International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jet.htm
2016 Vol. 6 (2) April-June, pp.8-15/Bello and Alamu
Research Article

DESIGN AND CONSTRUCTION OF A DOMESTIC BIOGAS DIGESTER

***S. K. Bello[1] and O. S. Alamu[2]**
[1]*Department of Mechanical Engineering, Lagos State Polytechnic, Ikorodu, Lagos State, Nigeria*
[2]*Department of Chemical Engineering, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria*
**Author for Correspondence*

ABSTRACT
Energy is a crucial element in industrialization and socio-economic development process of any nation. While in developing economies the world overtakes proactive measures towards making for energy shortfall and chart a new course for producing energy in the futurity, Nigeria is grappling with inadequate power supply, and the need to develop an alternative source of energy cannot be over emphasized. This paper suggests a way forward in the exploitation and development of biogas, for the rural communities. The trend in household cooking energy requirement in the rural areas of the country was examined. Domestic biogas plants convert livestock manure and night soil into biogas and slurry into fermented manure. This technology is feasible for small holders with livestock producing 50kg manure per day, an equivalent of 6 pigs or 3 cows. The size of the digester was focused to achieve desired output which is the biogas itself using anaerobic digestion and the substrate used is cow dung. 1m^3 of biogas produced was used for different applications such as: generation of about 1.2kwatt of electricity, 0.7kg of petrol fuel replacement, lightning of 60-100watt bulb for 6hours and cooking of 3 squared meals for 5-6 people. By converting cow manure into methane biogas via anaerobic digestion, the millions of cows in many countries of the world would be able to produce one hundred billion kilowatt hours of electricity, enough to power millions of homes across the world.

Keywords: *Biogas, Fermentation, Anaerobic, Manure, Slurry*

INTRODUCTION

Renewable energy is that energy that comes from renewable resources such as the sun, wind, organic matter and so on. These resources are constantly replenished by nature and cleaner sources of energy. Agricultural waste such as cow dung, poultry droppings and so on pose a lot of difficulties in terms of their disposal. These wastes from the basic raw materials are used for the generation of a renewable energy known as bio gas.

Anaerobic treatment is the use of biological processes, in the absence of oxygen, for the breakdown of organic matter and the stabilization of these materials, by conversion to methane and carbon dioxide gases and a nearly stable residue. As early as the 18th Century the anaerobic process of decomposing organic matter was known and in the middle of the 19th Century, it became clear that anaerobic bacteria are involved in the decomposition process. But it is only a century since anaerobic digestion was reported to be a useful method for the treatment of sewage and offensive material. Biogas refers to the gas produced by the biological breakdown of organic matter in the absence of oxygen. Organic waste such as dead plant and animal material, animal dung, and kitchen waste can be converted into a gaseous fuel called biogas.

Biogas is produced by the anaerobic digestion or fermentation of biodegradable materials such as biomass, manure, sewage, municipal waste, green waste, plant material, and crops (Cheshire, 1979). Biogas comprises primarily of methane (CH_4) and carbon dioxide (CO_2) and may have small amounts of hydrogen sulphide (H_2S), moisture and siloxanes.

The gases methane, hydrogen, and carbon monoxide (CO) can be combusted or oxidized with oxygen. Biogas is a renewable fuel, so it qualifies for renewable energy substitute in some parts of the world. Biogas can also be cleaned and upgraded to natural gas standards when it becomes bio-methane. The residues from agriculture and forest could provide 20% of the world’s energy constituent.

Biogas contributes to the technological and economical advancement of an economy by reducing energy cost and contributing to the social structure. It is an alternative source of energy in many countries of the world. Apart from the great potentials, it does not contribute to global warming Biogas production takes different time depending on the temperature, and process adopted. All types of organic wastes are suitable for producing biogas by the process of anaerobic digestion in a bio plant. Animal waste, poultry waste and so on are easier into biogas. The organic materials sourced from human, animal and plants wastes, reduced to 3-6mm in size for adequate digestion (Eze *et al*., 2009). Also water is needed in the bioconversion process. It enables quicker decomposition and fermentation of the wastes. It is sourced from the streams, ponds, rain and underground sources.
In recent time, the provision of adequate and readily available power supply has been a major concern in this country. The major means of generating power supply presently is through Hydro- electric source. Biogas is a suitable, affordable and alternative source of energy, as it entails conversion of waste to wealth, easy and simple to generate without necessarily requiring high skilled man power for its operation. Lack of biogas industry especially in Nigeria, increase in fuel prices and availability of waste makes biogas inevitable. With the incessant felling of trees which does not promote environmental aesthetic and wild life reserve, there is the need for an alternative source of energy. Thus, they increase the availability of oxygen in the air and reduce the effect of carbon on the ozone layer. The extraction of crude oil from earth crust has increased natural disaster such as earthquake, fire outbreak and so on. This design provides a lot of benefits economically and technologically. In the rural sector, biogas finds great application in cooking, lighting, and power generation

MATERIALS AND METHODS

Materials Used

The materials used in the fabrication of the biogas plant are as follows:

i. Mild steel (1.2 mm thick)
ii. Gas hose: it is used to transfer the gas from the digester to the gas holder.
iii. Black paint: it is used in the digester after sealing the top to maintain the temperature.
iv. ½’’ control valve: It controls the gas going into the gas contain

Since the motive of this design is to obtain biogas (methane) which is the popular cooking gas, the presence of impurities in the gas produced may lead to high consumption of the gas during usage, hence the need for purifiers to remove impurities presents in the gas. Such impurities include carbon (IV) oxide, moisture, and hydrogen sulphide. The gas produced in the digester is channeled through the pipe to the purifiers so as to remove these impurities. The purifiers are enclosed in a casing below the digester connected through 2 rubber pipe to the digester. The housing is made from material which will not react with the chemicals used as purifiers or gas produced so as to obtain the pure gas in the latter. Chemicals used in this design as purifiers are calcium chloride ($CaCl_2$) hydrated iron (III) oxide and calcium hydroxide. Calcium chloride solution has a high affinity for water thus; it helps remove any traces of moisture present in the gas. Hydrogen Sulphide is a corrosive gas which does not contribute so to say in the combustion of fuel. It is removed from the gas by hydrated iron (III) oxide. This can be shown by the equation below.

$$Fe_20_3 + 3H_2S \rightarrow Fe_2S_{3(S)} + 3H_20_{(L)}$$

Carbon (iv) oxide does not support combustion but it is produced along with the gas from the digester, which is then removed using calcium hydroxide. This can be shown by the equation below:

$$Ca(OH)_2 + C0_2 \rightarrow CaC0_3 + H_20$$

Digester Design Considerations

Digester tanks may be of any convenient shape and provided with a cover to retain the gas. The cover may be a fixed one or floating. A number of factors are to be taken into account to arrive at an optimum size of a biogas plant. These are: the volume of waste to be digested daily; the type and amount of waste available for digestion consistently; methods of stirring the contents if any; the availability of other cellulosic fermentable waste in that area and the type of cover. Generally no separate heating and stirring of the contents are needed for digesting cattle waste. Stirring arrangement may however be provided for farmyard waste and plant wastes. The design of any biogas plant depends on the objective of use. For this paper, the biogas plant is of a small size for ease of maintenance, and the waste material involved is limited to cow dung.

Method of Fabrication

The Mild steel of 1.2mm thickness was cut into required sizes for the cylindrical and conical part. Using a bending machine, the cylindrical part was bent and tacked at different points using a stainless steel electrode. The cylindrical part is therefore welded together. The truncated conical part is tacked and welded to the cylindrical part. A 2''plug and socket valve is welded along the length of the digester creating both inlet and outlet for the slurry since it is a horizontal digester. A 2mm steel rod is welded to both ends of the digester to provide support and a stirring arm for the digester. Both sides are passed through two journal bearing bolt the angle steel in the form of a table for stability with wheels attached for easy transportation. A typical biogas digester for home use is shown in Figure 1.

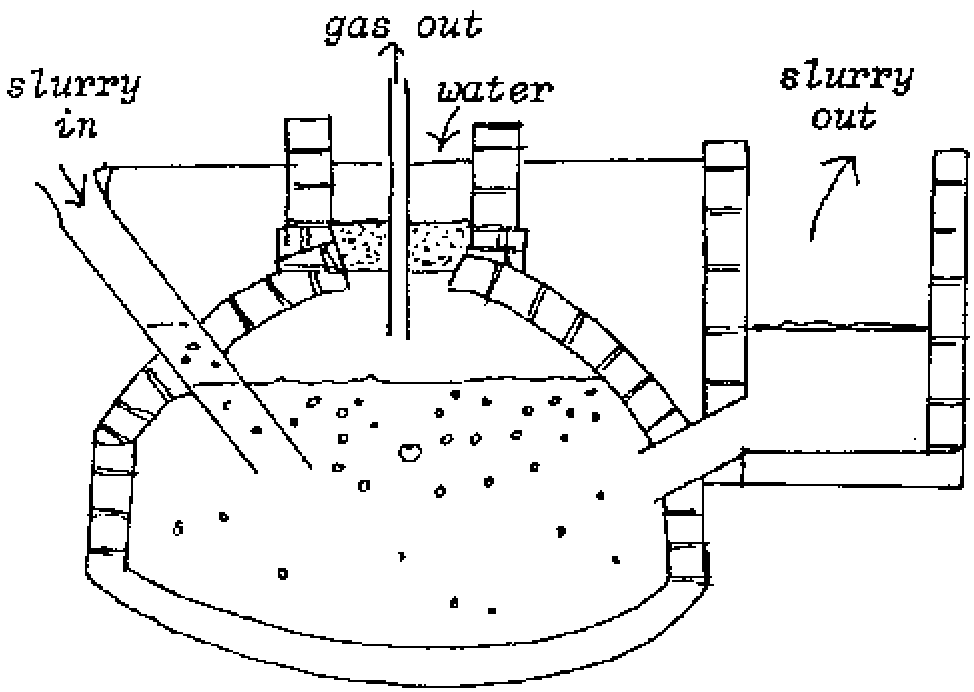

Figure 1: A Typical Domestic Biogas Digester

Biogas as a Source of Energy

Anaerobic digestion provides some exciting possibilities and solutions to such global concerns as alternative energy production, handling human, animal, municipal and industrial wastes safely, controlling environmental pollution, and expanding food supplies. The digestion process takes place in three stages: Degradation of the complex molecules (cow dong + water) into fragments of lower molecular mass by several types of fermentative enzymes; Further degradation of the fragments into acetic acids, hydrogen and carbon dioxide; The acetic acid, hydrogen and carbon dioxide produced in the above stages are then used by methanogenic archer (methane formers) to produce methane and carbon IV oxide from the acid and methane and water from hydrogen and carbon IV oxide. The reaction that takes place in the digester can be represented thus:

Cow dung + Water --> Methane + Carbon Oxide + Impurities + Slurry.

Table 1 shows the technology involved for biomass conversion in both wet and dry process as reported by Maishanu and Maishanu (1998). Biogas production takes different time depending on the temperature, and process adopted. El-Wakil (2002) in his findings reported the retention time for complete combustion which took place when used different substrates as shown in Table 2. All types of organic waste are suitable for producing biogas by the process of anaerobic digestion in a Bio Gas Plant. The organic materials sourced from human, animal and plant waste reduced to 3-6mm in size for adequate digestion. Water is needed in the bioconversion process, as it enables quicker decomposition and fermentation of waste. In this paper, emphasis was placed on anaerobic digestion. According to Rai (2004), methane production varies for different agricultural waste used as substrates as shown in Table 3.
The general equation for anaerobic digestion is given as:

$$CxHyOz + (x\text{-}y/4\text{-}z/2)\ H_2O \rightarrow (x/2\text{-}\ y/8 + z/2)\ CO_2 + (x/2 + y/8 - z/4)\ CH_4$$

For cellulose this becomes

$$(C_6H_{10}O_5)_n + n\ H_2O \rightarrow 3n\ CO_2 + 3n\ CH_4$$

Table 1: Biomass Conversion Technology: Wet and Dry Processes

Conversion Process		**Principal Product**	**Further Treatment**	**Product Fuel**
Wet Process	Anaerobic Digestion	Methane and carbon dioxide	Carbon dioxide removal	Methane
	Fermentation	Ethane is produced oil	Distillation	Ethanol
	Chemical Reduction	Mixture of oil	Fractional distillation	Hydrocarbon liquids
Dry Process	Liquid Faction	Char	Steam reforming and/or shift reaction	Methane
	Gasification	Char		Methanol
	Steam Gasification	Char		Higher alcohols
	Hydrogenation	Mixture of oils	Fractional distillation	Hydrocarbon liquids

Source: Maishanu and Maishanu (1998)

Table 2: Retention Time (Time for Complete Decomposition) for Different Material

S/N	**Material**	**Period**
i.	Cow and Buffalo Dung	50 days
ii.	Pig Dung	20 days
iii.	Poultry Droppings	20 days
iv.	Night Soil	30 days

Source: (El-Wakil, 2002)

Table 3: Methane Production from Typical Agricultural Waste

Type of Waste	**Volume of Yield/kg**	**Concentration in Biogas (%)**
Cow Manure	180-250	60-70
Pig Manure	210-300	58-60
Poultry Manure	350-400	58-65
Human Content	160-300	60-65
Green Plant	250-450	55-62
Straw	150-180	58-60

Source: (Rai, 2004)

RESULTS AND DISCUSSION

Biogas Properties

Energy value- 21,000-23,000 kJ/Kg
Generation velocity- 0.2 m/s
Air demand- 6.14m^3 of biogas
Pressure- 75-250mm H_2O
Density- 1.2 kg/m^3
Specific weight- 0.9

The Digester

The following equations are used for determining the size of digester and gas holder:
V_b= CM_O…………………………..1
V_r= M_O/P_m……………………….. 2
V_d= VrTr…………………………..3
Where: C= biogas yield per unit mass of feed stock (m^3/kg)
M_O= mass of dry feed stock (m^3/kg)
V_b= volume of biogas (m^3)
Pg= density of feed stock
T_r= retention time (days)
Vr= volume of slurry (m3)
The dimension of the digesters:
Depth of digester =540mm
Diameter of digester = 350mm
Diameter of inlet/outlet = 2’’
Height of inlet/outlet = 70mm
Volume of the Digester (V_d)
$\prod r_1^2h_1 + 1/3\prod r_1^2h_2 + \prod r_2^2h_3$
r_1= 0.175m
r_2= 0.07m
h_1= 0.45m, h_2= 0.09m
h_3= 0-07m
= $(22/7*0.175^2*0.45) + (1/3*22/7*0.175^2*0.09) + (22/7*0.07^2*0.07)$
= 0.043301+0.00289+0.000108
= 0.04727m^3
= 47.27 litres
Approximately 47 litres.
Maximum Acceptable Slurry in the Digester
3/4 of the volume of digester
3/4*47 = 35.25 litres
Approximately 35 litres
Drum density of slurry- 50kg/m^3
Gas Yield- 0.22m^3 (table cattle)
Using equation 1-3
Volume of Slurry= mo/p_m
M_o= 0.6kg
Pm= 50kg/m^3
Vr= 0.6/50= 0.012m^3= 12 litres
For every 12 litres of slurry,
Volume of Biogas (m^3) Produced (V_b) = Cm_o
M_o= 0.6
C= 0.3m^3/kg

V_b= 0.3*0.6= 0.18m^3/day = 180litres/day

Retention Time

$V_d = V_r*t_r$

$T_r = V_d/V_r$=47/12=3.92 days

Approximately 4 days

For every 3.5 litres of slurry charged into the digester, the retention time will be:

=4*3.5

=14 days

Estimated Efficiency of the Digester

µd=Theoretical gas yield per day/Gas yield per day

µd= (0.18/0.22)*100= 81.82%

Volume of the Gas Holder

$\prod r^2 h_1 + 1/3 \prod r^2 h_2$

$(22/7*0.075^2*0.35) + (1/3*22/7*0.075^2*0.05)$

=0.006186 + 0.000295

=0.006481m^3

=6.481litres

Gas Burner

The gas delivery is determined from rated theme heat of family burner, which is 21,400kg/hr

Coefficient of discharge is 0.78

Specific gravity =9.8m/s

Pg= 1.2kg/m^3

V_o= 6.14m^3

Spencer (1985) gives the important requirement for combustion of biogas in burners. These dimensions for burners consists of the nozzle primary mixing air, mixing throat, burner head and burner head number of holes. These dimensions are obtained from the following;

Apr = 2.78 (aVo)/R……………………(4)

Dn = Cd*10(I/R)*4pg…………………(5)

Dt = Dn(I+Vo/g)………………………(6)

Using equation 4, 5 and 6 respectively

Apr= 2.78(6.14)/22,000

Apr=0.078

Dn=0.7*10(21,4000/22,000)*4(1.2/75)

=0.7*10(0.097)*0.058

=1.7mm

Dt=1.7(21,400+6.14/9.81)

=1.7(21,406.14)*2182.1

=11618.5mm = 11.6m

Gas Line

Gas hose= 5/16’’ diameter

Pressure drop= 10mmH_2O

Design pressure for biogas= 75mmH_20

Other dimensions are:

P = 10mmH_20

P_2= 75mmH_20

$P = P_1-P_2$

$P_1=P+P_2$

P_1=10+75

P_1=85mmH_2O

Research Article

From the results obtained, 180 litres of biogas was produced from 12 litres of the waste slurry. 35 litres of slurry was maximum acceptable in the designed biogas digester having capacity of 47litres. As shown in Table 4, 1m^3 of biogas produced was used for different applications such as: generation of about 1.2k watt of electricity, 0.7 kg of petrol fuel replacement, lightning of 60-100 watt bulb for 6hours and cooking of 3 squared meals for 5-6 people.

Table 4: Application of Biogas

No	Application	1 m^3 Biogas Equivalent
1	Lighting	Equal to 60-100 watt bulb for 6 hours
2	Cooking	Can cook 3 meals for a family of 5-6
3	Fuel Replacement	0.7 kg of petrol
4	Shaft Powers	Can run a one horse power motor for an hour
5	Electricity Generation	Can generate 1.25 kilowatts of electricity

Conclusion

Provision of proper orientation and knowledge will help alleviate the problems of energy provision in Nigeria. The design provides a means of converting waste to wealth, thus, if the knowledge is properly disseminated, it will serve as a means of generating income for the unemployed youths in the society, reducing the level of poverty and crime thereby creating a better Nigerian economy. Biogas is a viable and alternative source of energy that is affordable, readily available, environmentally friendly and simple to generate using a biogas reactor.

By converting cow manure into methane biogas via anaerobic digestion, the millions of cows in many countries of the world would be able to produce one hundred billion kilowatt hours of electricity, enough to power millions of homes across the world.

Other benefits which this study provides are listed as; Inexpensive solution to problem of rural fuel shortage. Improvement in the standard of living of rural communities; Provides employment opportunities in small scale industries; Residual sludge is applied as top dressing; good soil conditioner and inorganic residue useful for land reclamation.

ACKNOWLEDGEMENT

It is a pleasure to acknowledge everyone who had contributed immensely towards this research project. The efforts of O.S Alamu who coauthored this work were sincerely acknowledged by the corresponding author.

REFERENCES

Cheshire MV, Sparling GP and Inkson RHE (1979). *In Straw Decay and its Effect on Disposal and Utilization* (E. Grossbard, edition), 65-71. (J.Wiley, Chichester, England).

El-Wakil MM (2002). *Power Plant Technology*, (McGraw Hill International, New York, USA).

Eze CL, Abowei MFN and Ayotamuno MJ (2009). Comparative evaluation of Batch and Continuous anaerobic digesters in biogas production from municipal solid waste using mathematical models. *Agricultural Engineering International: CIGR Journal Manuscript EE07 011* **10** 1-11.

Maishanu SM and Maishanu HM (1998). Influence of inoculums age on biogas generation from cow dung. *Nigerian Journal of Renewable Energy* **6**(1&2) 21-26.

National Non-Food Crops Centre (no date). *NNFCC Renewable Fuels and Energy Factsheet: Anaerobic Digestion* [Online]. Available: http://www.nnfcc.co.uk/publications/nnfcc-renewable-fuels-and-energy-factsheet-anaerobic-digestion .[Accessed 6th February, 2011]

Rai GD (2004). *Non-Conventional Energy Resources* (2nd edition), 331-3690, (India, New Delhi: Khpu Khanna).

Spencer DF (1985). Method of selectively separating CO_2 from a multi component gaseous [P]. *The Journal of Physical Chemistry* **89** 3279-3285

Biogas & Engines [Online] (No Date). Available: http://www.clarke-energy.com/gas-type/biogas/ [Accessed 21st November, 2011]

Claverton-energy [Online]. *Biomethane Fuelled Vehicles the Carbon Neutral Option* Available: http://www.claverton-energy.com/biomethane-fueled-vehicles-the-carbon-neutral-option.html. *Calverton Energy Conference*, October 24th 2008, Bath, UK.

State Energy Conservation Office (Texas) (No date). *Biomass Energy: Manure for Fuel.* State Energy Conservation Office (Texas), State of Texas [Online]. Available: http://www.seco.cpa.state.tx.us/re_biomass-manure.htm. [Accessed 3rd October 2009].

Alfagy [No Date]. *Be Green- Make Gas* [Online]. **(No Date).** Available: http://www.alfagy.com/index.php?option=com_content&view=article&id=54&Itemid=31

Biogas- Bioenergy [Online]. **(No Date).** Association of New Zealand. Available: http://www.bioenergy.org.nz/biomas.asp [Accessed 21st February 2010].

LNG Energy Projects [Online]. (No Date). Available: http://www.epa.gov/Imop/proj/

Safety Page, Beginners Guide to Biogas [Online]. (no date) Available: http://www.adelaide.edu.au/biogas/safety/), [Accessed 22nd October, 2007].

U.S Department of Energy, (No Date). *What is Biogas?* [Online]. Available: http://www.afdc.energy.gov/afdc/fuels/emerging_biogas_what_is.html. [Accessed 13th April 2010].