IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 16, Issue 6 Ser. II (Nov. - Dec. 2019), PP 01-06
www.iosrjournals.org

Potentialof ContainedLandfill as a Final Disposal Option for Solid Waste in Nigeria

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Abstract: *Despite its position on solid waste management hierarchy, landfill remains the most predominant solid waste disposal option in the world. The approaches adopted in Nigeria of open dumping, open burning and burying are inundated with environmental contamination due to lack of appropriate barriers such as bottom and side liners, covers and leachate collection and treatment facilities. The aim of this study is to evaluate the potential of 'contained' landfill as a final disposal approach for Nigeria.A contained landfill site was evaluated to determine its contamination potential and equipment where landfill gas quality and equipment were assessed on site and leachates were collected and tested in the lab. Laboratory tests conducted on leachate samples were pH, conductivity, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), ammonia (NH4), suspended solids (SS), volatile suspended solids (VSS) and Temperature.The results of the analysis show low organic loading such as COD of 2096mg/l, 3386mg/l and 672mg/l for the three cells compared to other studies.Also,methane recorded was low at a range of 0 – 16.7 for all cells. This may be due to the cells being at the stages of initial adjustment and maturation where microbial activity is slow. Treatment approaches are available to counter the negative environmental effects of leachate and landfill gas, and LFG has the potential to be applied in the generation of clean energy. However, this requires expertise, funding and equipment.*

Date of Submission: 13-11-2019 Date of Acceptance: 27-11-2019

I. Introduction

There is a steady increase in waste quantity and variety due to population growth and industrialization while the basic solid waste management system based on collection, transportation and disposal remains highly inefficient and ineffective in Nigeria [1; 2]. Although the solid waste composition in Nigeria suggests a recyclable content of over forty percent, recycling rate is estimated at 8-22%, while the main disposal options are open dumping, open burning and low composting rates[2; 3; 4; 5]. These approaches are inundated with environmental contamination due to lack of appropriate barriers such as bottom and side liners, covers and leachate collection and treatment facilities [6].

The waste is temporarily stored within households or at communal disposal sites in various sizes of bins, bin bags, baskets, buckets and directly on the ground at communal sites, which are basically open dumps [7]. Highly irregular collection of co-mingled waste is carried out by the state/local government directly, via contractors and/or informal waste managers [2; 3; 7; 8; 9]. Waste is typically transported by lorries, tippers, loaders, trucks, tractors, push carts and wheel barrows [2; 3; 10].Collection and transportation accounts for between 70-80% of total waste management cost in Nigeria, and is mainly funded by the government [11]. Irregular collection and transportation of waste is partly attributed to frequent breakdown of vehicles; and inadequate facility and equipment [2; 3; 12].

Landfills

Despite its position on solid waste management hierarchy, landfill remains the most predominant solid waste disposal option in the world[13]. Itis the cheapest, simplest and most practical waste disposal method considering economic, technical and regulatory aspects [14-16]. In addition, wastes treated by other methods generally have residuals that end up in the landfills. It is therefore an integral part of solid waste management, which aims at ensuring the protection of health and environment while conserving resources [17].Meanwhile, some developed European countries such as Germany and Netherlands are moving towards 0% land filling[18].Landfills are engineered facilities designed and operated for land disposal of solid or hazardous wastes in a manner that protects the environment [19; 20]. It is generally a large hole in the ground or above ground where wastes are placed and compacted, then covered to limit exposure into the environment [19; 21].
Contained' landfills are intended to ensure complete containment of landfill emissions with the emissions taken out in controlled systems for environmental safety. These sites require a larger degree of site design, engineering

and management and exercise a greater degree of control over risks associated with land filling of waste. This is achieved by using clays with very low permeability and/or installation of single or multi barrier clay-membrane systems at the base, sides and top of landfill cells. The composite multi-barrier clay membrane systems consist of sheets of synthetic materials interlaid with clay mineral material; leak detection, leachate collection and gas collection systems installed into the lining and beneath the capping material [22]. This type of landfill takes a high number of years to attain stabilization.

Solid wastes are characterized by physical, chemical and biological processes. The biological processes are mainly responsible for the drawbacks associated with landfilling – it's potential for environmental pollution and public hazard problems due to leachate and landfill gas. Landfill gas is made up of mainly methane and carbon dioxide, two significant greenhouse gases. Leachates are highly toxic liquids with great contamination capacity when they come in contact with ground water [20; 23]. The biodegradable matter in the landfill undergoes aerobic and anaerobic forms of decomposition. The chemical and biological reactions determine the quantity and composition of gas and leachate produced by the landfill and the management required [19].

Aerobic decomposition begins after waste is deposited and continues until entrapped oxygen is used up or is insufficient to support the process. This process mainly generates water, carbon dioxide, ammonia and sulfates with slight odour problems arising from organic esthers[19; 20; 24]. The anaerobic decomposition takes place in many stages with each stage having an impact on the gas and leachate production before stabilization. First, wastes are hydrolyzed and fermented by microbes to breakdown complex organic molecules with the production of hydrogen and carbon dioxide. Next, methanogenic bacteria break down fatty acids and alcohols into methane and carbon dioxide or methane and water in the presence on hydrogen. The stages of waste degradation occur concurrently in most landfill environments with methane to carbon dioxide ratio of 3:2.

The stabilization of waste proceeds is in five distinct stages with the rate and characteristics of leachate and gas produced reflecting the microbial processes in the landfill [20].

Phase 1: Initial adjustment phase

Initial placement of solid waste and accumulation of moisture to support microbial activity in the landfill occurs in this phase. This creates favorable conditions for biochemical decomposition [20].

Phase II: Transition stage

The placement is generally completed at this stage and the environment to anaerobic. Presence of nitrates and sulfates is detected and oxygen is replaced by carbon dioxide. Measurable concentrations of chemical oxygen demand can be detected in the leachate at the end of this phase.

Phase III: Acid formation

Production of high concentrations of intermediate volatile organic acids is recorded in this phase from continuous hydrolysis of solid waste and a decrease in pH.

Phase IV: Methane fermentation phase

Intermediate acids are consumed by methanogenic bacteria and converted into methane and carbon dioxide. Nitrates and sulfates are converted into ammonia and sulfides.

Phase v: Maturation

Biological activity begins to wane as nutrients and substrates become limited. Leachate strength becomes steady at low concentrations while gas productions drops significantly while oxygen and oxidized species begin to be detected.

Landfill Gas, LFG

Landfill gas is a by-product of solid waste decomposition in landfills. Landfill gas (LFG) is made up of methane (CH_4) and carbon dioxide (CO_2) gases, trace amount of toxic substances - H_2, and H_2S [25]. LFG concentrations of the same landfill cell are highly variable at different stabilization stagesdue to the heterogeneity of solid waste in landfill sites [16; 26].Landfill volume, organic content, moisture, temperature and the age of the waste are some of the major factors that influence LFG generation.

Landfills became an important contributor to anthropogenic climate change andthe largest source of GHGs, accounting for approximately 5% of global greenhouse gas (GHG) emissions[27; 28].The potential contribution of methane to the global warming is 21 times higher than that of carbon dioxide [29].

There are generally four approaches to dealing with methane to reduce their negative environmental effects. Firstly, aeration is used to reduce methane production by modifying covers to promote methane oxidation [31 – 33]. Secondly, diverting organic fraction of waste from landfills could efficiently reduce methane emission [34; 35]. Thirdly, gas generation potential and leachate strength of the residue can be reduced by mechanical biological pretreatment [36]. Finally, landfill gas (LFG) can be used to generate power[37 – 39]. Overall, the application of LFG on power generation is more environmentally friendly and sustainable as a potential clean energy [16].

Leachate

Leachate, the second by-product of landfilling, is the liquid that passes through alandfill and has extracted dissolved and suspended matter from its contents[40; 41]. It results from precipitation entering the landfill and inherent moisture in the waste [40]. Leachate generation is a major problem for municipal solid waste (MSW) landfills and causes significant threat to surface water and groundwater due to high amounts of organic and inorganic contaminants as well as high concentration of metals[40; 42; 43].

Leachate quality is influenced by solid waste composition and moisture in the landfill; landfill operation;climatic conditions and location [6; 41; 44]. It is generally different for the same place at different times and can be divided into early (less than five years old), medium-term (5–10 years old), and old landfill leachate (more than 10 years old),where the early or fresh leachate have higher concentrations [46]. Leachates are characterized by Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH, turbidity, conductivity, suspended solids, volatile suspended solids, ammonia and heavy metals [40].COD concentrations can range between 18800 and 47800 mg/l, BOD between 6820 and 38500 mg/L ammonia concentration as high as 2690 mg/L while suspended solids was found to be 940-2915mg/l. The CH_4 contents ranged from 14.5% to 65.6% for a subtropical landfill in Wuhan, China with CO_2 from 21.7% to 31.2% [16]. Other studies have reported COD concentrations greater than 20000mg/l and ammonia greater than 2000mg/l [41]. However, Henry et al., recorded COD and BOD of 14,000 mg/land 9800mg/l respectively from a new landfill raw leachate while the partially stabilized leachatefrom an older landfill had a COD of 3750 mg/ l and a BOD of 1125mg/l.

Biological and physical/chemical approaches are the basic types of treatment technologies available to treat leachates; where an integrated approach combining the two is commonly employed [40]. These technologies include aerated lagoons and activated sludge, anaerobic lagoons and reactors; air stripping, pH b treatment, carbon adsorption and ion exchange[40].

Landfills remain a significant method of disposing solid waste particularly in developing countries such as Nigeria, which is encumbered with lack of expertise and inappropriate selection of waste management techniques. Hence the aim of this study is to evaluate the viability of ‘contained’ landfill as a final disposal approach for Nigeria.

II. Material And Methods

A contained landfill site was evaluated to determine its contamination potential and equipment. Landfill gas quality and equipment were assessed on site and leachates were collected and tested in the lab.

Study Design: Quantitative and descriptive study

Study Location: The contained landfill assessed in this study is Southleigh, UK. It was operated for 22 years since 1983. It has a capacity of 3.65Mm^3, divided into 12 cells. Over the years of its operation, the guidance for management evolved with the development in landfilling practice and environmental legislation.

Procedure methodology

Leachate samples were collected and landfill gas was assessed insitu from three (3) cells. Cell I had been closed for 12 years, Cell II for 6 years and Cell III was operational at the time of assessment.

Site Assessment

Leachate samples were obtained from taps atthree (3) cells. Landfill gas was evaluated onsite at the 3 sample points using an infrared gas analyzer to establish gas quality (levels of methane, carbon dioxide and oxygen).

Laboratory assessment

Laboratory tests conducted on leachate samples tests were pH, conductivity, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), ammonia (NH_4), suspended solids (SS), volatile suspended solids (VSS) and Temperature.

A pH meter (JENWAY 3305) was used to establish pH by inserting an attached probe into the leachate and groundwater samples and results obtained from the pH meter screen.PH is the measure of Acid-Base chemistry with a scale of 0-14 in aqueous systems where acidic solutions have a pH below 7 and basic solutions above 7 [19]. The acid-base chemistry is important in the treatment of pollution and understanding the toxicity of chemicals discharged into the environment.

The conductivity, Ec, of each sample was determined by inserting a probe attached to the conductivity meter (JENWAY) directly into the sample and obtained from the pH screen. Conductivityis a measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride and nitrates [47].

2mls of the ground water was added to Chemical oxygen demand, COD, digesting tubes containing a solution of 86% sulfuric acid, mercury sulfate and chromium trioxide. The solution is heated to a temperature of

150^{O}C to reflux the mixture and the COD read off the calorimeter screen.COD tests are applied to evaluate poorly biodegradable or toxic waste [19]. This is the amount of chemical oxidant required to completely oxidize a source of organic matter.

The Biochemical oxygen demand, BOD_5, values were determined using a 50B YSI dissolved oxygen meter by inserting an attached probe into the prepared sample on the day of collection and after 5 days to obtain two DO readings S_1 and S_2 respectively. 1-day and 5-day dissolved oxygen of distilled water is also determined to be used in the BOD analysis (B_1 and B_2) using equation 1.

$$\frac{1}{F}[(S_1-S_2)-(B_1-B_2)]$$

The BOD is a fundamental tool in the assessment of waste treatment and water quality with the objective determining the amount of microorganisms in water [19]. BOD is the amount of oxygen utilized by microorganisms in oxidizing carbonaceous nitrogenous organic matter. The laboratory analysis of BOD_5 is the BOD exerted over an incubation period of 5 days.

Suspended solids (SS) and volatile suspended solids (VSS) are used as a measure of the number of microorganisms in the water or waste water [19]. Specific volumes of groundwater samples were filtered using a Buchner funnel and micro fibre filter papers. Water was suctioned into a suction jar with that uses an air compressor and the filtrate collected on the filter paper. The filtrate is dried in an oven at 105^{O}C for 2 hours and weighed. Suspended Solids,SS, is determined by:

$$\frac{D\ X\ 1000}{V_S}$$

D = weight of filtrate after drying and subtracting weight of filter paper
V_S = volume of sample

To obtain the Volatile Suspended Solids, VSS, the filtrate is further heated at 500^{O}C for the volatile content of the solids to disintegrate. This weighed to determine the Volatile suspended solids as:

$$\{[(A-C)-(B-C)X1000]\}/V_S$$

A = weight of filtrate after drying at 105^{O}C
B = weight of filtrate after burning at 500^{O}C
C = weight of filtrate paper

The palintest photometer 5000 was used in determining the ammonia at a wavelength of 640nm. The samples are measured by inserting the reagent tablets into the sample in a test tube and the LCD reading is recorded.

Heavy metals were obtained by adding 2mls nitric acid to each sample to attain a pH of 2, which dissociates ions into the solution to be detected. An SP9 atomic absorption spectrophotometer was used to determine four metals predetermined with different lamp settings and wavelengths. A thin suction tube is inserted into the samples for about a minute to determine the metals.

III. Result

Table 1 is depicting the landfill gas quality detected on site while Table 2shows the parameters used to characterize leachates at the Southleigh contained landfill.

Table 2: Gas quality at Southleigh landfill

Variable	Cell	Value
CH_4	1	19.8
	6	13.8
	12	0.0
CO_2	1	14.0
	6	1.7
	12	0.0
O_2	1	13.8
	6	16.5
	12	16.6

Table 1: Characteristics of leachate at Southleigh contained landfill

Variable	Cell	Values
pH	1	7.8
	6	7.5
	12	7.4
E_C	1	5.5
	6	18.3
	12	10.7
COD	1	672
	6	3386
	12	2096
BOD	1	33
	6	233
	12	267
NH_4	1	640
	6	1916
	12	1422
SS	1	113
	6	845
	12	159
VSS	1	79
	6	320
	12	113

IV. Discussion

Although landfilling is the most common approach for solid waste disposal globally, it's by-products – leachate and landfill gas (LFG) may have the potential to contaminate. The results of the analysis show low COD of 2096mg/l, 3386mg/l and 672mg/l for the three cells compared to the studies of [41], with COD greater than 20,000mg/l, range of 18800mg/l and 47800mg/l; and 14,000mg/l respectively. The BOD is also low based on a similar comparison where 33mg/l, 233mg/l and 267mg/l is compared to BOD of 1125mg/l as the lowest concentration. Some explanations for low concentration loadings of the leachate may be attributed to Cell I approaching stabilization where biological activity begins wanes as nutrients and substrates become limited while cell III is at the first transition stage where measurable concentrations of chemical oxygen demand is commonly detected [20]. The methane recorded in this study is also low at a range of 0 – 16.7 for all cells. This further indicatesCell III being at the initial adjustment stage of solid waste decomposition characterized by accumulation of moisture to support microbial activity and creating favorable conditions for biochemical decomposition [20]. Meanwhile, Cells I and II are at the maturation stage where biological activity begins to wane as nutrients and substrates become limited. Leachate strength becomes steady at low concentrations while gas productions drops significantly. Oxygen and oxidized species begin to be detected.

V. Conclusion

Contained landfills have the potential to pollute the environment from the leachate and gas quality from the analysis of this study. The low rates of methane gas and low concentrations of organic loadings detected in the leachate are as a result of the stages of the stabilization – initial adjustment stage and maturation stage. Although treatment approaches are available to counter these effects andlandfill gas has the potential to be applied in the generationof clean energy, this requires expertise, funding and equipment. Further evaluation of other technologies for the treatment of solid waste is recommended.

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