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DEVELOPMENT OF LOCALLY-FABRICATED BIODIGESTER FOR FERTILIZER PRODUCTION

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ABSTRACT
The effects of over dependent and continuous fertilizer usage indiscriminately on soil have resulted to the fertility and structural arrangement imbalance. Based on this, farmers have been searching for alternative substitutes to support their agricultural production and also maintain soil stability. However, such practice has been handled in local ways by gathering waste to dry before applying them directly. This technique does not totally eliminate the harmful pathogens in such waste but rather minimize them. This work therefore, aimed to design biodigester to compost cow dung waste into slurry, which was subsequently converted to biofertilizer for agricultural use. This aim was achieved by designing the digester, using the feedstock's properties to carry out detail material balances across it. The data generated from the input and output process streams were used to come up with the digester design specifications of 0.022 m^3, with the height, radius and clearance of 0.42 m, 0.14 m and 2 mm respectively. The digester was constructed based on these specifications and used to produce 1.4 kg of biofertilizer per batch. It was concluded that the digester is economically viable with 60 % waste conversion into useful product.

INTRODUCTION

One of the challenges often encountered in cultivating lands in Nigeria is poor conservation of soil nutrients (Razzaullah *et al*., 2002). This challenge however, had been handled over time by supplementing the soil with chemical fertilizers, which proved to have improved soil nutrients, however tend to cause soil structural imbalance as a result of leaching effects afterwards (Razzaullah *et al*., 2002). The work of Razzaullah *et al*. (2002) and Adekunle *et al*. (2017) reported that, the utilization of chemical fertilizer unsystematically on soil has negatively affected soil nutrients regeneration over the years. It was also stated in their findings that, chemical fertilizer been synthetic in nature and majorly produced from natural gas derivatives, will increase demand and competition with feedstock for energy generation. However, biofertilizer whose major feedstocks are manure and other organic waste has been identified as suitable substitute to chemical fertilizer, due to its environmentally friendly nature.

The strains of microorganisms in biofertilizeris efficient to increase nutrients supply and its uptake for plant growth (Anil *et al*., 2016; Andressa *et al*., 2017). However, chemical fertilizers been formulated from synthetic origin utilized more energy during the formulation processes (Neni *et al*., 2004; Khanom *et al*., 2008; Stanley, 2002). Moreso, the process of producing biofertilizer through digester is less cost effective when compared to chemical fertilizer production process due to their low operating temperature conditions (Hartman *et al*., 2002; Ozor *et al*., 2014).

Averagely, Nigeria generates 61 million tons of abattoir waste in a year as reported by Stanley, (2002) and James, (2003), which is one of the justifications for this work because useful byproducts from the waste such as cow dung slurry and methane can subsequently be converted into biofertilizer and energy respectively. However, the management of waste from abattoir which has inherent effects on the environment has been a problem due to the complicated similar system of handling solid waste treatment technique and cost of operation. To this effect, a simple and less cost-effective treatment technique using anaerobic digester has proven efficient in converting the waste into useful products. Therefore, such waste management system minimizes the waste and its potential pollution effect to the environment when disposed. This paper aimed therefore to design biodigester to produce biofertilizer for agricultural use.

METHODOLOGY

Design and Development of Digester

The input flow rate using the feedstock inflow and output outflow across the biodigester were determined through the detail material balance technique. Equation 1-3 showed the detail series of reactions involving the transformation of complex composting reactions. These Equations were adopted from the works of Ernest (1999) and Mir *et al.* (2016).

As reported in the work of Maz *et al.* (2001); Roy *et al.*, (2006); Wang *et al.* (2014); Ayesha *et al.* (2016); Staff, (2018), glucose hydrolyzed into its aqueous form, hydroxide and hydrogen aspresented in Equation 1.

$C_6H_{12}O_{6(s)} + 2H_2O_{(l)} = C_6H_{12}O_{6\,(aq)} + 2OH + H_2$ ...(1)

The simple sugar can also be broken down into either ethanol and carbon dioxide as shown in Equation 2.

$C_6H_{12}O_6 = 2CH_3CH_2OH + 2CO_2$ ...(2)

When methanogenic bacteria acted upon the decomposition of ethanol formed in Equation 2, the end products will be methane, carbon monoxide and other waste which was assumed in this work to be slurry. The slurry was subsequently converted into fertilizer as shown in Equation 3.

$CH_3CH_2OH = CH_4 + CO + \text{Slurry}$ ...(3)

From the law of conservation of mass, at steady state system, input is equal to the output. This law guides the principle of material balance. Also, it is important to state the basic engineering design assumptions and basis made. Therefore, the assumptions made are:

I. Basis: 6 kg of cow dung was composted
II. Amount of gases expected to be produced from the compost should be 60 % of the total mass. This is because, 60 % - 70 % of biogas is produced from cow dung compost as reported in literatures by Wang *et al.* (2014).
III. If the total gas within the system was assumed to be 60 % of the total feedstock composted, the remaining content such as slurry will be 40 %.
IV. Thus, 40 % of 6 kg = 2.4 kg of the slurry
V. The molar mass of the compounds involved are: CH_3CH_2OH= 46 g/mol, CH_4 = 16 g/mol, CO = 28 g/mol, the slurry = unknown

Considering Equation 3, if 6 kg of the feedstock (CH_3CH_2OH) has molar mass of 46 g/mol,therefore the molar mass of the slurry with 2.4 kg composition will be:

The molar mass slurry = 2.4x46/6 = 18.4 g/mol
Based on the 60 % assumption of the total gas (CH_4 + CO) involved
Mass of methane and carbon dioxide = 60/100 x 6 = 3.6 kg or 6 kg - 2.4 kg = 3.6 kg
Total molar mass of methane and carbon dioxide (CH_4 + CO) = 16 + 28 = 44 g/mol
Therefore:
The output stream in terms of mass = 2.4 + 3.6 = 6 kg
Total output stream in terms of molar flow = 28 + 18.4 + 16 = 62.4 g/mol
Amount of CH_4 in the total gas = 16/44 x60 = 21.82 %
Amount of CO in the total gas = 28/44 x 60 = 38.18 %
Amount of slurry in the system = 18.4/18.4 x 40 = 40 %
Therefore:
Total components amount = 21.82 + 38.18 + 40 = 100 %
Converting the percentage compositions into mass in (kg), the masses of the following components were determined as:
CH4 = 21.82/60 x 3.6 = 1.31 kg
CO = 38.18/60 x 3.6 = 2.29 kg
Mass of slurry was determined to be 2.4 kg (on the basis of 40 % assumption)
Therefore, the total output mass across the digester = 1.31 + 2.29 + 2.4 = 6 kg

Basic Assumption

The produced biofertilizer contains moisture, however if 60 % conversion is assumed, the weight of the moisture content present is calculated as follows:

Mass of the moisture content in the produced biofertilizer = 40/100 x 2.4 = 0.96 kg

Therefore, the actual mass of the biofertilizer = 2.4 - 0.96 = 1.4 kg

The Digester Design

The digester feedstock operating volume is given as:

(V_0) = Total substrate input ... (4)

In design and development, safety factors are incorporated in any process design to give room for allowances for the purpose of future improvement and re-design. The safety factor incorporated in the digester design as adopted from Perry's Chemical Engineers handbook by Robert *et al*. (2007) is given in Equation 5 as:

$$V_A = V_0/0.9 \quad ...(5)$$

Also, the relationship between volumeand height for cylindrical shape as reported by Sinnott (2003) and Robert *et al*. (2007) is given as:

$$V_T = \pi r^2 h \quad ...(6)$$

From Equation 6, V_T = Total volume, r = digester radius and h = digester height

For a cylindrical shape digester or reactor, h = 3r (Robert *et al*., 2007)

Therefore, equating for 'r' in Equation 6 and rearranged, it gives the relationship in Equation 7:

This implies that, $r = (V_T/3\pi)^{1/3}$ ...(7)

Design Assumptions and Basis

The operating temperature range = 25°C - 40°C.

Operation process: Batch operating process

Ratio 3:1 of cow dung to water was used to aid the composting process

To Determine Density of the Feedstock

The feedstock measured in (kg) was converted to volume to maintain consistency in the units. This was carried out using displacement technique.

The steps adopted are:

10 g (0.01 kg) of cow dung was weighed and kept in a beaker

150 ml of water was measured using measuring cylinder = V_1

The cow dung measured was dissolved in the measuring cylinder containing water

The solution was allowed to stand and observed for one hour

The total volume rise was recorded after an hour as 180 ml = V_2

New rise in volume (V) = V_2 - V_1 = 180 - 150 = 30 ml

Therefore, the volume needed to determine the density = 30 ml, which is equivalent to 0.00003 m3

This implies that, if the volume of cow dung usedand its mass are 0.00003 $m^3$and 0.01 kg respectively, the density will be:

(ρ) = 0.01/0.0003 = 333.33 kg/m^3

Thus, using 6 kg as the base weight, the volume will be:

6.0/(333.33) = 0.018 m^3

The volume of water used in the composting processed (based on the design assumption) = 2L which is also equivalent to 2/1000 = 0.002 m^3

Thus: V_O= 0.002 + 0.018 = 0.02 m^3

Using Equation 5, V_A= V_O/0.9 = 0.02/0.9 = 0.022 m^3

To determine the digester radius, Equation 7 was used:

Thus: $r = (VT/3\pi)^{1/3} = (0.022/3 \times 3.142)^{1/3} = 0.14$ m

Since h = 3r, therefore; r = 3 x 0.14 m = 0.42 m

RESULTS AND DISCUSSION

Material Balance Analysis of the Digester

The input flow streams and output products from the digester composting process that were obtained from the material balance analysis are presented in Table 1

Table 1: Material balance of the raw material decomposition across the digester

	Input streams		Output streams	
Parameters	Input mass (kg)	Composition (%)	Output mass (kg)	Composition (%)
Feedstock	6	100		
CO			2.29	38.18
CH_4			1.31	21.82
Slurry			2.4	40
Total	**6**	**100**	**6**	**100**

The total input feedstock in terms of weight is equal to the output streams flow as presented in Table 1, which was recorded to be 6 kg in both cases. Also, 100 % was obtained for both input and output flow composition, which are equal and desirable based on the law of conservation of mass. Moreso, the biofertilizer products obtained from the digester contains moisture, whose balances are presented in Table 2.

Table 2: Material balance of the products and the biofertilizer feedstock

Input streams			**Output streams**	
Parameters	Input mass (kg)	Composition (%)	Output mass (kg)	Composition (%)
Slurry	2.4	100		
Biofertilizer	-	-	1.4	60
M.C	-	-	0.96	40
Total	**2.4**	**100**	**2.4**	**100**

M.C = moisture content

As shown in Table 2, the output product streams and input streams are desirable because the values obtained were equal in terms of both masses recorded as 2.4 kg and percentage compositions of 100 % in both cases, which is in agreement with the law of conservation of mass. Also, the material balance analysis proved that, 40 % of the 6 kg cow dung feedstock was converted into biofertilizer on wet basis with 60 % conversion rate as shown in Table 2.

Design Specifications Results

The detail designed digester specifications are presented in Table 3. The 0.42 m of digester height obtained was three times as large as the radius of the digester specification recorded to be 0.14 m proved a good theoretical relationship between them.

Table 3: The digester design specifications

Digester components	**Dimensions**
Volume (m^3)	0.022
Height (m)	0.42
Radius (m)	0.14
Clearance (mm)	2.0

Plate I (a) and (b) showed the front-side-top views projections and 3D-view of the digester respectively.

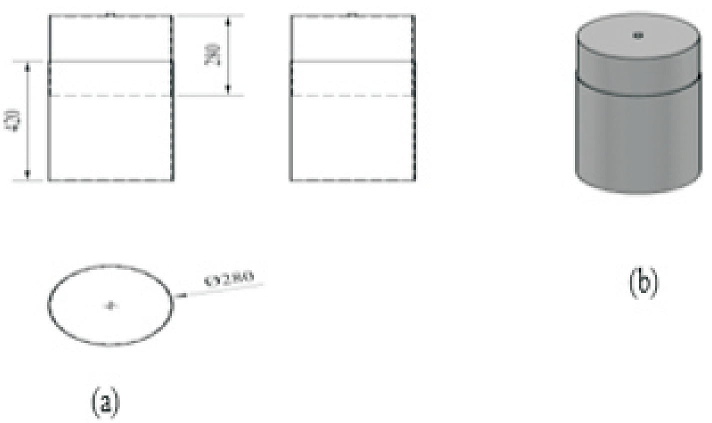

Plate I: (a). Front, side and top views projections (b). 3D-view of the digester

The Digester Material Selection

The resistance to corrosion and durability of stainless steel 304 was one of the major criteria for its choice of selection over other types of construction materials selected for the fabrication of the digester based on the designed specifications.

CONCLUSIONS

At the end of this investigation, the designed digester has total volume of 0.022 m^3 capable of producing1.4 kg of biofertilizer. The 60 % conversion achieved proved that this technique of waste management system is viable with low cost and simple operation process. Therefore, it is concluded that, anaerobic composting system was successfully developed and has proven to be a good choice for converting waste into useful product.

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