NIGERIAN JOURNAL OF ENGINEERING RESEARCH UNICROSS (NJERU)

Volume 1, Issue 2, 1st June, 2024

Comparative Evaluation of MSW Disposal Using Termites and Sanitary Landfill for Efficient Waste Management

Gitu Ikwa[a], Bassey, Iniko Ekeng[b].

[a, b] Department of Civil Engineering, University of Cross River State. Calabar-Nigeria.

*Corresponding Author: gitubassey@unicross.edu.ng

Received: 25th August, 2024 Reviewed: 30th August, 2023 Accepted: 19th September, 2024

Abstract:
Land-filling has remained the most customarily employed method of waste management in developing countries despite the increased attention to improvement of the Municipal Solid Waste (MSW) management. There is a worldwide need to find the right management approach to MSW and this research is evaluating an improved strategy for MSW management in Nigeria. Lignocellulose which comprises a significant portion of municipal solid waste (MSW) 40–70% in developed countries, including paper, wood, and yard waste are often shielded by lignin, posing a barrier to waste decomposition in a natural landfill condition. Lignin is known to be resistant to microbial degradation under low-oxygen conditions that normally occur in MSW landfills. This research was set up to assess the potential of termites digested MSW in efficient waste degradation and biogas production for green energy use. Assortment of MSW – Sugar bagasse, coconut shell, paper waste, jute bag, hard wood, sawdust and card board were introduced into designed termites' reactors and sanitary landfills, to evaluate their capabilities for MSW anaerobic digestion. Consequently, the volume of waste digestion was determined and the accompanying biogas emissions were intermittently collected and analyzed. Also, the sanitary landfill experimental conditions were set up to digest equal MSW substrates as those used in the termitary and the results indicated significantly reduced degradations and biogas production. The substrate degradation in the termireactors were observed to be faster and about 50% more effective than sanitary landfill for a period of 90 days and emission of biogas which constituted about 72% methane, 23% carbon dioxide and 5% hydrogen sulphide/others were observed to be about 60% faster using the termireactor.

Keywords: Termites, MSW, Termireactors, Anaerobic Digestion, Vermicomposting, Landfill.

INTRODUCTION

Municipal solid waste (MSW) is an aggregate of discarded and unwanted materials generated as man interacts with the environment, in his daily activities. Unfortunately, increasing amounts of municipal solid wastes is among the topics of major concern today in most of our cities, attributable to high population growth and the increase in per capital income [1]. Governments spend enormous amount of resources to dispose and manage these increasing volumes of waste that altogether constitute health hazards and environmental pollution in our urban space. Many scholars have considered various methods of managing these crises through the use of biomass of different kinds, aimed at achieving high and appreciable levels of sustainability, but the associated methane gas emission exacerbate global warming [2, 3].

Municipal solid waste (MSW) disposal and management is a critical issue, the world over, especially in Nigeria and other developing economies. Annually, a huge amount of municipal solid waste is generated which increasingly pose severe challenges to environmental safety, public health and human welfare [4]. The most ubiquitous MSW disposal and management strategy in Nigerian urban space is the landfill system [5]. Also preponderant is the substantial volume of MSW that are indiscriminately deposited on roads and roadsides, unapproved dumpsites, in water ways (drainage system), open sites and abandoned borrow-pits [4], with attendant damaging and harmful impact on the environmental landscape and human health. It has also been noted that improper disposal and inadequate management system of MSW could as well give rise to global warming, photochemical oxidant creation, acidification, ecotoxicity of water, eutrophication as well as abiotic resource depletion [6]. World Health Organization (WHO) and the United Nations International Children Education Fund [5] had reported that improper disposal of solid waste resulting in poor environmental sanitation. Decaying or non-existent sewage system and toilets could cause the spread various diseases (cholera, diarrhea and basic illness) that “kill a child in every 21 seconds” [7].

Lignocellulose comprises a significant portion of municipal solid waste (MSW) at about 40-70%, including paper, wood, yard waste, and textiles such as cotton fibers. Cellulose, the main biodegradable plant polymer, is often shielded by lignin, as well as hemicellulose [8, 9, 10, 11]. Although cellulose and hemicellulose can be converted to methane and carbon dioxide, lignin structure is highly resistant to biodegradation under anaerobic conditions that normally occur in MSW landfills. Lignin is known to often shield the other 2 components (cellulose and hemicellulose), preventing them from being degraded as well. Breaking down the lignin thus represents a significant challenge for landfills in terms of maximizing renewable energy production and reclaiming landfill volume [8].

Thus, there is a critical need to develop more effective methods of degrading lignin in the MSW landfill environment, which is inundated with low oxygen and relatively high temperature conditions. Lignin destruction can make cellulose and hemicelluloses available for anaerobic microbial conversion to biogas. This could potentially increase a landfill’s methane production by a factor of 2-3, depending on waste composition [8]. It has also been reported that by feeding on cellulose matter, termites generate methane gas, a waste energy content which offers good opportunities to generate low-cost and available energy. This can help increase energy access and reduce energy poverty in Africa [11]. According to Babatola, ignorance of renewable energy technology has meant that most people in developing countries rely primarily on solid fuel like wood to meet their cooking and lighting needs [12]. A key route to improving this scenario is to replace fossil fuel-based energy with renewable and low carbon energy technologies. There is a progressive global consensus that having a broad energy mix is likely to be the best method to achieving energy and climate change targets [13]. Biomass as a renewable energy source can contribute towards reducing greenhouse gas emissions, the decarbonisation of energy systems and the diversification of fuel supplies can contribute towards the development of long-term replacements for fossil fuels [14].

This study therefore is to evaluate the use of subterranean termites for efficient degradation of MSW and the prospects of harnessing the associated methane gas for global warming control and clean energy generation. In the process of MSW biodegradation, enormous amount of greenhouse gas – methane (CH_4) and carbon dioxide (CO_2) are produced. Many studies have determined that methane is a far more puissant greenhouse gas than carbon dioxide [13, 14, 15, 9, 16]. Due to methane’s ability to trap heat, it warms the earth 23 times more than carbon dioxide and has an atmospheric lifespan of about 12 years, one much shorter than that of other greenhouse gases [14, 9]. Exploring methane-trapping potential in the MSW management system could make methane elimination from the atmosphere a particularly effective method of combating global warming. Therefore, it could be contended that recovery projects that use methane for clean energy fuel have reasonable prospects for combating the effects of global climate change.

The enormous and increasing waste generation due to distressing population press1ure on land space and its attendant problems of air, water and land pollution necessitates innovative, sustainable and cost-effective approach to solid waste management. The energy from such biomass is projected to make possible Nigeria's ability to contribute to balancing future bioenergy demands. The present research work proposes to carry out field and laboratory investigation on the use of termites for efficient degradation of MSW and capture the resulting CH_4 for use to replace fossil fuel. This research is envisaged to unlock huge potentials in contributing to solving many environmental and socio-economic glitches related to MSW management and energy deficit, including bioenergy production, nutrient recovery, soil and water quality protection and reduction of greenhouse gas emissions.

MATERIALS AND METHODS

A. Experiments with different waste decomposers

Two sets of experiments (duplicate of each) using termites and sanitary landfill for waste decomposition and biogas production were carried out on equal amount of MSW components as substrates for about 6 months.

B. Collection of Samples for Substrate.

Waste composition

Seven constituents of municipal solid waste (MSW) - sugar cane bagasse, coconut shells, paper waste, pieces of jute, hard wood, saw dust and cardboard were collected from the piles of MSW at the Ikot Effanga landfill, Calabar. After removing debris from the assorted wastes, its dry weight was estimated by oven drying at 105°C to constant weight. The research was to compare the results of MSW degradation and methane generation by termites and MSW degradation and methane generation by sanitary landfill conditions.

C. Proximate Analysis of the Municipal Solid Waste Samples.

After mixing properly, a part of the sun-dried samples was ground to fine size for the proximate analysis. Proximate analysis was done as per international Standard. All analyses were done in duplicate samples.

Moisture: Moisture content was determined by drying 10 g sample in a pre-weighed dish at 108 ± 2o C in an electric oven for 1 h, and the dish was cooled in a desiccator, and weighed. The process was repeated till constant weight was achieved.

Volatile Matter: Volatile matter was determined by heating 1 g sample in a pre-weighed silica VM crucible covered with lid at 900 ± 10o C for a period of 7 min in the furnace.

Ash: One-gram sample was heated in pre-weighed silica crucible without the lid (to ensure presence of air) at 815o C for 1 h and the process repeated till constant weight was attained.

Fixed Carbon: Fixed carbon was determined by calculation with the formula: [100 – (Moisture + volatile matter + ash)].

D. Experimental Design

Design of In-situ termireactors

Termireactors were designed and constructed as in figure 1, each of rectangular base, made up from 3-mm-thick plexiglass sheets.

To assess the consumption of different MSW constituents by termites, the waste assortments were kept in an in situ termireactor of rectangular-based housing with conical roof to mimic the termites' mound shape, made with a 3-mm-thick plexiglass sheets. The termireactor was placed in a shallow pit (45 × 30 × 5 cm), dug in the ground by the side of an active termites' mound figure 1 - to evaluate the consumption of MSW constituents by termites. The termireactor had holes of 1 cm diameter at the bottom to allow termites access to the feedstock.

Fig. 1: The in-situ termireactor

E. Sanitary landfill

Sanitary landfill waste reactors were also constructed by digging pits measuring 45 x 45 x 15 cm, in which different assortment of MSW substrates were placed for digestion and covered with soil layers of about 1 inch.

Having achieved and incorporated the aforementioned task and component in the design, the trench is covered with further layers indicated in Figure

2 to minimize the escape of landfill gas and entry of rain water through the cover, and maximize the total landfill gas output.

l x w x h = 30cm x 45cm x 20 cm – 27,000cm^3

F. Assessment of waste degradation

About 1kg (fresh weight) of each of the feedstock was placed in the termireactor and in the sanitary landfill, while the equivalent dry weight of each substrate was simultaneously determined by oven-drying a known mass to a constant weight at 100°C. The substrates were moistened with tap water, to make the contents sufficiently damp but not soggy.

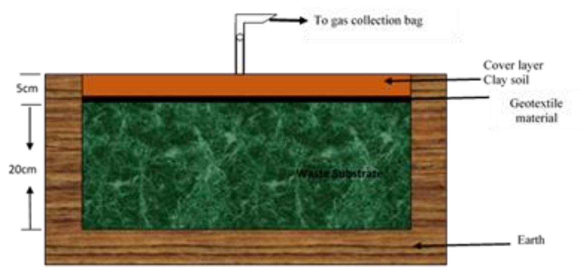

Fig. 2: Cross Sectional View of the Landfill Layers

G. Design Calculations

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

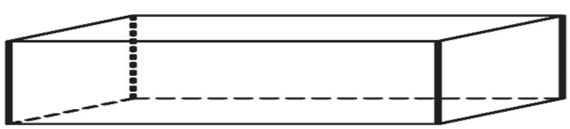

Fig. 3: A Cuboid Shape of the Landfill System

Considering that the cuboid shape of the Landfill System of 30cm x 45cm x 20 cm, is calculated as;

The volume of the truncated prism is given by Equation l x w x h = 30cm x 45cm x 20 cm – 27,000cm^3

H. Assessment of waste degradation

About 1kg (fresh weight) of each of the feedstock was placed in the termireactor and in the sanitary landfill, while the equivalent dry weight of each substrate was simultaneously determined by oven-drying a known mass to a constant weight at 100°C. The substrates were moistened with tap water, to make the contents sufficiently damp but not soggy.

The termireactor was covered with polythene sheets reinforced with plexiglass sheets at the corners to protect the substrates from rainfall, direct sunlight, and disturbance by other animals.

The waste sample was assessed once every 10 days by removing the covers in order to maintain adequate moisture content and to check any possible interference of other soil macro fauna like ants and/or other digesters in each of the termireactor and the landfill. The substrate remaining unconsumed by the termites after 30, 60 and 90 days, were carefully removed from the termireactors and air-dried. Any soil particles found to adhere to the surface of the residue were brushed off before the residue was oven dried at 105°C to constant weight. The substrates of the landfill were also removed after the same period, carefully airdried and measured. It’s been determined that up to 93% of the ingested food is assimilated by termites [17].

Very little of what termites ingest is excreted; the excreta are made up of organomineral aggregates which are carried away by the worker termites to line the termite nests [18, 19]. So, in this research work, the extent of substrate consumption was quantified on the basis of the remaining fraction of the substrate.

The sanitary landfills were also covered with thick cellophane material measuring 50cm x 50cm. The substrates in the sanitary landfills were removed after 30, 60 and 90 days and treated as for those in the termitary to determine their degradation by observed loss in weight.

Waste degradation by volume in the termitaries and sanitary landfills are shown in table I.

I. Gas measurement

As shown in table 2, the biogas collected after 30, 60 and 90 days were collected in a bag and the volume determined for each of the substrate used in the experiment.

The gas collected were analyzed for methane and carbon dioxide contents by Haldane Gas Analysis Apparatus. The ratio of methane to carbon dioxide determined was in the range of 60:40 – 58:42.

J. Composition of gases

Composition and volume of gases was measured on a regular basis, to determine its emission per volume of MSW with time. Firstly, gas production, gas composition and volume were measured every 10 days. Composition of the collected gases was measured using a K-G60-S4 Fixed multi-gas detector with infrared analyzer. This instrument is able to measure the concentrations of methane (CH_4), carbon-dioxide (CO_2), oxygen (O_2), and hydrogen sulfide (H_2S) in the gas bags.

K. Volume of collected gas

The volume of collected gas was measured using an air sampling pump (Universal XR Pump Model 44XR) and Defender 330.

III. RESULTS AND DISCUSSION

A. Proximate analysis

In the MSW samples collected, the average moisture content was about 10.07%. Major contents were of volatile matter at 68.07% and fixed carbon at 15.24%. Ash content was only 6.62. Volatile matter and fixed carbon together make the MSW a potential waste for the generation of biogas.

B. Comparative results of termites-digested waste and sanitary landfill digested waste.

Termites-digested and sanitary landfill waste experiments were conducted for 30, 60 and 90 days on the seven assortments of MSW - Sugar bagasse, coconut shell, paper waste, jute bag, hard wood, sawdust and card board wastes to evaluate varied levels of biodegradation and biogas production. With coconut shells, termites-digestion indicated 39 % degradation rate and production of 8.6cc of methane after 90 days while the sanitary landfill digestion showed lower values at 18% waste degradation and 3cc of methane during the same period (tables I and II; figures 4, 5 and 6). This indicates the potential of termites in degrading ligneous and other 'hard' substances which defy composting, vermicomposting, and other forms of bacterial action in conventional solid waste management systems. It may be due to the coexistence of lignocellulosic material in the coconut shell waste substrate [12].

For paper waste, termites degraded 44, 61 and 69 % after 30, 60 and 90 days, while the sanitary landfill degraded 22, 34 and 44 % of the paper waste within the same time period as shown in table I. The cumulative biogas production for 30, 60 and 90 days were 10, 30, 40 m/m3 (mean value of 3.94 cc) respectively. But with the same volume and type of waste substrate in the sanitary landfill digestion, no measurable biogas production was recorded at day 30, though some relatively not significant biofuel production was recorded from day 30 to day 60 and at day 90 as shown in table II and figure 7.

It is also significant that termites were able to degrade about 60% of cardboard within 90 days (Table I) though otherwise cardboard has been reported to be resistant to biodegradation [1]. As a result of its resistance to biodegradation, cardboard pieces are often used as bulking agents in composting/vermicomposting systems [19, 20].

TABLE I: COMPARATIVE PERCENTAGE CONSUMPTION OF DIFFERENT MSW SUBSTRATES BY THE TERMITE'S REACTORS AND SANITARY LANDFILLS.

	Termites Digestion			**Sanitary landfill Digestion**		
	Percentage of substrates consumed			**Percentage of substrates consumed**		
Substrates	**30 days**	**60 days**	**90 days**	**30 days**	**60 days**	**90 days**
Sugarcane bagasse	62	80	100	18	37	64
Coconut shell	16	26	39	0	8	18
Paper waste	44	61	69	22	34	44
Jute bag	22	40	56	12	18	28
Hard wood	20	50	68	0	13	22
Sawdust	60	77	100	23	31	40
Card board	20	45	60	13	16	22

For hardwood, it was observed that 20, 50 and 68 percent were decomposed by termites in 30, 60 and 90 days respectively, while during the same period, sanitary landfill decomposed relatively smaller proportion of 0, 13 and 22%. Sugarcane bagasse though showed the highest amount of degradation (Fig. 4) under the two experimental conditions; however, termite digestion was significantly higher at 100% after day 90. The sanitary landfill recorded a decomposition proportion of 18, 37 and 64 respectively.

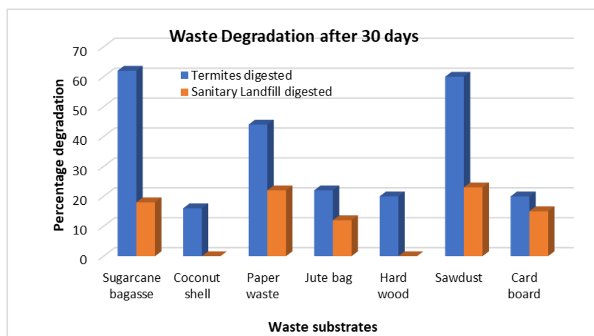

Fig. 4: Percentage consumption of MSW waste substrates observed at day 30.

The results for other waste substrates obtained under the termites digested and sanitary landfill conditions are also shown in table I. This results in table I also show that not only lignocellulosic material but other tough-to-degrade substrates like cardboard were also consumed by termites (up to 60%).

A comparative results evaluation of biogas production from the sanitary landfill experimental setup showed a significantly reduced biogas production at the same environmental and experimental conditions than the termites' reactors (see table II, figures 6 and 7).

TABLE II: COMPARISON OF METHANE GENERATION FROM TERMITORIES AND SANITARY LANDFILLS

Substrates	Termites Digestion			Sanitary landfill Digestion		
	Methane (cc) production			Methane (cc) production		
	30 days	60 days	90 days	30 days	60 days	90 days
Sugarcane bagasse	2	5	9	2	2	4
Coconut shell	1	3	8	0	1	3
Paper waste	0.5	1.5	5	0	0.5	1
Jute bag	1	1.5	2	0	1	1.5
Hard wood	2	4	7	0	2	4
Sawdust	2.5	3.5	6	1	2	3
Card board	1.5	2	5.5	2	1.5	3

For paper waste, cumulative methane production for 30, 60 and 90 days in the territory were 0.5, 1.5 and 5 cc. But with the same volume and type of waste substrate at sanitary landfill digestion, no measurable methane production was recorded at day 30, though some relatively not significant cumulative production was recorded after day 30 to day 60 and at day 90 as shown in table II and figure 7 and 8. It may be due to the coexistence of lignocellulosic material in the coconut shell waste substrate [20].

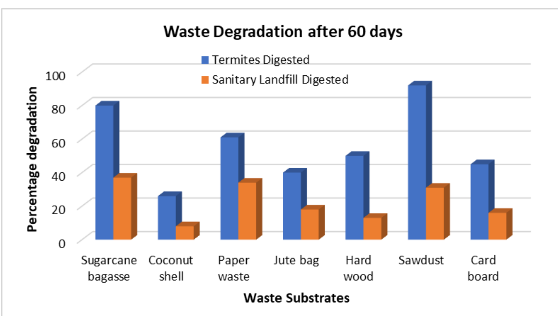

Fig. 5: Percentage consumption of MSW waste substrates observed at day 60.

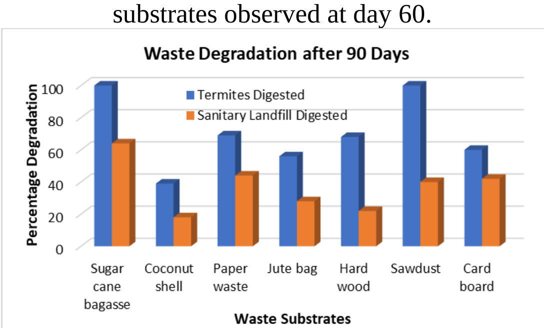

Fig. 6: Percentage consumption of MSW waste substrates observed in day 90.

A comparative results of biogas production from the sanitary landfill setup showed significantly reduced biogas production at the same environmental experimental conditions, using the selected substrates of MSW.

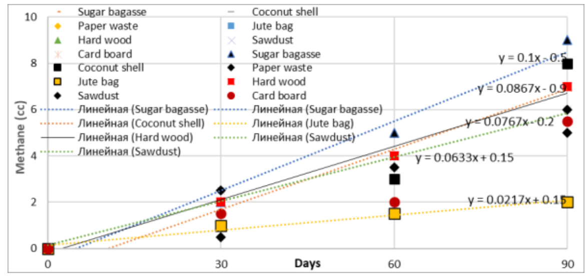

Fig. 7: Methane production from termites digested municipal solid waste

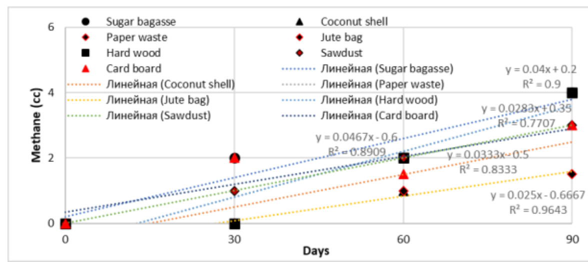

Fig. 8: Methane production from Sanitary landfill digested municipal solid waste

C. Discussion

The selected substrates - coconut shells, hardwood waste and torn jute bags which are known to resist normal anaerobic digestion, composting and vermicomposting condition of the landfill are successfully decomposed by termites. Results show that total biogas collected constituted about 72% methane, 24% carbon dioxide and 6% hydrogen sulphide/other gases.

This research has established that using the termigradation process for the treatment/management of MSW would:

a) increase the rate of degradation of MSW, and resulting biogas generation;

b) aid the capturing and harnessing of the accompanying biogas to maximize potential renewable energy production;

c) reduce the cost of MSW evacuation and management;

d) reduce the emission of greenhouse gasses in contrast to the traditional emission of obnoxious gas associated with MSW burning and decomposition in open landfills;

e) improve the database of green energy potentials of Nigeria.

Acknowledgement

This research was sponsored/funded by the Tertiary Education Trust Fund (TETFund) Institution Based Research (IBR), Batch 8 of the University of Cross River State (UNICROSS), Calabar. We are immensely grateful to the Vice Chancellor and the management of UNICROSS for making this FUND accessible for this research through the Directorate of Research and Development

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