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DESIGN AND CONSTRUCTION OF 250 LITERS PLASTIC BIO-DIGESTER AND EVALUATION OF BIOGAS PRODUCTION USING 4 CO-SUBSTRATES

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ABSTRACT

Biogas is a gas produced by the breakdown of organic matter in the absence of oxygen. This work involves the construction of (250L) plastic biodgiester using plastic 'Storex' tank as reactor vessel and non-corroding metal as the agitating device. The substrate used in this work includes rice husk, paper waste, maize husk and cow dung were perpetrated using hydrothermal process (except the latter) before been prepared in slurry form to achieve 8% solid content. A total 170 liters slurry was used to fed the digester. In this study, batch fermentation system was used. During fermentation, agitation of the reaction medium was carried out (6-8 times daily) with the aid of agitating device. Biogas production was measured by the downward water displacement method. Measurable gas was observed at the 13th day of the study (600ml), while highest gas production was observed at 47th day of the work (5500ml). Fluctuation in environmental condition such as temperature and changing in pH value leads to inconsistence daily gas production. The pH of the medium ranged from 4.45 – 6.85. The use of plastic material for the construction of biodigester and a non-corroding metal as agitating device aids biogas production. This is because the plastic is cheap, durable, consistent, and gas leakage problem can be easily controlled. Also a mixture of animal waste and plant waste materials with proper pretreatment of these wastes prior to discharge to biodigester has a positive effect on biogas yield.

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KEY WORDS

Biogas; Biodigester; Substrates; Pretreatment; Construction; Fermentation

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[I] INTRODUCTION

Rotting vegetable matter and some plant waste as well as detoxification of toxic compound present in waste waters are known to give up flammable gas. During the course of treatment, it was observed that the gas generated can be used as a source of heat and energy to power industrial plant. This same idea was brought to the United Kingdom in 1895, when the gas produced was used to light street lamps. In the early 1900s this system was developed in some other parts of the United Kingdom and in Germany for the treatment of sewage. Centralized drainage systems were being installed in many towns in Europe and anaerobic digestion was seen as a means to reduce the volume of solid matter in sewage. The gas produced was occasionally used as a source of energy, especially during the Second World War [1].

In Bombay 1930s the use of farm manure in a floating steel gas drum to generate methane was developed. This program provides villagers with cooking fuel. The first allusion to animal manure comes from Humphrey DAVY; who reported early in the 19th century the presence of this combustible gas in fermenting farmyard manure. This was used for the inversion of the safety lamp [2].

In the year 1940, many municipal sewage treatment plants in the United States and elsewhere were already employing anaerobic digestion as part of the treatment of municipal waste and thus generating methane which was used to generate electricity for the plant [3]. This indicates that in pollution control, the anaerobic digestion process is proven effective with additional benefit in the form of a supply of useful gas [3].

Biogas typically refers to a gas produced by the biological break down of organic matter in the absence of oxygen [4]. According to Uzodinma (2008) [5] define biogas as a renewable natural gas containing approximately 70% methane (CH4) and roughly 30% carbon dioxide and trace amount of other gases. Biogas can also be defined as a gas resulting from anaerobic degradation of waste materials, or industrial waste materials. It is viable alternative source of energy [6]. Biogas from renewable raw materials contains methane, carbon dioxide, water vapor and other gases in trace form which include hydrogen sulphide, hydrogen ammonia etc. [7].

Biogas is mixture of gas produced by methanogenic bacteria while acting upon biodegradable materials in an anaerobic condition. Biogas is about 20 percent lighter than air and has an

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ignition temperature in the range of 650 degrees to 750 degree Celsius. It is an odorless and colorless gas that burns with clear blue flame similar to that of LPG gas [8]. Biogas is lighter than air and highly explosive!

Biogas can be generated from a wide range of energy crops such as maize, wheat, sunflower, grass, animal manures and by-products from industrial processes. After anaerobic digestion, the digestion residue (spent medium) can be used as a valuable fertilizer for agricultural crops [9].

Millions of cubic meters of methane in the form of swamp gas or biogas are produced every year by the decomposition of organic matter, both animal and plant vegetables [10]. It is almost identical to the natural gas pumped out of the ground by oil companies and used by many people for heating houses and cooking meals [10].

Apart from the anaerobic digestion process, methane can also be produced artificially; for example, production of methane from wood products or the use of biomass in a process called thermal gasification. This is also a renewable source of methane [11].

Biogas can be generated from a wide range of energy crops such as maize, wheat, sunflower, grass, animal manures and by-products from industrial processes. After anaerobic digestion, the digestion residue (spent medium) can be used as a valuable fertilizer for agricultural crops [9].
Economical biogas production requires high biogas yields and guidelines on optimum energy production, optimum harvesting time, optimum nutrient composition, optimum conservation and pre-treatment technology must be development [12].
There are two basic types of organic decomposition that can occur during biogas production: Aerobic and Anaerobic.

All organic materials, both animal and vegetables can be broken down by these two process, but the products of decomposition are quite different in the two cases. Aerobic decomposition fermentation will produce carbon dioxide, ammonia and some other gases in small quantities, heat in large quantities and a final product that can be used as a fertilizer. Anaerobic decomposition will produce methane, carbon dioxide, some hydrogen and other gases in traces, very little heat and final product with a higher nitrogen content than is produce by aerobic fermentation [13].

The increasing global industrialization, urbanization population explosion in major metropolitan cities have significant affected the amount of wastes generated from municipal solid wastes. Beukering et al. (1999) [14] accounted on urbanization as an important factor that increases waste generation. Anand (1999) [15] focused on urbanization as an important variable in waste generation, while Halla and Majani (1999) [16] emphasized on population explosion as an important determining factor in waste generation. Thus, if these wastes are not properly managed, they may pose a severe threat to public health [17]. With over 80% of the industries in Nigeria located in the industrial cities of Lagos, Kano and Port Harcourt [17], the need to strongly pursuer the conversion of wastes generated into fuel (biogas) to reduce its nuisance value to the environment is important. It is known that potentially, all organic waste materials contain adequate quantities of the nutrients essentials for the growth and metabolism of the anaerobic bacteria in biogas production [18]. This biogas is a renewable high quality energy source that should be explored, particularly in developing countries where energy is costly, and is much needed for developmental activities. In the anaerobic process, a complex mixture of interacting microorganisms, mainly bacterial, carries out the complete degradation of organic materials of biogas. The breakdown of the complex organic compounds occurs in a 3-stage process, involving 3 main groups of independent microbes. They are fermentative, proton reducing acetogenic and methanogenic bacteria [19, 20].
On a global scale, investigations on biogas production have been performed from olive-mill waste water [11], plant biomass used for phyto-remediation of industrial wastes [21], when diluted with poultry manure [18], cotton wastes and food/vegetable residue [22]. However, in Nigeria, most studies used animal dung as substrate [17]. A few investigations have been made on other substrate such as water hyacinth [18] and aquatic weeds [22].

There are several physical and chemical parameters that are known to influence biogas production. Those parameters are listed below [23]

Temperature: Mesophilic temperature which is between 20^0C – 40^0C is the best temperature of which the methanogens can metabolize complex organic wastes.

pH: Anaerobic digestion will occur best within a pH range of 6.8 – 8.0. More acidic or basic mixtures will ferment at a lower speed.

Carbon Nitrogen Ratio: Anaerobic process requires both element, but when other conditions are favorable, a carbon – nitrogen ratio of about 30 - 1 is ideal for the raw material fed into a biogas plant.

Total Solid Content: For proper biogas production, the waste material should be prepared in slurry form with a solid content of about 10% so that the slurry can move freely inside the bioreactor.

Retention time: This is based on the temperature of the fermentation and the type of substrate used.
Agitation: This is highly required in some fermentation processes in other to avoid slurry being settled out and form a hard scum on the surface, preventing the release of biogas.

Other factors that aid biogas production are: feeding rate, acid accumulation, initial inoculum, types of substrate etc.

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BIO-ENGINEERING

Biogas production in Nigeria and other African developing countries has not been put into proper consideration in energy generating sectors thus, the use of biogas in houses for cooking and at industrial level to generate electricity which can be used to power industrial plants has not been put in proper position. This is so due to the fact that the government and people depend on the energy derive from fossil fuel. This result into various form of pollution which includes oil spillage, oil contamination of water source, heavy metals from automobile exhaust and effluent from oil refineries which are known to rendered the ecosystem unpleasant for man, animal, plants, and microorganisms. This research work aimed at (i) Design and construction of 250 liters household biodigester and (ii) Evaluation of the performance of the digester using mixture of substrates.

[II] MATERIALS AND METHODS

2.1. Biodigester design

The The 250L plastic biodigester was designed and constructed. It has 2 openings; one at the top of the biodigester in which PVC pipe (8cm in diameter) was inserted which serves as feeder and carries 15cm in diameter and 20cm in length plastic rubber (capped), thus serve as the feeding place for the biodigester. The second opening was located at the bottom. At the second opening a 4cm in diameter PVC pipe was inserted and also carries the same size of rubber plastic as in the feeder, thus allows easy removal of the spent medium. The two openings are in opposite direction to each other. The gas chamber is located inside the reactor vessel at the upper part of the digester. At the top of the gas chamber, a rubber hose with 0.5cm in diameter is inserted for gas collection. This is allowed to pass through the lid of the 5L rubber plastic of water displacement.

The water displacement unit is made up of 2 identical 5L transparent rubber plastic container labeled “A” and “B”. About 4 liters of water was discharged into “A” which is then transferred into “B” through a 1cm rubber hose connected to both containers. The water moved due to the pressure as a result of gas production. This can be seen in **Figure– 2**.

The agitating device is inserted from the top of the digester in form of a rod or shaft which carries the mixer i.e. blade (3 in number attached to the shaft at 1200 to each other) of 10cm in diameter. The shaft carries a roller or motor driven device with a diameter of 20cm, which aids agitation of reaction medium, facilitate and also makes stirring easy. The stirrer is also equipped with 3 metal bars (with a diameter of 1/10 of the digester diameter). Thus serves as baffle unit, prevent dislocation of the spagar and prevent vortexing during agitation. **Figure– 1** shows biodigester diagram.

2.2 Substrate collection and pretreatment

2.2.1. Collection

The substrates used in this study were collected in 4 different locations in Ogbomoso town. Rice bran was obtained from one feed mill industries along “Apake” area, corn husk from “Odo Oba” market, Cow dung from “Kara” and paper waste (Old newspaper) from “Sabo” area. The substrates are in equal proportion of 3.4kg each.

2.2.2 .Pretreatment

For ease of digestion as well as to have maximum biogas yield, substrate for biogas production must undergo one or more treatment before been charged into the biodigester. Three out of four substrates are known to contain cellulosic and ligninosic materials, therefore to remove these macromolecules, hydrothermal decomposition was carried out. This is done by milling the substrates into powdered form, followed by boiling at 100^0C for one hour or more. The substrates that involve in hydrothermal decomposition include rice bran, maize husk and paper waste.

2.2.3. Slurry preparation

After hydrothermal decomposition of the cellulose and lignin compound present in the 3 substrates mentioned earlier, pretreatment process continued by making the substrate in slurry form. This was done by mixing each substrate with water to achieve 8% solid content [24]. After successful slurry preparation the substrates are now ready to be feed into digester.

2.3. Digester feeding and inoculation

2.3.1. Feeding

The pretreated substrates were charged into the digester through the feeding port of the digester (feeder). This is aided with the use of big plastic funnel placed at the mouth of the feeder plastic thus ensuring easy movement of the substrate through the 8cm in diameter feeder PVC pipe. A total volume of 170L of slurry prepared substrate was used to feed the digester.

2.3.2. Inoculation

In this study, fresh rumen content of cow was use to inoculate the digester. The rumen content was collected and transported under anaerobic condition to maintain the viability of the microorganism. 20% inoculum density was used. This is to ensure that appropriate numbers of microorganism cells were used to initiate the fermentation. Inoculation is done through the feeder [25].

2.4. Fermentation

In this study, batch fermentation system was used. During fermentation, the digester was stirred at least 5 times (5 - 8 times) daily for about 20 - 30mins each time with the aid of agitating device. Also pH of the digester content was measured every week by opening of effluent tap to allow about 20 - 30ml of the digester mixture to flow into a beaker (this is done after vigorous agitation) and then read with a pH meter. The digester was run under mesophilic temperature.

2.5. Gas quantification

The gas generated was measured by down ward displacement of water. The volume of water displaced was measured daily. **Figure– 2** show water displacement unit.

2.6. Data collection

The volume of biogas produce was recorded on a daily basis. The mean weekly gas yield and other parameters were recorded. This was monitored for 10 weeks and 4days. The daily ambient temperature over these periods varied from 28^0C – 32^0C while the average was 29^0C.

[III] RESULTS AND DISCUSSION

3.1. Changes in pH value during fermentation

Figure– 3 shows the variations in pH value of the reaction mixture. This is taken at an interval of seven days. At the

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beginning of the work, the initial pH is 6.42, moreover after 7 days, change in pH value was observe to be 4.89 (acidic) which may be due to metabolic activities of the fermenting microbes. The pH values continue to fall till it reaches 4.45 at 28th day then rose to 5.48 at 35th day of the fermentation. The pH continues to rise till 56th day which is nearly close to neutral at 6.85. Fluctuation in pH may be attributed to the interactions and metabolic activities of microorganisms in the fermenting medium.

3.2. *Gas production*

A measurable gas production started at 13th day of the work after feeding the digester with the treated waste and the inoculum. Although this is against the work Chidi et al. (2008) [26] in which they reported to have a measurable gas production at 4th day of their work, this may be due to variation in temperature, inoculum density, viabilities of microbes and interactions, substrate composition as well as digester size and amount of substrate been feed into the digester.

At the 14th day of the work the volume of water displaced dropped from 600ml to 85ml, 3days after there is no water displacement which may be due to drop in environmental temperature. There after daily water displacement fluctuation continue between 55ml to 400ml, then rose back at 34th – 48th day with a displacement ranging from 1020ml – 5,500ml. The highest volume of water displaced was observed at 47th day of the work (5,500ml) which is correlated to the work of Uzodinma (2008) [5] in which they have gas production of 150 liters at 47th day of fermentation. Gas production was obstructed by heavy rainfall for about 8 consecutive days (49th – 56th) while it reawakes at 57th day but at lower rate, this may be due to cool weather and or reduction in nutrients content of the medium. This is represented in **Figure– 4**.

Gas production rate depends on the ability of microbes to utilize available nutrient under a favorable condition. These conditions includes physical parameters such as pH, temperature, agitation e.t.c. pH of the medium is one of the most important parameters that affect biogas production. When all other conditions are favorable, optimum biogas production occurs at pH value ranging from 6.5 – 78.5. Uzodinma and Ofoefuhe (2008) [27] reported that pH value of their work ranged from 5.93 – 7.73 which is higher than the pH recorded in this work, with a pH value ranging from 4.45 – 6.85. This may be due to differences in substrates composition.

Fig: 1. Plastic bio-digester

Fig: 2. Water displacement unit

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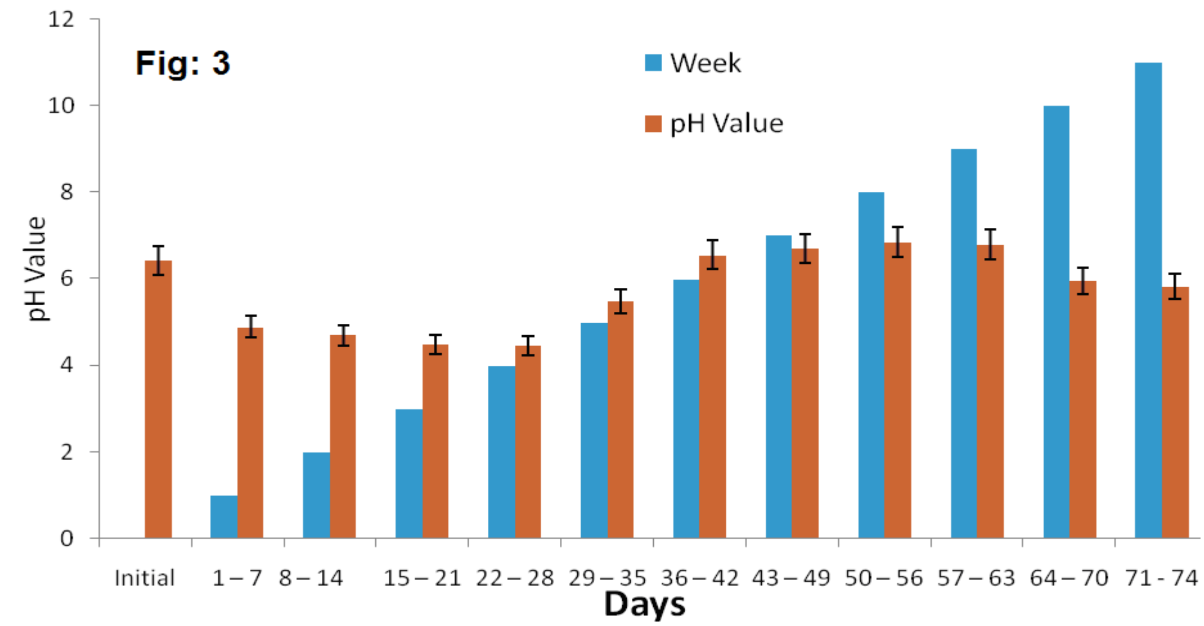

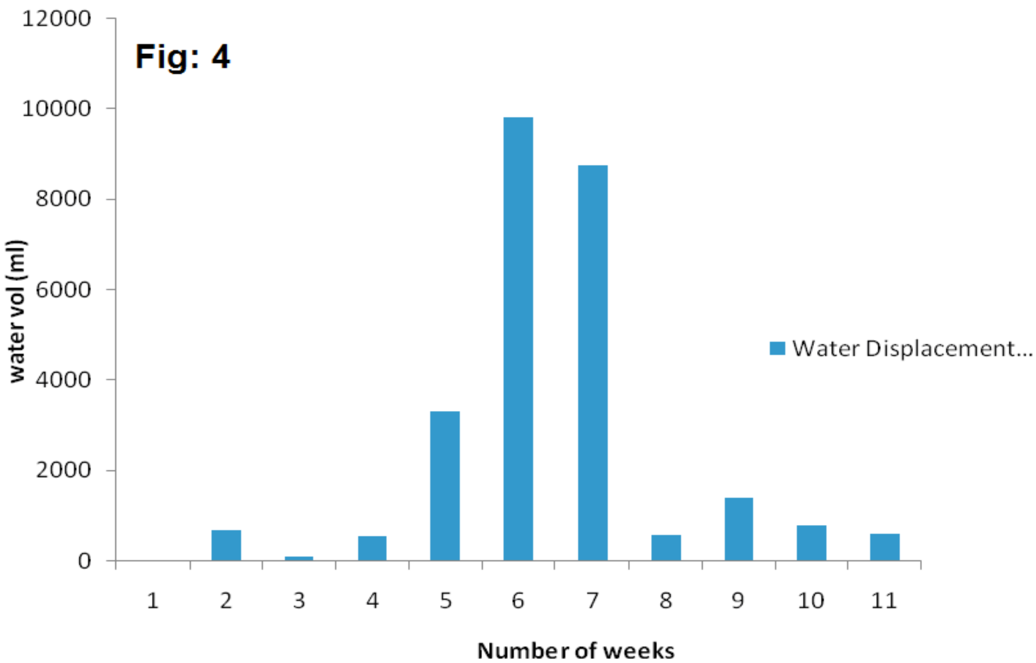

Fig: 3. pH Value and number of weeks; Fig: 4. Weekly water Displacement (ml)

[IV] CONCLUSION

From the results obtained and analysis of charts, graphs and tables, the following conclusions are made:
The use of plastic material for the construction of biodigester and non-corroding metal as agitating device should be employed during design and construction of biodigester for biogas production. This is because the plastic is cheap, durable, consistence, and gas leakage problem can be easily controlled. Also mixture of animal waste and plant waste materials has positive effect on biogas yield [27], and pretreatment of these waste prior to discharge to biodigester also aid biogas yield [18].

Batch system of fermentation makes the work simpler and economical because it does not required daily pretreatment of waste, feeding as well as daily remover of spent medium. Also the pH of the medium was found to range from 4.45 (acidic) –

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6.85 (neutral), this is within the ranges that support biogas production [28]. The work was carried out under mesophilic temperature that ranged from 25 – 27^{0}C during which gas production occurs, but gas production continue to ceased due to temperature reduction being a result of cool weather and heavy rainfall.

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CONFLICT OF INTEREST

There is no any form of conflict of interest

FINANCIAL DISCLOSURE

No financial sponsor in the form of person, institution or organization is involved in the present work

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