factor (~ 1.0-1.5), K is bedding constant (~0.1), P is pressure on pipe due to vertical earth load (P_C) plus live load (P_P), R is pipe radius, $(EI)_{eq}$ is equivalent pipe wall stiffness per meter of pipe length, E' is modulus of soil reaction.

Result obtained for the pipe ovality implies that the surface load and transmitted pipe pressure has a negligible effect on the bottom pipes of the landfill system, as the acceptable ovality of a pipe by ASME B31.1-2001 standard is 5% [18]. However, the effect might not be negligible in non-prototype landfill systems where large pipe diameters, large surface loads and high transmitted pressures are involved, as the level of friction, cohesion and direct contact between surfaces may be significant. This can be observed in the illustration shown in Figure 4.

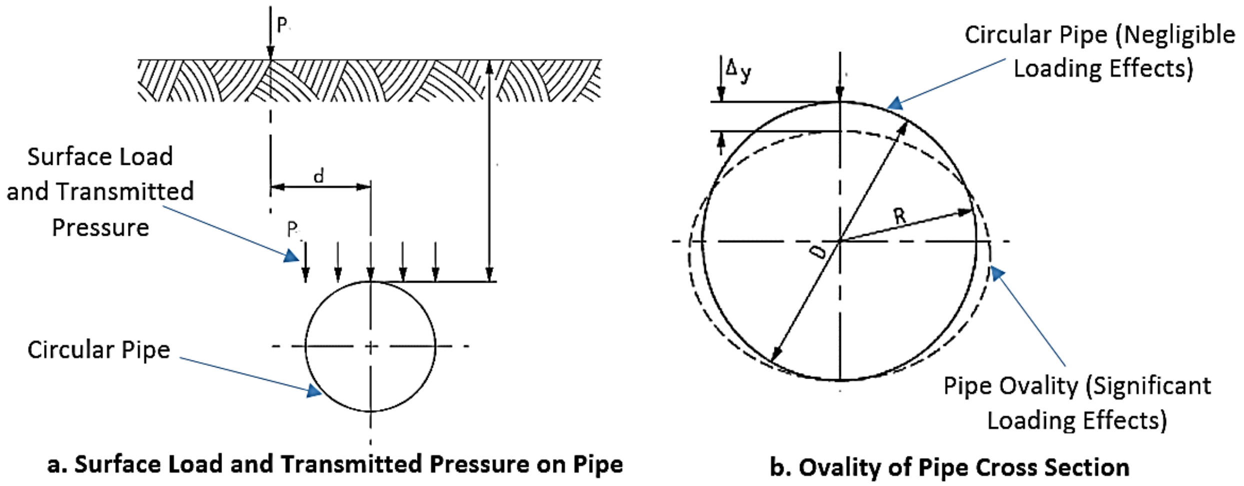


Figure 4: Effect of external forces (loads) on the landfill bottom pipes

2.5. Through-Wall Bending Stress

The through-wall bending stress due to ovalisation is given by Equation 8 (ASCE; 2001);

$$\sigma_{bw} = 4E\left(\frac{\Delta y}{D}\right)\left(\frac{t}{D}\right) \quad (8)$$

where, σ_{bw} is through-wall bending stress, $\triangle y/D$ is pipe ovality, D is outside diameter of pipe, t is pipe wall thickness, E is modulus of elasticity of pipe. Applying Equation 8;

$$4(155190.38)\ (0.001942)\ \left(\frac{0.05}{1.1}\right) = 54.796 \text{ psi}$$

$\sigma_{bw} = 0.3778$ MPa

If the imposed bending stress exceeds the ultimate tensile strength of the pipe material, failure may ensue, thereby affecting the performance of the pipe [19]. Some activities of the landfill construction process are pictorially shown in Figure 5-8.

Figure 5: Processing of clay for the landfill basal liner

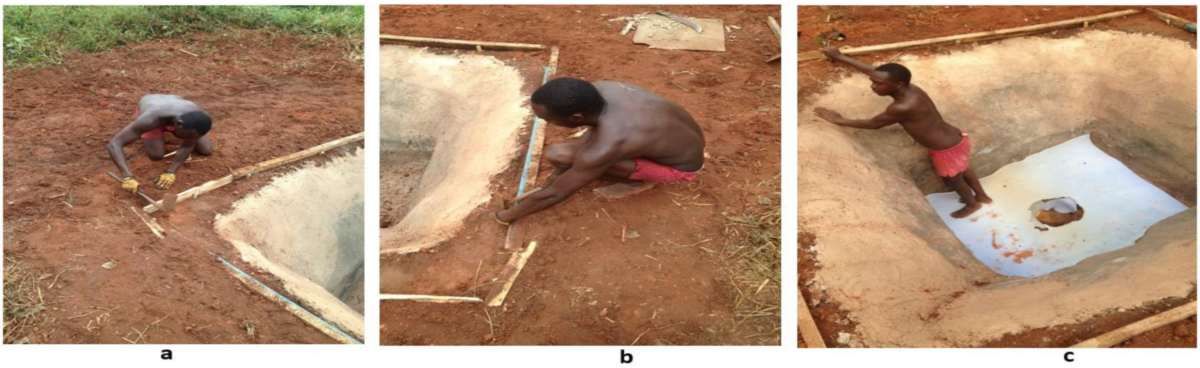


Figure 6: Preparing the interior and exterior parts of the landfill system for installation of HDPE liner

Figure 7: Installation of HDPE Liner, leachate collection pipes and gas extraction well

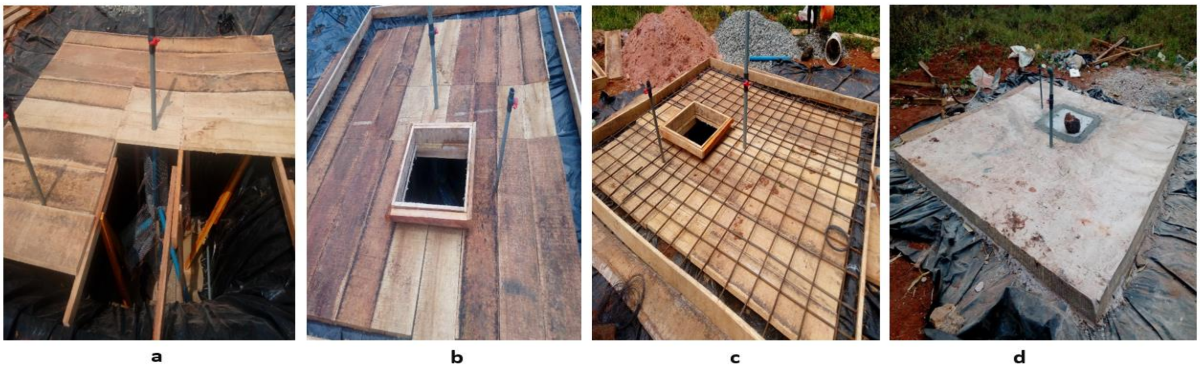


Figure 8: Construction process of the landfill cover

3. Results and Discussion

Table 2 represent the total amount of organic feedstocks by weight (kg) that were deposited in the final landfill design for possible landfill gas recovery.

Table 2: Mass distribution of landfilled organic feedstock

S/N	Fruit Waste (kg)		Food Waste (kg)		Miscellaneous Waste (kg)	
1	Water Melon	172.4	Fufu	54	Vegetable	171.7
2	Oranges	355.7	Garri	21	Cabbage	83.7
3	Cucumber	68.6	Yam	11.7	Plantain peel	172.6

4	Pawpaw	45.5	Rice	18.5	Plantain pedicle	75.7
5	Carrot	30.7	Beans	22.5	Cassava peel	64
6	Banana	40.6	Plantain	75.7	Okra	37.7
7	Cherry	47.2	Sweet Potatoes	23.7	Cow dung	76.9
8	Garden egg	5.8	Cocoyam	19.8	Pineapple peel	9
9	Pineapple	20.8	-	-	Yam peel	38.4
Sum		787.3		246.9		729.7
Total				**1763 kg**		

Landfill systems produce appreciable amounts of gas within 1 to 3 years, while peak gas production occurs from 5 to 7 years after waste materials have been deposited. Almost the entire landfill gas is produced within 20 years after waste is deposited, but small quantities of the landfill gas may however continue to evolve from the landfill system for a period of 50 years or more [20]. A low-methane yield condition, however implies that slowly decomposing waste will produce methane after 5 years and continue producing gas for over a period of 40 years. Different areas of the landfill system may be in different phases of the biodegradation process at the same time, depending on when the waste was originally deposited in the system [21].
For safe operation, gas build-up in a landfill system must be evacuated at regular intervals to prevent incidents of unforeseen landfill gas explosion [22, 23]. This is because the rate of organic waste decomposition (chemical reaction) in the landfill system increases with increasing temperature, thereby, increasing the landfill gas pressure as a result of landfill gas yield. As the landfill gas builds up, the available space within the confined landfill system is gradually accumulated with gas concentrations. When the available space is completely saturated with landfill gas, a critical point (Upper Explosive Limit-UEL) is reached where the landfill system can no longer accommodate the excess gas, and therefore gives way.
In this paper, incidents of gas explosion were prevented through the use of manually operated hand compressor that has two exits. This was employed in the evacuation of landfill gas from the landfill system, as the landfilled organic matter decomposed to generate gas. With one exit connected to the storage vessel, the other exit was connected to one end of the landfill gas filter (made of local materials such as iron sponge, iron fillings, Type-B silica gel, calcium hydroxide, palm kennel shell, cotton wool etc.), while the other end of the filter was connected to the landfill gas outlet as shown in Figure 9. Landfill gas was evacuated from the landfill system at regular intervals and the evacuation date and quantity was recorded as shown in Table 3.

a b

Figure 9: Landfill gas evacuation, purification and compression into gas cylinder

Table 3: Flame test after landfill gas evacuation and purification

Quantity of Gas (kg)	Flame Colour before Purification	Burning duration (minutes)	Flame Colour after Purification	Burning duration (minutes)
0.50	Yellow	61.42	Blue	87.50
0.45	Yellow	44.65	Blue	64.32
0.30	Yellow	27.94	Blue	37.40
0.27	Yellow	16.28	Blue	20.0
0.72	Yellow	80.63	Blue	110.57
0.68	Yellow	76.48	Blue	106.16
0.65	Yellow	68.12	Blue	103.17
0.66	Yellow	70.41	Blue	104.21
0.62	Yellow	60.58	Blue	98.19
0.70	Yellow	77.86	Blue	108.07
0.71	Yellow	78.61	Blue	109.58
0.69	Yellow	76.84	Blue	107.41
0.70	Yellow	77.92	Blue	108.38
0.68	Yellow	76.64	Blue	106.12
0.70	Yellow	78.72	Blue	109.02
1.02	Yellow	82.34	Blue	114.35
1.01	Yellow	82.87	Blue	114.02
1.03	Yellow	83.56	Blue	115.24
1.02	Yellow	83.00	Blue	114.28
1.02	Yellow	82.96	Blue	114.34
1.04	Yellow	83.64	Blue	115.47
1.01	Yellow	81.96	Blue	113.17
1.03	Yellow	83.12	Blue	114.21
0.81	Yellow	80.14	Blue	110.19
0.72	Yellow	78.92	Blue	109.15
0.71	Yellow	77.64	Blue	108.57
0.67	Yellow	75.25	Blue	106.45
0.70	Yellow	77.20	Blue	108.40
0.66	Yellow	70.53	Blue	104.46
0.71	Yellow	77.48	Blue	108.12
0.63	Yellow	63.32	Blue	99.19
0.70	Yellow	76.19	Blue	108.17
0.72	Yellow	76.24	Blue	109.18
0.69	Yellow	74.48	Blue	106.41
0.70	Yellow	75.96	Blue	108.38
0.68	Yellow	75.02	Blue	106.12
0.71	Yellow	76.34	Blue	109.32
0.70	Yellow	76.30	Blue	109.04

The quantity of purified landfill gas evacuated from the system was subjected to flame test to examine the burning characteristics. While the purified landfill gas burned with blue flame, variations were observed in the evacuated quantities and burning durations of the evacuated landfill gas as shown in Table 3. Considering the inconsistency in values obtained for the purified landfill gas in Table 3, it is likely that the landfill gas production have not attended a stable phase where numerous peak values are expected to correlate consistently with one another prior to gradual decline until it diminishes at zero when the landfill system is no longer producing gas. Variation observed in the purified landfill gas values may have been due to loses in connection points from the landfill gas outlet through the gas hose, hand compressor and gas filter to the cylinder where the evacuated landfill gas was stored. About 1Kg of the raw landfill gas and purified landfill gas were analysed using Optima 7 biogas handheld device. The landfill gas was analysed to determine the various impurities (compositions) present in the gas before and after purification as shown in Figure 10. Using Clarus 690 gas chromatograph, the landfill gas was further analysed to determine other physical properties which are presented in Table 4.

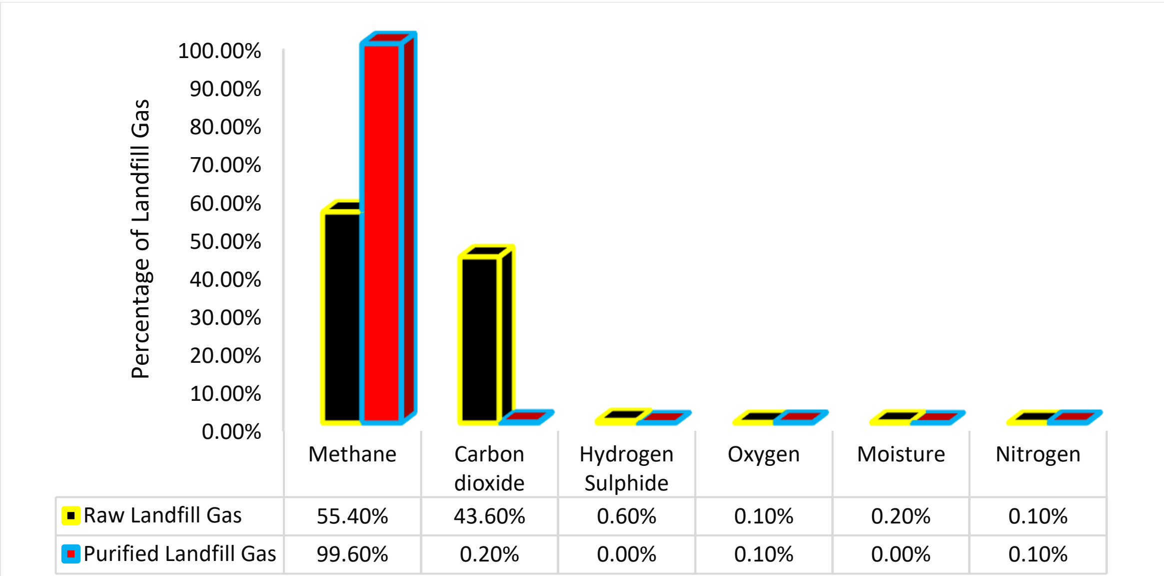


Figure 10: Landfill gas composition measured with optima 7 biogas

Table 4: Composition of the Landfill Gas

Property	**Value**	**Unit**
Flammable	Yes	-
Odour	No	-
Colour	No	-
Critical pressure	7.20	bar
Molecular mass	28.48	kg/kmol
Density	1.31	Kg/m^3
Solubility in water	0.022	mg/ml
Flasher point	-166	^{o}C
Gibbs free energy of formation	-2973	kJ/kg
Specific volume	1.46	m^3/kg
Heat (latent) of vaporation	202	kJ/kg
Calorific Value	30.2	MJ/m^3
Vapour (saturation) pressure	446000	mm Hg
Dynamic viscosity (μ)	1.32E-5	N-s/m^2
Kinematic viscosity (υ)	1.01E-5	m^2/s

A comparative study of the boiling time of water using Liquefied Petroleum Gas (LPG), Natural gas and landfill gas as the gaseous fuel is presented in Figure 11. The result indicates that the same amount of water heated with any of the aforementioned gaseous fuels will boil faster at 100°C with LPG, followed by natural gas before landfill gas. This is as a result of the difference in their calorific values of 30.2 MJ/m^3 for landfill gas, 38.7 MJ/m^3 for natural gas and 93.2 MJ/m^3 for LPG. This implies that LPG has a higher heating value and energy content than natural gas and landfill gas while natural gas has a higher heating value and energy content than landfill gas. Therefore, higher calorific value will result in less heating time and higher energy output [24]. Studies have shown that the high rate of consumption and urbanisation is due to rapid increase in human population, which has led to massive increase in waste generation at different [25]. The present study reveals the relevance of the energy content in organic fraction of MSW and the need for harnessing the energy for domestic and industrial purposes in rural and urban areas of Nigeria. It is a renewable energy resource that can offset the huge cost of importing Liquefy Petroleum Gas (LPG) also known as cooking gas as well as an avenue for reduction of GHG emissions into the atmosphere.

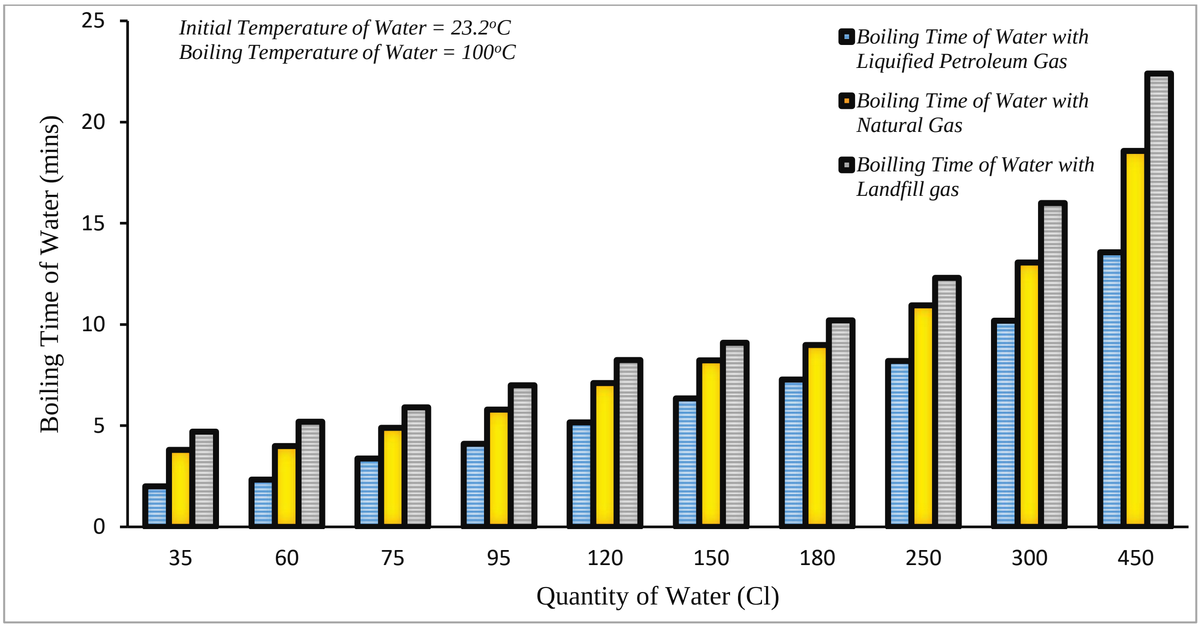


Figure 11: Comparative study of the boiling time between landfill gas and LPG

4. Conclusion

In this study, an Energy specific Landfill Prototype was successfully designed for proper waste disposal, landfill gas production and utilization in Nigeria. From the design calculations, base area of 1.44m^2, top area of1.44m^2, landfill volume of 3680 liters (3.68 m^3), vertical earth load pressure of -16473.8 Pa, allowable pressure of gas extraction pipe of 1.02042 MPa and through wall bending stress of 0.3778MPa. It was observed that the negative vertical earth load pressure (-16473.8 Pa) obtained had a negligible effect on the ovality of the pressure and drainage pipes, as the acceptable ovality of a pipe by ASME B31.1-2001 standard is 5%. The findings have shown that the adoption of engineered landfill technology can meet the energy demand in remote and rural areas in Nigeria, protect our environment from the effects of Green House Gas (GHG) emissions and ground water from contamination and also serve as a viable waste disposal alternative in Nigeria. Results obtained from this study also revealed that the concentration of carbon dioxide in landfill gas is significant, and must be purified to obtain a greener, cleaner and sustainable energy that can prevent negative foot prints on our environment. From the findings obtained in this study, the following recommendations can improve the implementation and operation of engineered landfill system in Nigeria.

i. Constructing the reinforced concrete landfill cover adopted in this study was very expensive, and can increase the loads acting on the landfill slope due to its mass. Therefore, studies should be carried out on cost effective methods and lightweight materials to avoid slope failure as a result of increasing loads induced by the landfill cover.
ii. As a result of microbial degradation of organic substrates in the landfill system, leachate collection system and gas extraction pipes are prone to clogging during operation. Therefore, improvements are recommended on the landfill design for ease of maintenance and effective extraction of leachate and gas from the landfill throughout its service life.
iii. Engineered landfill system should be designed as recyclable systems to allow the evacuation of decomposed organic feedstock (for compost manure to improve soil fertility for plant growth) after landfill gas recovery and deposition of new feedstock for continuous gas generation.

Nomenclature

ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
CAD	Computer Aided Design
GHG	Green House Gas
HDPE	High Density Polyethylene
LPG	Liquefied Petroleum Gas
MSW	Municipal Solid Waste
UEL	Upper Explosive Limit
NSR	Nordvastra Skanes Renhallning
P_{vu}	Vertical dead load pressure on bottom pipe
P_v	Vertical dead load pressure on landfill
γ	Unit weight of waste fill
μ	Dynamic viscosity
υ	Kinematic viscosity
c	Cohesion between the pipes and granular materials
D	Outer diameter of pipe
C	The height of fill above top of pipe
O_2	Oxygen
N_2	Nitrogen
CH_4	Methane
H_2O	Water
CO_2	Carbon dioxide
h	Height of landfill system from the internal base
H_2	Hydrogen
V	Volume of landfill system
P	Allowable internal gas pressure through the gas extraction pipe
t	Pipe thickness
Δy	Vertical deflection of pipe inches
D_1	Deflection lag factor
K	Bedding constant
P_C	Vertical earth load
P_P	Live load
R	Radius of the pipe
$(EI)_{eq}$	Equivalent pipe wall stiffness per meter of pipe length
E'	Modulus of soil reaction
I	Moment of inertia of the pipe walls
σ_{bw}	Through-wall bending stress
$\triangle y/D$	Pipe ovality
E	Modulus of elasticity of pipe

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