

QUALITY AND USAGE OF BIOGAS DIGESTERS IN UGANDA

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Student Name: LUTAAYA FRED
Student Number: 771028 A119

KTH Supervisor: Dr Andrew Martin
KTH Examiner: Dr Peter Hagström
Local Supervisor: Dr SB Kucel
Local Supervisor: Eng. Dr. A.M.Sebbit

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Department of Energy Technology
Royal institute of Technology
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KTH Industrial Engineering and Management

Department of Energy Technology

Approved by **Dr. Andrew Martin**	**Examiner** **Dr. Peter Hagström**	**Supervisors** **Eng. Dr. A. M.Sebbit**
DATE: 28.09.2012	**Commissioner** **Dr. S.B. Kucel**	**Author** **Lutaaya Fred**

Abstract

Global 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 as a renewable energy option 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 relatively low.

Several installed biogas plants have failed and those working are not working to the expectation of the technicians and their owners. This research presents results of the study carried out to establish the performance of farm based biogas systems so as to assess the challenges faced by the users and to identify the possible causes of failure for the non-operational systems.

A survey of 144 biogas plants was carried out after which performance monitoring of selected digesters in the districts of Luwero, Kampala, Wakiso, Mbale, Jinja and Mukono. It was found that 55% of the surveyed biogas plants were not operational and others not performing to the users expectations. Most of the plants monitored were operating in the temperature range of 18°C-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 workmanship during construction works, poor operation practices, availability of other cheap fuel alternatives, laziness and lack of interest amongst the users, lack of alternative sources of feedstock and system blockages.

Furthermore, there is need to sensitize people on the need for using alternative sources of energy such as biogas and improved cooking stoves for fuel saving as most of them use wood and charcoal as supplementary fuels. This would reduce global warming through reduced deforestation and bring about environmental sustainability as a whole.

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To all those who have rendered me whatsoever courage and support throughout the entire course and project accomplishment

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I wish to extend special thanks to all the Local owners of Biogas Digester across the country most especially those in Kampala, Luwero, Mukono, Jinja, Mbale and Wakiso where further tests were carried out for their genuine and kindly cooperation throughout the entire research period and I believe that they will implement the advise and knowledge we shared through the entire process in exactly the same way am going to use the knowledge and skills obtained to advance in my carrier.

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List of Acronyms

GBA	Germany Biogas Association
COD	Chemical Oxygen Demand
E	East
FAO	Food and Agricultural Organization
HRT	Hydraulic Retention Time
MSW	Municipal Solid Wastes
MEMD	Ministry of Energy and Mineral Development
N	North
OLR	Organic Loading Rate
pH	Potential of Hydrogen
RT	Retention Time
SS	Suspended Solids
TSC	Total Solid Content
VS	Volatile Solids
V	volume
IRDI	Integrated Rural Development Initiative
C/N	Carbon dioxide to Nitrogen ratio
ADRA	Adventist Development and Relief Agency
AMREF	African Medical and Research Foundation
SSWARS	Sustainable Sanitation and Water Renewal System
BMP	Biochemical Methane Potential

CHAPTER ONE: INTRODUCTION

The economic prosperity and quality of life of a country are closely linked to the level of its per capita energy consumption and the strategy adopted to use energy as a fundamental tool (Amigun et al. 2008). However, like in many developing countries, there is over-dependence on a few conventional energy sources such as biomass (firewood, charcoal and crop residues), petroleum products and grid electricity as the driver of economic development. Energy plays a central role in national development process as a domestic necessity and major factor of production, whose cost directly affects price of other goods and services (Amigun and von Blottnitz, 2007).

Traditional biogas in Uganda 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 draught which have left the population homeless and without food (WEO, 2009).The fuels are mainly used for heating and lighting in households and institutions such as schools and hospitals, commercial settings such as restaurants and hotels; and small scale industries such as lime, bricks and tiles making, agro-based industries (tea, tobacco) and fish smoking (Sebitt et al., 2004). Most biogas systems that are built in Uganda use cow manure as the main source of substrate for the system.

Biogas technologies have had a long history in Uganda. According to a report of the Uganda Domestic Biogas Program (UDBP, 2010) biogas technology has been present in Uganda since 1950 and by 2008 the estimated number of systems was around 800 a great improvement over the 100 that were estimated to exist in 1990. The same source also point out that the failure rate can be estimated between 15-20%, and the main causes for failure are limited skills by the constructors of the systems and an inadequate operation and maintenance by the household. The report also points out that the main barriers for the diffusion of this technology have been a lack of technical capabilities and the comparatively high upfront cost.

Uganda being an agricultural-based country, she possesses large quantities of crop residues and animal wastes. They are largely unutilized as alternative fuel sources but to a good extent as manure. Crop residues are burnt in fields as a means of disposal while animal wastes are left to decay without control hence emitting gases such as methane, a potential greenhouse gas to the atmosphere hence contributing handsomely to global warming (Sebitt et al., 2004).

Agricultural residues have been used for generation of heat and light in Uganda through direct combustion of the solid fuels and biogas generated from anaerobic digestion processes. They are however utilized by a very small portion of the population. Direct combustion of agricultural residues is not only inefficient but also

inconveniencing because of the low fuel density and the requirement for large storage facilities. On the other hand, the use of biogas is convenient, clean, fast and efficient (Sebitt et al., 2004).

Uganda has the 3rd fastest population growth rate of 3.2% per year coupled with economic development. These parameters are placing a heavy burden on the environment and natural resource base and utilization. Over the past 15 years from 1990 to 2005, Uganda lost an approximated 27% of its total forest and woodland cover. Some districts such as Mayuge have experienced extensive loss of forest cover while forests in Nakasongola have been severely depleted. The rapidly declining forest and woodland cover is aimed at sustaining about 91% of the country's energy needs as wood and charcoal (MFPED, 2002).

While it is very encouraging that fuel saving devices have been developed (such as the famous charcoal stove), it is sad that the rate of fuel saving trails far behind the ever increasing demand for fuel resulting from rapid population growth. This means that there will always be an inexhaustible demand of wood for fuel by the population which will lead to more destruction of forests leading to an environmental imbalance. While tree planting has been carried out and promoted, this method alone will not achieve the desired goals since there will always be a lag phase between when trees are planted and when they are mature. Due to this phenomenon, an independent method of fuel production should be encouraged so that even deforested areas are left to regenerate (Sebina, 1998).

The driving factor is that biogas has potential for meeting energy needs of the population if well managed. This is coupled with the fact that the manure from anaerobic digestion is a better quality fertilizer than biomass waste and hence can lead to better agricultural yields and hence boosting food supply and economic development in the long run.

While it's clearly understood that the capital costs of building a biogas plant are high, it has remained unclear why even people who can afford to pay for the technology have little or no knowledge of it and thus rely on other forms of energy such as generators, solar, kerosene and wood for their cooking and lighting needs (UDBP, 2009).

Therefore, there was need to carry out a survey on some of the existing operational and non-operational digesters in Uganda to determine the challenges faced by the users and the possible causes of failure of the non-operational biogas plants. This would act as a basis for suggesting possible solutions to the challenges and failure mechanisms in all upcoming and future biogas interventions in Uganda.

1.3 Problem Statement

The 250MW Bujagali hydro power station now in operation is expected to reduce electric power demands especially on the lighting side. However the dependency on fuel wood and charcoal as the main source of energy still continues to increase along with the population.
Efforts to develop fuel saving technologies have had little impact since the rate of fuel saving trails the ever increasing fuel demand because of increased population growth.

Furthermore, Tree planting is seen as a sustainable solution to forest-cover depletion, however it is not enough and practical since there is always a time lag between when trees are planted and when they mature. Due to this, an independent method of fuel production should be encouraged so that even deforested areas are left to regenerate. Therefore to reduce wood fuel consumption and its related effects a combination of two categories of measures should be used:

(i) Measures which reduce wood fuel demand.
(ii) Measures which increase biomass supply.

This calls for the development of alternative renewable energy sources such as biogas and fuel saving technologies such as improved cook stoves (which reduce wood fuel consumption by high heat retention). There is need to develop biogas technology and to develop guidelines for the operation of the digester and biogas slurry for high efficiency.

The conversion of biomass fuels in Uganda is still inefficient with the majority of the population using 3-stone fires mainly in rural areas. This has caused rapid depletion of the biomass resource especially wood and has as well led to poor health conditions among the people resulting from the fuel smoke pollutants.

1.4 Research Objectives

1.4.1 Main objective

The main objective of this research is to investigate the possible causes of failure for biogas plants in Uganda.

1.4.2 Specific Objectives of the Research

- Identify selected functional and non-functional biogas systems in a few selected districts in Uganda.
- Identify the major challenges faced by biogas users and the causes of system failures
- Propose possible measures to address the challenges and the failure causes identified.

1.5 Justification of the Research.

Critics suggest that renewable energy is not environmentally friendly while their opponents argue otherwise thus there is need to assess the impact of renewable energy to the environment.

Since, there is good potential for biogas in Uganda and its exploitation has been witnessed, investigating the challenges affecting its quality and usage for improvement will positively impact Uganda's energy crisis and pave way for environmental conservation and sustainability.

1.6 Scope of the Research.

The research was limited to the Investigation of the different types of biogas technologies, their operational challenges and biogas usage for domestic applications.

CHAPTER TWO: METHODOLOGY

2.1 Introduction

This chapter discusses the methods and procedures that were used to accomplish the research as discussed in detail below

2.2 Identification of Case Study Areas.

The study areas were Kampala, Wakiso, Luwero, Nakaseke and Mukono in the central region and Mbale, Sironko and Jinja in the Eastern region. The districts that were chosen are densely populated with about 140 persons per square kilometer (MFPED, 2002). In all the districts chosen, substance faming and charcoal burning are the leading economic activities and wood fuel in form of firewood is the most largely used source of energy for heating. Since the areas have a high population and largely depend on wood fuel, there are energy, health and environmental threats resulting from deforestation thus leading to desertification and global warming. Because of the need for more land to suit the economic activities in the regions, zero grazing of cattle is highly emphasized and for that reason, the areas have the most biogas in the country.

2.3 Sampling Procedure and Size

Emphasis was put on the districts of Mukono, Mbale, Kampala, Luwero, Wakiso and Jinja. The districts had been strategic areas for many organizations and extension workers for biogas technology, have the best methods of cattle grazing and reasonable access to information concerning modernization of agriculture. Since cow dung is the major feedstock used for biogas in Uganda, these areas have the required raw materials to support the technology. The sampling included all the shareholders of the technology and those with operational and non-operational biogas plants. Different districts had varying numbers of biogas plants but in total, about 144 biogas plants were surveyed.

2.3.1Type of people interviewed during the survey

The major groups of people interviewed included

- The cooks who use the gas stoves
- Technicians
- Operators responsible for mixing and feeding materials into the digester
- Digester Mansons
- Plant owners

2.4 Data collection and Analysis Methods

Both primary and secondary relevant Data from the various biogas plants within the scope was collected and analyzed using Microsoft excel 2007. The data collection techniques are discussed below.

The primary data collected consisted of social, economic and demographic characteristics of households such as age, size of the household, knowledge and experience of the household in biogas production and usage and educational background. Also, data on the associated costs for biogas technology, user perception, sizes of the different plants, types of plants, the age of the plant, the type of feedstock used, causes of failure, the different uses of biogas and its slurry was collected.

2.5 Interviews, observations and checklists

Interviews were carried out with the Mansons, the users, plant operators and some extension workers and they involved several questions designed to achieve the objectives of the study.

Observations were made during site visits and these were based on intuition, experience and knowledge and they involved detailed inspection of the process of feeding the digesters, the state of the biogas piping systems, the working condition and state of the plant, the gadgets such as stoves used at the final stage, the nature of yields obtained from slurry usage and the health, safety and environmental aspects involved.

A questionnaire in Appendix A_1 was also designed to capture data regarding the social-economic aspects of biogas technology as a whole and it is data from these questionnaires that was used to assess and evaluate the major factors hindering biogas usage and development in the country.

Checklists were used to identify any sources of leakages on the plant and any health and environmentally unsafe acts done around the plant.

CHAPTER THREE: RESULTS AND DISCUSSION

3.1 Regions Covered during the Survey

The districts covered were found in four major regions of the country as in the table 3.1 and some of the existing biogas digesters are shown in Appendix $A_{2.}$

Table 3. 1: Districts covered during the Survey

Name of District	Number of plants
Kampala	20
Luwero	33
Mukono	15
Jinja	12
Mbale	36
Wakiso	28
Total	144

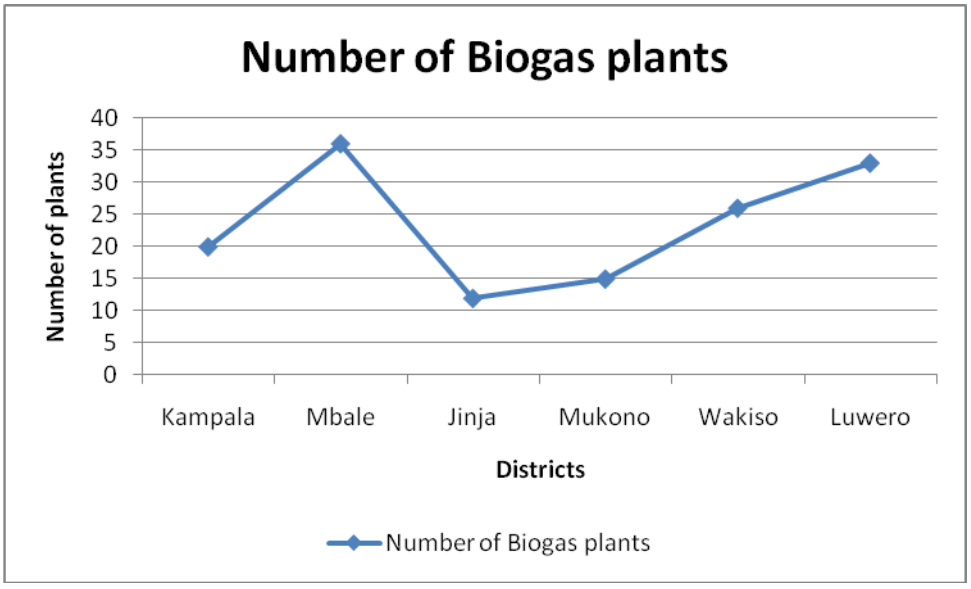

Figure 3. 1: Distribution of Biogas Plants by surveyed Districts

From the table 3.1 and Figure 3.1, it was found that the Mbale and Luwero districts have the highest number of biogas plants while Jinja and Mukono have the least. The findings were associated to:

- Mbale and Luwero have effective knowledge sharing centers for biogas and renewable energy as a whole and there is effective agricultural extension work in the districts.
- The availability of cheap labor for Mansons during construction and feeding of digesters especially in the initial stage.
- Availability of organized grazing systems such as zero grazing for cattle leading to proper and constant supply of feedstock for plant sustainability
- Developed perception for people on biogas usage

- High costs and scarcity of alternative fuels such as wood and charcoal due heavy restrictions on deforestation.
- In districts like Jinja, the people have a poor perception for the use of biogas and most of them are lazy that they can hardly sustain a biogas plant thus limited growth of the technology in the area.
- High costs of construction materials due to high transport costs
- Places like Jinja have limited availability of lean labor for construction and feeding of digesters as most of the people engage in fishing activities around the lakes and rivers and others mainly in business.
- There is limited knowledge sharing on biogas and renewable energy as a whole in places like Jinja.

3.2 Types of Digesters Surveyed

From a total of the 144 biogas plants surveyed, 80% of the total digesters were of fixed dome type, 10% were of floating drum type, 5% were tubular, 2% bio-latrines while 3% were old and improved Carmatec types as shown in Table 3.2.

Table 3. 2: Types of digesters surveyed by percentage

Type of digester	Number of plants	Percentage (%)
Fixed dome	115	**80**
Floating drum	15	**10**
Tabular	7	**5**
Bio-Latrines	3	**2**
Carmatec	4	**3**
Total		**100%**

From the analysis above, it was noted that fixed dome types were more common than any other type because of the reasons below.

- Fixed domes are easier to construct irrespective of the round shaped digester.
- Fixed domes requires fewer materials compared to carmatecs
- Fixed domes are easier to maint-ain since the users and operators can easily agitate the slurry and feedstock while in the digester.
- Fixed dome digesters are more reliable and efficient because of their shape and digester conditions created therein. This increases gas production and eliminates leakages.
- Bio-latrines were almost inexistent as they consume a lot of feedstock and most people have a very poor perception of the gas from bio-latrines.
- Tabular and floating biogas plants failed a lot and from the research, most of them did not work due to their associated social economic challenges.

3.3 Working Conditions of the Plants Surveyed

From the survey, only 55 biogas plants out of the 144 surveyed were operational compared to 78 plants that were not operational. The rest of the systems were either still under construction or temporarily not in use. Table 3.3 and figure 3.2 show a summary of the working conditions.
Note: All the biogas plants with tubular digesters were not operational.

Table 3. 3:Operating conditions of surveyed digesters

Condition	Number	Percentage
Operational	55	38
Non-operational	78	54
Others	12	8
Total	144	100

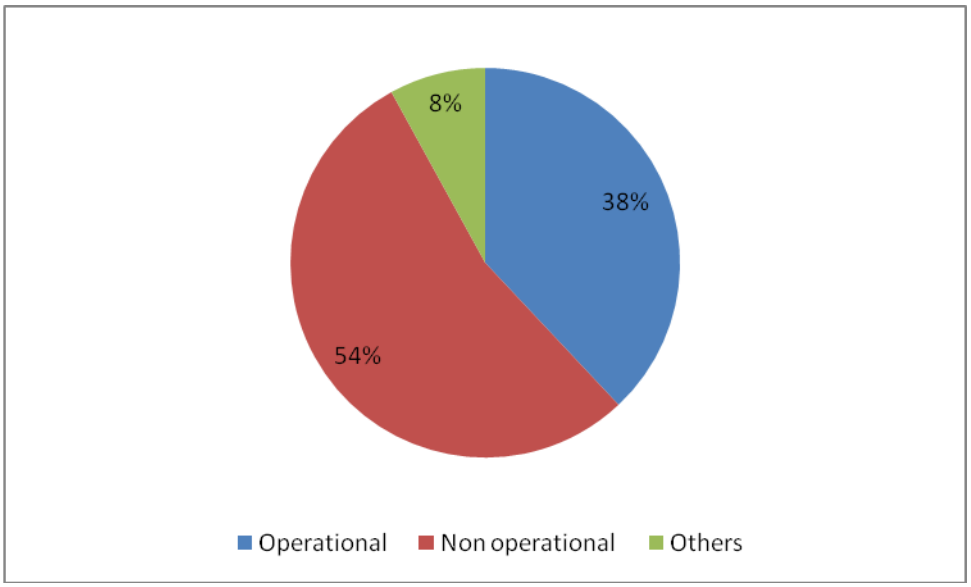

Figure 3. 2: Operating conditions of surveyed biogas plants

Reasons for the above findings

- Most operational plants had owners with clear knowledge of how to feed and maintain their plants and highly depended on them for all heating purposes.
- Most of the operational plants were of fixed dome type and hardly failed irrespective of the numerous failure mechanisms. This was associated with the effective supervision of the quality of the materials and the mixing ratios during construction and installation
- Many operational plant users had animals on zero grazing whereas non-operational plant owners had cattle on free-range system during day time thus inadequate feedstock to maintain their plants
- Most of the working plants had been constructed with high quality materials such as clay bricks and rightful mixing ratios unlike the non-operational plants that were constructed with soil bricks that failed quickly with time.

3.4 Failure time of biogas plants surveyed

It was also noted that 74% of the biogas plants surveyed failed within less than 10 years of operation. Thus most of the plants surveyed failed before their design life as in the table 3.4 and figure 3.3.

Table 3.4:Failure time of surveyed biogas plants

Failure time	Number of plants	Percentage
Less than one year	37	16
1- 4 years	56	24
4- 10 years	79	34
More than 10 years	33	14
Not sure	27	12

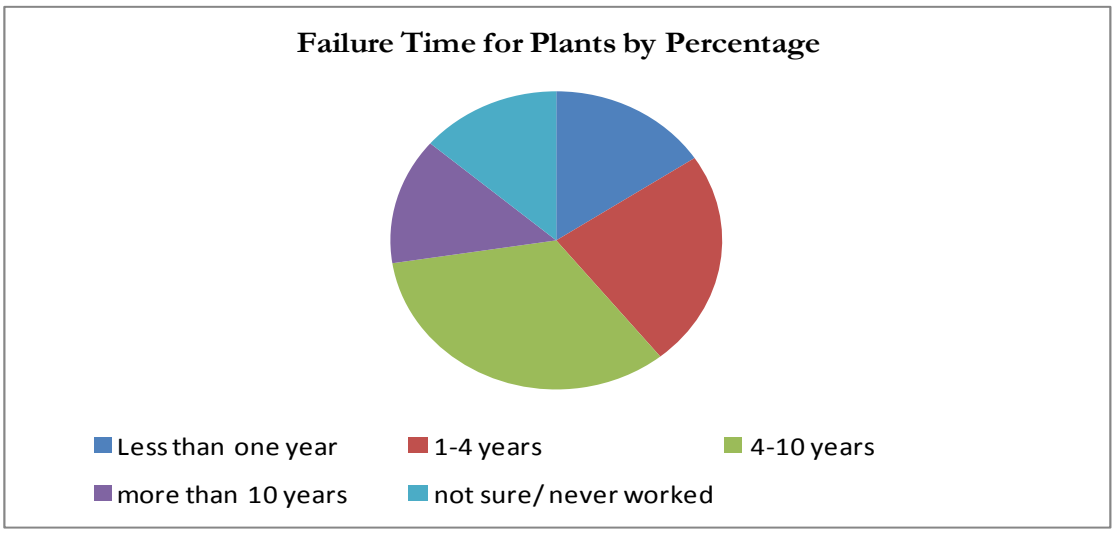

Figure 3.3: Failure time for surveyed biogas plants

Reasons for the above findings

- Most of the plants that failed in less than 10 years had been constructed using low quality materials
- Others were initially loaded before properly drying and this interfered with the heat retention abilities of the digester hence failure.
- Most of the plants that failed within less than a year failed due to lack of sufficient feedstock as most of their owners did not have cattle but owned them on the assumption that they would acquire feedstock from their neighbors
- Some owners were old and thus could not effectively manage the feeding sequence of their plants hence failure

3.5 Source of funding for the biogas plants surveyed

From the research, it was observed that most of the biogas plants were built with assistance from nongovernmental organizations such as Heifer Project International, ADRA, AMREF, SSWARS, AFRICA 2000 Network, SEND A COW, KULIKA and others. Government has built only 2% of the total biogas plants

surveyed as shown in the Figure 3.4 of those desiring to own the technology as in the table 3.5.

Table 3.5:Source of Funding for the surveyed biogas plants

Source of funding	Percentage contribution
Government	2
Non-governmental organization	72
Individual funding	26

Most of the nongovernmental organizations such as AMREF, ADRA and Heifer Project gave farmers cows, sensitized them on how to look after them and as well gave them funding to construct biogas plants so as to create maximum usage of the Animal for improved social and economic development.

It was also noted from individuals who funded construction of their own biogas plants that the total cost of constructing a biogas plant of 6m³ fixed dome types ranged between $1,000 and $1,200.

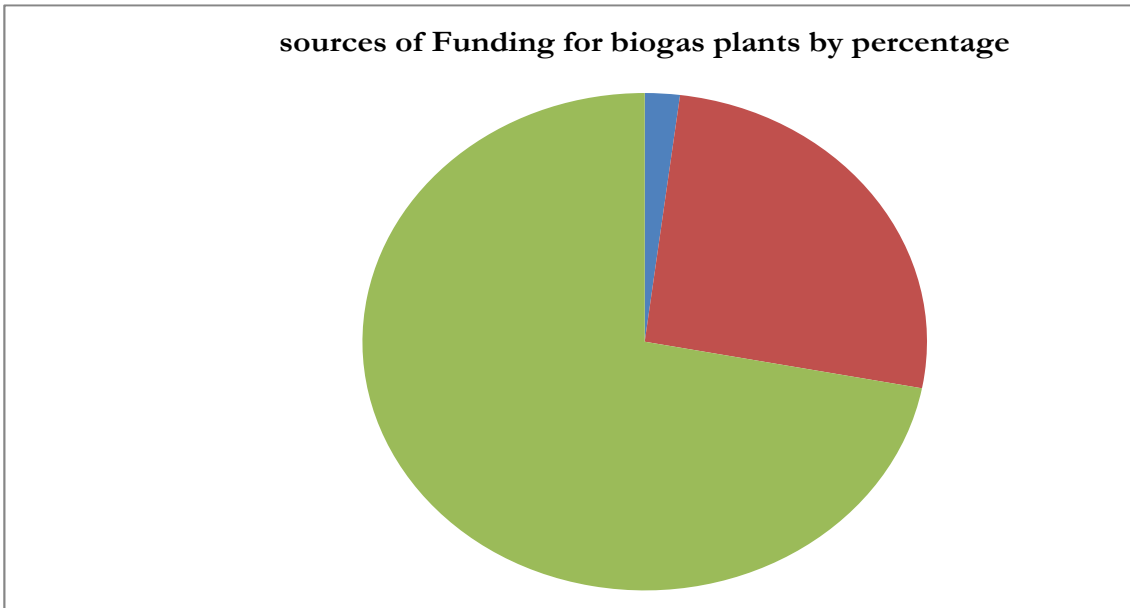

Figure 3.4: Sources of funding for surveyed biogas plants

Based on the above findings, it was observed that;

- Many private individuals cannot afford the initial costs of owning a biogas plant as most of them can hardly afford their basic needs and thus look at biogas usage as a luxury.
- Most people have large families that the basic plant to accommodate them is way too expensive for them and thus choose alternative fuels such as wood and charcoal without the associated lump sum initial costs.
- Some people have the cattle and can manage a biogas plant but they have little knowledge about the technology.

3.6 Major sources of Feedstock Materials used in the surveyed digesters

It was found that all the biogas plants surveyed used animal waste as a feedstock material as shown in the Table 3.6.

Biogas plants using cow dung were most efficient and common with a high degree of gas quality. Very few were using human waste while none of the plants depended on agricultural waste as a feedstock.

Some users especially in Kampala were found to get their feedstock materials from their neighbors who had cows or had just more animals but without biogas plants. This also contributed to failure of biogas plants for such people as supply was cut off due to change jealousy and change selling off of animals by their owners.

Table 3.6:Nature of feedstock materials used in the surveyed biogas plants

Feedstock Material	Number of plants	Percentage
Human waste	1	1
Pig dung	3	2
Cow dung	140	97

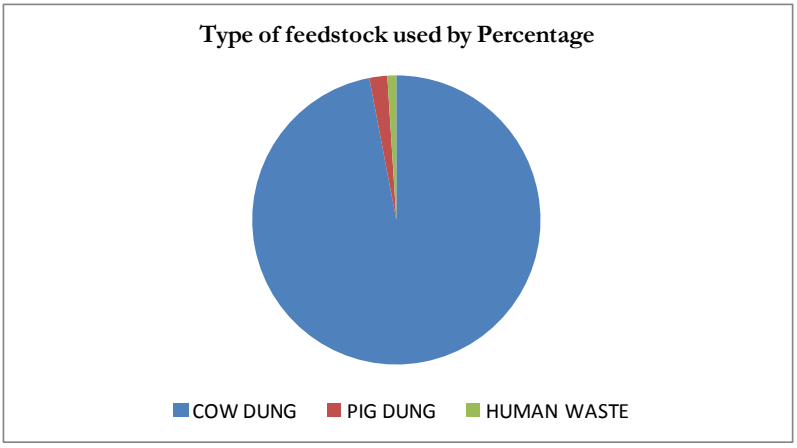

Figure 3.5: Types of feedstock used by percentage

Reasons for such findings

- Cows produce more wastes than any other domestic animal and thus are more reliable for feedstock
- Pig dung produces a lot of gas but has a lot of ammonia that affects gas quality and quantity.
- Cow dung is easy to collect and is relatively cleaner

It was also noted that almost all biogas users visited had no knowledge of the possibility of mixing and feeding different feed-stocks into their digesters. This was the case in every household were they had more than one type of cattle. They claimed that they had not been informed of the possibility by the technicians who constructed the digesters and their extension workers.

Most biogas plant 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 it is difficult to estimate the Total Solids fed in the digester. However, some users had specific feedstock/water ratios although these varied from one person to another e.g. 2 basins of cow dung to 1 jerry-can of water, 1 wheelbarrow of cow dung to 1 jerry-can of water etc.

- It was observed that systems with specified ratios were in most cases, better in terms of operation and gas production than those where mixing was by experience.
- It was found out that feedstock preparation was being done in nearly 90% of all the biogas plants surveyed. The preparation activities mainly involved removing of stones and trash from feed-stock as well as mixing with water.

3.7 Uses of Biogas

Most of the biogas plants surveyed were generating gas used for cooking food stuffs, heating water and lighting.
In some households, the gas was used for both cooking and lighting at the same time. In the case where the gas was used for cooking only, the gas was not enough for both cooking and lighting or the lamps were not functional. There were no cases where a biogas plant was producing gas for only lighting or power generation. Thus there is need to establish the viability of biogas for electricity generation in Uganda as this will help in rural electrification of the country. The analysis is shown in the Table 4.7.

Table 3.7:The different uses for biogas

Nature of use	**Number of plants**
Cooking	33
Lighting and power generation	0
Only lighting	0
Cooking and lighting	111

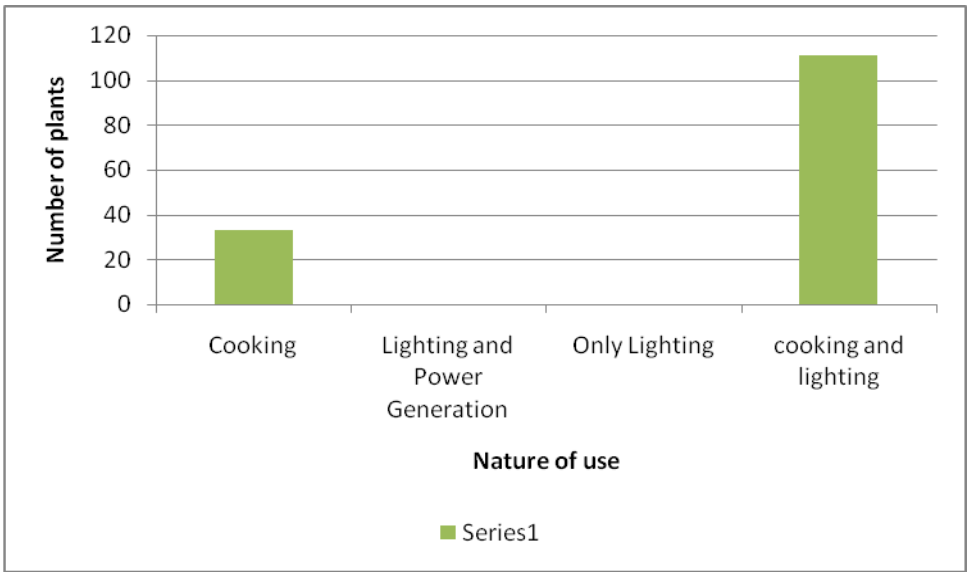

Figure 3.6: Graphical analysis for the use of biogas amongst the surveyed digesters

Reasons for such findings

- Biogas is too weak to be used for power generation because of its poor properties
- Most of the lighting gadgets used are of poor quality and fail within a short while thus require a lot of improvement for improved biogas usage.

3.8 Uses of digester slurry

Over 70% of all the biogas users surveyed were using the slurry as a fertilizer to improve their agricultural produce. This led to high farm yields that were used to feed their families and some of them were sold to generate income for medical care, school fees and clothing. The slurry from the digesters is a very good fertilizer because of the reasons below.

- The digestion process frees the mineral elements in the feedstock and makes them readily available.
- The freed mineral elements are immediately utilized by crops thus increasing their productivity.
- The farmer gains in time and utilizing all the important minerals elements in the cow dung thus achieving ultimate benefits

Most of the users for biogas used the slurry to grow matooke, vegetables, cereals and root crops such as cassava as indicated in Table 3.8.

Table 3.8:Major crops grown using biogas slurry

Type of crop	Percentage (%)
Matooke	10
Vegetables	15
Matooke and vegetables	65
Cereals	5
Root crops	5

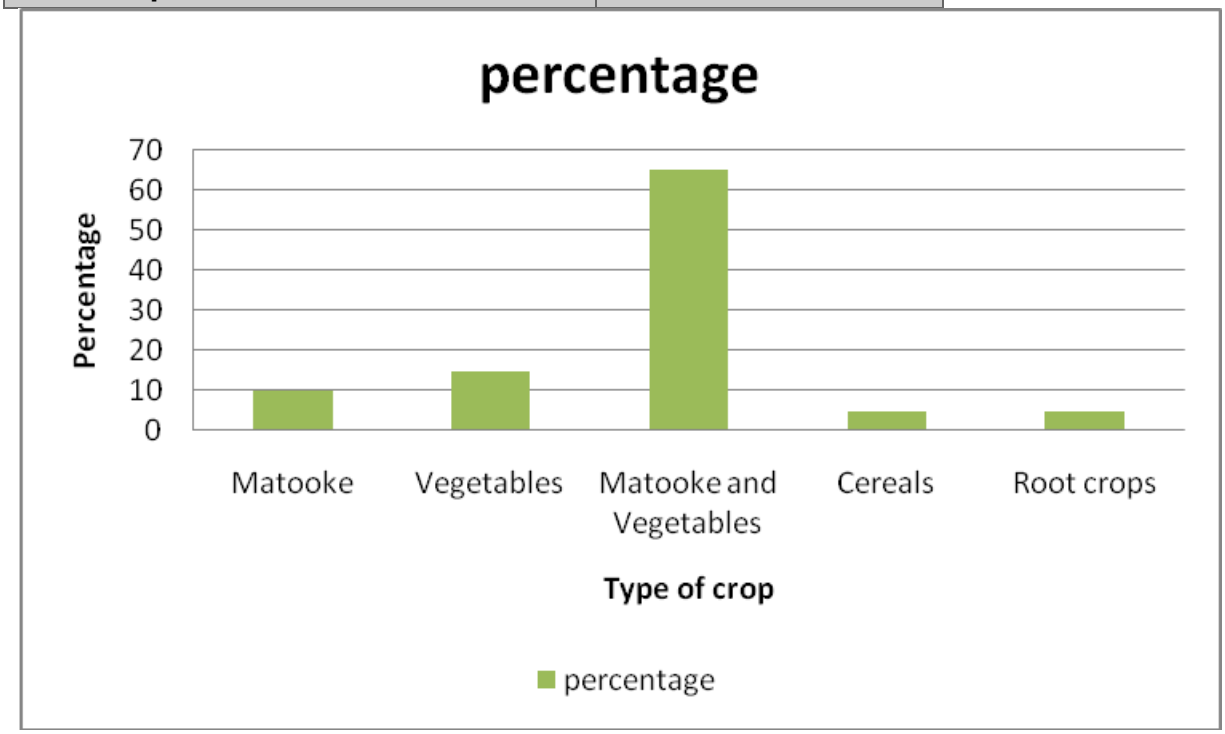

Figure 3.7: Types of crops grown using digester slurry

From Figure 3.7, it is evident that many biogas users especially in the districts of western and central districts grew both vegetables and matooke with the slurry obtained from their digester. This ensured constant food supply and improved family incomes for better standards of living.

3.9 User's Perception for Biogas

From the survey, most of the respondents were still interested in using biogas and liked their biogas plants based on their realized benefits as in the Table 4.9 and Figure 3.8.

Table 3.9:User perception for biogas

Need for continuation	Percentage
Yes	78
No	5
Not sure	17

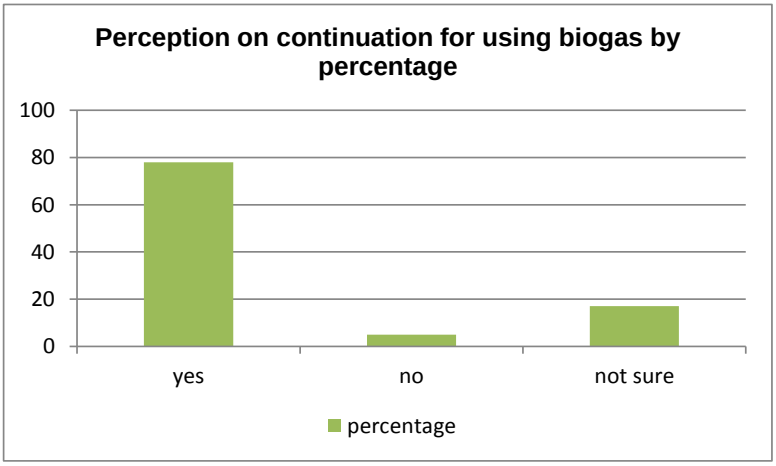

Figure 3.8: Users perception for future biogas usage

Reasons for the above response

a) Positive response

- It is fast when cooking
- It is convenient as one can cook at any time
- It is clean thus improves health conditions
- The slurry from the digester makes a good fertilizer
- It saves firewood, charcoal and paraffin thus saving and improving the quality of life

b) Negative response

- It is not reliable due to unstable conditions inside the digester
- It requires a lot of labor
- The slurry has a bad smell
- Sometimes it is a dirty venture feeding the digester in the extreme weather conditions
- It was noted that most of the respondents were not interested or aware of the environmental benefits of using biogas in fact during the survey only three respondents mentioned something to do with environmental protection in form of reduced deforestation.
- All the 232 respondents used the slurry from the biogas plants as manure for their fields and plantations and from the observations the yields from the fields were good as was also testified by the respondents.
- Only a small percentage (5%) of the respondents were fed up of using biogas and this was especially from the fraction whose biogas systems never worked or worked for a very short period of time. The respondents with negative attitude over the use of biogas were old people over (70 years) and did not have any helpers. Others complained that the labor put in the system maintenance was not worth the amount of gas produced.

- As was seen for most of the systems visited the gas production had reduced and for most of the respondents the produced gas was not enough to meet their cooking needs.

3.10 Consistency of Bio-gas Production

From the research conducted on the reliability and dependability of biogas plants, it was observed that some biogas owners knew and monitored their gas plants for consistency as in the Table 3.10.

Table 3.10:Consistency for biogas production of the surveyed digesters

Degree of Consistency of biogas production	Number of plants	Percentage of plants
High	52	36
Low	30	21
Not sure/ not working	62	43

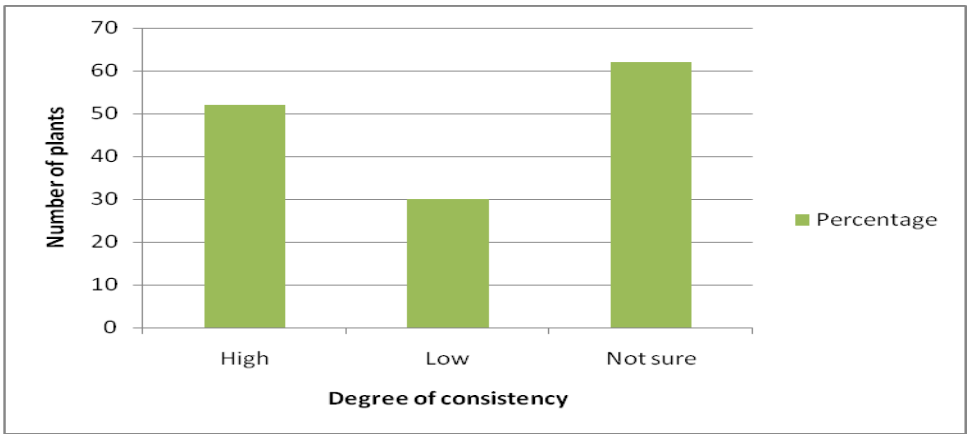

Figure 3.9: Degree of consistency for biogas production

Reasons for the above response

- Most biogas digesters especially in Jinja district failed to produce the required or expected volume of gas because of the big sizes of feedstock materials ranging from dried animal manure that did not mix well to foreign materials such as forage. This was attributed to lack of knowledge to prepare feedstock, lack of motivation as most of this work was done by children and laziness among the operators and owners.

- Some biogas plants were rectangular in shape while others were circular but just imperfect. This created differences in digester conditions for anaerobic digestion, gas pumping pressure, storage and retention causing contamination and pressure drops within the pumping system.

- Some inactive digester owners especially in Jinja and Mukono sought this technology thinking they would get feedstock from their neighbors and friends who had cattle but did not use their animal wastes for anything productive such as biogas production and farm manure. After getting supplies for a short period of time, the suppliers learnt about the technology and decided to own plants as well that the feedstock could not accommodate two or more plants at the same time and some just cut off supplies because of hatred. This was attributed to lack of knowledge by the plant financiers and construction personnel to sensitize these plant owners on the how to manage a biogas digester.

- Plant owners with a high degree of consistency monitored their plants very well through constant feedstock loading and proper feedstock processing before loading unlike others

- Most users whose plants had a low level of consistency had little feedstock to sustain the plants and this called for bringing in more cattle or changing the grazing system from semi free-range to total zero grazing.

- Most users who were not sure about their gas consistency had little knowledge on biogas and were more focused on the use of alternative fuels such as wood and charcoal which alternatives accelerated deforestation, global warming and reduced sustainability.

- For many biogas plants with low consistency levels, challenges resulted from low quality materials used during construction and poor feedstock processing.

- Most of the feedstock that was feed into the digesters had a lot of imperfection such as poor mixing ratios, foreign bodies and already dried feedstock that had already been drained of the entire methane component required to generate biogas. This was attributed to laziness and lack of enough sensitization.

- Most plant owners complained about their plants having a lot of gas but without the ability to burn. They fed their digesters well and maintained them well but after a critical analysis, the gas had a high moisture content resulting from poor mixing ratios and poor quality of the pipes used to transport the gas to the cooker.

- Some of the biogas of the people interviewed did not burn well because of leakages in the piping system probably because of poor maintenance and fitting.

- From observation, some of the biogas did not burn well irrespective of the good quality. This was attributed to poor maintenance and presence of numerous bends in the piping system. For an efficient piping system there should be absolute minimization of such bends to a maximum of three bends in the entire system. Some biogas owners shifted their biogas stoves without the knowledge of the technicians to points higher than the gas storage.

- Most of the biogas plants visited had high volumes of solidified feedstock or slurry that could not flow to the overflow chamber. This was attributed to poor feedstock properties resulting from poor processing and untimely stirring for uniformity.

Financial benefits of using biogas

From the survey, almost every biogas user identified a financial trade off from biogas usage. These trade-offs came as a result of reduced spending on wood fuel, charcoal and improved charcoal stoves that were destructive and very expensive. Table 3.11 is analysis of associated savings for Mr. Matovu, a farmer with a 10m³ plant in Mukono district per annum.

Table 3.11:Financial savings from biogas usage

Item	Quantity before	Quantity after	Expenditure before	Expenditure after	savings
Improved stoves	3	1	30,000/=	10,000/=	20,000/=
Wood fuel	200 heaps	20 heaps	400,000/=	40,000/=	360,000/=
Charcoal products	10 bags	2 bags	500,000/=	100,000/=	400,000/=
Total			930,000/=	150,000/=	780,000/=

- These savings were used to educate children and take care of other financial needs of the family.
- Mr. Matovu claimed that sometimes, they used charcoal to prepare dished that consumed a lot of fuel such as beans and used charcoal and wood fuel on when the gas production levels had dropped for a while.
- He also explained the improved health standards of his family as a result of reduced exposure to particulate matter and obnoxious gases that used to cause respiratory disorders to his family.

3.10.1 Gas Composition

The gas composition for the monitored digesters was found to be in the range of 50 - 60% as shown in Table 4.3 which is within the theoretical range for biogas yields quoted in literature for different feedstock types. This composition is dependent on the percentage of proteins, fats and 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%.

3.10.2 Gas Utilization

Most users used biogas for mainly cooking and lighting. The efficiency of the burning component is largely determined by a suitable mixture of gas and air that enters the heating appliance and in turn is dependent on the following factors:

(a) Pressure: The Biogas digester unit generates variable pressures, thus there may be a need for frequent adjustments. Gas pressures above 20-centimeter water column give satisfactory results. This is adequate to force gas and air into the appliance, at pressures less than 20-centimeter water column, the gas-air mixture may not reach the appliance. In this case, there is need to adjust the mouthpiece further into the appliance and re-adjust as the gas pressure increases again. Remember that if the mouthpiece is too far from the appliance, there will be lack of air to the mixture.

(b) Efficiency of the appliances used. A gas efficient-appliance should have the following basic features:

- Inlet channel should be smooth to reduce resistance of the gas-air flow.
- Spacing and size of air holes should be proper.
- The Volume of gas-air mixing channel should be large enough for complete mixing.
- Gas Jet holes should not be too large nor too small but just large enough to allow for easy passage of mixed gas and air.
- The appliance should not only be simple, economical and lean to make, purchase or maintain but at the same time be durable.

(c) In case a stove is being used, users should observe the following.

- A good flame is pale blue in color and strong with a hissing sound.
- If the flame shifts around or is unsteady, it is probably due to either insufficient air or too large holes in the gas-feed tube. Adjustment is necessary.
- If the flame has a red or yellow tint, this may mean either that there is too much air or gas intake or that the gas-feed tube needs to be enlarged.

(d) If the gas is being used for lighting, the following precautions need to be taken

- First use the lamp without a mantle. Check if the flame is pointed down, pale blue in color, and burning evenly with a "hissing sound. If so, the lamp is good and the mantle may now be attached.
- Use denatured alcohol to soak and ignite the mantle. Leave the gas petcock off until all the alcohol has burned off. This provides the mantle to be "white".
- Newly light the lamp. If the flame wanders, this indicates that either there is insufficient air and the gas tube has to be raised or the gas-feed tube is too large and has to be changed to a smaller one.
- If the flame is reddish, it either means there is not enough gas or there is too much air. Push the gas-feed tube further into the lamp, or make the gas-feed tube hole larger, or it may be due to mantle quality, or may be due to a high $C0_2$ content in the gas. Frequent adjustments and experiments are needed until the desired results are produced.

3.10.3 Biogas composition of the surveyed digesters

This was done by zeroing down to nine digesters in the districts of Kampala, Luwero, Mukono, Mbale, Wakiso and Jinja where gas composition, temperature and pH were monitored as explained below.

For gas composition, only the burning component (CH_4), carbon dioxide (CO_2) and Hydrogen sulphide were given special emphasis

The gas composition for the monitored digesters was within in the range 50 - 60% as shown in the table below. This composition is dependent on the percentage of proteins, fats and carbohydrates in the feedstock.

From Table 3.12 and 3.13, the digesters had sufficient methane gas to provide for the burning component in biogas thus if given special attention, the technology can be effective and useful.

Table 3.12:Variation in Composition for the monitored Digesters

Digester	**CH_4 (% by Volume)**		**CO_2 (% by Volume)**		**H_2S(ppm)**
	Range	Average	Range	Average	Max Value
Digester 1 (Kampala)	51-58.8	54.9	41.2-49	45.1	208
Digester 2 (Mukono)	52-53	52.5	47-49	48	279
Digester 3 (Mukono) fed with pig waste	57-59	58	41-46	43.5	202
Digester 4 (Jinja)	41-45	43	30-38	34	-
Digester 5 (Wakiso)	54.5-55	54.75	45-45.5	45.25	212
Digester 6 (Mbale)	55-57	56	43.48.8	45.9	215
Digester 7 (Luwero)	51.8-53.5	54.15	44.6-47.1	45.45	149
Digester 8 (Wakiso)	52.9-55.4	51.95	47.1-49	48.05	312
Digester 9 (Jinja)	51-52.9	52.65	46.5-48.2	47.37	190

Table 3.13:Chemical composition of the surveyed digesters

Digester	**Average CH_4**	**Average $C0_2$**	**Max H_2S**
Digester 1	54.9	45.1	208
Digester 2	52.5	48	279
Digester 3	58	43.5	202
Digester 4	43	34	0
Digester 5	54.75	45.25	212
Digester 6	56	45.9	215
Digester 7	54.15	45.45	149
Digester 8	51.95	48.05	312
Digester 9	52.65	47.37	190

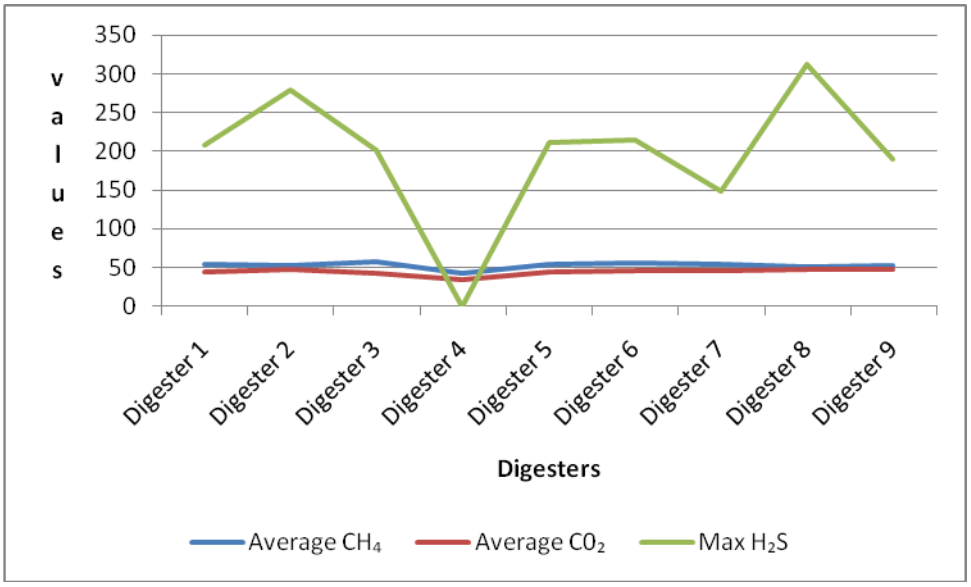

Figure 3.10: Graphical presentation of the Variation in Composition for the monitored Digesters

Because of the sufficient ambient and digester temperature and pH conditions there is sufficient production of biogas in the digester and this encourages increased use of the technology.

- Most users or plant operators fed the digester with mixed feedstock from different places that had different moisture contents due to exposure to extreme environmental conditions thus the generation and accumulation of hydrogen sulphide gas.
- Sulphide gas was also generated from free falling and splashing cow dung around the kraal and the digester and thus generated hydrogen sulphide gas after exposure to extreme environmental conditions.
- The digester with no traces of hydrogen sulphide gas had just started producing biogas and only fresh feedstock and feedstock stored away from direct sunshine was being fed into the digester.
- Most users and operators fed the digesters with insufficiently prepared and dried feedstock thus the low values for methane and the high values for hydrogen sulphide gas.

3.10.4 pH and Temperature composition of Gas in the surveyed digesters

The values obtained for pH were in the normal working range of anaerobic micro-organisms. 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 methanogens.

From the results obtained (Figure 3.10), it can further be noted that all the digesters sampled were working in the Psychrophillic range, at temperatures less than 25^0C 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.

It was also noted that Thermophilic operated digesters have high yields and higher conversion rates than Mesophilic digesters and so does Mesophilic digesters compared to Psychrophillic 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.

Table 3.14:Temperature and pH Composition of a few selected digesters

Content	**Temperature (^{0}C)**		**pH**	
Digester	**Ambient**	**Digester**	**Range**	**Average**
Digester 1	24	23.4	5.96-6.48	6.22
Digester 2	25	23	6.0-7.14	6.57
Digester 3 fed with pig dung	30	24	6.25-6.90	6.575
Digester4	26	22.8	6.98-7.35	7.165
Digester 5	21.8	21.4	6.33-7.03	6.68
Digester 6	18.3	20.5	6.21-7.14	6.675
Digester 7	21.9	23.4	7.33-7.35	7.34
Digester 8	27.8	22.6	7.25-7.29	7.27
Digester 9	19.4	19.2	6.98-7.04	7.01

Methane forming bacteria are sensitive to pH conditions and changes in the slurry. Their optimum range is between pH 6.8-7.2 although they may tolerate a pH level of 6.5-8.0.

Under acidic conditions, the methane producing bacteria cannot consume all of the acids being produced by the acid-forming bacteria and may stop digestion. When this situation arises, lime and grass ashes should be added and the digester given some time to stabilize.

If alkaline, the acidic Carbon dioxide produced during digestion will correct the condition overtime.

To determine whether the slurry is acidic or alkaline, a Litmus paper test is used. Since the pH (litmus) paper only shows extreme changes in pH levels, this test is used only when gas production has ceased and the probable cause is due to pH problems.

Furthermore, the pH value of anaerobic digestion substrates influences the growth of methanogenic microorganisms and affects the dissociation of some compounds of importance such as ammonia, sulphide, organic acids for the process. According to a research by Mshandete et al (2006), the pH of a normal 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 a condition alkalinity in the digester.

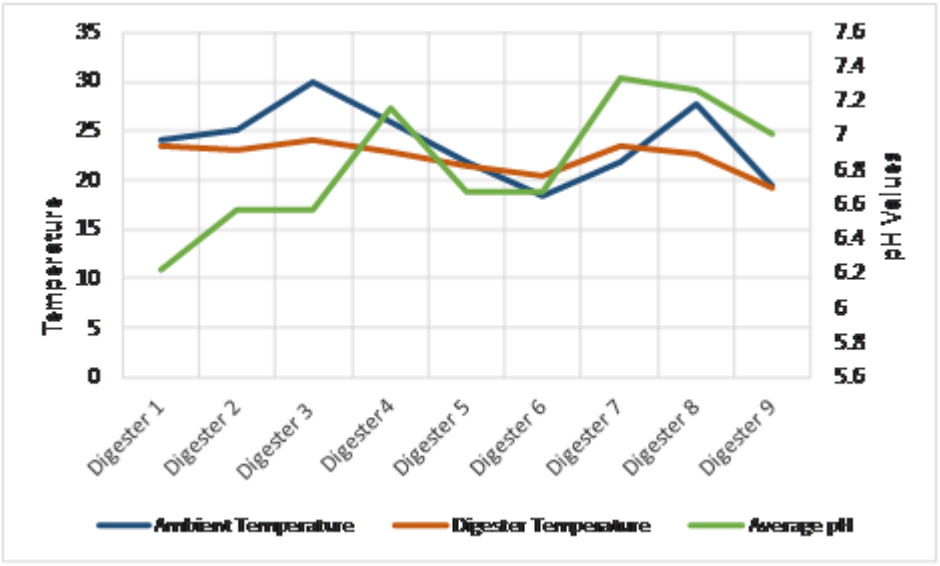

Figure 3. 11: Variance of pH with Temprature for selected Digesters

- For most of the biogas plants, ambient temperature is higher than the digester temperature mainly because of the bio-chemical reactions taking place within the digester.

- Digesters 1, 2 and 3 produced more gas and were very consistent. This was based on the low pH values within the digester hence high activity levels of the methane forming bacteria.

- Digesters 7 and 8 had low gas volumes and quality due to high pH values thus rendering the methane forming bacteria inactive during certain intervals.

- All the digesters in sampled had biogas sufficient enough for cooking operations in every household for a good number of days. This was based on the fact that they all fit in the psychrophilic range of temperatures suitable for biogas production.

Precautions to be taken while Operating a Biogas Plant

a) Mixing Slurry for Regular Loading

- About 1 liter of water is usually added to every kilo of feedstock. During the initial loading, a uniform thick mixture must be obtained for effective results. However, there is no fixed water-manure proportion since this will depend on the type of feedstock being used and its moisture content. The technique will be developed through experience.

- All material that should not go into the digester as previously mentioned must be strictly watched and removed.

- Avoid feeding the digester with feedstock from different places as these cause variations in properties within the digester and causes instabilities in the formation of bacteria for gas production.

- Only fresh feedstock should be fed into the digester so as to reduce generation of hydrogen sulphide in and around the digester so as to improve the health standards around and to protect the piping network.

b) Regular Loading of Input Materials and Removal of Effluent from Outlet Chamber

- The loading of feedstock materials should be done regularly though the amount of slurry should be in accordance with the requirement of the particular digester volume and its retention time. If less slurry is being loaded than what is required, there will be low gas production as the bacteria will be starved.

- All the feedstock loaded into the digester should be fresh at least not more than a day old for effective results and must be free of all materials unsuitable for anaerobic digestion.

c) Stirring or Agitation

- The slurry is mechanically agitated with a stick or piece of wood in order to stimulate bacterial activity and break the scum layer which forms organic matter at the slurry surface and this restricts gas flow through the slurry to the gas holder. If left undisturbed, the scum would get thick and harden, which may require opening the digester to remove it. Stirring should be done after every two days for at least 3 minutes in the morning and 3 minutes in the afternoon. The stirring should be 360° in one direction in either directions.

d) Servicing Scum Problem

- Release all gas within the digester. Manometer reading should be zero.
- Disconnect gas piping closest to the digester.
- Remove manhole.
- Inspect the scum layer and check its thickness,
- Remove scum manually with buckets through the manhole.

e) Periodic Cleaning of the Digester

- The digester may need to be emptied at intervals to remove the settled sludge and other inorganic solids, like sands and stones that accumulate at the bottom of the digester. The materials are removed manually through the manhole, with the use of buckets. This is also an occasion to check for any possible leakages and structural damages.

- Users or operators should take necessary precautions when entering a digester. Since the gas can be poisonous gas.
    (i) Apart from the normal schedule, complete emptying of the digester should be done if the following conditions occur:

    - Stirring becomes too difficult due to heavy accumulation of inorganic solids (sand, pebbles, etc.).
    - Gas production ceases completely. This may be due to the introduction of toxins (detergents or disinfectants) into the slurry.
    - If Gas production slows down despite regular daily loading. There may be leakages in the structure and piping system. Likewise, excess slurry will result in raw material wastage since the slurry will not be fully digested. The loading of new slurry materials displaces an equal volume of effluent to the outlet chamber. This effluent must be removed. Otherwise the digester would be overloaded. One way to check correct digester level is that at zero gas pressure, the slurry should be at the level of the outlet chamber floor.

f) Repairing Masonry Work within the Digester

Due to a variety of causes, a need to repair the digester may arise. If the damage is serious, the wall or a whole section may have to be rebuilt. But normally, the damage is only in the form of cracks or leaks and repair work would be much easier using the following techniques.

- Clean the damaged portion. Inspect and determine extent of damage
- Carefully chisel a wide "V'-shaped groove. Roughen the edges.
- Attach 2-3 layers of chicken wire to the wall with nails at 30 centimeters from either sides of the crack.
- Apply cement or water paste to the entire area. This is to ensure good adhesion.
- Plaster cement-sand (1:3) mortar at least 13 millimeters thick with a Roughened finish.
- Allow to dry for at least 2 weeks before Inspection.
- Use only flashlights inside the digester. No smoking or open flames candles and lanterns near or within the digester.
- Prepare a long piece of pipe or hose (one end attached outside of the pit) through which the worker inside the pit may breath. Also it is advisable to have a second person to pull him out if he accidentally loses consciousness.
- Any feeling of dizziness or discomfort in breathing is enough warning for the person to get out of the digester. He should rest and take fresh air. It is not advisable for one person alone to do the work. Someone should be constantly watching from the outside of the pit who can respond to any emergency. A safety line should be attached to the worker inside.

g) Biogas Leakages

- Ensure that the plant has a regular shape for uniformity of properties inside the digester for efficient biogas production.
- Ensure that no poor quality materials such as bricks and cement, improper fittings are used anywhere on the plant so as to avoid cracks and subjection of the piping system to extreme environmental conditions leading to system failure.
- Ensure that the appliances used are of a good quality and have no leakages.
- Ensure that you reduce the number of bends in the piping system so as to reduce pressure drops in the system for constant flow.
- Ensure that the cover on the gas storage tank is leak proof by keeping a layer of water on top all the time.

3.10.5 Challenges and Causes of biogas System Failures.

Out of all the plastic bag digesters visited, only two had lasted for more than 4 years and these were found in Mbale district, the rest lasted for less than a year. The major causes of failure for this type of digester though cheap to install were:

- Exposure to sunshine that causes deterioration of the bags
- Malice from neighbors that led to destruction of bags by piercing as was experienced in Kabale district where the digester was pierced two times at different points.
- Poor planning and siting of the digesters was also another common challenge where digesters were not properly located to allow easy flow of the slurry to gardens, this increased the labor requirements and time required for one to empty the expansion chamber and take the manure to the gardens leading to abandonment.
- Improper installation of pipes was also a challenge for example in cases where the digesters were located in gardens. The pipes were at times cut during cultivation or damaged during processing of produce.
- Inadequate Preparation of feedstock in some areas caused blockage of digesters thus calling for empting within the digester's first year of operation as the trash covers the effective area for digestion thus forming insufficient biogas.
- There is lack of enough locally trained technicians to maintain the existing plants and this leads to abandonment in case the plant fails to generate biogas.
- Poor workmanship in form of poor mixing ratios and low quality materials caused digester to work for a very short time; this was witnessed in form of cracks on different digesters, expansion chambers and large clearances through which the gas escaped.

- Poor maintenance and operational techniques by the owners of the systems also led to low gas production, gas leakages and in some cases failure of the systems. As was observed, digesters were overfed in some cases causing the feedstock to go through the digester before it was fully digested

- Death of animals or shifting animals to bigger farms away from home; in some districts the biogas digesters failed after loss of cows that system owners had. Most of the animals given to farmers were exotic and died from east coast fever; others that did not die of diseases were maliciously killed by people leaving the biogas users without any feedstock.

- A number of cases also encountered were spoilt valves that brought about leakages. Some owners of biogas systems did not look after the valves very well, a number of these valves were found buried in water, covered by soil and therefore corroded or broken

- Some of the respondents were negligent or lazy and could not manage the systems appropriately. This was a challenge especially for systems that were given free of charge to people. In Nakasongola and Luwero two systems were completed but were never fed even when the owners had access to feedstock.

- Most biogas owners were not aware of the environmental benefits from the using biogas. In fact during the survey only a few people mentioned something to do with environmental conservation, this further hinders the dissemination of biogas technology since the environmental benefits are not usually built into the cost of the system.

- For most of the digesters visited the gas production was not constant and in most cases the gas production rates had reduced, this is probably due to: feedstock getting out of the digester before being fully digested either because of short-circuiting (as a result of dead volumes in the digester or in the displacement chamber) or higher water-feedstock ratio during mixing. This was observed for some digesters that had bubbles in the expansion chamber and depressions in the slurry which indicated the existence of gas in the slurry.

- In addition to poor workmanship there are also cases of substandard materials and appliances. In most cases lamps supplied were found to be of poor quality and thus failed to perform to the user's expectations and failed too soon.

CHAPTER FOUR: CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

From the research conducted, observations show that biogas has a high potential in Uganda and thus, exploiting it will help to alleviate the energy crisis in Uganda to some extent however more improvements and additions of other renewable energies are required.

It was also observed from the analysis of results and interaction with the research participants within the scope that many biogas owners and future potential owners need to be sensitized by renewable energy engineers and renewable energy extension workers on:

(i) The need for using biogas
(ii) The environmental, health and social economic benefits of using biogas
(iii) The disadvantages of using wood fuel
(iv) The advantages of supplementing biogas with improved energy options and accessories
(v) Their roles in reducing global warming and environmental variability through biogas usage
(vi) How to maintain a biogas plant for ultimate benefits
(vii) How to properly use the slurry from the digester for social economic benefits resulting into improved standards of living
(viii) The need for biogas owners to volunteer in training so as to improve their plant operating conditions so as to ease usage and stimulate popularity

Most of the biogas plants owned use cow dung and pig dung as feedstock thus other feedstock materials need to be communicated and their feasibility investigated and tested as those without animals could not access and enjoy the benefits of the technology.

It was concluded that pig dung contains a lot of ammonia gas and requires a lot more processing than cow dung before feeding it into the digester and using it for cooking.

It was observed that many people had more feedstock supplies but either they knew nothing about the technology of they could not afford the initial investment costs for a biogas plant.

Most of the biogas plants failed because of poor structural designs and structural failures

It was also concluded that most users invested little efforts in maintaining biogas plants thinking the benefits come easily.

It was concluded that many biogas plants whose failure was structural related were constructed with poor materials especially with poor mixing ratios resulting from lack

of sufficient competence among the masonries and poor workmanship behaviors amongst them.

Many biogas plant owners do not keep records whichever operation done on the plant thus making it difficult to maintain the plant for ultimate benefits.

Many biogas owners that used supplementary wood fuels did not use energy saving stoves and this would accelerate deforestation and global warming

There were many people in the area of scope that reared birds such as broilers for meat and layers for eggs but had no knowledge of generating biogas from chicken wastes.

4.2 Recommendations

4.2.1 Structural Recommendations

Masonries need to be trained on how to effectively and efficiently construct biogas plants to the rightful shapes, sizes and texture for ultimate quality and quantity. Many biogas units have not produced as much gas as they should and many others have just gone out of use. A properly built structure and sufficiently available raw materials may not produce the desired results due to faults during operation and poor maintenance. The People's Republic of China, for instance, observed that properly constructed biogas structures generally 30% to the plant's success and 70% is contributed by proper operation and maintenance of the unit.

The digester has to be checked before initial loading for any leakages on all chambers and the piping system

There should be not more than three bends or elbow in the piping system for minimum pressure losses in the system

The digester should not be more than 20 meters away from the gas consumption point or destination for minimum pressure losses

The stove should be fabricated to soot the size of the plant, the size of the family and the amount of gas produced.

The dome shape kind of digester should be promoted for efficient production and usage of biogas.

4.2.2 Operational Recommendations

Proper initial loading contributes to the eventual good performance of the unit. There are a number of guides to keep in mind.

Starter or Seeding; the initial raw materials should contain slurry with a high bacteria population. This is also known as the starter. About 5-10% of the total slurry volume should be added when the digester is about 25% full.

Cattle dung is a good starter since cattle have methane producing bacteria in their stomachs. Starter can also be made from any manure by adding to it 5-10% old slurry obtained when cleaning the digester. Starter can be prepared by storing manure in a container while constructing the digester.

The slurry should be mixed to the right ratios of 1: 1 in most cases with clean water and clean feedstock for ultimate biogas production.

Users and owners should ensure availability of water on top of the lid so as to mitigate any gas leakages that could cause unreliability

All accumulated moisture in the system should be removed after at least every week so as to increase reliability and improve gas efficiency

All appliances used in the entire process from feedstock preparation to gas usage must be kept clean so as to avoid failure resulting from accumulation of scum, chemical and mechanical failure.

Before putting any slurry into the digester, the owners or operators should ensure to first open all valves to relieve any built-up pressure in the digester dome. It is advisable not to connect the piping system to the digester when loading.

Manure and water should be mixed thoroughly until there are no more lumps and the mixture will assume a thick pea-soup or thick mungbean-soup consistency. This will increase gas production since the bacteria will have more surface contact with the manure.

The digester should be stirred at least once or twice a day to ensure uniformity of properties and slurry settlement for efficiency.

Biogas plant owners should be trained on how to keep records of whatever operations they do on the plant such as the feeding dates and quantities, the emptying dates and stirring dates and durations for efficient monitoring and maintenance.

The overflow chamber must be offloaded or emptied on every digester loading. This prevents abnormal overflow, promotes health and safety and improves efficiency

Operators should never fill the digester past the ring beam level, which is the same level as the outlet chamber floor. Check again to ensure that there is no build-up pressure at this time within the digester.

More slurry should be added to the digester before three or more days past the previous loading. This gives bacteria a chance to convert all the digester contents into useful biogas and slurry manure with minimal interference.

Materials that hinder anaerobic digestion such Earth or sand and other soils should not enter the digester as they cause problems by hastening the

accumulation of such materials within the digester. These materials should be allowed to settle-out while mixing the slurry in the mixing pit.

Materials such as Straw, grasses, leaves, metals and any other foreign material of non-uniform shape, size and category should be removed since these materials will float on the surface of the slurry and cause scum problems which may consequently reduce gas production and manure overflow

Materials known to be toxic to anaerobic digestion such as Oil, soap, detergent, disinfectant and many others should be eliminated and avoided into the digester as they disrupt bacteria activity or may even kill the bacteria

4.2.3 Environmental Recommendations

All potential biogas owners should be sensitized on the advantages of using biogas before they own the plant. This will give them knowledge of their role in the struggle to reduce global warming and achieving sustainability.

Users must be encouraged to cover the inlet and outlet chambers of the plant so as to ensure a healthy environment for ultimate benefits.

Users must ensure that all valves are closed after use. This eliminates escape of the gas and also ensures a healthy environment.

Potential biogas owners should be advised to plant trees while using biogas as an additional measure to combat global warming and achieve sustainability.

While they use other fuel types such as wood, they should be encouraged to use high heat retaining stoves and improved charcoal products. This will reduce deforestation and create sustainability.

Plant owners and operators must ensure ultimate cleanliness of the plant, the area and all operational accessories to avoid causing poor health to family members and neighbors. This creates a healthy and clean environment thus leading to ultimate benefit from the plant.

4.2.4 Social Economic Recommendations

The organizations constructing biogas plants to users must always make a social economic analysis for these people before constructing for them these biogas plants. This will help the users to ultimately benefit from using biogas. This is very important because in cases where users do not have their own feedstock, maintaining biogas plants becomes a social –economic burden on lives thus worsening their standards of living.

Since the plant gives users wastes that they can use as manure or a fertilizer, they should be sensitized on how to engage in improved farming methods for better agricultural yields. This will result into ultimate utilization of the plant and improved household income and better standards of living.

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Appendix A_1: Survey questionnaire

Data collection sheet (July to December 2010)

This questionnaire is strictly for research purposes and information given will be treated with confidentiality. Your response is highly welcome.

1. Name of respondent…….....

2. Age of respondent……

3. Level of education for the respondent or family head…….....

4. District of respondent……

5. What type of biogas digester are you using?

(a) Fixed dome (b) Floating drum (c) Plastic bag (d) other specify…….....

6. Reason for the choice of this plant

(a) low cost

(b) Easy to operate

(c) Generates more gas

(d) I had no say over the choice of plant

(e) Easy to construct ?

(f) Other specify

…….

7. Who financed construction of your biogas plant?

(a) Government (b) NGO (c) own capital (d) relatives

(b)If NGO state its name……

8. How much did it take to construct the biogas plant and its auxiliary components?

……

(a) <1,000,000 (b) 2, 000,000-3,000,000 (c) 3,000,000-4,000,000 (d) >4,000,000

9. What do you use the biogas for?

(a) Cooking (b) Lighting (c) Power generation (d) Cooking and lighting

10. Is the biogas plant operational?

(a) Yes (b) No

11. How long did or has the biogas plant worked?

(a) <1 year (b) 1 to 4 years (c) 4 to 10 years (d) >10 years

12. If not operational, what caused its failure?

……

13. If operational, does it still generate the same amount of biogas as when first used?

(a) Yes (b) no (c) not sure

14. If the gas production has reduced, what could be the cause?

……..……

15. What type of feedstock do you use?

(a) Animal dung (b) Human excreta (c) Vegetable matter (d) other

16. If animal dung, how many animals do you have?
…….……

17. What type of grazing system do you use?
……..

18. If vegetable matter;

How many Kg?
……...

19. What type of plant?
…….……...

20. Reasons for the preference of the above type of feedstock?

(a) It is the only one available in this area

(b) It is the cheapest

(c) Easy to prepare

(d) Other please specify ……

21. Do you supplement biogas with another source of energy?

(a) Yes (b) No

22. If the answer is yes in the question above then why?

(a) The gas does not cook well

(b) The gas is not enough

(c) Other alternatives are easy to use

(d) Other

Specify……

23. What alternative fuel or source of energy do you use?

(a) Fire wood (b) electricity (c) charcoal

24. If wood or charcoal, do you use improved stoves?

(a) Yes (b) No

25. Do you carry out any maintenance operations on the plant?

(a) Yes

(b) No

26. If the answer to question 19 is yes, what type of maintenance activities do you carry out?

……

27. If the answer to question 19 is no, why?

……

28. Are there locally available trained technicians who help you with maintenance?

(a) Yes (b) No (c) Not sure

29. If yes to question 20, what are the reasons for using other alternative sources of energy?

……
……
……

30. Do you carry out any preparation activities on feedstock materials before you feed it into the digester?

(a) Yes

(b) No

31. If yes to question 22, what activities?

……

32. If no, why?

……..

…….

33. When mixing the feedstock materials with water, what ratios do you use?

……..……...……

34. Are you always keen on the accuracy of the ratios?

(a) Yes (b) No

35. How often do you stir inside your biogas digester?

(a) Once a week n(b) once every two week (c) once a month

(d) When gas stops coming (e) never

36. Where do you get your feedstock from?

(a) Own animals (b) Neighbors

37. What do you use the digester slurry for?

(a) Waste (b) Farming

38. If the answer is farming in question above, what type of crops do you grow?

(a) Cereals (b) matooke (c) vegetables (d) root crops (e) Both vegetables and matooke

39. Do you keep records every time you work on the digester?

(a) Yes (b) No

40. Do you still want to use biogas?

(a) Yes

(b) No

41. If yes, why?

……..……

42. If no, why?

……..……

Appendix A_2: Pictures showing construction works of some biogas Plants, biogas usage and agricultural slurry products



A_2-1 during and construction of a fixed dome biogas plant at Namalere



Figure A_2-2: Two lamp designs, one without glass and the other with glass



Figure A_2-3: Shows Newly Constructed Biogas Fixed Dome type in the South Western Hoima - Uganda



Figure A_2-4: Poor workmanship: Large clearances between the drum and the digester lead to that a lot of gas escapes.



Figure A_2-5: Plastic tank digester that was tested but never worked! Digester cracked probably due to bad design criteria.



Figure A_2-6: Digester in Mukono that was not well fed and with no prior sorting of feedstock before loading



Figure A_2-7: Recurrent problems on most digesters, leakages on pipes at the connections.



Fig A2-8 Showing construction of the weak ring and the plant neck respectively

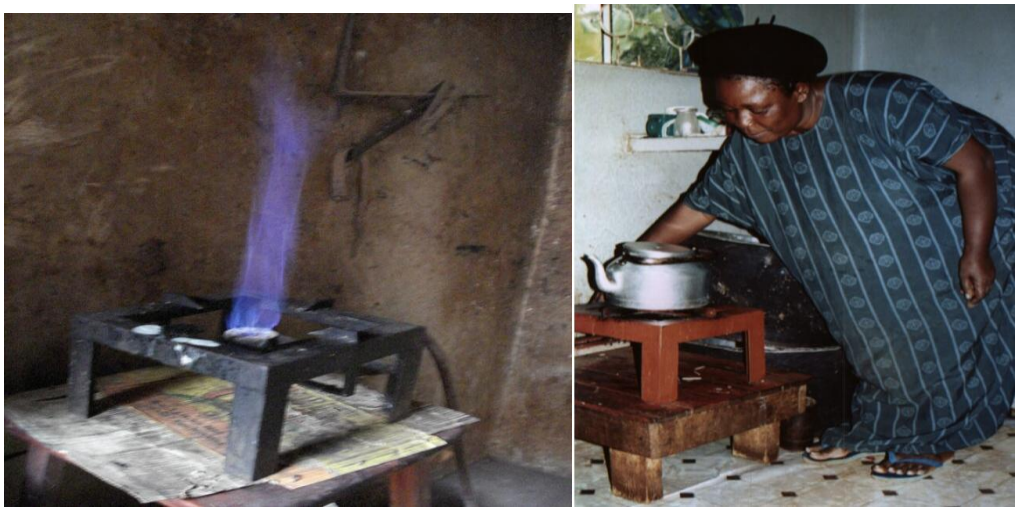

Fig A2-9 Showing how a biogas flame from a productive plant is capable of heating water and foods




Fig A2-10 showing the related efficiency for biogas in cooking activities



Fig A2-11 showing biogas cooking and lighting respectively



Fig A2-12 showing a well constructed fixed dome digester at Namalere and a floating drum digesters respectively



Fig A2-13a showing Matooke improved yields from using biogas slurry in Mukono district



Fig A2-21b showing Matooke improved yields from using biogas slurry in Mukono district