Challenges to the Sustainability of Small Scale Biogas Technologies in Uganda

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ABSTRACT
Concerns of climate change, increased greenhouse gas emissions and security of energy supply have accelerated the search for alternative energy sources both in developed and developing countries. Developing countries are now embracing utilization of biogas to meet some of their cooking and lighting needs. In Uganda, despite the introduction of biogas in the 1950's, the technology has not received considerable acceptance and as a result its penetration has remained low. Several installed biogas plants have failed and those working are not working to the expectation of the owners. This paper presents results of study carried out to establish the performance of farm based biogas systems, to assess the challenges faced by the users and to identify the possible causes of failure for the non-operational systems. A survey of 212 biogas systems was carried out after which performance monitoring of selected digesters in the districts of Mityana, Bushenyi, Kabale, and Mbarara was done. It was found that over 55% of the surveyed biogas systems were not operational and others not performing to the users expectations. Most systems monitored were operating in the temperature range between 18°C and 25°C with the gas quality ranging between 50-60% methane. Most digesters showed evidence of high organic loading rates indicated by traces of biogas at the expansion chamber. The identified causes of failure were poor system maintenance, poor operation practices, availability of other cheap fuel alternatives, lack of interest from the users, lack of alternative sources of feedstock, poor workmanship and system blockages.

Key words: Biogas; Feedstock; Gas quality; Methane; pH

1.0 INTRODUCTION

Biogas is a form of renewable energy that is generated from anaerobic breakdown of organic matter. Anaerobic digestion can be used for industrial or domestic purposes to manage waste and or release energy. Biogas can be produced from a variety of organic raw materials and utilized in various forms such as for cooking, lighting, electricity generation and for powering vehicles. Given the flexibility of use of different feedstock for biogas production and the flexibility of use of biogas in various forms, biogas provides an alternative source of energy for rural areas without access to the grid.

In Uganda, traditional biomass is the major contributor to the energy balance of the country with over 90% of the energy needs of the country being met by traditional biomass, this is not sustainable and has led to the disappearance of the country's forest cover and increased occurrence of catastrophes such as floods, land slides and draught which have left the population homeless and without food. According to the international energy agency data base for electrification of different countries Uganda as well as other countries in Sub Saharan Africa has low electrification rates compared to other countries and also have high poverty levels compared to countries from other continents emphasizing the link between energy access and poverty; for example Uganda had a total electrification rate of 9% in total with 42% of urban population having access to electricity and only 4% in rural areas with access to electricity (WEO, 2009). The ever increasing population growth has further put pressure on the available resources and led to an increase in the demand for all services such as energy, water, education, health care and others. It should be mentioned that the population of Uganda as of mid 2010 was at 31.8 million growing at a rate of over 3.1% according to the Uganda Bureau of Statistics (UBoS, 2010). Efforts by the Government of Uganda to increase energy access have been redirected to include the use of renewable energies in the energy mix as outlined in the country's Renewable Energy Policy to increase the use of modern renewable energies such as solar, wind, biofules, from 4% to 61% by 2017 (MEMD, 2007) and also to scale up the number of household biogas systems to 100,000 units by 2017 from the current level of less than 1000 units.

A number of studies have been carried out in Africa and Asia about utilization of farm scale biogas systems. Sendegeya *et.al* (2005) studied the benefits of using biogas in households in Uganda with an emphasis on the socio-economic benefits based on the experience of a long term user as a typical example from which savings on the energy bill was realized as well as freedom from dependence on expensive petroleum based fuels. Kasisira and Muyiiya (2009) studied the effect of mixing pig dung and cow dung on biogas yield from which an increase in biogas yield was realized with mixtures in proportions 1:1 giving maximum biogas yields. This provides an alternative in case there is insufficient feedstock for either pig dung or cow dung. Therefore, this study was carried out with the aim of identifying the challenges to the dissemination of farm scale biogas systems and ascertaining the performance of the technologies by monitoring process parameters.

2.0 MATERIALS AND METHODS

The research was carried out through surveys of existing systems and monitoring of selected biogas digesters. During the survey of biogas systems data concerning biogas plant installations in Uganda was collected using questionnaires, interviews and observations. Data collected during the survey was mainly qualitative where structured questionnaires were used as guidance during the interviews and discussions with biogas users, of help were the open-ended unstructured interviews with the respective plant users. The key people interviewed included the cooks who use the gas stoves, the operators responsible for mixing and feeding materials in the digester as well as the owners of biogas systems. Observations at the digesters, feeding systems, discharges of slurry as well as biogas accessories like stoves and lamps were also used. After completion of the survey a few biogas systems were selected to monitor the performance parameter mainly pH, temperature and gas quality. The pH was monitored using by a pH meter i.e. pH/ORP/Temperature Meter with resolution 0.001pH and accuracy +/- 0.01pH. Several samples were taken at different points in the digester using a long stick and a sampling tin. Then using a pH meter, the pH was measured at the different points of the digester; on the digester top, middle and bottom points. Temperature was monitored by temperature meters i.e. Geotech, GA 2000 Plus and pH/ORP/Temperature Meter. By using a 1-m temperature probe, which was inserted into the digester through the expansion chamber, the temperature was determined by the GA 2000 Plus gas analyzer. The temperatures were further ascertained by taking samples from digester using a long stick and a tin as was done for pH measurements with the temperatures being measured using pH/ORP/Temperature Meter with resolution 0.1°C and accuracy +/-0.5°C immediately after the samples were drawn from the digester

A gas leakage detector was used to check for any gas leakages at different points along the gas systems and also gas production at the digester expansion chambers. Gas composition monitoring was also done using the Gas analyzer (Geotech, GA 2000 Plus). Gas analysis was done on various days with varying conditions/circumstances with the gas samples being taken at the gas burners. Gas samples were taken on different days with each sample having more than five readings from which the average gas composition was calculated.

3.0 RESULTS AND DISCUSSION

3.1 Biogas Digester Types

A total of 212 biogas digesters were surveyed; 82% of the total digesters were of fixed dome type, 9% were floating drum, 7% were tubular and 1% was bio-latrines. The other types were old and improved Carmatec types which are fixed dome types. Figure 1 shows the proportions of the different types of biogas digesters surveyed.

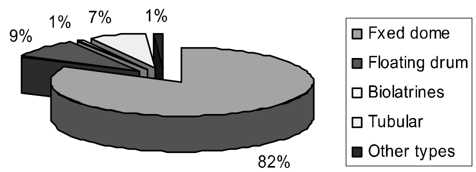

Figure 1: Biogas digester types

The major reasons given for the selection of fixed dome types were their durability, access to construction materials while others did not have a choice since these systems were given to them by Non Governmental Organizations. Over 72% of the systems surveyed were built by assistance from NGOs and only 26% built using individual funds.

3.2 Digester Life Span

A total of 117 digesters (55%) were not operational compared to only 78 digesters (37%) that were operational. The rest of the digesters were still under construction or temporarily not in use. All the biogas plants with tubular digesters were not operational. It is important to note that 72% of biogas systems (Figure 2) surveyed failed within less than 10 years of operation. Many of them failed before their design life usually over 20 years for fixed dome types.

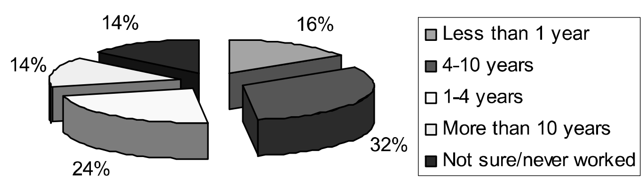

Figure 2: Biogas system failure before lifetime.

3.3 Causes of Digester Failure

From the survey, the major causes of failure of biogas digesters included; poor planning and siting of the digesters, where digesters are not properly located to allow for easy flow of the slurry to gardens making the process labour intensive. Preparation of feedstock where improperly done led to digester blockage, filling up fast of the digesters and thus a reduction in the amount of gas that could be produced since feedstock contains foreign materials such as stones and sand. Poor workmanship was also another cause of digester failure and this was worsened by lack of locally trained technicians in the proximity of the biogas system owners to rectify digester failures. Poor maintenance and operation techniques such as over feeding digesters and failure to drain water from the condensate traps also led to blockage of gas lines, low gas production, gas leakages, and in some cases system failure. Lack of feedstock was also a challenge to the systems mainly due to death or sale of animals, also users not aware that they could use alternative feedstock for the digesters such pig waste, food wastes and others.

User perception was also another cause of digester failures. Digesters were neglected due to laziness on the side of operators and the "I don't care" attitude since most owners never used their funds to construct the systems. It was actually found out that only 17% of all the digesters surveyed were funded by their owners. The rest were constructed with funding from various donors.

a. Buried Valve **b. Rusted valve due to water** **c. Poorly constructed digester**

Figure 3(a-c): Some of the causes of failure

As shown in Figure 3, neglected valves that usually get blocked and poorly constructed usually cause the systems to stop working.

Figures 3(a) and Figure 3(b) were for neglected valves that rusted and led to eventual failure of the biogas digester since the gas does not reach the intended users. In some cases digesters were poorly constructed and as a result cracks were observed and hence such digesters never worked at all as seen in Figure 3(c)

3.3 Digester Feeding and Slurry Use

From the survey carried out all digesters were using animal waste as feedstock with cow dung the most widely used as shown Figure 4.

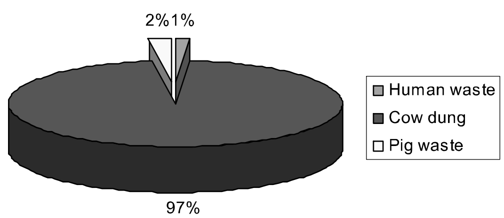

Figure 4: Main biogas feedstock materials in Uganda

It is important to note that almost all biogas users visited had no knowledge of the possibility of mixing and feeding different feed-stocks in their digesters. This was the case every in households were they had more than one type of animals. Also noted was that most biogas system owners did not have a predetermined ratio to use for mixing the feedstock (animal waste) with water. They all use experience to attain a sticky "porridge-like" mixture as they were trained to do. The challenge with this approach is that is difficult to estimate the total solids and thus the volatile solids fed in the digester which affects gas production. It was also found out that feedstock preparation was being done in nearly 90% of biogas plants surveyed. The preparation activities mainly involved removing of stones and trash from feed-stocks as well as mixing with water. All the 212 respondents used the slurry from the biogas plants as manure for the gardens and from the observations the yields from the fields were good as was also testified by the respondents

3.4 Performance Monitoring

Nine digesters in the districts of Mityana, Bushenyi, Kabale and Mbarara were monitored for gas quality, temperature and pH. The results from the exercise are discussed in the following sections.

3.4.1 Gas Composition

The gas composition for the monitored digesters was in the range 50 – 60% as shown in Table 1 which is within the theoretical range for biogas yields quoted in literature for different feedstock; this composition is dependent on the percentage of proteins, fats carbohydrates in the feedstock. Teodorita (2008) gives the values for each feedstock with cow dung giving on average 60% methane, pig dung 65%, and poultry manure 60%. Thus the values obtained are within this range with the maximum methane content in the biogas being 59%.

Table 1: Gas composition for different digesters as measured at the gas burner

	CH_4 (% by Volume)		CO_2 (% by Volume)		H_2S (ppm)
	Range	**Average**	**Range**	**Average**	**Max. Value**
Digester 1 (Mityana)	51-58.8	54.9	41.2-49	45.1	-
Digester 2 (Mityana)	51-53	52	47-49	48	-
Digester 2 (Mityana) fed with pig waste	54-59	56.5	41-46	43.5	200
Digester 3 (Mityana)	40-45	42.5	30-38	34	-
Digester 4 (Bushenyi)	54.5-55	54.75	45-45.5	45.25	212
Digester 5 (Bushenyi)	50.7-54.5	52.6	45.5-49.3	47.6	184
Digester 6 (Bushenyi)	51.2-57	54.1	43-48.8	45.9	215
Digester 7 (Kabale)	52.9-55.4	54.15	44.6-47.1	45.45	149
Digester 8 (Kabale)	51-52.9	51.95	47.1-49	48.05	310
Digester 9 (Mbarara)	51.8-53.5	52.65	46.5-48.2	-	-

3.4.2 Temperature and pH

pH measures the acidity or alkalinity of a solution. The pH value of anaerobic digestion substrates influences the growth of methanogenic microorganisms and affects the dissociation of some compounds of importance for the process (ammonia, sulphide, organic acids) Teodorita (2008). According to research carried out by Mshandete *et al* (2006), the pH of a normal and very good anaerobic process was found to be between 6.5 – 8.5 with pH in the range of 5.0 – 5.5 inhibiting methane formation. Also when an increase in pH accompanies the rise of biogas production, the methanogens consume volatile fatty acids and generate alkalinity. Table 2 gives the measured values for pH and temperature inside the digesters

Table 2: pH and temperature values

	Temperature (^{0}C)		pH	
	Ambient	**Digester**	**Range**	**Average**
Digester 1 (Mityana)	24	23.4	-	-
Digester 2 (Mityana)	25	23	-	-
Digester 2 (Mityana) fed with pig dung	30	23	-	-
Digester 3 (Mityana)	26	22	-	-
Digester 4 (Bushenyi)	21.8	21.4	6.33-7.03	6.68
Digester 5 (Bushenyi)	18.3	20.3	6.21-7.14	6.675
Digester 6 (Bushenyi)	21.9	23.4	7.33-7.35	7.34
Digester 7 (Kabale)	27.8	21.3	7.21-7.29	7.25
Digester 8 (Kabale)	19.4	19.2	6.97-7.04	7.005
Digester 9 (Mbarara)	-	-	-	-

The values obtained for pH were in the normal working range of anaerobic microorganisms. It was also noted that pH varied slightly with depth inside the digester meaning that the digester could be taken as having zones representing three of the four stages of biogas formation acidogenesis, acetogenesis and methanogenesis.

From the results (Table 2), it can further be noted that all the digesters seen were working in the psychrophilic range, at temperatures less than 25°C according to Teodorita (2008), which indicates that they do not enjoy the advantages of mesophilic and thermophilic digestion ranges. There may be no effective destruction of pathogens if present in the feedstock, the growth rate of methanogenic bacteria is low and therefore need for higher retention times as the process is slower and less efficient. Also it has been shown that thermophilic operated digesters have high yields and higher conversion rates than mesophilic digesters and so does mesophilic digesters compared to psychrophilic digesters according to Teodorita (2008). Another notable feature was that the temperature inside the digester was mostly independent of the ambient temperature. In most cases it was lower than the ambient temperature and changes in the ambient temperature had no effect on the digester temperature.

4.0 CONCLUSION

The study shows that a large number of installed systems fails before half their life span and the identified causes of failure are not technical thus can be solved to improve on the sustainability of biogas systems and the negative perception of the would be users. From the findings of the monitoring exercise all digesters monitored had the concentration of methane above 50% which is the recommended for combustion and the pH was within the normal operating range for anaerobic digestion. However, it was also noted that for nearly all the digesters, the digester temperatures were below the ambient temperature and the temperature range for bacteria to work well and produce enough gas in a shorter period of time. This means increased required number of days for the feedstock to be fully digested. Therefore, this could explain why most digesters visited in the survey could not meet the cooking needs of the households with some only limited to boiling water or tea. This calls for optimization of digester designs using data based on local conditions as well as comparing the data for different regions of the country since these regions may have different conditions. There is need for continuous training of biogas users on proper mixing of feedstocks and the benefits of mixing different substrates to increase gas production. For sustainability, funding organizations should only supplement the resources from the potential biogas owners rather than fully paying for the biogas systems. This would create a sense of ownership among the owners and hence the drive to maintain and keep the systems in good working conditions.

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