Design of Biogas Plant for Rural Households in Uganda (Case Study: Apac District)

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ABSTRACT

Biomass is the major source of domestic energy for both rural and urban areas in Uganda. This translates to million tonnes of round wood for firewood and charcoal per year. Biomass future demand can be assumed to be proportional to population growth. By the year 2025, Uganda will require 42.6 million tonnes of wood for household energy use for her estimated 55 million people then. This research looked at a typical rural set-up in Apac district to represent the general situation in Uganda. The domestic sector energy demand in Uganda is over 80% of the national energy demand, and biomass contributes 92.3%. The study designed a domestic biogas plant, which if adopted can reduce the biomass consumption by a significant percentage. Many nationalities in Uganda and East Africa are cattle keepers, therefore the raw material (Cow dung) will not be a problem. From the research and design, a family with between 5 to 10 cows can produce a minimum of 2.5 m^3 of gas which is adequate for lighting and cooking for an average rural household of six people. This will lead to better standard of living through improved household income from milk, meat, organic fertilizer, employment of biogas masons and conservation of the environment by saving the metric tonnes of trees being fell for firewood and charcoal. This project is in line to the millennium development goals (MDGs) 1and 7.

KEY WORKS: Biogas, Biomass, Energy, Rural Household, Uganda

1.0 INTRODUCTION

Uganda has of recent been affected by the current climate change challenges in a number of ways. Population increase and consequent utilisation of biomass has partly been responsible for the situation. Current impacts of climate change was evident in Eastern Uganda especially in Teso sub-region where floods displaced thousands of people from their homes in 2007 and later in 2009, drought hit the same area and many lives were lost due to hunger. About 80% of Uganda's population live in rural villages where there are almost no alternatives to biomass fuel. Cooking takes a lot of round wood and the need to cook with cheap smarter charcoal in urban areas have increased the situation of the rural people to engage in charcoal production for sale to urban centres. The domestic energy consumption from different sources is as in figure 1. Biomass usage prevents people from working as they have to spend large amounts of time to search for and collect wood. It also causes respiratory problems and eye sicknesses due to carbon monoxide and smoke besides destroying the natural habitat for coexistence. This project was therefore aimed at developing biogas technology into an important domestic energy source to minimise the problem.

About 92% of Uganda's energy demands are satisfied by wood and charcoal which according to NFA biomass study, (2009) has caused loss of 27% of the total forest and tree cover in the last 15 years. At this rate of deforestation, Uganda will be importing wood fuel by 2020. Apac District is located approximately 250 km north of Kampala in Northern Uganda. It lies between longitudes 32° E and 34° E and latitudes 2° N and 3° N and is therefore very equatorial in climate and environment. The vegetation of Apac is predominantly dry savannah, good for cattle keeping. It has dry and wet seasons with the wet season extending from April to November. The total annual rainfall is usually 1,330 mm and on average, the maximum temperature is 29°C and the minimum is 17°C.

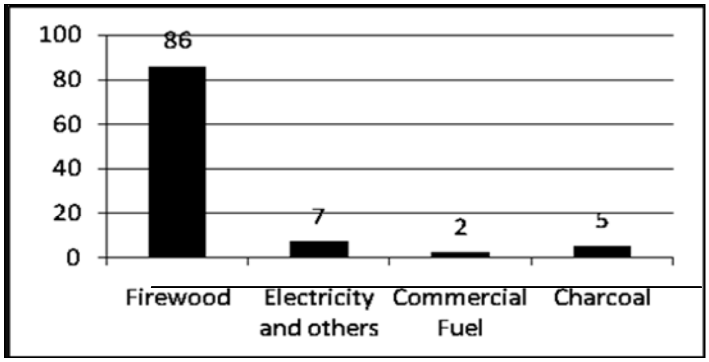

Figure 1: Uganda's domestic energy consumption mix 2002 (Sebbit *et.al.* 2004**)**

The 2002 population census found a population of 415,578 people with a population density is 106 persons per km^2 in Apac (UBoS 2002). With a population growth rate of 3.5 per cent, the report projects a population of over 911,448 people by 2025. The study specifically targeted Inomo Sub County in Kwania County, with household population of 21,770 and density of 124 persons per square kilometre as per January 2010. Over 99% of the population use firewood and charcoal.

2.0 BIOGAS CONCEPT

Biogas is generated through a process of anaerobic digestion of organic materials from human and animal waste, crop residue, agro-industrial waste and other biomass materials. The energy obtained from waste materials like plants, animals and humans is what is referred to as biomass energy. According to Mathur and Rathmore, (1992), the content of biogas is as shown in Table 1.

Table 1: Composition of biogas

Composition of biogas	Percentage	Properties and Remarks
Methane	55-70	Main source of energy, lighter than air and has ignition temperature of approximately 700^{o}c with specific gravity of 0.86 and a flame factor of 11.1. Its flammability in air is 6-25%(safer than other gasoline)
Carbon dioxide	30-45	Green gas. Use for photosynthesis
Nitrogen, hydrogen sulphide and others	1-5	

The calorific value of biogas is approximately 20 MJ/m^3 (4700Kcal/m^3) and methane is responsible for the energy obtained from biogas depending on the biological process and type of biomaterial. An average dairy cow produces about 55 kg of solid waste each day, which adds to 20 metric tons of dung per annum. Unmanaged livestock waste can create negative environmental impact (air pollution and ground water contamination) which this project set to address. The methane created through anaerobic digestion of manure has proven to be 21 times more damaging than carbon dioxide, aggravating to climate change. Around 3.0 kwh of electricity could be generated daily from the dung and urine of just one cow.

2.1 Potentials of Biogas

Duggal, (2002) found out that biogas contains 400-6000 calories /m^3 thus providing a convenient source of energy at low cost. A comparison of biogas with other forms of fuel energies and results are as in the Table 2.

Table 2: Comparison of 1m^3(600calories) of biogas with other energy sources

Energy	Alcohol	Petrol	Crude oil	Gasoline gas	Charcoal	Electricity
Quantity	1.1litre	0.8 litre	0.6 litre	1.5 m^3	1.4 kg	2.2 kwh

Table 2 show the immense potentials of the biogas as energy source. Biogas system can be designed for individual family or community use.

2.2 Factors that affect Biogas Production

Rai, (2000) says the ideal temperature for methane producing bacteria is about 35^{0}C, just about blood temperature. Low temperature reduces gas production and nearly stops at 10^{0}C. Plants built underground tend to have stable temperatures within daily allowable fluctuation of 1^{0}C and in Apac the minimum is 17^{o}c. The time required for the organic matter to be digested in the digester is called the retention time and is temperature dependant. The higher the temperature the faster the bacteria use the food in the slurry and the sooner it needs replacement. Methane producing bacteria are anaerobic, thus air should be excluded. Bacteriology multiplication depends on the sort of dung and the temperature level. Carbon (in the form of carbohydrates) is utilized for energy provision for the bacteria and Nitrogen (as proteins, nitrates, ammonia, etc) is the chief nutrients of anaerobic bacteria. The required ratio according to (Mathur and Rathore, 1992) is 25-30:1. At any given time, the bacteria will find its own pH level and this is usually 7-8, but can have ±0.5. This is checked using a litmus indicator paper. Suitable solid content (dry matter concentration) is 7-9%. More water results in more CO_2 produced, while more solid content result in scum formation all affecting gas production, therefore need for control and balancing. Toxic and harmful substances result from medications and type of feeds given to the animals, but the effect is so minimal that can be ignored.

3.0 DESIGN METHODOLOGY

3.1 Field Survey

Assessment of the number of cattle per household was carried out to establish the raw material requirements for the plant sustainability. Preliminary surveys to identify the availability of the water and local materials for construction and to assess the condition of the proposed sites were also carried out. The number of persons per household was found to be seven and they showed willingness to use biogas. The analysis and design was based on the information obtained from other scholars like Rai, (2000) and field data. The average number of cows per household was found to be 10, and the quantity of dung per cow was experimentally estimated to be 10Kg/ cow per day, during worse period of dry season. For the design purpose, this study adopted 6 persons per household as per the population census of 2002.The success of a biogas plant in the rural areas primarily depend on the selection of the plant design, size, site, materials of construction, type of plant, method of construction and acceptability. Monitoring its operation, repairs and maintenance are required for optimum working and utilization.

3.2 Components of Biogas Plant: A complete biogas plant will have the gas generation sub-system (the digester), feed and slurry handling sub-system (the inlet and outlet of the slurry), gas distribution and utilisation sub-system (the pipe work and terminal appliances) refer to figure 2.

3.3 Selection of Model, Design and Construction

This was based on technical, economic and social considerations. The size to use depends on the availability of biodegradable materials and amount of gas required. In this case the quantity of cow dung and the use of the gas (cooking and lighting were considered). To design for the volume of plant, knowledge of gas required per day, number of cattle available, number of family members (requirement of gas for cooking and lighting), purpose and, hydraulic retention time were the factors of interest. Construction time and labour resources required to build a biogas plant vary depending on several factors. The most important consideration is the availability of people interested in carrying out this kind of work. A biogas digester which is the apparatus used to control anaerobic decomposition was proposed to be constructed of brick masonry. This is a sealed tank or pit that holds the organic materials, and some means to collect the gas that is produced. Many different shapes and styles of biogas plants have been experimented with: horizontal, vertical, cylindrical, cubic, and dome shaped. This project adapted the dome shape shown in figure 2. The bottom line is that the construction should be simple with low demand of materials, cheap labour and low in cost and easy to build. The foundation is constructed using the plain concrete slab of grade 25. The wall (Plastered) should be impermeable to avoid percolation of water from the sides. The slurry mix tank (inlet chamber) is also provided using masonry construction. Its size is decided such that it can hold charging material for at least one day. It is fitted with a pipe which leads into the digester. The outlet chamber/ manure pit/ drying bed is constructed having an outlet pipe leading the digested slurry from the digester into the chamber where it is removed and utilized as manure. The gas is lead out from the top of the dome to a pipe network for consumption.

4.0 DESIGN AND DIMENSIONS

4.1 Calculations

The number of cows per household as found on average = 10.
The amount of dung per cow = 10 kg given the fact that the cows move far from home to graze. However, with zero grazing practice a dairy cow produces about 55 kg of dung per day.
The amount of dung to be used for the design therefore = 10 x 10 = 100 kg per day.

4.2 Gas requirement per day

Size of household = 6 persons on average, (Uganda population census, 2002).

Cooking:

Quantity of gas required for cooking per person = 0.227m^3 (Rai, 2000).
Therefore, required gas per day per household = 0.227 x6 = 1.35m^3 of gas.

Lighting

Quantity of gas required for lighting per 100 candle lamps (i.e. ≈60 watts electric bulb) = 0.125m^3 per bhp-hour (Rai, 2000). Assuming 3 lamps are required per household for 3 hours per day, required gas per day per household = 0.125 x3x3= 1.13m^3 of gas.

4.3 Total volume of gas required:

Gas required for Cooking + Lighting= 1.35 m^3 + 1.13 m^3 = 2.45 m^3 of gas. Take 2.5 m^3 of gas for design. Basing on the amount of gas required per day, 1 kg of fresh dung produces 0.05$m^3$of biogas, (Duggal, 2002), this implies for 2.5 m^3 = 2.5 /0.05= 50kg of dung per day.

Number of cows= 50/10 = 5 cows. This is adequate compared to household average of 10.

4.4 Plant capacity

For the purpose of this project, the fixed dome type biogas plant was preferred. According to Rai, (2000) the digester volume is given by the formula:

$$V_d = V_f t_r \qquad (1)$$

Where V_d = digester volume, V_f = volume of the fluid (slurry) in the digester, and t_r = hydraulic retention time. But also,

$$V_f = \frac{M}{\Psi} \text{ .... (2)}$$

Where, M = mass of dry input and Ψ = density of dry material in the fluid.
Density of dry dung in the fluid is given by; Ψ = 50Kg/ m^3.
Using equation (2), Volume of daily slurry charge, V_f = Mass/Density
1Kg of fresh cow dung = 0.18Kg of dry dung (measured from the field). Therefore 50Kg = 50x0.18 = 9Kg of dry weight of dung per day. Wet dung contains about 82% water.
Volume of fluid, V_f = 9/50 = 0.18 m^3/ day.
Let Hydraulic Retention time be 30 days (~ 8 – 50 days, Rai, 2000).

From equation (1), volume, $V_d = 0.18 * 30 = 5.4 m^3$ .... (3)

Actual digester volume = 1.1V_d (10% more to provide allowance for disengagement of gas)

Actual volume of digester therefore = 1.1x5.4 = 5.94 m^3, use 6 m^3

Using United Nations data for fixed dome type biogas plant, the gas production rate in tropical climate range from 0.4 to 0.5 m^3/day per 1 m^3 of digester volume, Taking an average of 0.45 m^3, 2.5 m^3 gas required per day = 2.5/0.45 will need 5.6 m^3 of digester volume; 6 m^3 is adequate.

4.5 Digester Dimensions

Height: Diameter ratio = 0.9, (U.N 1984).

H/D = 0.9, H = 0.9D...(4)

But $V = 0.785D^2H$

$6 = 0.785x0.9D^3$

Dimensions: D = 2.04 m; H = 1.84 m. Refer to figure 2 for the drawings

Table 3: Capacity, daily requirements of cattle dung and biogas produced

Plant Capacity(m^3)	Daily Fresh dung (kg)	Fresh Slurry (l)	Number of Cows	Number of People	Cost in Uganda (US$)
1	25	50	2-3	3-4	1800
2	**50**	**100**	**4-6**	**6-8**	**2160**
3	75	150	6-9	9-12	2700
4	100	200	8-12	12-16	3240
6	150	300	12-18	18-24	3888

Adapted from the International Network for Sustainable Energy, 2006

Cost of owning and running a biogas plant per day on average is US $ 0.25, with a life of 20 to 30 years. The initial cost may be well above the average income of the majority of the rural population. There is need for government intervention inform of biogas loans, plastic digesters and also training of biogas technicians for construction and maintenance.

4.6 Durability and Reliability

The average recorded life expectancy of a model is important in deciding which model is best suited to rural households in Uganda. The user would expect to invest in a model with the longest life expectancy. The average life expectancy of the fixed-dome plants was found to be from 20-30 years. Structurally the dome shape has the required strength to carry the soil above and avoid the need for structural design and strict supervision during construction. It also requires minimum repair and maintenance, (Singh *et al*., 2005)

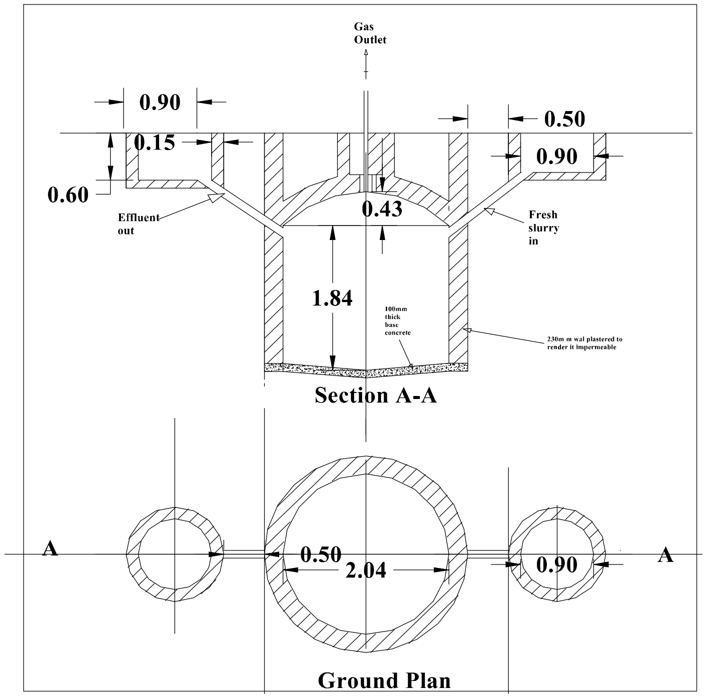

Figure 2: A dome shape biogas plant (Singh *et al*., 2005)

4.6 Benefits of Biogas:

a) Cheap and reliable source of domestic energy.
b) Reduce foreign currency expenditures on electric appliances.
c) Methane being a green gas, its domestic use for cooking and lighting will greatly reduce its release to the atmosphere.
d) Thousands of metric tons of round wood cut for firewood and charcoal will be spared leading to natural conservation of the environment, in line to MDG 7.
e) Sicknesses due to the use of firewood and charcoal will be history.
f) There will be job creation in form of construction and maintenance of biogas plant (MDG 1)
g) Will lead to improved economic status of the population as the energy and time spared from collecting firewood may be diverted to other activities like farming which will reduce hunger.
h) May encourage cattle keeping which economically will provide milk, meat and also be used for ploughing.
i) Effluent use as fertiliser will lead to improved agricultural output which is in line to MDG 1(Eradication of extreme poverty and hunger)

5.0 CONCLUSIONS AND RECOMMENDATIONS.

5.1 Conclusion

Basing on the findings of this project work, the following conclusions and recommendations have been reached:

a) At a cost of US $ 2000 and 4-6 herds of cattle, a family of 5-8 people can acquire a biogas plant to meet their daily cooking and lighting energy for between 20 to 30years, (Shasul and Naimul, 2006).The average of 10 cows is adequate.
b) The fixed dome type biogas plant was chosen because of low cost and cheap technology.
c) The size of the plant digester volume was determined to be $6m^3$.
d) The major economic activity of the rural populace in this study area is cattle keeping and subsistence farming which provides disposal system for the by-product of the biogas plants in form of manure/fertilizers.
e) The situation on the ground warrants the implementation of a biogas energy initiative as the major domestic energy for cooking and lighting.

6.0 RECOMMENDATIONS

It is recommended that:

a) Biogas being cheap, reliable and easy to construct can be sustainable, and as such is a necessary technology which needs exploration to benefit the rural population.
b) There is need to sensitise people about the use of biogas as a cheap, reliable source of energy.
c) Government should come in to promote the use of biogas through financing of the construction at a community level or initiate the creation of biogas loans. This can be a good supplement to the ongoing rural electrification programme.
d) Need for training technicians in biogas technology as it is a new thing.

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