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Design and Fabrication of Small-scale Bio-digester for Bio-fertilizer Production from Locally Sourced Construction and Organic Materials

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Abstract Applying chemical fertilizers causes environmental pollution, but bio-fertilizers produced from bio-digesters provide an environmentally friendly alternative. This study designed and fabricated a bio-digester having 22 kg size, 42 cm height and 32 cm inner diameter. Galvanized steel, fiber glass and stainless steel were used for fabrication. Holes were provided for organic materials (poultry dung, cattle dung, cooked jollof rice and beans), stirring shaft and control panel. Organic materials were sourced in Ota before microbial characterization, grinding and mixing were conducted. Retention time was 28 days and digestate samples were obtained at 7 days interval for analyses. *Bacillus, Pseudomonas* and *Escherichia coli* species were commonest bacteria isolated. Digestate analyses on 28th day in mg/l were; pH (7.2); Temperature (32 °C); Nitrogen (18251); Phosphorus (6215); Carbon (98236); Potassium (1379.3); Electrical conductivity (15.00); Calcium (71.8); Magnesium (60.0); Manganese (73.5); Iron (19.5); Zinc (31.6); Aluminium (2.4); Biological oxygen demand (226.1); Chemical oxygen demand (99.3); Total solids (8.85%); Moisture (0.55); and Escherichia coli ($8.1 * 10^5$ MPN/G). Organic materials were fit for bio-fertilizer production since digestate results met United States Environmental Protection Agency standards, but further studies can vary mixes in separate digesters for optimized results.

Keywords: Organic materials, Retention time, Bio-digester, Bio-fertilizer

I. Introduction

Environmental preservation is becoming increasingly popular globally because of environmental pollution. Environmental pollution usually caused by indiscriminate use of chemical fertilizers, improper waste disposal, unregulated fossil fuel exploration and production of greenhouse gases often results in global warming, ice melting, irregular rainfall, wildfires and climate change [1, 2]. Consequently, the controlled exploration and exploitation of natural resources, coupled with the proper disposal of wastes generated from such activities, or the conversion of the wastes into useful energy are some of the methods recommended by the United Nations and other regulatory bodies [3, 4]. These methods will effectively reduce environmental pollution and its attendant consequences in the planet, if they are properly implemented.

Consequently, researchers have developed various environmentally friendly ways of converting wastes to wealth, while also generating affordable energy necessary for industrial development, especially in developing countries [5]. Among the different methods developed by scholars for affordable energy generation from wastes is the production of bio-

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fertilizers [6]. Bio-fertilizers are environmentally friendly organic manures that do not just enrich agricultural soil, but also preserve the natural state of the soil [7]. Furthermore, bio-fertilizers provide critical nutrients for plant growth, through improvement of the microbial processes taking place in the soil. Also, bio-fertilizers make it easier for plants to assimilate nutrients through breakdown by microorganisms [8].

According to [9], this breakdown by microorganisms usually happen under anaerobic conditions in a reactor called bio-digester. Similarly, some of the unique properties of bio-fertilizers which make them desirable alternatives to chemical fertilizers are chemical oxygen demand, biological oxygen demand, temperature, pH, bulk density, carbon/nitrogen ratio and total solids content [10]. Some of the bio-fertilizer properties and their minimum standard requirements are shown in Table 1. The total solids content of bio-fertilizers include all the dissolved, colloidal and suspended solids in each grab sample which forms the bulk of the fertilizer [11]. The organic materials introduced into the bio-digester make up the primary substrates which are converted by the microbes into bio-fertilizer [12]. This is important because in the continuous mode anaerobic digestion system, secondary substrates (fresh materials) can be continuously added to the mix at predetermined intervals, to increase microbial activities in the bio-digester [13]. Conversely, in the batch mode anaerobic digestion system, the organic materials required for bio-fertilizer production are thoroughly ground and mixed before they are poured only once into the bio-digester. Therefore, to guarantee the optimal functioning of this system, co-digestion of different organic materials having nearly the same essential parameters in the bio-digester should be carried out [14].

Also, if there is a continuous process that is fed for a long period with a substrate that is very uniform (a sugar-rich material), it may become difficult to digest fats and proteins in such a system [15]. This will result in the death of most of the microbes that have the capacity to break down proteins and fats.

However, substrates that are not too uniform enhance the growth of multiple types of microbes in the digester [16]. Therefore, multiple co-substrates are desirable because they increase the possibility of a robust and stable process. If a diverse microbial community is able to develop and grow through the decomposition of various components, the process will develop the ability to handle large future differences in co-substrates composition [17]. Furthermore, co-digestion enhances the chances of the process to manage substrates that contain harmful components. If there are various microorganisms at the beginning which fulfill the same functions as the breaking down of sugars, the process will continue to perform as expected [18]. Therefore, in order to accomplish a stable digestion process with a variety of organic materials, co-digestion should happen under controlled conditions in a bio-digester.

It is also critical to understand the composition of the organic materials to have a suitable mixture of various components, thereby having a regular supply of substrates provided to the microbes [19]. Consequently, this understanding will help in maintaining the essential operating parameters in the bio-digester at optimal conditions. According to [20, 21], some of the essential parameters for this process that must remain optimal are; pH (between 5.5 and 8.5); temperature (between 30 °C and 35 °C);

Table 1: USEPA (2024) Standards for Bio-fertilizer Production

Parameters (mg/l)	**Horticulture**	**Agriculture**	**Orchards/ Silviculture**
Color	Dark brown	Brown	Brown
Odor	No offensive odor	Low odor	Low odor
Ph	5.5 to 8.0	5.0 to 8.0	5.5 to 8.0
Salinity (ds/m)	Less than 3.0	Less than 6.0	Less than 3.0
Nutrients	N.P.K. Mg. Ca	N.P.K. Mg. Ca	N.P.K. Mg. Ca
Water retention	>100% (200% preferred)	>100% (200% preferred)	>100% (200% preferred)
Total solids	8.0	8.0	8.0
% moisture	35-55%	35-55%	33-55%
Temperature	25 – 35 (°C)	25 – 35 (°C)	25 - 35 (°C)
Particle size	½”	½” to 1”	Less than 1”
Stability	Highly stable	Highly stable	Highly stable
C/N ratio	20:30	20:30	20:30
Weed seeds	None	None	None
Inerts	<1%	<1%	<1%
Pathogens (MPN)	Coliform: <1000 Salmonella: <3	Coliform: <1000 Salmonella: <3	Coliform: <1000 Salmonella: <3
Metals/Trace elements	Must pass	Must pass	Must pass

carbon/nitrogen ratio (should be 20:30); retention time (between 15 and 30days); and total solids content (between 7% and 9%). When these essential parameters are maintained at their optimal ranges, the microbial community in the bio-digester will thrive throughout the retention time, thereby producing a nutrient-rich bio-fertilizer eventually.

Furthermore, [22] reported that there are three major design types of anaerobic digesters and these designs vary based on climate differences, retention time, type and amount of organic materials to be used. These designs are; covered anaerobic lagoons, plug flow bio-digester and total mixed digester. Anaerobic lagoons resemble covered ponds where organic materials are introduced at one end and the sludge is withdrawn at the other end. This type of affordable digester is mostly used for dairy or swine dung and uses a flush system to transport the fertilizer. However, this method has a low reaction and temperature rate, and the solids can become clogged at the digester base. Consequently, mixing is impossible because the lagoon is covered, while more energy and time are also required to screen the solids [23].

For the plug flow digester, a long tube is used to transport organic materials from one end to another. After digestion of the organic materials, more materials can be introduced through the inlet again. The success of this digester is linked with using organic materials having higher solids content ranging between 11% and 14% [24]. This type requires less maintenance as fewer moving parts are available. For the total mixed digester, the organic materials are poured into a single reactor and an agitation system is introduced to mix the content while it is being digested. Thereafter, a flush system is used to collect the sludge at the end of the process [25]. This system is more popular because of its efficiency, ease of agitation, affordability and compactness.

However, according to [1, 2, 6, 30], most poultry farms in Nigeria usually dispose their wastes (animal dung) indiscriminately into the open environment, while many farmers also rely on chemical fertilizers for their agricultural needs. These acts of indiscriminate waste disposal and application of chemical fertilizers often result in environmental pollution, while also contributing to climate change. Based on the available designs, this study therefore designed and fabricated a total-mixed low-cost batch mode anaerobic bio-digester for bio-fertilizer production, using locally sourced construction and organic materials.

II. Materials and Methods

A. Materials and equipment used

The materials used for this study were; fresh poultry dung, fresh cattle dung, freshly cooked jollof rice, cooked beans and potable water. Furthermore, the equipment used for this study were; anaerobic bio-digester, pH meter, thermometer, milling machine, weighing scale, agar plates, incubator, autoclave and atomic absorption spectrophotometer (AAS).

B. Materials sampling and microbial community analyses

The poultry and cattle dung used for this study were obtained at an integrated animal farm in Ota Township, while the freshly cooked jollof rice and beans were collected from a restaurant located at Downtown Area, Bells University of Technology, Ota, Ogun State, Nigeria, located within longitude 3° 9' 41.5908" E and 3° 10' 37.9596" E and latitude 6° 41' 0.2112" N and 46° 41' 27.8988" N. The poultry and cattle dung were obtained raw, while the food materials had been cooked because [26] reported that freshly cooked food containing significant oil, carbohydrates and fat contents aid in the survival and optimal functioning of microorganisms required for the digestion process. The materials were stored in sealed containers and thereafter transported into the Laboratory of the Department of Civil and Environmental Engineering, Bells University of Technology, Ota, Ogun State for the commencement of digestion and composting.

For the analyses of the microbial community, 45 ml samples each of the poultry dung, cattle dung and food materials were collected and refrigerated at – 20 °C, in order to allow for the total genomic Deoxyribonucleic acid (DNA) of the samples to be extracted. Eventually, a polymerase chain reaction and gel electrophoresis were conducted sequentially to analyze all the bacteria present according to [27, 28]. The food wastes were thoroughly ground into required fractions and made to pass through the 20-mesh sieve diameter (1mm diameter screen size) in order to make it easier for the microorganisms to consume and digest the materials easily. Furthermore, the organic materials had a combined weight of 12kg, with 5liters of potable water measured to mix the materials well before pouring them into the bio-digester to on the first day of the experiment. Subsequently, 1 liter of potable water was added at seven days interval throughout the retention time.

The seven days interval of water addition allows for the continued thorough mixing and breakdown of the organic materials in the bio-digester, which also provided a larger surface area for the microorganisms to easily complete the digestion and composting process. The retention period in the bio-digester adopted for this study was 28 days as recommended by [29]. Care was taken to prevent the entry of atmospheric air into the bio-digester during the weekly water addition and regular agitation of the organic materials.

C. Design and fabrication of bio-digester

The 22 kg pilot batch bio-digester was fabricated according to the design of [30] as shown in Figure 1. It was built with a cylindrical shape having an airtight lid to provide the anaerobic condition required for the success of this experiment. Three different materials were used in the fabrication; galvanized steel, fiber glass and stainless steel. Galvanized steel was used to fabricate the outermost layer to prevent corrosion of the structure, while also ensuring ease of transportation. Fiber glass was selected for fabrication of the middle layer to avoid heat loss, while also guaranteeing constant temperature within the layer. Stainless steel was adopted in fabricating the innermost layer for prevention of corrosion due to interaction between acids and bases that will be generated in the mixture. The digester dimensions were 42 cm height, 32 cm inner diameter and 22 kg size.

The bio-digester cylindrical shape was selected because of its lesser material consumption and ease of construction relative to other shapes. Furthermore, it encourages maximum heat retention necessary for optimal microbial activities in the bio-digester throughout retention time. Three holes were drilled above the bio-digester to provide inlet for loading organic materials, to allow for the control panel built for regulating pH, and to accommodate the shaft of a stirring system having flat stirring paddles. Since the digestion system used for the study was the batch mode and the bio-digester volume is 22 kg, the total mass of the substrates and working volume adopted were 12 kg as recommended by [30]. This is because providing adequate working volume in the bio-digester makes bio-fertilizer collection easier when the process is over.

However, if the entire space in the bio-digester is used up during loading, it becomes impossible to achieve even mixing of the organic materials, thereby inhibiting thorough digestion.

D. Collection and laboratory analyses of digestate samples

On a weekly basis, digestate samples were

Figure 1: Designed and Fabricated Bio-digester

obtained from the bio-digester for the laboratory analyses of their physical, chemical and microbial parameters. Samples were obtained on day 7, day 14, day 21 and day 28, respectively and were taken to the Central Research Laboratory, Bells University of Technology, Ota, Ogun State, Nigeria for analyses. The parameters analyzed were; pH, Temperature, Total Solids Content, Zinc, Aluminium, Iron, Moisture Content, Nitrogen, Phosphorus, Potassium, Carbon, Carbon/Nitrogen Ratio and Escherichia Coli. The laboratory analyses were carried out according to [31] standards, while the results obtained were compared with [32] standards for bio-fertilizers.

III. Results and Discussion

A. Microbial characterization

The results obtained from the analyses of the microbial community revealed that microorganisms present in poultry dung, cattle dung and food materials were; *Pseudomonas* species,
Flavobacterium species, *Methanobacterium* species, species and *Staphylococcus* species. The results also showed that the bacteria isolated mostly existed within the mesophilic temperature range (25 °C and 40 °C) and these were; *B. licheniformis, S. epidermidis, P. cepacia, P. Aeruginosa, L. casei, S. xylosus, S. saprophyticus, S. aureus*, *L. brevis and L. plantarum*. These bacteria identified confirmed that the organic materials used were suitable for anaerobic digestion and bio-fertilizer production, because [3, 13, 30] earlier concluded that these microorganisms are critical for driving the process.

B. Physical and chemical analyses

The physical and chemical results obtained as revealed in Tables 2, 3, 4 and 5 showed that the pH and temperature parameters analyzed on the 28th day were within the [32] standards as shown in Table 1 and this was also responsible for the sustained growth and survival of the microorganisms. These results are in agreement with the findings of [6] which reported average pH value of 7.4 and temperature value of 33 °C.

Table 2: Digestate Sample Results at 7 Days

S/N	Parameters	Results (mg/l)
1	pH	7.2
2	Temperature	25 (°C)
3	Nitrogen	17560
4	Phosphorus	5210
5	Carbon	92390
6	Potassium	1371.5
7	Electrical Conductivity	14.2
8	Calcium	69.7
9	Magnesium	57.3
10	Manganese	71.3
11	Iron	18.3
12	Zinc	29.4
13	Aluminium	2.2
14	Biological Oxygen Demand	210.3
15	Chemical Oxyen Demand	98.2
16	Total Solids Content (%)	7.34
17	Moisture Content	0.52
18	Escherichia Coli	69000 (MPN/G)

Table 3: Digestate Sample Results at 14 Days

S/N	Parameters	Results (mg/l)
1	pH	7.2
2	Temperature	28 (°C)
3	Nitrogen	17595
4	Phosphorus	5350
5	Carbon	94120
6	Potassium	1388.2
7	Electrical Conductivity	14.6
8	Calcium	72.6
9	Magnesium	59.6
10	Manganese	70.8
11	Iron	79.9
12	Zinc	29.8
13	Aluminium	1.6
14	Biological Oxygen Demand	214.8
15	Chemical Oxygen Demand	102.1
16	Total Solids Content (%)	7.98
17	Moisture Content	0.65
18	Escherichia Coli	72000 (MPN/G)

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Table 4: Digestate Sample Results at 21 Days

S/N	Parameters	Results (mg/l)
1	pH	7.3
2	Temperature	30 (°C)
3	Nitrogen	18101
4	Phosphorus	5490
5	Carbon	97050
6	Potassium	1415.8
7	Electrical Conductivity	14.4
8	Calcium	70.3
9	Magnesium	61.2
10	Manganese	74.9
11	Iron	20.2
12	Zinc	31.3
13	Aluminium	1.9
14	Biological Oxygen Demand	220.6
15	Chemical Oxygen Demand	100.6
16	Total Solids Content (%)	8.55
17	Moisture Content	0.55
18	Escherichia Coli	77000 (MPN/G)

Table 5: Digestate Sample Results at 28 Days

S/N	Parameters (mg/l)	Results (mg/l)
1	pH	7.2
2	Temperature	32 (°C)
3	Nitrogen	18251
4	Phosphorus	6215
5	Carbon	98236
6	Potassium	1379.3
7	Electrical Conductivity	15
8	Calcium	71.8
9	Magnesium	60
10	Manganese	73.5
11	Iron	19.7
12	Zinc	31.6
13	Aluminium	2.4
14	Biological Oxygen Demand	226.1
15	Chemical Oxygen Demand	99.3
16	Total Solids Content	8.85
17	Moisture Content	0.55
18	Escherichia Coli	81000 (MPN/G)

Similar to the microbial results, the temperature range obtained from the digestate samples was the mesophilic type, while the average pH value in the results was 7.2. These results according to [6], are the optimal values for anaerobic digestion, thereby confirming the fitness of the digestate for use as bio-fertilizer. Similarly, [32] also recommended a pH range between 6.5 and 7.5 for bio-fertilizer production, although a pH range between 6.0 and 7.0 can also be suitable. Likewise, the electrical conductivity value obtained on the 28th day revealed that salts and sulphates such as sulphur, potassium, phosphate and heavy metals like iron, zinc, magnesium, manganese and aluminium were significantly present as shown in Tables 2, 3, 4 and 5. This according to [33] could lead to the production of foul odour in the bio-digester if care is not taken, because when these essential elements are present in high amounts, the bacteria necessary for optimal functions will become inhibited.

Furthermore, other results obtained as shown in Tables 2, 3, 4 and 5 showed that the biological oxygen demand, the chemical oxygen demand, the total solids content, the moisture content and the Escherichia Coli values were mostly within [32] standards as shown in Table 1. This shows that the anaerobic condition in the bio-digester was favourable enough, because a minimum total solids content of 8 will provide enough feedstock for the microorganisms to survive. Consequently, this was responsible for the sustained microbial growth and activity in the bio-digester as shown in the high values of Escherichia Coli. Similarly, [6] reported that the moisture or water content of a bio-digester is highly instrumental for the optimal mixing of its constituents. When there is adequate mixing of the constituents in the bio-digester, the anaerobic bacteria will survive.

Also, total solids are the commonest determinants of both inorganic and organic solids in the bio-digester. Conventionally, the biological oxygen demand and the total solids concentration of an anaerobic medium can be used as the indicator of the general performance of the septic system. In addition, [1] reported that the total solids content of a bio-digester are usually high at the beginning of the process, but after the process of settling in the system, the solids content level often falls. This fall in the solids content may signify that the materials have been consumed by the microorganisms. Therefore, when compared with the requirements of [32] as shown in Table 1, the digestate in the bio-digester met the minimum requirements for bio-fertilizer. These results further underscore the importance of having the total solids content of a bio-digester within the optimal range, to guarantee optimal microbial growth and bio-fertilizer production.

IV. Conclusion

In this study, a 22 kg bio-digester was designed and fabricated for bio-fertilizer production. Through standard microbial characterization techniques, *Bacillus, Pseudomonas* and *Escherichia coli* species were the commonest bacteria isolated. The 22 kg bio-digester designed and fabricated was adequate for bio-fertilizer production as it provided the standard anaerobic condition needed throughout the 28 days of retention. The important operating conditions in the bio-digester such as pH, temperature and total solids content facilitated the success of the bio-fertilizer produced. The data obtained through the physical, chemical and microbial analyses after 28 days of retention confirmed the fitness of the digestate for use as bio-fertilizer, because the results fell within United States Environmental Protection Standards (USEPA) (2024).

Further studies can consider varying the organic materials in separate bio-digesters for optimized results.

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