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Performance Evaluation of Biogas Yield from Organic Fraction of Municipal Solid Waste using Plastic Digester

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ABSTRACT

80 kg of organic fraction of municipal solid waste was mixed with water in ratio of 1:2 to form slurry which was charged into fixed dome AD plant made of plastic digester. This was subjected to complete hydraulic retention of thirty eight days under the condition of mesophilic temperature range of 35.5ºC-37.5ºC. Optimum biogas yield at each respective temperature and pressure were taken note of. The results obtained shown that increased in the average temperature and pressure lead to an increase in biogas yields from municipal solid waste. A total of eight (8) evacuations and 7.495 kg of biogas was obtain from 80 kg of organic fraction of MSW for hydraulic retention time of thirty eight (38) days. It was obvious from the results obtained that improve mesophilic temperature favored optimum biogas yield and this was as a result of the good insulation properties of the fixed dome digester used. Therefore, plastic digester is a good alternative biogas plant for anaerobic co-digestion of municipal solid waste.

Keywords: Municipal solid waste, organic fraction, hydraulic retention time, mesophilic temperature, biogas yield

1. INTRODUCTION

Municipal solid waste (MSW) management is a major environmental problem facing Nigeria [1]. The level of solid waste generation in Nigeria is alarming with an increasing population pressure and socio-economic factor [2]. For instance, majority of Nigeria's urban cities are struggling to clear heaps of (MSW) generated on a daily of which large percentage of such waste can be utilized for biogas production. MSW continuous rise in generation resulted in Nigeria with the rapid increase in urban growth resulting partly from the increase in population status [3]. One cannot boast of any single town/city in Nigeria being rural or urban that can claim of finding a lasting solution to the problem of filth and huge piles of MSW in Nigeria [4-5]. In Nigeria just like every other developing country across the world, MSW is dump indiscriminately and this had led to blockage of drainage system, thus causing environmental pollution [6]. At present, the generally practiced waste management preference in Nigeria involves the collection of mixed waste materials and subsequent dumping at designated dumpsites [7].

Municipal solid waste generated in Nigeria generally consists of food remnants, plastics, paper, textile, metal, glass and the generation rate is estimated at 25 million tons annually at a daily rate of 0.24-0.66 kg/day/person [4,9,10]. Waste can be defined as any unwanted material deliberately thrown away. Managing generated waste in Nigeria is a major problem due to poor implementation of standards and policies [11]. Generally, waste management simply means all waste activities that entail to manage waste [12]. This process includes; waste collection, waste transportation, waste monitoring, waste processing and disposal [13]. On the other hand, waste management can be defined as the collection, transportation, recovery, recycling and disposal of waste [32], as well as the supervision of such operations and the after care of disposal sites including the actions taken as a dealer or broker. The first stage in waste management is to appropriately understand the type of waste generated and this will aid the design of appropriate collection and disposal strategies. Several researchers have reported generation of biogas from organic biodegradable fraction of municipal solid waste via the anaerobic digestion process [14-17].

The anaerobic digestion (AD) process which is a greenhouse technology has to deal with the generation of methane rich biogas via the biological degradation of organic biomass such as food waste, agricultural waste, wastewater, etc. [18-20,33-35]. The AD process is a waste management technology that can be practice for the treatment and utilization of MSW. It is also a promising method for waste reduction and energy recycling [21]. The technology is generally accepted by developed countries such as Germany, Sweden, USA, Denmark etc., which have over the years implemented rigorous waste disposal legislation [22]. Besides, the development of exceedingly efficient renewable energy processes is on the increase across the world especially from the year 2000 to 2015 [24]. The AD process is acceptable as an efficient method for treatment and recycling of organic waste because it has proven to be promising method for waste reduction and energy generation [25]. Biogas produce from AD process is a mixture of flammable gases obtained by the anaerobic digestion processes of organic material such as organic fraction of MSW [26]. In percentage by composition, biogas consists of 40-70% of methane (CH_4), 30-50% of carbon (IV) oxide (CO_2) and 5-10% of other gases which include hydrogen sulphide (H_2S) and water vapour (H_2O) [19]. Biogas production from organic waste if properly managed is a viable option for wood and fossil fuel which over the years had been used by average Nigeria as means of energy usage for heating and lightening. In comparison to natural gas, it can be used for cooking and powering of internal combustion engine provided it is free from impurities [27]. Biogas production from organic waste is a valuable renewable energy and with an improve biogas digester such as plastic digester that can maintain improve mesophilic temperature range of 36^{o}C to 37^{o}C as reported by Ebunilo *et al.* [28], optimum biogas production can be achieved. In this research work, a fixed dome plastic digester designed for biogas production was evaluated for performance using organic fraction of municipal solid waste as substrates.

2. MATERIALS AND METHODS

2.1. Design Requirement

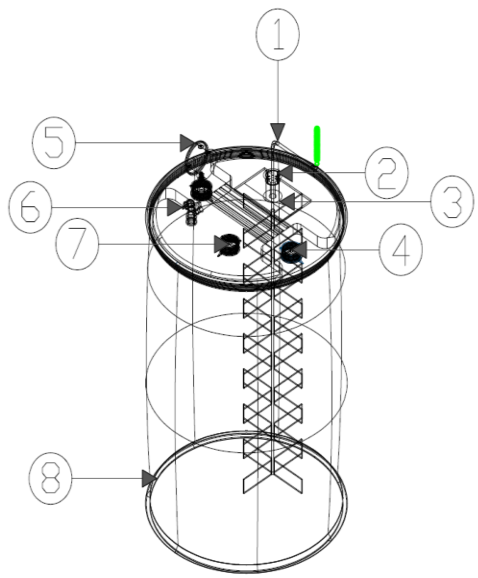
To ensure that an efficient plastic biogas digester is fabricated, the following design requirements were drawn.

1. Total gas pressure
2. Gas pressure
3. Density of slurry
4. Height of slurry
5. Stresses induced by total pressure
6. Force require to turn the stirrer
7. Temperature

2.2. Design Consideration

The following list of factors was considered in the design process of the plastic digester.

1. Materials
2. Reliability
3. Maintenance
4. Functionality
5. Durability
6. Safety
7. Cost



S/NO.	DESCRIPTION
1.	STIRRER
2.	BEARING
3.	BEARING SUPPORT AND BASE
4.	CHARGING PORT
5.	PRESSURE GAUGE
6.	EVACUATION VALVE
7.	DISCHARGE PORT
8.	PLASTIC TANK

Figure 1 Skeletal view of the Plastic Digester

Figure 2 Fabricated Plastic Digester

2.3. Materials for Fabrication

Thermoplastic (polyethylene) material is used in the fabrication process. The choice of polyethylene was based on the fact that polyethylene (PE) is easy to weld, has impact resistance, has exceptional abrasion resistance, high tensile strength, it is easily machine and has low water absorption.

2.4. Conceptualization

Conceptualization is an idea, containing the objects, concepts, and other entities that are presumed of interest for some particular purpose and the relationships between them. The components of the plastic digester are; stirrer, bearing, bearing support and base, charge port, pressure gauge, evacuating valve, discharge port and plastic tank. The stirrer, pressure gauge, evacuating port and charging port is located at the top of the plastic tank. The discharge port is located at the base of the plastic tank. Figure 1 shows the skeletal view and Figure 2 shows the fabricated plastic digester.

2.5. Design of Plastic Digester Tank

The total pressure in the tank is the pressure developed by the gas and the slurry and is given by Equation (1)

$$P_T = P_G + P_S \quad (1)$$

where,
P_T = Total internal pressure
P_G = Gas pressure
P_S = Slurry pressure
But,

$$P_S = \rho g h_S \quad (2)$$

where,
P_S = Slurry pressure
ρ = Density of slurry
g = Acceleration due to gravity (9.8m/sec^2)
hs = level of slurry in the plastic digester

2.6. Hoop Stress in the Plastic Digester

The hoop stress is the force exerted circumferentially (perpendicular both to the axis and to the radius of the object) in both directions on every particle in the cylindrical wall (Figure 3).

$$\sigma_\theta = \frac{F}{tl} \quad (3)$$

where,
σ_θ = Hoop or circumferential stress
F = Force exerted circumferentially on an area of the cylinder wall
t = Radial thickness of the cylinder
l = Axial length of the cylinder

However, for a thin-walled, the vessel must have a wall thickness of not more than above one tenth of its radius. This allow for treating the wall as a surface using the Young-Laplace equation for estimating the hoop stress created by the internal pressure on a thin wall cylindrical pressure vessel.

$$\sigma_\theta = \frac{Pd}{2t} \quad (4)$$

where,

$P=P_T$ = Total internal pressure
t = Wall thickness
d= Mean diameter of the cylinder
σ_θ = Hoop or circumferential stress
Also,

$$F = W = Mg \quad (5)$$

$$\rho_S = \frac{M_S}{V_S} \quad (6)$$

where,
F = Force acting along the axis of the cylinder
M_S = Mass of the slurry = 126.9kg (Measured)
g = Acceleration due to gravity
W = Weight of the slurry
ρ_S = Density of slurry
Vs = Volume of slurry

2.7. Design of Stirrer
Figure 3 shows the isometric dimensioned view of the stirrer of the plastic digester.

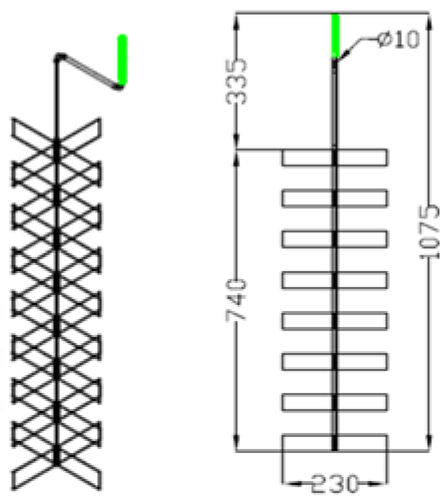


Figure 3 Isometric Dimensioned View of the Stirrer

2.8. Force acting on the Stirrer Blade
The force acting on the stirrer is given by Equation (7)

$$F_S = Force \times Area = \rho_S g h_s \times A \quad (7)$$

But;
$$A = 2\pi rh + 2\pi r^2 \quad (8)$$

$$V = \pi r^2 h \quad (9)$$

Also;
$$V = Ah \quad (10)$$

where;
h= Height of plastic cylinder
r= Radius of plastic cylinder
h_s =Height of slurry

2.9. Tests

Collected organic fraction of MSW was measured with a weighing balance and recorded (80 kg). The collected samples of MSW was grounded into pieces to increase its surface area for easily decomposition [15], and mixed with water in ratio of 1:2 [29] before it was finally charged into the plastic digester and made air tight. The slurry in the digester content was stirred several times per day with the aim of mixing the substrates inside the digester for efficient biogas generation [14]. The pressure and temperature readings were at each evacuation; the gas generated was dried, and compressed into a storage cylinder. Before each evacuation of biogas, the initial mass of the gas storage cylinder and the final mass after the biogas evacuation were recorded. The mass biogas evacuated was calculated by subtracting the initial mass of the biogas storage cylinder from the final mass [14].

That is:

$$M_{be} = M_{fbe} - M_{ibe} \quad (11)$$

where,
M_{be} = Mass of biogas evacuated
M_{fbe} = Final mass of the biogas storage cylinder
M_{ibe} = Initial mass of the biogas storage cylinder

3. RESULTS AND DISCUSSION

Figure 4 shows the results of variation of pressure with biogas yields. It was observed that the higher pressure, the higher the quantities of biogas yields. The highest quantity of biogas yield was obtained as 2.05 kg and this value was obtained at a pressure of 1.34bar as depicted in Figure 4. Conversely, the lower value of biogas yield was achieved at 0.35 kg at the lowest pressure of 0.689bar.

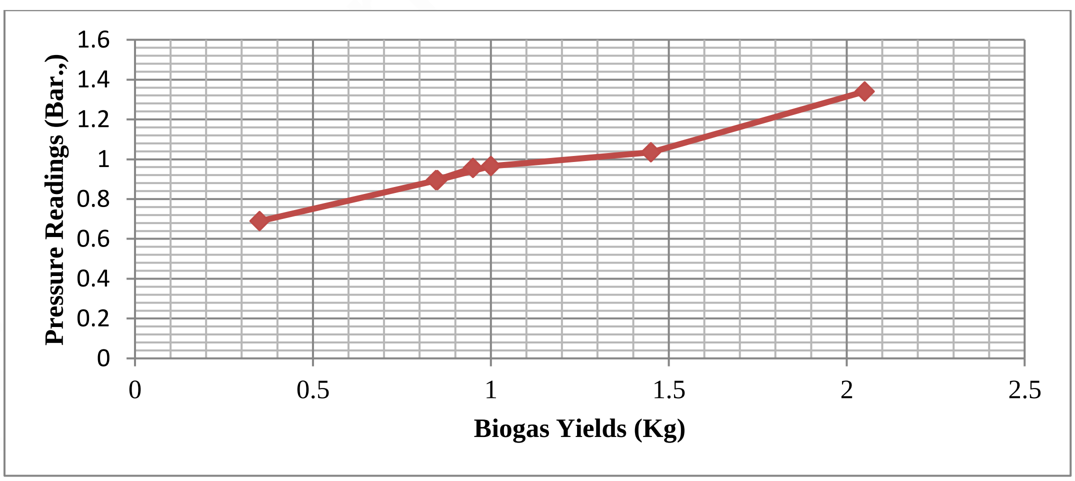


Figure 4 Graph of Pressure Readings against Biogas Yields

Figure 5 shows the graph of temperature performance evaluation of MSW in the plastic digester. It was observed that temperature is directly proportional to biogas yields from MSW. The results revealed that an increased in temperature bring about corresponding increase in biogas yield and vice-versa. According to [20], an improved mesophilic temperature leads to a shorter hydraulic retention time as a results of fast decomposition of substrates, thus, less time required for complete digestion of organic materials (i.e. more biogas yields) since more methanogenic bacteria are working upon substrate and also more destruction for diseases causing microbes. Besides, a stable temperature that ranges between 35.5ºC and 37.5ºC were obtained. The stable temperature in the digester favored methanogenic bacteria. Mathanogenic forming bacteria are very sensitive toward changes and variations of temperature in the digester especially at a very high or very low temperature ranges where the productivity of the biogas dropped significantly [30]. Besides, a sudden change in temperature reduces the production of biogas, and on the long run might stop the process [20]. Therefore, with stable mesophilic temperature recorded, the fabricated plastic digester favored improved biogas yield.

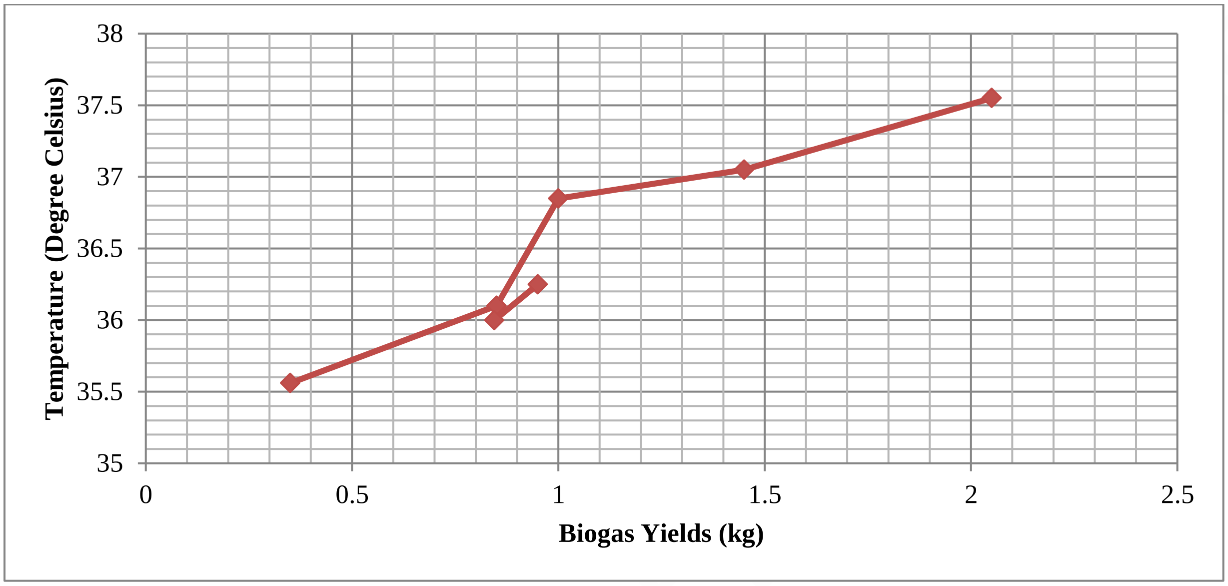


Figure 5 Graph of Temperature against Biogas Yields

4. CONCLUSION

In this research work, a fixed dome plastic digester was used to co-digest the organic fraction of MSW. The results of the analysis show that a total of eight (8) evacuations and 7.495 kg of biogas was obtain from 80 kg of organic fraction of MSW for hydraulic retention time of thirty eight days. Besides, high quantity of biogas was yielded at an improved mesophilic temperature that is above 35.5ºC. Also, a high pressure build up led to an increase in the quantity of biogas yield that was evacuated. Therefore, organic fraction of MSW generated daily in Nigeria can be properly managed using AD process. Moreover, if the technology is fully implemented in Nigeria, the huge amount of MSW that is generated on a daily basis can be converted to energy, for household and commercial use.

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