Construction and Leakage Detection of a Dome-Type Biogas Digester in a Village at Abuja, Nigeria

1Boniface Oloche, 1Ibrahim Ozigis, 1Kafyayt Adeyemi and 2Elias Ikpe
1Department of Mechanical Engineering, University of Abuja, Nigeria
2Department of Civil Engineering, University of Abuja, Nigeria
profoloche@yahoo.com | idris.ozigi@uniabuja.edu.ng | kafyayt.adeyemi@uniabuja.edu.ng | eliasiikpe@yahoo.com

Abstract — This work presents construction and leakage detection of dome-type biogas digester. The constructed biogas digester with local materials is rated at 10m3 capacity. The biogas digester foundation, cylindrical wall and dome vault were 10 cm thick and made of High Strength Concrete (HSC) at ratio of 1:1:1.2. The pressure in the constructed biogas digester was tested using a liquid manometer. The pressure gauge level difference of 48 cm (4.7 KN/m2) was obtained, which later dropped to less than 20 cm (1.96 KN/m2) indicating presence of leakage in the biogas digester. Cracks in the biogas digester were located after a careful examination at the cylindrical wall and dome top, which were scaled and sealed with wet cement. The manometer test was again conducted and yielded pressure gauge level difference of 60 cm (5.88 KN/m2), without dropping for over 20 minutes, which implies no leakage in the biogas digester.

Keywords - Biogas, Digester, Leakage, Pressure, Climate Change

1 INTRODUCTION

Many technologies exist today to tackle the problem of unsustainable use of biomass for household energy consumption. These technologies include but are not limited to solar and wind. However a lot of challenges are associated with these technologies amongst which are high initial capital cost. A biogas digester is recognized worldwide as rural energy-efficient and waste-handling sustainable technique. The development of biogas promotes waste handling and reduces greenhouse gas emissions. It also improves sanitation and energy for quality life in rural areas (Resende, et al, 2014). Biogas is produced when organic material is digested in an anaerobic environment. The organic materials typically consist of cattle manure, agricultural residues and waste water (Wargent, 2009). The use of biogas for heating, lighting and cooking has been in practice for a long time in Asia (Nepal, India etc).

In Nigeria, the use of bio digesters is not widespread but the abundant energy available from biomass can be meaningfully introduced into the nations energy mix through the development of a comprehensive programme on bio digesters (ECN, 2014). Examples of such sustainable programmes exist in Asia and East Africa. The environmental, economic and social benefits of utilizing biogas in households’ most especially rural households are immense. Of the common tasks in domestic activities that require energy, cooking is the most energy intensive activity followed by lighting and heating. A research carried out on domestic energy use in the North East revealed that 77.57% of energy used for domestic activities in urban households are sourced from biomass and 99.09% of domestic energy use in rural households are from biomass. This biomass sources are firewood and charcoal and does not include biogas. The research also showed that 35% of surveyed households are ignorant of the implications of unsustainable charcoal and firewood consumption. Common bio digesters designs are fixed dome, floating drum and plug flow type. The fixed dome digesters (Figure 1) are the most common model developed and used mainly in biogas production. Fixed dome digesters are usually built underground.

They are built with bricks and concrete which is advantageous in terms of maintenance cost. Apart from being difficult to clean, leakage could occur through concrete pores when pressure increases. The size of the digester depends on the location, household size, and the amount of substrate available on a daily basis. A formula exists for calculating the volume of a bio digester. In Nigeria, a 6 m3digester can satisfy the energy needs of a household of 9 if they require 2.4 m3 of cooking gas and cook 2.8 times in a day [Adeoti et al, 2001]. Biogas digester with delivery capacity in the range of 5 m3/day to 50 m3/day is on the increase with over 30 biogas plants in operation across Nigeria as at 2015. However, the utilization of biogas for cooking and lighting has varying success due to challenges such as design, construction, operation and maintenance of the biogas digester as well as leakages from the constructed digester among others challenges (Usack et al, 2012; Liu et al, 2008).

In line with its goal to reduce poverty and support development, the World Bank in collaboration with the West Africa Productivity Programme and the University of Abuja developed a biogas facility that would generate electricity for residents in rural communities. The dome-type biogas digester plant is located at Kilankwa in Kwali Area Council, Federal Capital Territory. The settlement is rural with active cassava farming and garri processing as well as cattle rearing. Kilankwa has been without any form of electricity from the national grid. It also has educational institutions and health centres which are all powered by generators. The use of generators are not environmentally friendly as it releases poisonous gases that are harmful when inhaled and affects the atmosphere in terms of concentration of volatile organic compounds and particulate matter. The biogas digester was built on an open level surface, hard clay soil, low water table and for use of the area traditional ruler.

Leakage detection in biogas digester requires careful probing, search, and examination to find cracks and to provide remedies to arrest the source of leakage. Failure of anaerobic digester has several consequences such as
financial loss; non-availability of biogas; undesirable flow of gas can cause environmental pollution and explosion (Godi, et al., 2013; Tumwesige, et al., 2014).

2 PROBLEM STATEMENT

Climate change is one of the global issues of our time. Concentration of carbon dioxide and methane in the atmosphere arising from unsustainable energy consumption needs to be addressed. During construction and use (operation), leakage leading to emission of Methane in a biogas digester can occur. Leakage from biogas digesters increases emissions of Methane and carbon dioxide into the atmosphere. These are GHG which contributes to global warming. Methane has a Global Warming Potential of 21. Nigeria is a signatory to the Kyoto protocol which makes it very necessary to monitor our GHG emissions to keep the global temperature at a rate not exceeding 2oC. There is also the risk of fire outbreak within a community when Methane leaks from the biogas digester. The economic efficiency of the biogas can be reduced due to the wasted Methane that has been emitted. In large biogas plants, this becomes a real source of concern therefore a manometer test is performed as a means of leakage detection prior to putting the bio digester into use.

3 METHODOLOGY

3.1 Construction

The biogas digester plant construction procedures adopted were as in Samer (2012). The 3.3 m circle was marked out using measuring tape and stake on surface of ground at the location. The pit of 3.3 m diameter was dug to the depth of 2.0 m (Fig.1). Similarly, the slurry discharge chamber with dimensions of wider and narrow widths of 1.3 m and 0.7 m respectively were marked out. A perpendicular distance of 1.1 m between the two widths was dug to a depth of 2.0 m. The process is called setting out. High Strength Concrete (HSC) with mix ratio 1:2:3 was produced and spread at bottom of dug pit as foundation to support the load of filled-up biogas digester. The foundation floor was slightly sloped from 30 cm at feed inlet side to 25 cm at the far end of slurry discharge chamber (Fig. 1). A rod 5 mm thick was shaped into rectangles of 6 cm by 10 cm. The rectangle had its 5 cm parting sand and clay of 4 cm thick was spread. The inlet feed and gas outlet pipe openings. Parting sand and clay of 4 cm thick was spread on top of the ceiling board (Fig.2). HSC mixture was produced and spread up to 10 cm thick to form the dome vault concrete thickness. Concrete casting started from the digester freeboard to cover the base of the dome vault and spread to the top of the dome.

The other part of the 5 cm rectangle projected out. This was covered by concrete wall for binding the concrete wall and foundation of the digester. A steel formwork was constructed using flat sheet 2.4m x 1.2m x 2mm for the concrete wall with a 12 mm diameter mild steel rod as reinforcement arranged at a spacing of 15cm. The High Strength Concrete (HSC) mixture (40N/mm²) was poured into the cavity created by the formwork to the dug digester pit to form the concrete wall of the biogas digester except at the manhole. The slurry discharge chamber of three walls was built and connected through manhole of the biogas digester. The dome vault was constructed by installation of a wood guide post located at bottom center of biogas digester. Formwork made of hardwood timbers and planks to withstand weight of concrete for dome construction were used. Wood pillars were installed round the circumference of the biogas digester. Wood structure of dimension 5cm x 7.5cm plank in the form of mesh network was constructed to form the dome vault over the digester (Fig.2).

The inlet feed and gas outlet pipes were placed and held by 2mm diameter wire on the wood mesh network structure. The feed pipe was made to slope with its bottom end held at 60 cm away from the bottom of the digester. Ceiling board was nailed over the mesh network structure except at the feed inlet and gas outlet pipe openings that are not covered. Parting sand and clay of 4 cm thick was spread on top of the ceiling board (Fig.2). HSC mixture was produced and spread up to 10 cm thick to form the dome vault concrete thickness. Concrete casting started from the digester freeboard to cover the base of the dome vault and spread to the top of the dome (Fig.3).

![Fig.1. (a) Plan view and (b) Sectional front view of dome-type biogas digester at Kilankwa II, Kwali, Abuja](image1)

![Fig. 2. Wood mesh network rafter structure for dome vault](image2)
Curing was done by covering with blue polythene spread on top of the dome vault after pouring water each day. About 200 liters of water was poured inside the digester each day for five days. This is to prevent crack and ensure proper setting of the concrete structure. On the sixth day, the formwork was removed. Treatment of the concrete surface was done using cement/sand slurry before commencement of plastering of the concrete and sealing of cracks.

3.2 Leakage Detection

There are different methods of leakage detection. The pressure method operates using a procedure whereby the biogas digester is pressurized before the start up and the decrease in pressure is monitored. A fast pressure decrease is an indication of possible leakage. Other methods of Methane leakage detection include semiconductors, heat conductivity, catalytic combustion and Flame Ionization Detector (FID). The leakage detection procedures adopted were as in Clemens, et al., 2012. The wooden blocks of dimension 60 cm x 60 cm x 10 cm thick and wooden diameter of 43 cm x 4 cm thick were force fitted into the manhole and bottom of feed pipe inside the digester by two technicians. Wet clay and cement were used separately to seal all the openings (except gas pipe) and any likely source of air leakage inside the digester. Two positive displacement pumps were connected together using plastic pipe and valves. The pipe system has a second T-junction valve in which one line runs to form the liquid manometer (Fig.4).

Liquid column in the U-tube manometer has one arm open to atmosphere, while the other pipe was connected to the gas outlet pipe at the top of the dome vault. On completion of the piping connections, simultaneous pumping of the two pumps was started to pressurize the digester for a period of about 20 minutes. To measure pressure in liquid manometer, the pumping process was stopped and valves 1 and 2 were closed, while valve 3 remained open to read the pressurized biogas digester. A fast decrease of pressure on the column indicates presence of leakage in the digester. In a situation where there is no sufficient gas, the procedure is to engage pumping of air into the digester through gas outlet pipe. The pumping took 30 minutes to bring water-slurry inside digester to 10 cm level from the surface level at feed inlet as well as slurry outlet. The gas outlet plastic pipe was tightened with clip to avoid any gas escape. If there is no reduction of slurry level to 120 cm within 5 hours, then there is no leakage. However, if there is a reduction of slurry level to 120 cm within 5 hours, it implies leakage exists. This will require emptying the entire slurry from the digester and then re-plastering the interior walls, roof and joints of the digester to prevent any leakage.

4 RESULTS AND DISCUSSION

The results and discussion presented which includes tables and figures were on construction and leakage detection of a dome-type biogas digester plant.

4.1 Construction of Dome-Type Biogas Digester

The construction began from site investigations, which include location as well as the selection of component parts of the biogas digester plant. The biogas digester location implies proximity to the kitchen, open to atmosphere and direct sunlight, waste availability and clearance of more than 10 m from any large tree which is similar to site selection procedure for biogas digester in Jiang, et al., 2016; Samer, (2012), and Rajput (2011). The biogas digester will utilize cow dung as described in Lebofa and Haba (2011), Abarghaz, et al., 2011 and Anaswara (2015). The technical data for the biogas digester plant are as shown in Table 1. These are the data arrived at during the initial energy survey of the locality which aims at determining average household size, average household energy consumption per day and sources of energy for domestic activities. The component parts of the biogas digester are the digester, slurry discharge chamber, gas storage dome vault, feed inlet pipe and gas outlet pipe with specifications as shown in Table 2. These are essential for material costing and labor. Biogas digester is a rural based technology, therefore, local materials for construction gets priority to minimize cost. The plan and section drawing of the biogas digester are as presented in Fig.1. However, commercial biogas digester will incorporate load and stress analysis for concrete structure sitted in clay (Otim, et al., 2007 and Desal, et al., 2013). The completed dome-shaped biogas digester is as shown in Fig. 4.
4.2 Leakage Detection Prior to Commissioning of Dome-Type Biogas Digester

Pressure testing at downstream of the digester was achieved by using a manometer test rig with its component parts. It measured the difference in the pressures of the slurry and biogas generated in the digester as shown in Fig.4. The pressure gauge level difference of 48 cm (4.7 KN/m²) was obtained, which later dropped to less than 20 cm (1.96 KN/m²) indicating presence of leakage in the biogas digester. Cracks in the biogas digester were located after a careful examination of the cylindrical wall and dome top, which were scaled and sealed with wet cement (Environmental Agency, 2013). The manometer test was conducted again and yielded pressure gauge level difference of 60 cm (5.88 KN/m²), without dropping for over 20 minutes, which implies no leakage. Leakage detection is necessary to avoid collapse of structure and emission of pollutant on the environment (EA, 2013 and BEE, 2004). In this work, leakage detection was carried out prior to commissioning the biogas digester. Leakage detection is also to avoid cost of removing feed and water from the digester (Usack, et al, 2012). Interior monitoring of pressurized biogas digester in this work is different from smoke test and hydraulic testing to detect gas and water leakages, respectively (RCSD, 2008). A reduction of water level after a period indicates presence of leakage while leakage detection using smoke test is mainly suitable for big leakages shown as visible smoke outside of digester (Clemens, et al, 2012).

5 CONCLUSION

Complete dome-type biogas digester with part such as digester, gas storage dome vault, slurry discharge chamber, feed inlet and gas outlet pipes were constructed with available local materials. Construction defects and leakage are among the challenges in the use of biogas plants in Nigeria. Application of engineering skills in provision of specifications of component parts and dimensions will not only minimize error in results but will eventually promote modeling in design of biogas digester that will operate efficiently. Furthermore, manometer test rig to detect crack in biogas digester has demonstrated that there are no limits to the use of fluid engineering applications. The incorporation of manometer will also ease detection of decrease of gas, which will prompt operators of biogas digesters to either add cattle dung or remove slurry from the digester as a quality control tool.

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