Studies on Settlement Pattern, Gas Production and Rate of Degradation of Putrescible Via Primary Leachate Generation in Tropical Climate of Nigeria

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***Abstract*---The study on settlement pattern, gas production and rate of degradation of putrescibles was investigated in this study from a prototype landfill in Federal University of Agriculture Makurdi-Nigeria using proposed water balance model. Fresh putrescible were collected from the university community to fill the single celled prototype landfill and allowed to degrade under natural condition for 50 days. Principal leachate and gas generation were recorded in-situ while other parameters were obtained from the waste settlement. Moisture content and pH variation were observed in a typical cell/bed (depth 60cm) during phase I and phases II of the experiment. A uniform settlement was recorded as a drop in height of the substrate column and maximum settlement was attained after 40 days. Field capacity decreases with waste volume and time. TOC and G_{cell} values of 2.5 and 2.7 respectively were established insitu for determination of the time rate of degradation. The time rate of degradation of putrescibles from the study is described as first order polynomial function (R^2 = 0.9866) with respect to FC but expressed as an exponential function in terms of height and wet weight of substrate (R^2 = 0.9505 and R^2 = 0.9943 respectively).**

***Index Terms*---Landfill, Putrescibles, water balance model, Degradation rate, settlement, gas and primary leachate**

I. INTRODUCTION

Food and Agricultural organization reported that one-third or more of food never makes it from the farm to our table, they are lost to waste or spoilage [1]. Food waste occurs along the entire spectrum of production, from the farm to distribution, retailers consumer. As a result, nearly one billion people go to bed hungry every night. The decomposition of the food waste, either plant or animal, called *putrescible* in this context, is an important field of study within food science and environmental engineering.

According to [2] spoilage of food is attributed to contamination from microorganisms such as bacteria, molds, and yeasts, along with natural decay of the food [3],. The decomposition process is aided by shredding, adding water and aeration by regularly turning of the mixture. Worms and fungi further break up the material. Aerobic bacteria manage the chemical process by converting the inputs into heat, carbon dioxide and ammonium.

Setting societal and environmental issues aside, the direct economic cost of food waste is a $1 trillion mountain, and growing [1] [4] . Wasted food has far-reaching effects globally. In the U.S., up to 40% of all food produced goes uneaten [5], and about 95% of discarded food ends up in landfills [6]. It is the largest component of municipal solid waste at 21%. [3] In 2014, more than 38 million tons of food waste was generated, with only 5% diverted from landfills and incinerators for composting. [6] Decomposing food waste produces methane, a strong greenhouse gas that contributes to global warming which has become an increased burden on the environment. [7] It is estimated that reducing food waste by 15% could feed more than 25 million Americans every year. [8]

This food waste can often be used for composting or can be a resource for heat, electricity, animal feed and fuel in future, trough dry anaerobic digestion (DAD) which is an attractive method for the stabilization of solid organic waste with high solid concentration (22–40%) as reported by [9]. Reference [10] reported that utilizing food wastes produces products of higher value that have a place in the our society rather than been disposed of along with municipal solid wastes (MSW) in landfills or dump-sites which creates a breeding ground for vector, pest, odor, and greenhouse gas (GHG) emissions into the atmosphere. Useful energy forms such as bio-hydrogen, biogas, and bio-alcohols through waste-to-energy routes for global sustainable growth are added advantage. Biomass energy can play an important role in reducing greenhouse gas emissions, the use of biomass for energy offsets fossil fuel greenhouse gas emissions. At present, biomass is mainly used as a traditional fuel[11]. Many energy scenarios suggest large shares of biomass in the future energy system. The availability of this biomass are not always separately analyzed. Furthermore, large-scale utilization will have large consequences for land demand and biomass infrastructure, which should be assessed. Many studies have been undertaken to assess the future biomass energy potential [12- 15].

Biomethanation and Biogasification are popular terms used to describe the techniques of energy recovery from putrescibles [16]. The end product is the formation of approximately 60:40 mixtures of methane (CH_4), carbon dioxide (CO_2) and simultaneously generating an enriched sludge fertilizer [17 - 19] attested to the fact that during the anaerobic digestion (AD) process, 30 – 60 % of the digestible solids are converted into biogas. This can be burned in a conventional gas boiler and used to generate heat or electricity or both with an energy content of 22.5 MJ/m^3 as an added advantage and can be used as heat for nearby buildings including farmhouses, and to heat the digester. The natural generation of biogas was reported by [19] as an important part of the biogeochemical carbon cycle by methane producing bacteria (Methanogens) which are the last link in a chain of micro-organisms that degrade organic material and return the decomposition products to the environment.

As part of an integrated waste management system, [20] [21] has it that AD reduces the emission of landfill gas into the atmosphere, products can therefore, help farmers reduce their requirement for non-renewable forms of energy such as fossil fuels, and the digestate can be stored and then applied to the land at an appropriate time without further treatment, or it can be separated to produce fiber and liquor. The fiber can be used as a soil conditioner or composted prior to use or sale. The liquor contains a range of nutrients and can be used as a liquid fertilizer which can be sold or used on site as part of a crop nutrient.

When food waste goes to landfill, which is where the vast majority of it ends up, it decomposes without access to oxygen and creates methane, which is 25 times more deadly than carbon dioxide [22]. Whichever way you look at it; food waste is a major culprit in destroying our planet, and in fact if food waste were a country, it would be the third largest emitter of greenhouse gases after China and the USA [23]. The volume of these greenhouse gases and methane produced depends to an extent the rate of degradation of the food waste. This is why it is necessary to investigate the time rate of the degradation of the food waste and gas production in this study.

The aim of this study is to apply the water balance (WB) model in investigating the rate of degradation of putrescibles and gas generation in our municipal solid waste stream. The specific objectives are to investigate the time it takes for putrescible to undergo complete degradation in tropical climate of Nigeria via primary leachate (PL) generation.

II. METHODOLOGY

In this study, the rate of degradation via the amount of leachate generated considering trench method of waste disposal was investigated water balance model on a prototype landfill site in the Department of Agricultural and Environmental Engineering of Federal University of Agriculture Makurdi (FUAM).

Everyday food waste was regularly collected from kitchen and markets arena, characterized and stocked in a single celled prototype landfill (60cm by 60cm x 60cm) (Plate 1). While filling waste every day, the wet waste which (included cooked food) were placed first followed with the dry waste (mainly vegetable and fruit peels). This helped in reducing the generated foul odour to a certain extent. Apart from this, a layer of cover soil of 2cm thickness was placed on top of the waste to contain the odour. After filling up the cell, the substrate was left to degrade naturally. Turning of waste is done at regular intervals so that it helps in aerobic digestion of the waste thereby accelerating the decomposition. Primary leachate was collected daily through the leachate collection system (Plate 2)

Plate 1: Filling the cell with Putrescible

Plate 2: Leachate collection system

The observation period of eight weeks in the typical cell was used for the study in two different phases as explained below.

Phase 1 (Dumping) - in this phase, every day kitchen waste was dumped in cell. This took one week. During this period occasional rainfall happened which has increased the moisture content in the waste.

Phase II (Degradation) -in this phase the contents in the cell were kept open to degrade naturally. Frequent turning and breaking clods if any was done in this phase. This phase took another four weeks.

1) *Model Description*

The WB model proposed by [24] was applied to this single cell in this study bearing in mind that field capacity (F_C) of the waste changes rapidly during the first few days of operation. Thereafter F_C decreases gradually due to waste material degradation resulting in additional settlement. The amount of leachate obtained was computed for the period of eight weeks. The key parameters and modeling procedure were F_C, P_L and Time Interval (t).

Moisture content (M_C) of the waste in excess of F_C can be considered the main P_L generating component. The method presented by [25] was adopted to determine the moisture holding capacity using the following equations:

$$W(t)=F_C(t)*D(t) \qquad (1)$$

Where;

t = denotes the time from disposal of MSW,

W = is the mass of water held in waste (kg)

D = is dry weight of waste (kg).

$W(t\text{-}\Delta t) = F_C(t\text{-}\Delta t) * D(t\text{-}\Delta t)$ (2)

$= (F_C - \Delta F_C) * (D - \Delta D)$ (3)

Therefore the P_L (kg) is the difference in water content at any given pair of times:

$P_L(t) = W(t) - W(t\text{-}\Delta t)$ (4)

Where;

Δt = is the time interval.

Equation 4 simply states that moisture content at any time step equals the amount of water held in the waste, calculated for previous time step. Therefore *W(0)* (i.e. water held in waste at the first time step) will be the same as initial moisture content.

2) Model Assumptions

The model first assumed that;

- a single cell is waste filled and covered with cover material.
- The P_L collection system consisted of a layer of drainage gravel across the entire base of the cell, a geo-composite on the perimeter slopes, and a drainage gravel trench leading to a leachate collection system (Plate 2). The granular drainage media extends across the entire base.
- The leachate collection system collection system was a 5l plastic container.
- The deposited waste was neither compacted by earth moving equipment nor used daily cover.

3) The waste in the Bio-cell was therefore allowed to compact by its own weight. The total amount of waste deposited in the cell was determined and the organic content was also determined.

4) *Model Application*Here an attempt was made to estimate the amount of leachate generated at prototype landfill site. Part of the key parameters such as physical characteristics of the waste and climate data were sourced from previous studies, while parameters such as F_C and its variations as well as gas generation data were generated in situ.

5) Procedure

The term "cell" used hereafter is referred to the space filled with Putrescible in *H/h* days. A single cell water balance is provided for any desired period of time, considering the leachate component and the gas generated.

Biogas is produced within a landfill as a result of aerobic degradation of putrescibles. Assuming that the organic carbon content of the waste can partly be converted to biogas, the total amount of gas to be produced can be estimated using the following equation [26].

$G_{cell} = 1.868\, C\, (0.014\, T + 0.28)$ (5)

Where;

G_{cell}= is the total gas quantity (m^3/ton),

C = is the Total Organic Content (TOC) (kg/ton) and

T = is temperature in degrees of Centigrade.

P_L generated as a result of changes in moisture content, gas production and F_C at any given time can be determined for the cell using the following equation:

$PL_{cell}\ (t) = FC_{cell}\ (t - \Delta t)[\,D - G_{cell}\ (t - \Delta t) * d{-}FCcell\,t\ D{-}\ Gcell\,t{*}d$ (6)

Where;

d = *overall gas density*

The amount of water lost as vapour during gas generation, can be assumed to be about 0.01 kg per cubic meters of gas produced according to [25]. Therefore the total amount of water lost through waste degradation process can be determined as follows:

$WG_{cell}\ (t) = W_{cell}\ (t) + 0.01 d G_{cell}\ (t)$ (6)

The overall leachate quantity at time t for a single cell excluding infiltration/evaporation will be;

$PL_{cell}\ (t) = FC_{cell}\ (t - \Delta t)[D - G_{cell}\ (t - \Delta t) * d] - C_{cell}\ (t\,)[\,D - G_{cell}\ (t)\ *\ d] + WGcell\ (t)$ (7)

III. RESULTS

Table 1 present the main characteristics of the waste while Table 2 present the waste settlement pattern and gas generation at the dumpsite.

Table 1: In situ waste characteristics

Characteristics	in-situ value
Moisture content:	42% by weight
Density of fresh waste:	0.05 kg/m^3
Density of waste at landfill:	0.08 kg/m^3
Total Organic Carbon (TOC):	35% by weight

The range of variation in moisture content of the waste is about 40% to 44%. Values of other parameters are reported as single shut estimates followed by consistent field measurements.

Table 2: Waste settlement pattern and gas production

t (days)	H cm)	T(^oC)	pH	G	ΔG	G- ΔG
0	58	37	3.1	2.7	0	2.7
7	35	34	3.6	2.4	0.3	2.1
14	31	36	4.3	2.5	-0.1	2.6
21	22	36	5.7	2.5	0	2.5
28	24	35	7.1	2.4	0.1	2.5
35	18	37	8.9	2.7	-0.3	3.0
42	12	37	9.5	2.7	0	2.7
49	9	37	10.2	2.7	0	2.7

Estimation of initial F_C and its variation is a crucial task in modeling leachate quantity. The result of the evaluation of the time rate of degradation process of the food waste in the prototype dumpsite is as presented in Table 3 while Table 4 is the results of the application of model parameters in the proposed model for the degradation of putrescibles in FUAM

IV. DISCUSION

Results of the experiment presented in the study are discussed here. Figure (1), (2), (3) and (4) shows the waste settlement pattern, moisture content, pH variation and gas generation observed in a typical cell/bed (depth 60cm) during the I and II phases of the experiment.

It was observed that the waste attains a maximum of 40-50% settlement over a span of 40-50 days in the cell and. The settlement was recorded as a drop in height of the substrate column in the cell concerned. The time rate of settlement was best described by an exponential function with a regression coefficient of 0.95 which is as a result of non-uniformity in precipitation (Figure 1). A general decrease was observed with time.

Table 3 Primary leachate and degradation process of the food waste in the prototype dumpsite

Time(days)	F_C(%)	ΔF_C	F_C -ΔF_C	D(kg)	ΔD	D-ΔD	W(t)(kg)	W(t-Δt) (kg)	P_LW(t)- W(t-Δt)
0	100	0	100	10.0	0	10	1000	1000	0
7	81	19	62	7.9	2.1	5.8	639.9	359.6	280.3
14	76	5	71	6.6	1.3	5.3	501.6	376.3	374.3
21	61	15	46	5.2	1.4	3.8	317.2	174.8	175.3
28	53	8	45	3.5	1.7	1.8	185.5	81	104.5
35	47	6	41	3.0	0.5	2.5	141.0	102.5	38.5
42	32	15	17	2.7	0.3	2.0	86.4	34	52.4
49	22	10	12	2.3	0.4	1.9	50.6	22.8	27.8

t = denotes the time from disposal of MSW *W* = is the mass of water held in waste (kg) *D*= is dry weight of MSW (kg).

Table 4 Model parameters from the degradation of food wastes

Model Parameter	Furmula	Calculated Value
Area of cell (Acell)	L x B	0.36m^2
Volume of cell (Vcell)	L x B x H	0.216m^3
Volume of waste (Vww)	L x B x h	0.208m^3
Volume of cover material (Vcm)	L x B x 2	0.076m^3
Volume of substrate (Vs)	Vww + Vcm	0.284m^3
Mass of wet waste Mass of oven dried waste (D)	Mww Mdw	16.64kg 10kg
Density of waste	Mww/Vww	0.08kg/m^3
Mass of water (Mw)	Mww-Mdw	6.64kg
Volume of water (Vw)	Mw/ 1000kg/m^3	0.00664m^3
Field Capaciyty (F_C) Over all gass density	Mw/Mdw D	0.664 0.554kg/m^3
Primary leachate (PL)	*W(t)- W(t-Δt)*	1053kg/m^3(1.053m^3)
Weight of empty crucible	M_1	18g
Weight of empty crucible + 5g of compost	M_2	23g
Weight of empty crucibles + ash	M_3	20g
TOC Gass produced from cell (G_{cell})	(M_2 – M_1)/(M_3-M_1) 1.868 C (0.014 T+0.28)	2.5 2.7

Field capacity (*Fc*) decreases with time and height of waste substrate in the cell meaning that it is a time dependent variable; therefore F_C as well was introduced as a function of time in degradation. According to [25] [27] [28], influencing parameters for the drop in volume recorded as settlement are the composition of the waste, operation practices and factors affecting biodegradation particularly moisture content. The rate of degradation as a function of F_C is been described by a first order polynomial function with high correlation of 0.98 regression coefficient (Figure 2)

Figure 3 shows the wet weight content variation of the waste during the I and II phases. This is said to have direct implications on the waste settlement as higher initial moisture in the fresh waste makes it more compressible. Since the substrate in the cell is solely organic kitchen waste a uniform settlement pattern is observed without much differential settlement. Though differential settlement can happen to an extent in biodegradable waste, certain operational and maintenance practices which are followed in the experiment such as sorting, pre-treatment (turning and compacting) can ensure that differential settlement (if any) is taken care of. The frequent turning of the waste reduced the particle size and rendered the process more aerobic making the decomposition faster and consequent settlement faster. Reference [29] has earlier noted that the rate of settlement is greater due to increase in degradation.

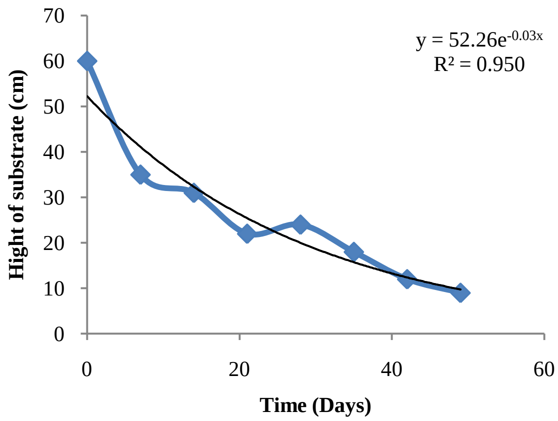

Figure 1: Time rate of Settlement of Substrate

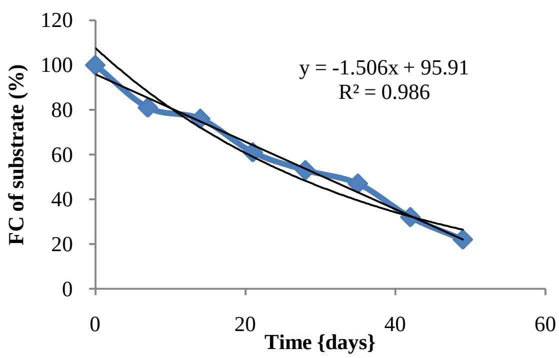

Figure 2; Trend in F_C of substrate vs time

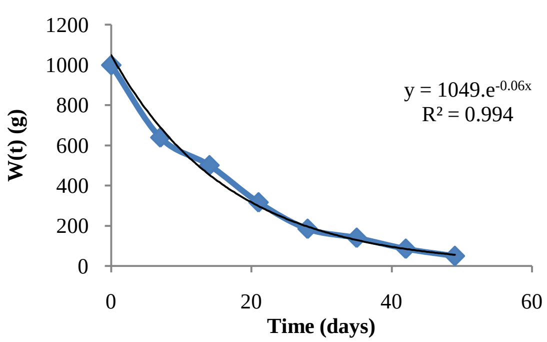

Figure 3: Variation of wet weight with time.

The significance of attaining 40-50% settlement is that it aids in ensuring enough space to run the cyclic process in which dumping of waste and degradation alternates. This in turn enhances the chance for development of landscaped landfill that can be implemented as a continuous and sustainable process as reported by [30].

The primary leachate as a function of degradation increases sharply in the phase I of the experiment due to high initial moisture content but decreases with time in phase II of the experiment in a nonlinear manner. Gas generation however is almost constant with time although staggering increase and decrease were recorded which could be attributed to turning process of the substrate. Each turning increases aeration for microbial activities hence momentarily increasing gas formation.

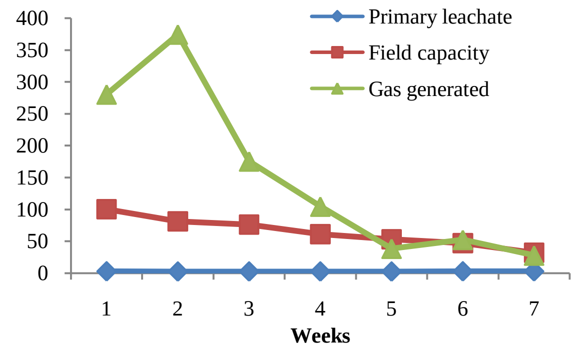

Figure 4: Primary leachate, field capacity and gas generation as function of time

V. CONCLUSION

The experiment that is documented in this paper was conducted as a part of a broader urban level scheme of developing n landfills both at neighbourhood and small urban levels. The results from the experiment suggests that, if through an organized segregation of urban waste, its biodegradable putrescibles fraction can be brought to a designated landfill space and left to degrade naturally over a specific period of seven weeks (49 days). The degraded refuse which is of high nutrient content can support the soft elements of landscape thereby turning an open dump/landfill into a landscaped landfill. The leachate generated can be a data base for studies an groundwater contamination. Methane formation over time gives idea into mitigation of ozone depletion but if properly harnessed, it become economic boast as it can be used for energy generation for several purposes. By considering the number of households, their expected quantity of waste generation within the neighbourhood premises a monogram can be prepared with depths, degradation time, primary leachate and gas generation as variables which can be a database for the authorities determining the area required for developing landscaped landfills in a particular neighbourhood.

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