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DESIGN AND FABRICATION OF AN ANAEROBIC DIGESTER

M.S. Abubakar[1*] and S.A. Bello[2]

([1]Department of Agricultural and Environmental Engineering, Faculty of Engineering, Bayero University, Kano, Nigeria
[2]Food Crop Production Technology Transfer Station, Federal Ministry of Agriculture and Rural Development, Kano, Nigeria)
[*]Corresponding author's e-mail address: amshuaibu.age@buk.edu.ng

Abstract
Anaerobic digester is a physical structure that provides a conducive environment for the multiplication of micro-organisms that degrades organic matter to generate biogas energy. Energy is required in agriculture for crop production, processing and storage, poultry production and electricity for farmstead and farm settlements. It is energy that propels agricultural mechanization, which minimizes the use of human and animal muscles and its inherent drudgery in agriculture. The energy demand required to meet up with the agricultural growth in Nigeria is high and growing every year. In this study the design and fabrication of an anaerobic digester was reported which is an attempt to boost energy requirement for small and medium dryland farmers in Nigeria. The design of the digester includes the following concept; the basic principles of anaerobic digestion processes, socio-economic status of the dryland farmers, amount of biogas to be produced. Finally, the digester was fabricated using locally available raw materials within the dryland area of Nigeria. At the end, preliminary flammability test was conducted and the biogas produced was found to be flammable.

Keywords: Design; fabrication; anaerobic; digester; energy; biogas

1. Introduction

One of the major ongoing challenges facing human societies especially in the developing countries like the dry land of Nigeria is how to continue to provide energy in usable forms for heating, lighting, cooking and machinery operations in the face of decline in fossil fuel reserves. Similarly, population is increasing proportionately rising energy needs, and environmental and global warming concerns are growing (Omer, 2008). Energy is required in agriculture for crop production, processing and storage, poultry production and electricity for farmstead and farm settlements. The energy demand required to meet up with the agricultural growth of Nigeria is high and growing every year. And as we know, it is energy that propels agricultural mechanization, which minimizes the use of human and animal muscles and its inherent drudgery in agriculture. The low level of agricultural mechanization in Nigeria as reported by Itodo (2007), can be attributed largely to the lack of affordable energy, leading to the dismally low power-use intensity of 0.18 kW/ha as compared to globally recommended average of 0.4 kW/ha. Furthermore, the level of power usage in Africa is very low and is estimated at 0.038 kW/ha representing 10% of the minimum requirement for efficient agricultural production (Kline, *et al.*, 1969). However, international attention is shifting to renewable energy technology that utilizes biomass as raw materials in an air-tight container called digester (Itodo, 2007).

The digester is a physical structure that provides a conducive environment for multiplication of microorganism and the end products are biogas. The technology is considered attractive and appropriate because they are both available and affordable for the local farmers (Itodo, 2007). There are many reports on the utilization of various biomass resources ranging from agricultural, municipal, industrial, and animal wastes to produce biogas via anaerobic (without oxygen) digester processes (Adebusoye, *et al.*, 2007; Aggarangsi and

Teerasountornkul, 2011; Richard, *et al.*, 2010). The biogas is expected to supplement fossil fuel in terms of energy supply. The first anaerobic digester was built in 1859 by a leper colony in Bombay, India (Svoboda, 2003). In 1895, the technology was developed in Exeter, England, where a septic tank was used to generate gas for the sewer gas destructor lamp, a type of gas lighting (Hashimoto and Varriel, 1978). Also, in 1904, England, the first dual-purpose tank for both sedimentation and sludge treatment was installed in Hampton. Svoboda (2003), reported that in 1907 a patent was issued for the "imhoff" in Germany which was also an early form of digester. A digester is often described as an extension of the digestive system of the herd itself (Dave and John, 2006; Lawal, *et al.*, 1995). All digesters perform the same basic function. They hold materials in the absence of oxygen and maintain the proper conditions for methane forming microorganisms to grow. Controlled anaerobic digestion is by no means a new concept. Large scale industrial digesters and small domestic digesters are in operation in many places around the world (Adeyanju, 2008; Garba and Sambo, 1992; Lawal, *et al.*, 1995).

The purpose of all these digesters is to produce combustible biogas which can be burned to provide energy for a whole range of uses. Anaerobic digestion facilities have been recognized by the United Nations Development Programme as one of the most useful decentralized sources of energy supply in the households for cooking and lighting (Abubakar, 1990; Fernado and Dangogo, 1986). Apart from the conventional waste materials used for the production of biogas as mentioned above, there exist an alien grass in the dry lands which have now invaded the irrigation canals, rivers, ponds, ditches, and low land areas *(Fadama)* of Nigeria (Garba and Sambo, 1992). The grass commonly called Typha grass (*Typha latifolia*) or cattail, and locally called *"Kachalla" or "Gerontsuntsu"* in Hausa is a perennial marsh with high starch content. The root contains about 80% carbohydrate (30-46% starch) and 6-8% protein which makes it an excellent resource for biogas production especially when co-digested with animal dung as inoculums (Adeyanju, 2008; Baba and Nasir, 2012; Berglund and Boresson, 2006; Dipu, *et al.*, 2011). Furthermore, the invasion of typha grass is considered threat and nuisance to biodiversity of the ponds, lakes, rivers, ditches and low land areas (Mooney, 2004). The grass impedes water circulation along irrigation canals, rivers and ponds, creating an ideal breeding ground in the stagnant waters for mosquitoes and hosts of bilharzias. This is besides hosting of quill birds that wipe out an entire farm produce (Richardson, *et al.*, 2000). The cumulative effects of these impacts were a downturn in economic productivity. But Akinbami, *et al.*, (2001), reported that these vast and abundant typha grass resource is still begging for utilization in Nigeria. In the dry lands of Nigeria presently, there is quite a bit of ideological interest in anaerobic digestion and biogas production, particularly from the intensive farmers, but there are no many examples of digesters in operation. Farmers could be interested in the technology for the fact that it is a good and clean alternative energy source (biogas), efficient cattail weeds disposal system as well as soil amenders and liquid fertilizers are all a by-products of the technology. As a renewable energy technology, biogas from typha grass has the potential to reduce dry lands dependence on fossil fuels where at least it cannot be substituted for electricity generation, cooking, lighting, and heating as ethanol production for engines operation are awaited. To address these problems, the typha grass could be eradicated by utilizing it to co-generate biogas, a renewable energy source that is user and environmentally friendly, is a welcome

relief in the face of decline and growing demerits in fossil fuels and firewood use and the need for supplemental energy source in agriculture in Nigeria.
This study presents the design and fabrication of a small scale working digester suitable for operation on the average farm in the dry lands. The aim is to develop an anaerobic digester for co-generation of biogas for cooking purposes using typha grass, from locally available materials with less cost.

2. Materials and Method

2.1 Design Consideration, Assumptions and Calculations

The design of this digester for the biodegradation of Typha grass/cow dung and the attendant production of biogas was based on certain factors which affect the performance of the digester. These factors are the type of waste, the rate of waste generation, its nature and solid contents of the waste considered were such that the waste are capable of flowing on their own or forming slurry with water and eventually flowing and so can be used in continuous operation and again the local environmental conditions, like the ambient temperature was also considered. On the engineering materials used which includes shaft, sheet of metal, Worm and worm gear, and auger assembly. Factors considered are strength, machine ability, durability, availability, affordability as well as maintenance of the digester. The dimensions of the various components were chosen so as to minimize size, weight and cost of the digester and at the same time not compromising the efficient operation of the components. The loading and turning which is the major daily activities by the operator was supported with a stair steps to reduce fatigue. In designing the digester, the top cover was made frustum shape to accommodate the flat seated worm and worm gear which is centrally located to carry the 22 mm diameter turning shaft. The middle cylinder was made 100 cm in diameter to suit the hopper (feeder) assembly improvised for feeding in the substrates. The lower cone shaped bottom was so shaped to allow for easy flow of spent slurry to be discharged by gravity. Assumptions made were as follows:

i. Batch operated type digester.
ii. The cylindrical diameter is 1m based on the feeding auger improvised and used for the construction with
iii. Retention time (RT) of 20 days.
iv. Torsional shear stress of stirrer shaft (42 MPa for mild steel).
v. Slurry loading (Sd) rate of 40 Litres of slurry per day.

The procedure of design for the biogas digester by Itodo, (2007); Budzianowski, (2012); Khurmi and Gupta,(2005); Rajendra (1999); Aggarangsi and Teerasountornkul (2011) were adopted, as presented below:

2.1.1 Digester Tank Volume

The volume of the digester tank was made from 18 mm gauge mild steel sheet metal comprises of three composite solid of upper frustum, middle cylinder and lower cone shaped bottom. It has a combine volume of about 1 m^3.

2.1.2 Digester Cylindrical Volume

The digester cylindrical volume (V_D) was determined from the retention time (RT) and the amount of slurry to be loaded into the digester daily (Sd). This amount being the quantity of wastes (typha grass, cow dung and water) with mixing ratios (1:6:6). Or (3 lit. 18. 5 lit. and 18.5 lit.) equivalent to 40 L/day.

The digester cylindrical volume is calculated from the relationship below:

$$V_D = S_d\left(\frac{L}{day}\right) \times RT(days) \quad (1)$$

where,

V_D is the digester cylindrical volume determined to be 800 lit equivalent to 0.8 m^3

Sd is the amount of slurry loaded into digester daily in litres/day = 40 litres per day

RT is the retention time in days which is 20 days

2.1.3 Digester Cylindrical Height

The digester height was calculated from the digester volume obtained in equation (1) from the following equation:

$$V_D = \pi \times r^2 \times h \quad (2)$$

$$0.8\ m^3 = 3.142 \times 0.5\ m^2 \times h$$

where;

V_D is digester cylindrical volume = 0.8 m^3

r is the radius of the cylinder = 0.5 m

h is height of the cylinder estimated to be 1.0 m

2.1.4 Volume of Frustum Top Cover

The frustum volume of the digester was obtained from the following relationship below:

$$V_{FT} = \frac{1}{3} \times \pi \times t \times (R^2 + r^2 + R \times r) \quad (3)$$

where,

V_{FT} is the frustum volume calculated to be 0.082 m^3

R is the radius of bigger circle which is 0.5 m

r is the radius of small circle which is 0.2 m

t is the height of frustum estimated to be 0.3 m

2.1.5 Volume of Cone Shape Bottom

The cone shape bottom of the digester was estimated from the relationship below:

$$V_{CB} = \frac{1}{3} \times \pi \times r^2 \times h \quad (4)$$

where,

V_{CB} is the volume of the cone shape bottom cover estimated to be 0.092 m^3

h is the height of cone determined to be 0.35 m

r is radius of the cone = 0.5 m

2.1.6 Design of Total Digester Volume

The total digester volume consists of a frustum top cover, middle cylinder and cone shape bottom cover and was obtained by summing volumes of the individual shapes. Therefore, a mathematical relation below was used:

$$T_{DV} = V_D(A) + V_{FT}(B) + V_{CB}(C) \tag{5}$$

where,
T_{DV} is the total digester volume estimated to be 0.974 m^3
V_D is the cylinder volume determined to be 0.8 m^3
V_{FT} is the volume of Frustum top cover calculated to be 0.082 m^3
V_{CB} is the volume of cone shape bottom is 0.092 m^3

2.1.7 Power Required to Mix the Digester Content

The following formula was used in determining the horse power needed to mix the digester contents as given by Dave and John, (2006):

$$P_D = 0.185 \times \%TS \times Liquid\ Capacity\ (V_D + V_{CB}) \tag{6}$$

where,
P_D is power required to mix the digester content 0.7279 kW or 1 hp
V_D is the digester cylindrical volume 0.8 m^3
V_{CB} is the cone shape volume bottom 0.092 m^3
TS = % total solid of slurry determined to be 0.125

2.1.8 Torque of Stirrer Shaft

The twisting moment (T) was obtained by the following relations as reported by Khummi and Gupta, (2005):

$$P = \frac{2 \times \pi \times N \times T}{60} \tag{7}$$

where,
T is the torque of the stirrer shaft = 86.56 Nm
P is the power transmitted by the shaft obtained from human efforts = 0.544 kW
N is the speed of shaft in rpm, say 60 rpm

2.1.9 Stirrer Shaft Diameter

The stirrer shaft diameter was found from the following equation as reported by Rajendra, (1999):

$$d = \sqrt[3]{\frac{16T}{\pi\tau}} \tag{8}$$

where,
d is the stirrer shaft diameter found to be 22 mm
T is the torque of the stirrer shaft estimated as 86.56 Nm
$\tau$is the shear stress of the shaft materials which is 42 MPa as mild steel constant

2.1.10 Hopper Design

The shape, location and dimension of the hopper were selected to ensure mass in-flow of the slurry. The dynamic angle of repose of melon seed was adopted as equivalent angle of the typha grass after size reduction. It then followed that the angle of inclination of the hopper to the horizontal is 43^0. To avoid e frequent loading of the digester hopper, 20 litre slurry volume was chosen as the equivalent hopper capacity.

2.1.11 Solid out-let

A 60 mm diameter ball valve was chosen considering the conical shape of bottom cover designed. This will allow for easy out flow of the substrates after digestion.

2.1.12 Frame

The frame is made up of a 3 inches (76.2 mm) gauge angle iron. This was chosen to withstand both the weight of the structural work and the weight of the slurry.

2.2 Material Selection and Construction

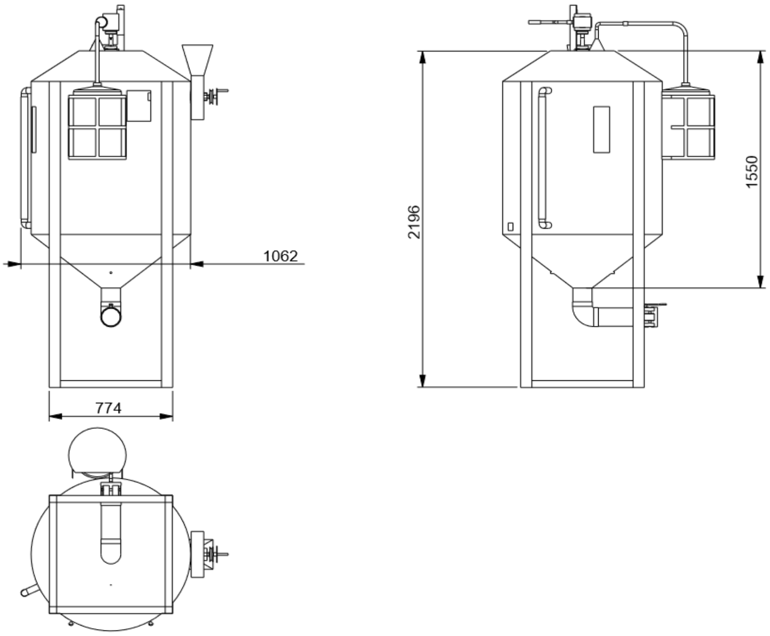
The materials used for the fabrication of the digester were made up of mild steel sheet and angle iron. This is because of easy workability, durability, availability, cheapness and strength of the mild steel materials. Appropriate gauges and grades of the materials was selected and used for the construction. The dimensions and nature of the materials was as determined in the designed calculation and will last long without failure. The prime mover (Human efforts) for (feeding and turning) selected will provide the required horse power for the maximum load required by the digester. The inner coating with Bitumen substance and the outer finishing (Black body) was meant to make environmental effects manifest. The heat from the sun (ambient) will serve the purpose reliably given the capacity and work load it was subjected to in the design. The construction was carried out using electric arc welding, bolt and nut as described by Adebusoye, *et al.*, 2007; Itodo, 2007; Matthew, 1982.

2.3 Description and Operational Procedure of the Digester

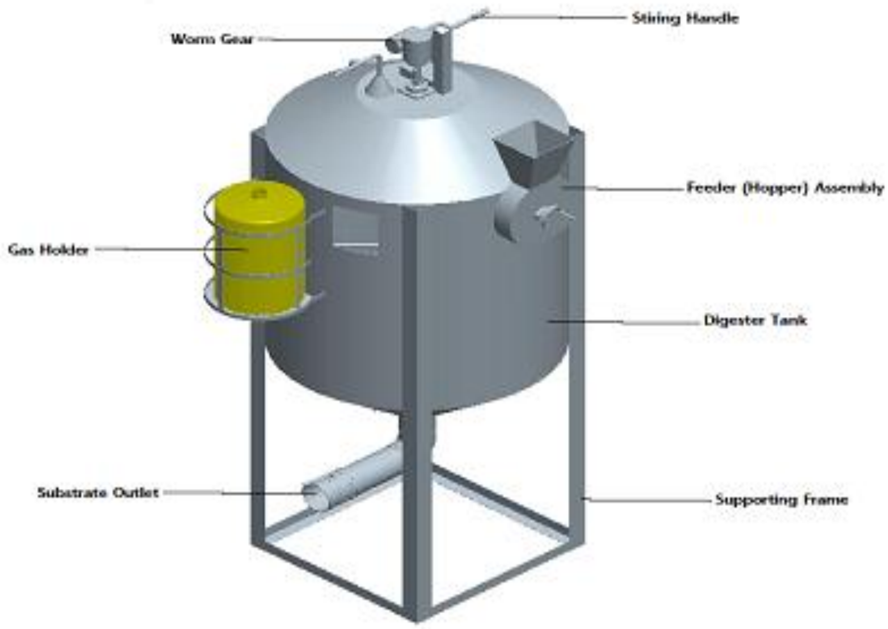
The anaerobic digester consisted of a digester tank, substrate mixer with turning bar, feeder (hopper) assembly, gas holder, solid outlet and supporting frame. The digester tank is a cylindrical container of approximately 1 m^2 (0.974 m^3) in volume which holds the substrate inside it. It is made of mild steel sheet (G 18). The base of the digester was made conical in shape to allow for easy flow of the slurry after digestion. A 60 mm diameter ball valve was centrally fixed to the bottom to serve as the regulator for the solid outlet. The frame was made of 35 mm $\times$35 mm angle iron. The height is 500 mm; the width is 300 mm and length of 300 mm. The frame was to provide the digester with rigid support. The substrate mixer comprises of a turning shaft with fingers powered by an improvised worm gear that transmit circular motion of human efforts to rotary motion of the shaft. The shaft is 22 mm diameter as designed and 180 mm long. Also attached to it are 8 number equally spaced fingers for efficient mixing of the content. The shaft was inserted and fixed into a cone at the base to enhance rigidity.

In operating the digester, the already mixed sample of the substrate (slurry) was put into the digester tank via the feeder (hopper) assembly. The substrate was poured into the digester continuously until the level of the slurry rises and catch-up with the feeder tip and then seals the system against air. Attached to it is a hopper assembly for feeding the digester with feedstock driven by an auger which is powered by human efforts. In the same vein, the mixing of the substrate inside of the digester is achieved by a worm gear which converts rotary motion into circular motion turning the substrate. It is powered by human efforts. The outer surface of the digester was painted black to enable environmental effects manifest since the dry land ambient temperature is in the range of 37^{0}C which corresponds to the mesophilic temperature range required for biodegradation.

Figure 1 (a and b) present the orthographic and exploded views of the digester. The main components of the anaerobic digester are the digester tank, substrate mixer, feeder (hopper) assembly, gas holder, substrate outlet and the support frame.



(a)



(b)

Figure 1: (a) Orthographic view of the digester, (b) Exploded view of the digester

3. Conclusion

The problem posed by the use of fossil fuels, firewood, burning of dung cake, improper disposal of animal waste and the nuisance posed by typha grass forced the dry land farmers to look for alternative sources of energy in the form of biogas and that was addressed by developing an anaerobic digester for co-generation of biogas.

The anaerobic digester for biogas production developed was made up of three composite solids of upper frustum, middle cylinder and lower cone shaped bottom with combined volume of 0.974 m^3. In designing the digester, the top cover was made frustum shape to accommodate the flat seated worm and worm gear which is centrally located to carry the 22 mm diameter turning shaft. The middle cylinder was made 100 cm in diameter to suit the hopper (feeder) assembly improvised for feeding in the substrates. The lower cone shaped bottom was so shaped to allow for easy flow of spent slurry to be discharged by gravity. The anaerobic digester was successfully designed, constructed and at the end, preliminary flammability test was conducted and the biogas produced was found to be flammable

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