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Review

Appraising the combustion of biogas for sustainable rural energy needs

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This paper shows the combustion of biogas in rural households' appliances. Biogas has been known since 1800s as an odourless and colourless gas with high combustion rate. Its use is beginning to gain ground in most developing countries like Nigeria due to its availability, ease of generation and environmental friendliness. Developing countries are characterized by poor infrastructural development, inadequate energy and water supply, poor health delivery system, etc. which hinders economic and social development. Most sources of rural households' energy are firewood, animal dung, crop residue and kerosene which are associated with negative environmental impacts. The study was carried-out by articulation of past literatures on biogas combustion and consumption in household's appliances and internal combustion engines. The study ascertains from the past studies high efficiency of biogas compared with natural gas and liquid petroleum gas (LPG) on stove-top burner, oven and two panel flue heater. It was observed that, biogas consumption is higher in all the appliances under investigation as compared to natural gas and LPG. The study recommended public enlightenment on biogas technology and its associate benefits to rural areas. The government and NGOs should encourage the application of this technology through financing of pilot projects in community leaders' households which will extend to the populace. The technology should also be embraced because it is associated with environmental hygiene.

Key words: Efficiency, hygiene, sustainability, developing countries, biogas.

INTRODUCTION

The rate of energy consumption and waste generation in developing countries necessitates the adoption of technologies that promote renewable energy and the conversion of waste into viable commodity. Biogas technology is one of such systems, it is cost effective and environmentally friendly (Brown, 2003). According to Matthew (1998), after the advent of the oil boom of the 1970s in Nigeria, there has been a growing national concern on shortage of energy supply. Similar problem has been envisaged around the globe (Oslaj and Mursec, 2010; Preston and Murgueitio, 1992; Mattocks, 1984). In the United States of America for instance, several million gallons of fuel is consumed on daily basis for transportation and other activities to meet their daily needs (Habmigern, 2003). These fuels are obtained from non-renewable sources which will not guarantee production in the nearest future. In addition, their production is associated with negative impacts on the environment. Sustainability is a current global trend which addresses issues concerning environmental impacts. It was defined as development that meets the needs of the present generation without compromising the ability of future generations to meet their needs (World Commission on Environment and Development, 1987). To achieve sustainability, the use of sustain-

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Table 1. Composition of biogas.

Substance	Symbol	Percentage
Methane	CH_4	50 - 70
Carbondioxide	CO_2	30 - 40
Hydrogen	H_2	5 - 10
Nitrogen	N_2	1 - 2
Water vapour	H_2O	0.3
Hydrogen sulphite	H_2S	Trace

Source: Yadava and Hesse (1981).

able energy sources (such as biogas, solar photovoltaic and wind) (Pick et al., 2012; Oslaj and Mursec, 2010) must be adopted in developing countries.

Biogas has been known since early 1800s in different parts of the world to complement most household energy needs (Stanley, 2006). Rapaport (1995), defined biogas as 'a mixture of methane and carbon dioxide produced by anaerobic bacteria as they digest organic materials'. It is composed of methane, carbondioxide and other small amounts of gases as shown in Table 1.

Biogas is lighter than air and has an ignition temperature of approximately 700°C as compared to diesel oil of 350°C; petrol and propane of about 500°C (Brown, 2003). The temperature of the flame is 870°C (Brown, 2003). In rural areas, biogas are used in modified form for stove, refrigerator, water heater, diesel engine, gas lamps and indeed any piece of equipment that uses liquid petroleum gas (LPG) (Engineers Without Borders, 2004).

Rural areas are characterized by inadequate provision of essential amenities like power supply, water, road, hospital and schools. Biogas production reduces the risk of exposure to smoke from firewood which causes respiratory illness and promotes deforestation. It reduces shallow ground water contamination from nearby pit latrines and soakaway. It also saves money, replacing electricity or liquid gas as a source of energy for cooking (Aquilar, 2001). Interest in biogas as a viable energy resource has spread throughout the globe in the past two decades (Stanley, 2006). Biogas digester operates throughout Asia, with more than 100,000 reported in India, 30,000 in Korea and several million in China (Mattocks, 1984). Biogas produced from a town septic tank was used for street lighting in Exeter England in the late 1800s and today used as a source of energy for operations in sewage treatment plants in most parts of the world (Rapaport, 1995). Also in Pnatna, India, 24 seat pour-flush latrines serve several thousand people and generate sufficient energy to light a 4 km road (Li, 1984). Also, Vijay (2006) outlined the use of biogas in cars, buses, tractors, auto rickshaws, irrigation pumps and in rural industries. The calorific value of the gas is about 6 kWh/m^3 which corresponds to about a litre of diesel oil (Brown, 2003). These associated advantages necessitate the adoption of biogas technology in rural areas of the developing countries.

The major disadvantage in using the gas is the presence of hydrogen sulphide. The hydrogen sulphide combines with water vapour to form a corrosive acid. Water heating appliance, utensils and refrigerators are particularly at risk. However, according to Brown (2003), biogas can be rid of the sulphide using iron oxide filters, as given in the following equations:

$$FeO + H_2S \rightarrow FeS + H_2O$$

$$2FeS + O2 \rightarrow 2FeO + 2S$$

ANAEROBIC DIGESTION

Biogas is produced from a process known as anaerobic digestion. Anaerobic digestion is the process of bacterial decomposition in the absence of oxygen. It is a natural phenomenon that occurs in everyday life, that is, plants and animals die and are recycled by nature. Swamp areas, landfill wastes, septic and soakway tanks, farm wastes, animal dung, poultry wastes, abattoir wastes, etc. are potential sources of anaerobic digestion (Pick et al., 2012). The major by-products of the anaerobic digestion are: Biogas and a semi-solid effluent or sludge (Brown, 2003; Mattocks, 1984).

Biogas

Biogas is a mixture of gas produced by methanogenic bacteria while acting upon biodegradable materials such as raw cow manure, human excreta, vegetable waste and water in an anaerobic condition (SDdimension, 1997).

Biogas is about 20% lighter than air and has an ignition temperature in the range of 650 to 750°C as compared to diesel oil, 350°C; petrol and propane of about 500°C; it is an odourless and colourless gas that burns with clear flame at a temperature of 870°C (Brown, 2003; Sathianathan, 1975). Biogas is known by many names: swamp gas, marsh gas, "will o' the wisp" and gober gas (Mattocks, 1984).

Biogas can be used in the same way as many other combustible gases. It can be used in a modified gas stove, refrigerator, water heater, diesel engine, gas lamp and in any piece of equipment that uses liquid petroleum gas (LPG) (Engineers Without Borders, 2004).

Effluent

Effluent (called slurry or sludge) is the residue of inputs that comes out of the compensation chamber after the substrate is acted upon by the methanogenic bacteria in an anaerobic condition inside the digester. The effluent is the second by-product that comes out of the digester after

Figure 1. Oil drum biodigester.

Figure 2. Flotation tube.

Figure 3. Cooker burner using biogas.

Figure 4. Water boils by biogas.

after extracting biogas. It is a stabilized manure almost pathogen free and has proved to contain high quality organic materials for plant nutrition and fish production (Karki and Gautam, 2000). It has no odour and neither dissemination of diseases/weeds and comes out from the compensation chamber in one of the following forms (SDdimension, 1997):

1. A high rather solid fraction, mainly fibrous material, which float on the top forming the scum.
2. A very liquid and watery fraction remaining in the middle layer of the digester.
3. A viscous fraction below which is the real sludge.
4. Heavy solids, mainly sand and soils deposited at the bottom.

The above separation can be less in the slurry if the organic matters fed into the digester are homogenous, using appropriate ratio for urine, water and excrement; and intensive mixing before feeding the digester leads to homogenous slurry (SDdimension, 1997).

BIOGAS APPLICATIONS

Figure 1 shows oil drum biodigesters used for the production of the biogas in Ahmadu Bello University, Zaria, Nigeria, while Figure 2 shows flotation tube used for collection and storage of the biogas produced from the biolatrine system (Stanley, 2006).

Biogas can be stored in tractor tubes or in a flotation container as observed in Stanley (2006) and Forst (2002). This can be adopted in the rural areas for the storage of the biogas produced for immediate use. In an experiment conducted by Stanley (2006), biogas was used in cooker burner to boil water as shown in Figures 3 and 4.

This was also articulated by Brown (2004), ITDG (2004) and Shannon (1997), that biogas combust effecttively on cooker burner. Figures 5, 6 and 7 shows biogas burning from a gas valve with visible flame enhanced by wood and paper (Stanley, 2006).

The use of wood and piece of paper were to enhance the visibility of the combustion which is odourless and colourless that burns with clear flame at a temperature of 870°C (Brown, 2003; Sathiarathan, 1995) (Figure 8).

Some studies (Stanley, 2006; Brown, 2003; Shannon, 1997) have compared the combustion of biogas different on equipment and households appliances. Shannon (1997) compared the combustion of biogas, natural gas and LPG on stove-top burner, oven, two panel heater and flued heater. It revealed that biogas consumption is high-

Figure 5. Wood enhanced the visibility of biogas combustion.

Figure 6. Paper enhanced the visibility of biogas combustion.

Figure 7. Blue flame burning on biogas.

Figure 8. Flame of fire from biogas.

er in all the appliances under investigation as com-pared to natural gas and LPG as shown in Table 2.

Natural gas and LPG are obtained from non-renewable sources which are associated with environmental and health hazards. Biogas on the other hand, is environmental sustainable in the sense that it is renewable and obtained from renewable sources. This makes biogas environmentally sound.

Biogas has high efficiency as observed in ITDG (2004), 1 m^3 of biogas can make three (3) meals for a family of five to six. In BSP (2001), the efficiency of biogas stove was studied under perfectly controlled, semi-controlled and uncontrolled external conditions. The results show that the efficiency of biogas on the stove was 49.44, 43.8 and 32.26%, respectively, which are high. In another study by CES (2001), the overall efficiency of biogas was 57.4% higher than that of LPG, kerosene and wood stove with frequencies of 53.6, 49.6 and 22.8%, respectively. These shows that biogas has high efficiency of combustion in stove. Table 3 also shows the consumption ption rates of biogas and time taken in cooking using modified gas stove.

Table 4 and Figure 9 show various households equipment and the quantity of biogas consumed in litre per hour for lighting and cooking. Household gas burner consume 200 to 450 L/h of biogas to cook 350 to 1000 g of pulse as shown in Table 3, while a gas lamp of 60 W bulb equivalent consume 120 to 150 L/h of biogas, etc. Brown (2003) and Forst (2002) have measured the quantity of consumption and performance of biogas on different household equipment which proved excellent. Figure 10 shows the storage bag for biogas as observed in Forst (2002).

Internal combustion engine are improvised to use biogas. Engine carburetors and injectors are the major parts which need partial or no modification to burn

Table 2. Typical consumption figures - domestic appliance.

Appliance	Approximate consumption (m^3/h)		
	Biogas	Natural gas	LPG
Stove-top Burner (9 Mj)	0.5	0.25	0.1
Oven (8.5 - 10 Mj)	0.40 - 0.60	0.20 - 0.30	0.08 - 0.12
Small, two-panel heater (11 Mj)	0.55	0.30	0.11
Large, flued heater (44 Mj)	2.20	1.10	0.44

Source: Shannon, (1997).

Table 3. The consumption rates of biogas in cooking using modified gas stove.

Amount cooked	Time (min)	Gas (L)
1 L water	10	40
5 L water	35	165
500 g rice	30	140
1000 g rice	37	175
350 g pulse	60	270
700 g pulse	70	315

Source: Brown (2003).

Table 4. Consumption of biogas by various equipment.

Equipment	Amount of gas (L/h)
Household burners	200 - 450
Industrial burners	1000 - 3000
Refrigerator, 100 L depending on outside temperature	30 - 75
Gas lamp, equivalent to 60 W bulb	120 - 150
Biogas/diesel engine per bhp	420
Generation of 1 kWh of electricity with biogas/diesel mixture	700

Source: Brown (2003).

Figure 9. Modified gas stove and pressure lamp attached to biogas storage container. Source: Forst (2002).

Figure 10. Flotation storage tank. Source: Forst (2002).

Figure 11. Biogas packed in cylinder for car consumption. Source: Vijay (2006).

Figure 12. Packed biogas for household application. Source: Vijay (2006).

smoothly on biogas as dual or whole. In ITDG (2004), it was observed that 1 m^3 of biogas generate 1.25 kWh of electricity, or power a one horse power internal combustion engine for 2 h which is equivalent to 2.5 L of petrol (Vijay, 2006). In Quenum (2007), it was also observed that 1 m^3 of biogas burned on electric generator to produce 2 kWh of electricity. This figure is projected to 4,612,320 kWh electricity per year for a pig farm with flock of 3,206. In another study by Siripornakarachai and Sucharitakul (2007), a Hino K-13CTI 13,000cc 24 valves diesel bus engine was modified to operate on biogas. The engine was coupled to a 3-phase 4-pole induction motor to produce electricity at 50 Hz. The study established optimal engine efficiency at 28.6%, while the generator power output was 134.20 kW with emission of CO and NOx at 1,154 and 896 ppm, respectively. It was observed that emission of CO and NOx were significantly low as compared to same emission from a 2.3 kW petrol generator of 916 and 1.8 ppm, respectively (Stanley, 2011).

Vijay (2006), articulated packaging of biogas for cars and home use in cylinders (Figures 11 and 12).

It was observed that one (1) cylinder filled with 120 m^3 biogas bottle equals to eight (8) of 6 kg CNG cylinders and the 6 kg CNG cylinder equals 6 L of petrol (Vijay, 2006). The gas filled in these cylinders equal to 6 multiple by 8 which is 48 L of petrol per day.

King and Mintner (1998) ascertained the removal of impurities present in biogas which is fed into an internal combustion engine. Biogas supplied to the engine flows through a filter which removes hydrogen sulphide and merceptans and also through a coalescer to remove water vapour.

In Mehta (2002), the production of biogas per cow and the quantity of electricity generated were compared. The electricity generated per cow by European generator was 0.15 kW on a continuous basis, while in America it was 0.2 kW. The difference in the generation was owed to animal size and feed. Mehta (2002) estimated the potential of electric power generation that can be produced by number of cows in farm (Table 5).

In PREGA (2006), the production of biogas and the electric power output in summer and winter were studied. It was observed that 40 m^3 of biogas was generated per day in summer, while 80 m^3 in winter with electricity generation of 80 to 160 kWh/day. While GEDA (2003), included the estimation of plant capacity of biogas production per day, which range from 15 to 85 m^3 as shown in Table 6 and Figure 13 shows the China dome digester used for the biogas production. The corresponding cattle population, dung required, quantity of electric power generated size and the running hours were also estimated.

GEDA (2003) established that 15 m^3 of biogas per day is produced by 25 to 30 cows which can run a 3.5 KVA/3.0 kW diesel generator for 4 to 5 h per day. Subsequently, 220 to 250 cows produce 85 m^3 and run

Table 5. Maximum demand and electric power potential.

Number of cows	Electric power potential (kW)
30	6
60	12
200	200 20 40
400	80

Source: Mehta (2002).

Table 6. Plant capacity of biogas and electricity generation.

Plant capacity (m^3/day)	Cattle population required	Dung required on daily basis (kg)	Possible size of DG set to be coupled with biogas plant	Approximate DG running per day and total unit generation/day
15	25 -30	225	3.5 kva/3.0 kW (single phase genset)	4 - 5 h/day (12 to 15 units/day)
25	62 -70	625	3.5 kva/3.0 kW (single phase genset)	7 - 8 h/day (20 - 24 units/day)
35	85 - 95	875	7.5 kva/6.0 kW (Three phase genset)	5 - 6 h/day (30 - 36 units/day)
45	120 - 130	1130	7.5 kva/6.0 kW (Three phase genset)	7 - 8 h/day (45- 50 units/day)
60	150 - 160	1500	10 kva/8.0 kW (Three phase genset)	9 - 10 h/day (80 - 90 units/day)
85	220 - 250	2125	10 kva/8.0 kW (Three phase genset)	13 -14 h/day(120-130 units/day)

Source: GEDA (2003)

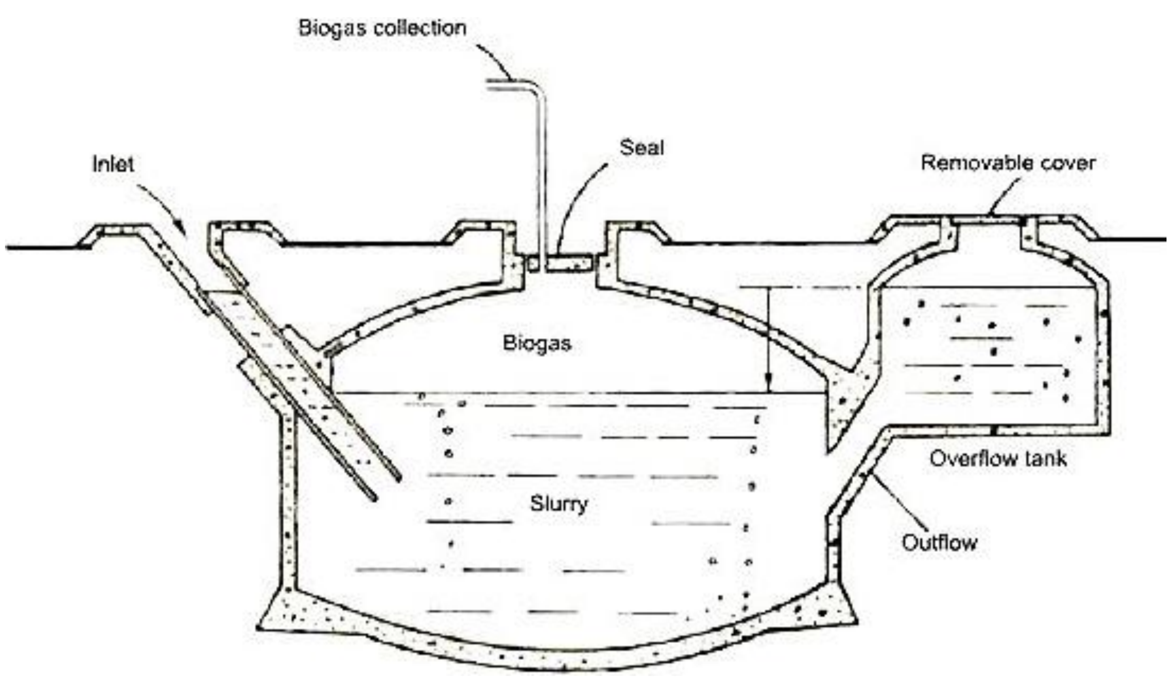

Figure 13. China dome digester. Source: Kangmin and Ho (2006).

10 KVA/8.0 kW diesel generator for 13 to 14 h per day.

Conclusion and recommendations

From the findings, biogas has been a viable source of energy which has been practiced for a very long time in China, India, Korea, etc. because of its cheapness, accessibility and sustainability. It has been observed that biogas production is a process of waste disposal (both solid and liquid) and environmental sanitation. Biogas has been tested and proved to perform well in household appliances (cooker burner, gas lamp, electric power generators and on cars). No environmental contaminant is associated with the production of biogas. The technology requires no or less expertise and this will suits the nature of the Nigerian rural populace. It will enhance the income generation and reduce spending of the poor. It was recommended that public enlightenment on biogas technology and its associated benefits should be disse-minated. The government and NGOs should encou-rage the application of this technology through financing of pilot projects in households of rural head which will be extended to the entire populace.

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