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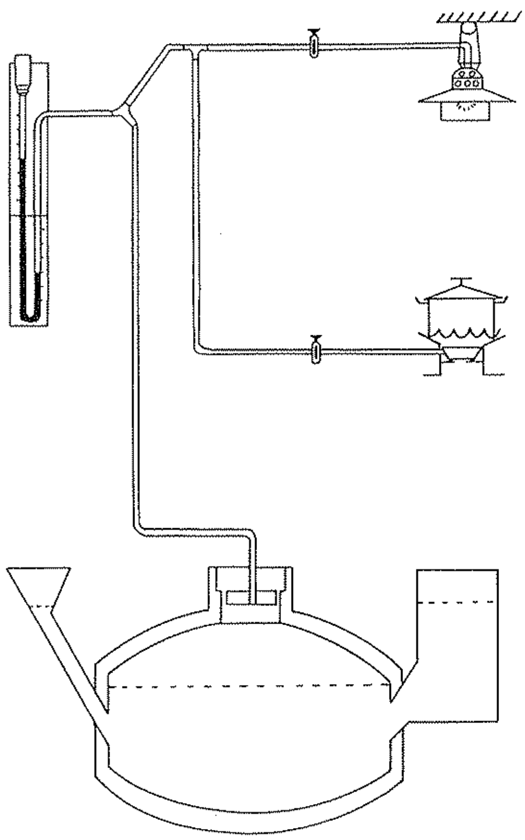
Biogas as an Alternative Energy Source in Uganda

Report from a Minor Field Study

Ayieko Kisonyo Singoro



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PREFACE

During the months of February and March 1987, I carried out a minor Field Study (MFS) in Uganda. The study had the purpose of finding out the energy utilization by Ugandan peasants with the aim of establishing the possibilities of introducing biogas systems in the countryside. The study was carried out through interviews of families in the countryside, administrators at different levels and professionals working in the fields of rural development, agriculture, forestry and energy utilization in general.

This report is the result of the above study and serves as part of a programme for the Masters of Science degree in Agricultural Engineering at the Swedish University of Agricultural Sciences. The study was financed by the International Rural Development Centre at the same University.

My sincere gratitude to my supervisors:

- Dr. Anders Almquist, Swedish University of Agricultural Sciences; Department of Agricultural Engineering.

- Lennart Thyselius of the Swedish Institute of Agricultural Engineering.

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- Miss L. Kagobe.

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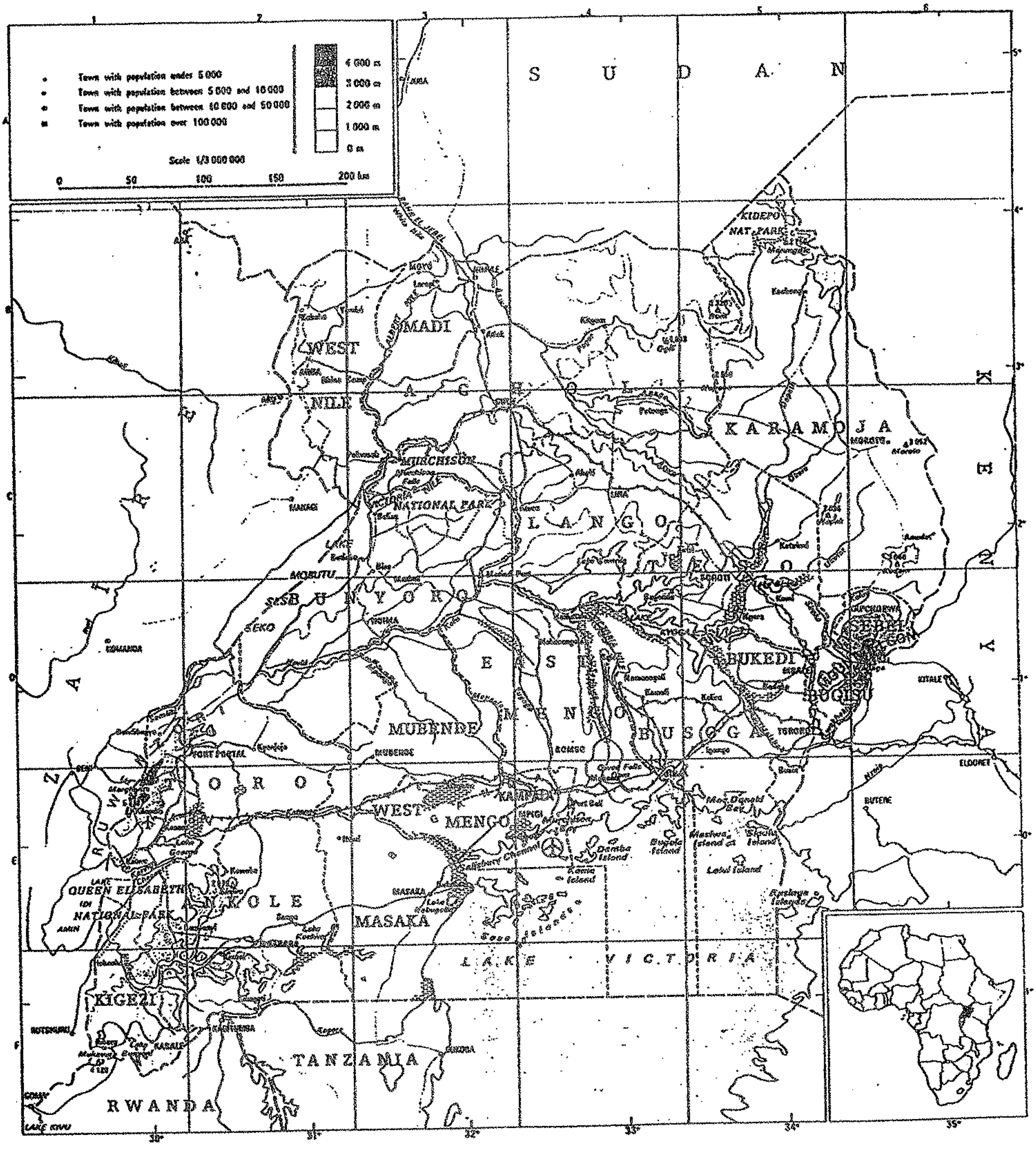


MAP OF UGANDA

1. INTRODUCTION

Uganda is a country with varied geographical features, having high plateaus, mountains and lakes. It has an area of 237 000 km^2 with 28 500 km^2 of it consisting of lakes and swamps. The population was estimated to be 13.2 million in 1984.

The country is mainly agricultural with 95 % of the export earnings coming from agriculture and about 90 % of the population living in the countryside.

Crops grown include bananas, maize, different types of millet, cassava, potatoes, vegetables and fruits as food. Coffee, tea, cotton and sugarcane are among the cash crops grown. There is animal keeping too, cattle, sheep, goats, pigs and chicken are kept.

Before the arrival of foreigners from Europe and Asia, the main sources of energy in the country were solar, wind and wood. Wood was virtually the only fuel used for cooking, heating and lighting. The three-stone open fire type system was standard. The coming of foreigners was accompanied by an introduction of new types of fuel, i.e. fossil fuel and hydro-electric power. These new types of fuel were mostly introduced in the urban areas where most of the foreigners resided. The rural areas have largely remained unchanged except for lighting where the use of paraffin is wide-spread.

The rising costs of imported fuels and cooking devices since the 1970s' has forced most urban dwellers to rely more on the indigenous woodfuel in the form of charcoal for cooking purposes.

One of the potential new sources of energy, which could provide energy requirements for small communities, is biogas. It is an environmentally clean source of energy. Its production does not demand sophisticated technology. It can be generated at the site of demand and therefore there is no need for capital investment in energy distribution systems. Organic matter required for its production is abundant and free of charge in most parts of Ugandan countryside.

The recent softening in international oil prices has not diminished the difficulties that energy importing developing countries are facing. The relatively cheap price of oil is still not easily affordable by the people of Uganda with per capita annual GNP of a few dollars. Even with a low per capita energy consumption (100-150 kg. of oil equivalent) the net annual oil import uses more than 20 % of their total foreign exchange earnings. Even so hardly any oil products get to the rural people.

The effectiveness of biogas technology to treat agricultural and animal wastes in a sanitary manner and produce biogas as a convenient source of fuel in a decentralised system, has been demonstrated.

Faced with fast growing population and hence diminishing agricultural land, the wood supply for energy use in the rural and urban areas is going to be very limited. Biogas production, therefore, can be considered as part of an integrated farming system in which the effluent from digestion is used as fertilizer for crops and trees. This integrated system can provide fuel and fertilizer and solve problems of food, nutrition and rural development.

This report is an attempt to provide the reader with general information about the energy situation in Uganda and, particularly, the question of whether possibilities exist of introducing biogas systems in the countryside. It is a description of the anaerobic process, material resource requirements, operational conditions, available design options and the end uses of biogas. Also included, is a brief look at the Chinese pilot project, possible effects of biogas systems on rural life and a brief economic analysis, recommendations, conclusions and summary.

2. AIMS AND IMPLEMENTATION OF THE PROJECT

The aim of the study was to find out the energy utilization by Ugandan peasants with the aim of trying to establish the possibilities of introducing biogas systems in the country-side (see appendix 1). The best was done to attain the above objective but there were limiting factors which affected the whole process.

It turned out that going through the whole study proposal, as it is, needed that a small area be chosen and an intensive household energy survey carried out something that would have needed more time and resources. One and a half months sickness just made the situation worse. Communication turned out to be very difficult especially in the rural areas. One hired a bicycle in a few cases but most of the distances had to be covered on foot.

An attempt was then made to carry out a general survey of the energy situation in the country. This explains the absence of concrete scientific results in this report. It should also be remembered that there is very little statistical data available in Uganda as a result of the political instability which the country has gone through for the last sixteen years.

As a result of the above difficulties, this report consists of the review of literature available on biogas and on Uganda, and the results of the information obtained through interviews with people. Chapter three consists of information obtained from the personnel in the Ministries of Energy, Agriculture and Forestry and Animal Industry and Fisheries. The information was obtained from the personnel both at the Ministry Headquarters and out in the Districts. Information about the rural energy situation was mostly obtained from the rural people.

Chapters four and five are a result of literature review while chapters six and seven are partly the result of information collected from the rural households and partly a result of a review of the material available on the Chinese pilot project. These chapters also include information about the performance of the pilot project digesters which was obtained by talking to the owners of the plants, reading the test reports available and the physical observation of the plants.

Chapter eight is a result of observations made in the rural areas and the projections made are based on the effect of other technologies introduced among the rural people for example the ox-plough. Results obtained in other parts of the world are also taken into consideration. Information about the problems of biogas is a result of observations of the pilot project and talking to the people involved. Chapter nine, The Economic Analysis, is based partly on literature review and partly on information obtained from various functionaries and rural people in Uganda.

NOTE: See Appendix 2 for the journeys made around the country and Appendix 3 for the list of people interviewed and institutions visited.

3. ENERGY SITUATION IN UGANDA

3.1 The national energy situation

The energy sector like the rest of the economy, has suffered severely during the 1970s and 1980s. The main problems are the high cost of imported petroleum, a shortage of electric capacity for medium and long term development, a shortage of fuelwood and low efficiency in use of fuelwood and other types of fuels. Little maintenance and investment has been possible in the electricity system and the procurement, transport and distribution of petroleum products supplies has also been beset by many difficulties. The rest of the institutional structure is weak, fragmented, and poorly co-ordinated and this is recognised to be a major obstacle in the development of the energy sector.

The government has made efforts to better co-ordinate the development of the energy sector. A fully fledged Ministry of Energy has been created to deal with all matters pertaining to energy and the oil desk in the Bank of Uganda is being strengthened to ensure that the country gets good value from the foreign exchange payments for oil and oil related products.

Total imported petroleum products was 183.9 thousand tonnes in 1985 which cost $ 78.7 million. The transport sector accounted for 75.7 % of the consumption of the total oil imported, the industrial sector 17.5 % and the domestic consumption accounted for 6.8 % (7). Most of it is used in the urban areas. This shows that very little of the commercial fuel gets to the domestic sector in the rural areas.

3.1.1 Rural energy consumption

As is the case with many developing countries, a relatively complete data base exists regarding the consumption of commercial fuels in Uganda. Energy balances for electricity and liquid fuels are reasonably easy to establish because energy retail companies keep fairly accurate records. Such statistics are commonly published by state and International organisations. However, such estimates ignore the bulk of the energy used by rural households for domestic purposes. Since the informal sector handles most trading in woodfuel, no records are kept. Hence, estimates of rural domestic energy use can only be obtained through household surveys.

Whereas in the past, rural households had access to wood as a free commodity, wood is acquiring a monetary value in rural areas in many parts of Uganda, as its scarcity and marketing potential increase. The ability of households to reallocate resources to meet fuel and building requirements without negatively affecting their standard of living, particularly their ability to satisfy other basic needs, is becoming increasingly problematic for an increasing rural population.

The involvement of men in fuel collection, a job that traditionally was left to women, is a sign of increasing fuel supply shortages. In some areas, even the pattern of eating has changed, people eat only two meals a day instead of three. This has a negative effect on the health of the people especially the children. Signs of under-nourishment are observed among children despite the abundance of food.

Although economic development and improved living standards for the population should lead to a change from woodfuel to more efficient and cleaner fuels, the continued price escalation of imported fuels and large amounts of capital necessary to build hydroelectric and other forms of energy sources hinder this transition. The tendency is for poor rural households to start using agricultural residues, a free commodity, when wood gets scarce, rather than purchase other energy forms due to financial limitations.

Animal draught power is used in many parts of Uganda. Although the scope for more utilisation of this form of energy is still great since livestock is and will continue to be a part of farming, it is severely limited by lack of appropriate equipment, innovations and training for both the oxen and the farmers. Before land pressure is sufficiently high to push the animals out of the land, and experience in Asia shows that his could take a very long time, efforts must be made to improve thir use and efficiency.

A high percentage of the land cultivated is done by hand tools bearing in mind that bananas, the staple food in Uganda are mostly hand cultivated and very little mechanization, if any, has been done in this area. Labour is supplied by the seasonal requirements usually characterised by severe bottlenecks.

3.1.2 The role of urbanization on energy patterns

Urbanisation in Uganda started with the emergence of kings and other traditional leaders. Before the arrival of foreigners from Europe and Asia, the main source of energy for domestic use were solar, wind and wood. Wood was the only fuel used for cooking, lighting and heating. The three-stone open fire system was the only stove in use.

With the arrival of foreigners, other stoves and fuels were introduced in urban areas where these foreigners resided, but since then little of it has gradually spread out into the rural areas. Fossil fuels and hydro-electric power were the new forms of fuel introduced. The stoves were pressure stoves burning paraffin, the metallic charcoal braziers, gas stoves, the paraffin wick-stoves, electric cookers, etc.

The metallic charcoal brazier was widely accepted and used by the middle and low-income groups because of their low costs. In high income families, the fossil fuel stoves and electric cookers were used. But due to unreliable supply of these fuels, the charcoal brazier is now practically found in every urban household, except in those of the poorest income groups who are still using the three-stone open fire system (2). The rising costs of fossil fuels, electric appliances and their unreliable supply are factors that have contributed to the scarcity and increasing commercialization of wood fuel. Urban households, unlike most rural ones, usually purchase their woodfuel. One interesting thing to note is that, it is very rare for the rural people to fell trees for their household firewood needs. Rural domestic fuel needs are normally met by collection of dead wood from around the farming landscape and at times, cutting twigs from a living tree or by using agricultural wastes like maize cobs.

Most of the trees on the out-skirts of urban centres have been cleared and trucks have to travel long distances to deliver charcoal to urban areas contributing to the well known colonial relationship between the urban and the rural areas.

3.2 Woodfuel supply

Uganda is one of the many countries experiencing a woodfuel deficit. 12 % of the country's total area is covered by forests and woodlands according to Patience J. Turyareeba of the Forest Research Centre, Nakawa, Kampala.

Current woodfuel consumption is estimated at 18.3 million m^3 (including wood for charcoal burning) and is expected to rise to 27.5 million m^3 by the year 2000. Present production is about 15.6 million m^3, thus 17 % less than the demand (13).

Among the factors contributing to fuel shortage in Uganda is the inefficient use of fuelwood and charcoal. The efficiency of the open fire is between 5 to 10 % while that of the metallic brazier is between 10 - 15 %. There are improved stoves that have been developed by a company called "Black Power" which have an efficiency of between 30 and 45% but they are much more expensive and therefore beyond the financial capability of most households (2).

Other factors causing fuel shortage are:

- Delay in restoration of forest plantations.
- Slow establishment of new plantations and increased population pressure. Woodfuel shortage is most acute in parts of West Nile, Soroti, Rakai, Mbarara and Kabale Districts (13).

Apart from domestic fuel supply, woodfuel is also used in tea, coffee, tobacco and brick-making industries. Charcoal is also used in lime, steel, cement and foundry works.

Some of the steps being taken to alleviate the woodfuel crisis include:

- The design by the forest research centre, Nakawa of a more efficient charcoal burning kiln which unfortunately has not been disseminated because of the high construction costs. It is made of bricks and has a steel roof. Replacing the steel with bricks could be the solution but the problem of transporting the bulkwood to the stationary kiln will still remain.

- Replanting of the depleted forest area is underway. There are plans to replant the pre-urban plantations by the year 1993. People are encouraged to get involved in agroforestry farming practices.

- The designing, testing and production of improved and more efficient burning stove models by government and non-government organisations.

- The development of other alternative energy sources for example hydro-electric power, wind, biogas, etc.

4. BIOGAS PRODUCTION

Methane formation from organic material has been recognised for more than 200 years but no major advances in the understanding of this process were made until a good cultivation technology for the production of the strict anaerobic methane forming bacteria became available about 20 years ago.

Anaerobic treatment of complex organic materials can be considered in its simplest form to be a three-stage process as shown in Fig. 1.

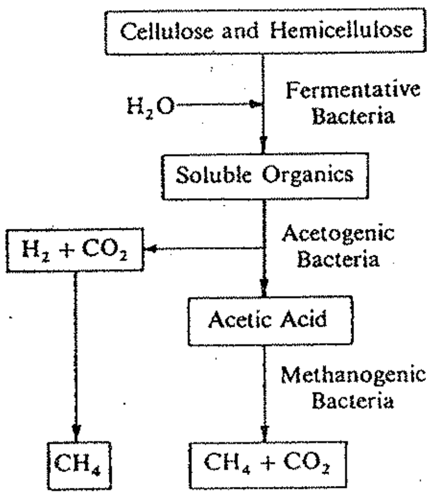


Fig.1. Anaerobic fermentation of organic solids (10).

In the first stage, a group of anaerobic micro-organisms, primarily cellulolytic bacteria, acts upon the organic polymers. The reaction is an enzymic hydrolysis of polymers to the individual monomers. These monomers are fermented to various intermediate substances, primarily acetate, propionate and butyrate. Additional acetate is produced by a second group of micro-organisms commonly termed acetogenic bacteria. The acetate production is probably accompanied by a co-reaction of carbon dioxide reduction with hydrogen gas (5).

The simple organic materials and carbon dioxide that have been produced are either oxidised or reduced to methane by micro-organisms. The main ones are the methane producing or methanogenic micro-organisms of which there are many varieties. The breakdown of simple organic acids and alcohols into methane and the reduction of carbon dioxide by hydrogen to methane may be represented by the following reactions:

i) Acid breakdown into methane

$$2C_3H_7COOH + 2H_2O \longrightarrow 5CH_4 + 3CO_2 \quad (6)$$

ii) Oxidation of ethanol by CO_2 to produce methane and acetic acid

$$2CH_3CH_2OH + CO_2 \longrightarrow 2CH_3COOH + CH_4 \quad (6)$$

iii) Reduction of carbon dioxide by hydrogen to produce methane

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O \quad (6)$$

The overall reaction can be represented by the following reaction:

$$(C_6H_{10}O_5)n + nH_2O \xrightarrow[\text{of methane bacteria.}]{\text{through the action}} 3nCH_4 + 3nCO_2 + \text{a small amount of heat} \quad (1)$$

This is a complex bio-chemical process and a balance must be maintained through the stages. If the acid production stage proceeds at higher rate than the methanogenic stage, acid will accumulate and inhibit the last stage, slow it down and actually stop it.

4.1 Raw material

In most family size digesters, animal waste, cow-dung in particular has been the raw material used most. This has been due to the fact that it is readily available close to the digesters and fairly wet so that it reduces the amount of water needed. There are plenty of other types of raw materials that can be used in biogas digesters and all yield different amounts of gas (see Fig. 2). Manure from animals like pigs, chicken, sheep, goats, etc. are examples of raw materials that are available on farms in Uganda.

In China, human excreta is widely used to produce gas for domestic use at household level, but in Uganda, like in many other countries, cultural beliefs, traditions and taboos can be strong inhibitions against its use.

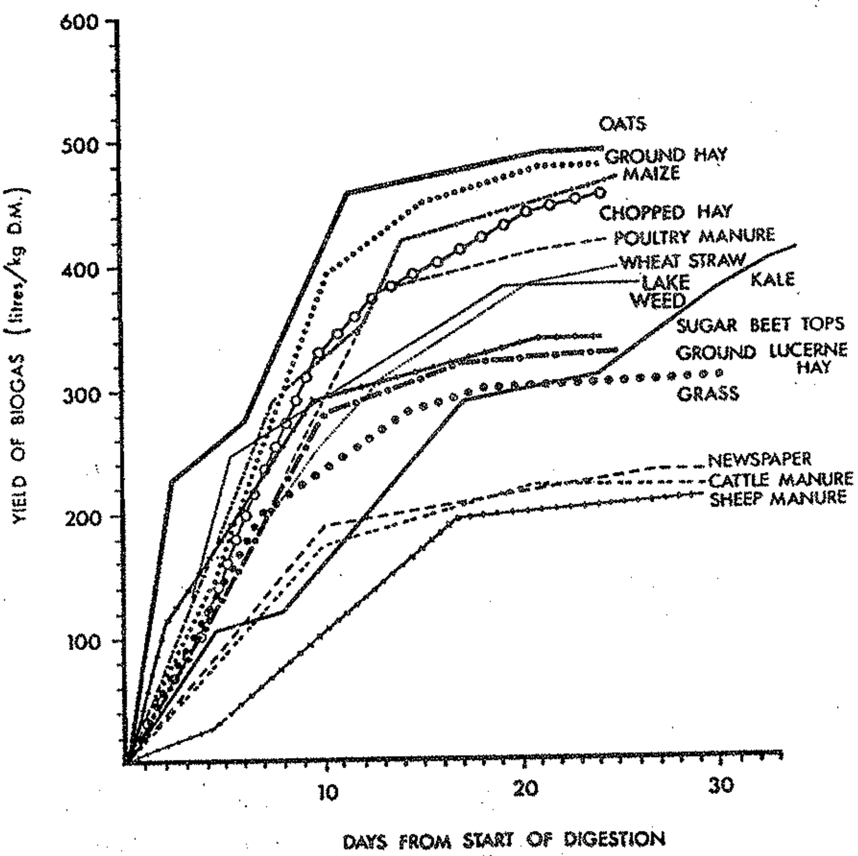


Fig. 2. Yield of biogas obtained from digestion of various crops and waste materials at 37°C (12).

Crop residues and other waste materials can form very important raw materials for gas production at household level. As can be seen on Figure 2, vegetable materials yield higher amounts of gas than animal manures. Crop residues available in the countryside include : banana residues including peels, leaves and trunks. Others are maize-stocks, sweetpotato vines, cassava peels plus tops, coffee husks, fresh weeds, etc. With a food production of about 9.5 million tonnes (7), there will be 95 million tonnes of residues available assuming that 10 % of biomass produced on the farms is consumed as human food (8). The problem of collection and transportation of this biomass should be recognised.

Experiments show that there is a higher gas yield if the raw materials are mixed instead of using a single one like cow-dung. The use of farm residue will reduces the dependence on cow-dung so that even households with a small number of farm animals or even none can still operate a plant.

4.2 Carbon nitrogen ratio

The microbial population involved in anaerobic digestion requires sufficient nutrients to grow and multiply. Each species requires both a source of carbon and of nitrogen. If there is too little nitrogen present the bacteria will be unable to produce the enzymes which are needed to utilise the carbon. If there is too much nitrogen, particularly in the form of ammonia, it can inhibit the growth of the bacteria. The optimum carbon nitrogen ratio is between 20:1 and 30:1 although one could get as low as 45:1 and as high as 16:1 in the case of paper pulp and sewage mixtures respectively (11).

Table 1 shows carbon: nitrogen ratios for various materials and it even confirms the necessity of mixing cow-dung with other wastes for optimal gas production.

TABLE 1 (11). Typical Carbon: Nitrogen Ratio for Various Materials.

Material	C/N Ratio
Saw dust	200-500:1
Wheat straw	150-200:1
Bagasse	150:1
Seaweed	80:1
Chicken manure	8- 36:1
Horse manure	33:1
Whey	30- 40:1
Cow manure	18:1
Alfafa hay	18:1
Nonlegume vegetables	11- 19:1
Sewage sludge	13:1
Grass clippings	12:1
Silage liquor	11:1
Blood	3- 4:1

4.3 Temperature and retention time

There are two temperature ranges within which anaerobic digestion can take place, mesophilic temperature range 25-45°C and thermophilic temperature range 40-65°C. Within the mesophilic range, the optional operating temperature is between 30-35°C for maximum gas production while in the thermophilic range it is between 45 and 60°C. It should be put into consideration here that higher temperatures than 35°C will need extra heating even under tropical conditions. These optional ranges varies with types of waste materials being digested (11). It is known that different bacteria predominate in the two different temperature ranges i.e. mesophilic and thermophilic.

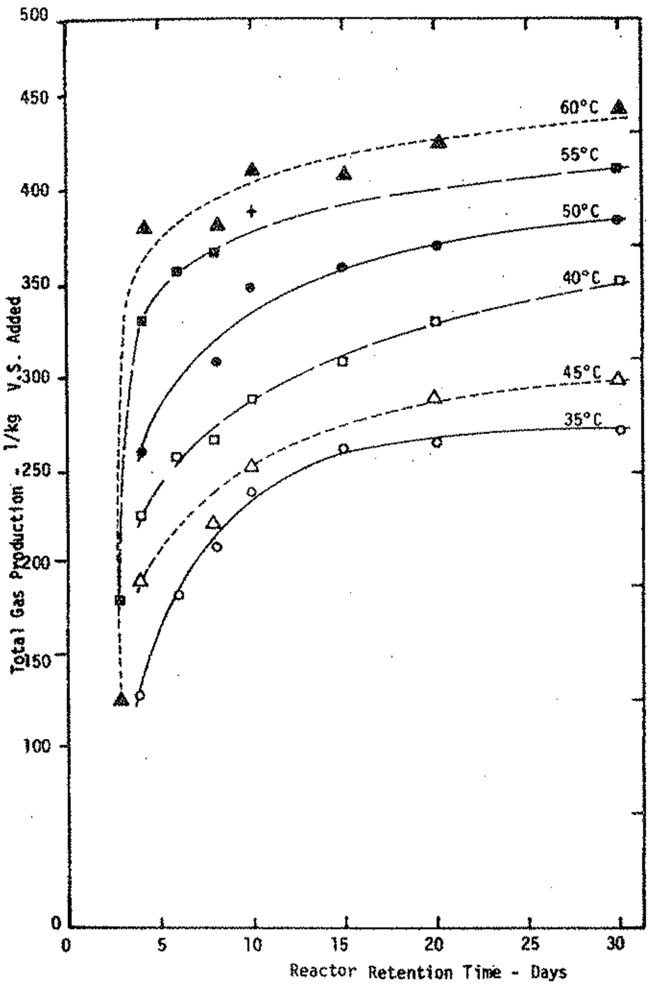


Fig. 3. The effect of temperature and retention time on the production of gas from urban refuse (10).

Figure 3 shows a clear variation in gas production with retention time and temperature changes.

4.4 PH

The digester bacteria is sensitive to the PH of the liquor. It is known that gas production proceeds very well as long as PH is maintained between 6.6 and 7.6 with the optimum appearing at between 7.0 and 7.2 (10). When the PH drops below 6.6, significant inhibition of the methanogenic bacteria occurs and at about 6.2, the acid conditions exhibit acute toxicity to the bacteria. But the fermentive bacteria will continue producing acid until the PH drops to 4.5 and when this happens, the digester is said to be 'stuck' or 'pickled'. This condition should be controlled when the PH appears likely to drop below 6.6 by adding alkali.

4.5 Types of digesters

Digesters vary widely with regard to complexity and layout. No simple design can be considered as ideal, since many factors affect their arrangement and construction. The design of a digester and the engineering associated with it, depends upon the type and volume of waste it requires to process, together with other factors such as the geographical, environmental and social conditions applicable to the particular situation.

Digester can, for convenience, be loosely grouped into the following categories :

i) Batch digesters
ii) Continually fed digesters
iii) Plug flow digesters
iv) High rate digesters
v) Anaerobic contact process
vi) Multi stage digesters

4.6 Characteristics of digester gas

The gas produced during anaerobic digestion of organic materials consists of a mixture of gases notably methane and carbon dioxide with small amounts of other gases such as hydrogen sulphide, carbon monoxide and hydrogen.

Methane is the simplest and most abundant hydrocarbon and the chief constituent of natural gas. Typically, biogas has between 50 to 65 % methane with 20 to 40 % carbon dioxide. The physical properties of methane and carbon dioxide can be seen in table 2 below:

TABLE 2. Some physical properties of CH_4 and CO_2 (11).

	CH_4	CO_2
Molecular weight	16.04	44.01
Boiling point at 1 atm.	-164.0°C	-56.6°C
Freezing point at 1 atm.	-182.5°C	-78.5°C
Density at 0°C, 1 atm.	0.7172 kg/m^3	1.976 kg/m^3
Critical temperature	-82.5°C	+31.0°C
Critical pressure	4.628 MN/m^3	7.142 MN/m^3
Heat capacity at 15°C, 1 atm.	2.219 KJ/kg°C	0.822 KJ/kg°C
Ratio Cp/Cr	1.307	1.303
Flamable limits in air	5.3 - 14% by vol.	-
Caloric value at 15°C and 10.325 Kpa.	37.71 MJ/m^3	-

Methane is odourless, colourless and tasteless but the other gases contained in digester gas gives it a slight smell of low garlic rotten eggs. Methane has a very low solubility in water, at 20°C and 1 atm. pressure only three units of the gas (volume) can be dissolved in 100 units of water.

The complete combustion of methane produces a blue flame and a great amount of heat and the chemical reaction is :

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O + 890\ KJ \quad (1)$$

One cubic metre of methane on complete combustion can reach a temperature of 1400°C and release 36 - 40 MJ (biogas can release 23 -27 MJ) (1).

Hydrogen Sulphide (H_2S)

Data available show wide variations in the amount of hydrogen sulphide present in biogas, normally the expected value for a digester working well on sewage sludge is between 100 to 3000 mg H_2S per cubic metre biogas. The gas reacts readily with metals such as copper or iron and their oxides. So if metal pipes are used, the concentration tends to diminish as the gas flows through them.

Hydrogen Sulphide is highly toxic and even at low concetrations can be hazardous, the maximum allowable for prolonged exposure is 0.002 % and even this causes eye irritation. A concentration of 0.1 % paralyses sense of smell and causes instant unconciousness. It is also the most stubborn gas when it comes to the corrosion of machine parts in the application equipments, engines, lamps, stoves, etc.

Hydrogen

There is usually no more than 1 or 2 % hydrogen in biogas, likely because of the many bacteria that can readily utilize it, particularly the methanogenic bacteria. The gas is highly inflamable but due to its small concentration, it has little or no effect at all on the calorific value of biogas. It is not poisonous, though, of course, if present in large quantities in the air, may cause asphyxiation due to a reduction in percentage of oxygen.

Carbon Monoxide

Carbon Monoxide is a highly toxic gas since its affinity for hemoglobin is greater than that of oxygen. Biogas normally has a carbon monoxide concentration of well below 1 % and often like 10 -100 ppm concentrations as low as 100 ppm cause slight headache after some time and 0.1% causes unconsciousness in just over one hour and death in four hours.

Nitrogen

Any appreciable quantity of nitrogen showing up in routine gas analysis is usually indicative of a leakage of air into the system. There will always be small quantities present since the raw materials will usually contain some due to their previous contact with the air. Usually, less than 4 % is present and often much smaller.

Oxygen

Oxygen is a dangerous gas when present in digesters because of the risk of explosions when mixed with methane. It is usually a sign of leakage and hence also a possibility of methane leaking into the surrounding air which is a more hazardous situation since with only 5 % methane in the air, a mixture occurs in which a flame is self-propagating.

Ethane and Other Low Molecular Weight Hydrocarbons

Methanes reactivity with carbon dioxide and its small potentials of polymerization, leads to the formation of other paraffin gases such as ethane, propane and butane in small quantities. These paraffins are also found in natural gas and all will react to some extent with chlorine to produce dichloromethane, chloroform, carbon tetrachloride and chlorethanes. It is important that chlorine-producing substances do not come into contact with this lower molecular weight hydrocarbons, as much for their co-reactivity forming chlorine derivatives, as for the explosive mixtures that they can produce.

5. USES OF BIOGAS

In Asia, 95 % of all the biogas plants are of family size type and therefore the principal uses of their output are cooking and lighting (5). The situation in the Ugandan countryside is bound to be that, nearly all the gas is going to be used for cooking and lighting. But the gas can also be used for other purposes like refrigeration, generation of electricity use in transportation vehicles, for running irrigation pumps and even in the curing of tobacco (see Fig. 4 for use and its equivalents). For some of these purposes it becomes necessary to compress and store the gas in portable containers and carry it to the place of application. For cooking and lighting, biogas does not need to be purified. However, if the gas is to be stored or transported, then hydrogen sulphide has to be removed to prevent corrosion of storage bottles. This can be accomplished by iron filings. Once sludge has formed on the whole surface it is time to replace them. Carbon dioxide should also be removed as there is no advantage in compressing it. Being an acidic gas, it can be absorbed in any alkaline solution, such as sodium or calcium hydroxide. In the field, the practice is bubbling the gas through lime water.

Through a three stage process, the methane gas can be condensed and be stored in metallic cylinders at a pressure of 20 - 35 MN/m^2 (200-350 atm.). Those stages are:

a) From atmospheric to about 1 MN/m^2 (150 psi.)
b) From 1 MN/m^2 to about 3 MN/m^2 (450 psi)
c) From 3 MN/m^2 to about 14 - 20 MN/m^2 (2000 - 3000 psi.)

The gas can also be stored in flexible bags made of a variety of materials such as PVC, rubber and polyethelene.

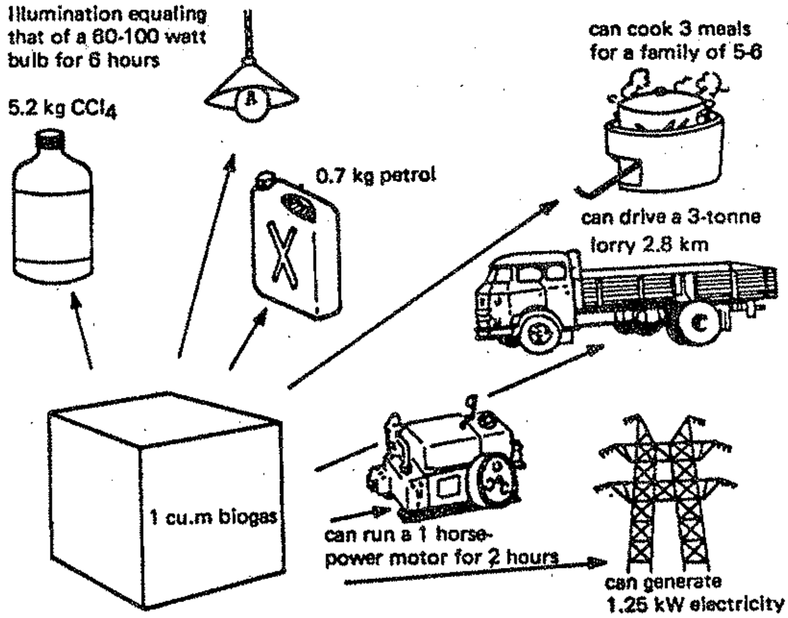


Fig. 4. The uses and equivalents of biogas (1).

5.1 Cooking and lighting

As mentioned earlier, cooking and lighting are bound to be the two most dominant uses of biogas among the rural people in Uganda. Simple and cheap appliances commonly made from locally available raw materials will have to be used, but the fact should not be ignored that biogas requires good burning vessels to allow complete combustion and hence good results. Normal combustion of biogas with plenty of oxygen produces carbon dioxide, water and a great amount of heat as illustrated by the formula:

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O + \text{Heat (890 MJ)}$$

If the gas is burned in open air, the flame should be forceful, pale-blue in colour and make a hissing sound. If it waves and is pale-blue in colour, then there is too little air (oxygen) and hence incomplete combustion. On the other hand, if the flame is short, yellow and unsteady, then there is insufficient biogas and too much air. These two conditions produce low temperatures and bad results.

The basic structures of both stoves and lamps are similar and common. The common elements include a nozzle (mouth piece), an air inlet, and a mixing chamber. The biogas stove is completed by adding the fire-sieve plate and the lamp by adding a 'roofstock of lotus' and a mantle. The gas enters the mixing chamber through a nozzle at a very high speed causing a low pressure and the air will then be drawn into the mixing chamber to mix with the biogas. Due to the fixed direction of gas flow in the mixing chamber, the mixture will rush only to the openings of the fire-sieve-plate in the case of the stove and to the 'roofstock of lotus' in the case of the lamp, for combustion. The brightness and force of combustion of the gas stoves and the lamps depend mainly on the gas pressure, the mixing ratio of the gas and air and the condition of the mixture. Fig. 5 shows an example of a biogas stove and a lamp.

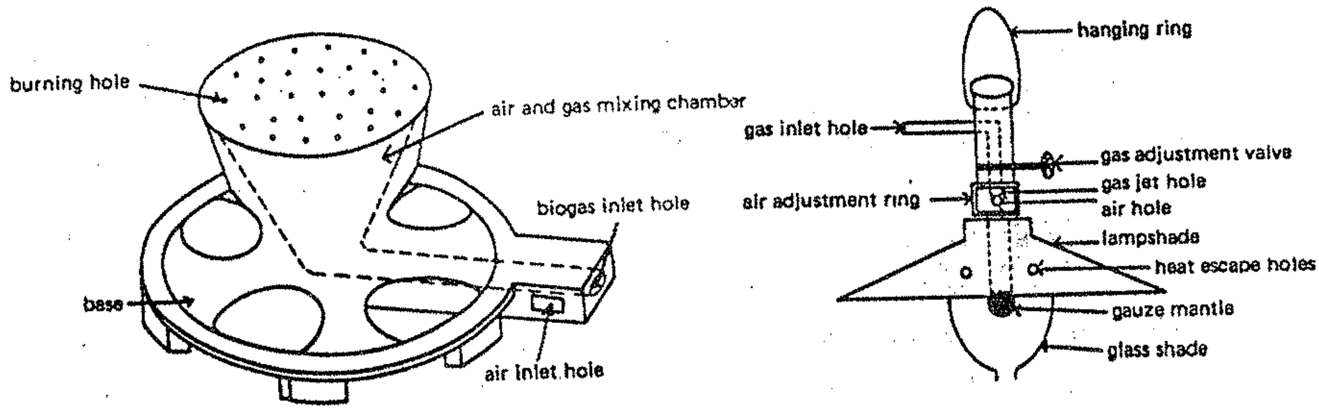


Fig. 5. An example of the showerhead gas stove and a hanging lamp.

5.2 Heating

Heating is one of the common areas where biogas is used and since natural gas is already in widespread use, the question of availability of suitable appliances does not arise. Uganda with its beautiful tropical weather shall not need heating the living houses, on the contrary, cooling them is required in some areas and situations. But there are many other areas including industrial heating where biogas can be utilized.

Methane has many advantages over other fuels, the most important in relation to its use in heating, being the non-polluting quality of its combustion products. This makes it a clean fuel, that can be used in food industries where a high degree of cleanliness is particularly imperative.

In the case of drying food products, one can blow the exhaust gases through the material without any danger of contamination making heat exchangers unnecessary and therefore, reducing costs.

Gas burners can be made very efficient, thanks to the widespread use of natural gas. Coal-fired and even modern oil-fired boilers can be converted to biogas with improved efficiency (3). For direct space-heating, application gas-fired infrared tabular heaters may be used which will burn biogas directly. These radiant heaters are suitable for many industrial heating requirements and can be fully automated and thermostatically controlled (11).

5.3 Driving engines and generation of electricity

Gas driven engines are not a new idea. Infact, the pioneer engines were meant to run on gas. In 1860, Joseph Etiene Lenoire constructed an operable gas engine. Nicolaus Otto built his 4-cycle engine in 1876 primarily to run on gas. One engine was driven with biogas in India as early as 1907. Since the turn of this century, biogas from sewage treatment plants has been used to run stationary engines in Europe and the USA. These engines drive alternators which generate electricity to provide power, light and heat to the plants. Heat from exhaust gases and cooling water from these engines is typically used to maintain the digester sludge temperatures.

Uncleaned biogas contains water vapour, hydrogen sulphide, carbondioxide, methane and suspended particles that are carried along during gas production. The gas is unsuitable for use in engines under this state.

The small amounts of water vapour in the gas would normally not present a very serious problem except when it combines with hydrogen sulphide to form sulphuric acid which will corrode the inlet systems. In any case, when the inhibitive components of the gas are removed, the water vapour will also be reduced.

Large amounts of carbon dioxide will have the effect of reducing the power output from the engines. An engine will produce half as much power when run on biogas with 50 % carbon dioxide compared to when it runs on gas with only 20 % carbon dioxide (3). But small amounts of carbon dioxide can be favourable in engines: the combustion is smoother, the value of toxic agents in the exhaust gas is reduced and it has been observed that torque is increased in lower speed ranges.

Hydrogen sulphide is the most problematic component of biogas when it comes to its use in engines. Apart from its toxicity, it is also highly corrosive. With excess air, it burns to sulphurdioxide (SO_2) which in turn combines with oxygen (O_2) and water (H_2O) to form sulphuric acid. This acid has the bad habit of raising the dew point of the exhaust gas. Water vapour has a dew point of between 50°C and 65°C while sulphuric acid will increase it to between 90°C and 160°C depending on the concentration. All machine parts which come in contact with the condensate are endangered by corrosion and constructing them corrosion-proof, of course, increases the costs.

The negative effects of hydrogen sulphide and carbon dioxide in running engines with biogas necessitates their removal from the gas. Methods to remove the two gases from biogas are available. Low level hydrogen sulphide can be removed by passing the gas through heated iron oxide. Carbon dioxide will be removed if the biogas is bubbled through a solution of calcium hydroxide where the carbon dioxide reacts with calcium hydroxide to form calcium carbonate precipitate.

The methods above can be used in a small scale gas system, but in large installations, it may be necessary to install full scale alkali or organic scrubber. These processes involve an absorption stage in a liquid reactant or solvent medium. The medium is regenerated by stripping the gases from it so that it can be re-used. One of the most commonly used cleaning methods in gas industry is the bubble column process (Ceirbotol process, Fig. 6). It is one of the cheapest for gases with low levels of carbon dioxide. The method employs a solution of monethanolamine (MEA) compound which reduces carbon dioxide and removes hydrogen sulphide. The biogas passes up through a packed tower, against a flow of the aqueous low-temperature solution of MEA. The acid gases are absorbed and the remaining cleaned gas leaves from the top of the column. The MEA solution then enters a stripping column where the carbon dioxide and hydrogen sulphide are released upon heating by a conterflowing steam, the regenerated and cooled MEA solution is then turned to the top of the absorber tower.

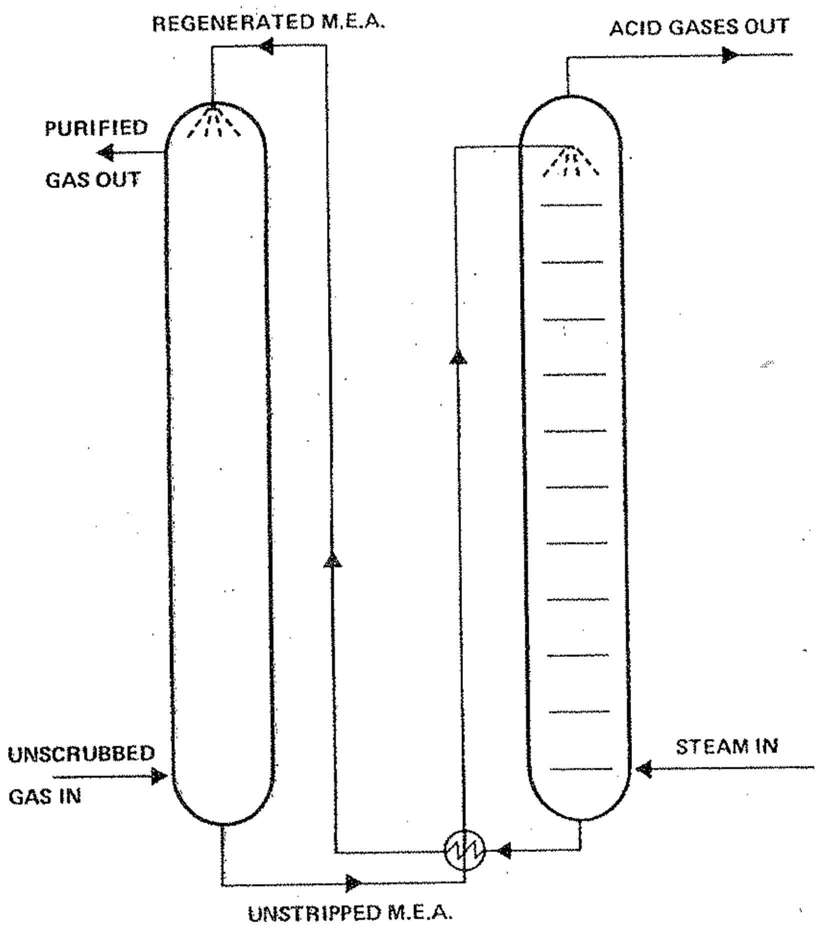


Fig. 6. Simplified flow diagram of MEA Scrubbing Process (11).

Other cleaning methods include the carbonate process where potassium carbonate or organic carbonate is used with added catalysts and operates mainly by physical absorbtion. Molecular sieve absorbants can also be used for removal of carbon dioxide and drying of biogas. Synthetic zeolites such as sodium or calcium aluminosilicates absorb carbon dioxide and water vapour and are regenerated by heating. Cost is a limiting factor in the use of this method in small scale biogas systems.

Carbon dioxide and water vapour can also be removed during the compression and cooling of biogas for the sake of transportation and storage. Compressing the gas to 1 MPa and cooling it to -40°C will cause the carbon dioxide to condense and, of course, the water will have condensed at a much higher temperature. The removal of impurities has the effects of increasing the calorific value of biogas and reducing the storage capacity if any is required.

Biogas engines

A complete combustion of biogas in air engine requires an optimal supply of air which depends on the methane in the gas. With 65 % methane about 6 to 6.5 m^3 of air per m^3 biogas is necessary. Flame velocity is important, it is reduced by the presence of carbon dioxide and nitrogen, and raised by hydrogen. Low flame velocity means a slower combustion process hence low power output. General advantages of gaseous fuels where biogas is included are :

good anti-knock qualities, absence of contamination and sludge formation, no need to add the polutant tetra-ethyl lead and more homogeneous mixture conditions in the cylinder (3).

There are two types of engines that can run on biogas, the gas-otto engine and the gas diesel engine also known as dual fuel engine. In a gas-otto engine, the combustible gas/air mixture sucked in, is ignited through high efficiency sparking ignition. This type of engine has a 15% power drop compared to a petrol engine because of the lower calorific value of the air/gas mixture and lower flame velocity.

In gas-diesel engines, the gas air mixture is ignited through a pilot injection of diesel fuel. The engine needs an avarage 10 - 30 % diesel for ignition with a full load and up to 100% with partial load. The combustion chamber is the same as in a diesel-engine so it can run on diesel alone if need be. Diesel engines can be converted into biogas diesel engines in the following way; keep the fuel system of the original engine, install a biogas-air mixer between the air filter and the intake of the diesel engine.

Work done on biogas engines show that many failures are caused by hydrogen sulphide. A number of components could be replaced by others made of different materials but attacks on small-end bearings cause particular concern. These bearings are normally highly stressed and can not be easily replaced by another material. It is not easy in smaller engines, to protect them by flooding them with oil as in larger and more costly engines. The wear of the cylinder bore cause increasing quantities of gas, carrying hydrogen sulphite leaking into the crankcase and hence attacking the small-end bearings. This can greatly reduce the life time of biogas engines compared with the conventional ones.

Generating electricity

Apart from water pumping, grainmilling, drying of farm products, curing of tobacco, kiln-drying of tiles, etc, biogas can also be used in engines for electric power generation. Using the electricity generated with biogas for lighting is easier, more convenient and economical than directly using biogas for the purpose. The electricity generated with 0.75 m^3 of biogas can light 25 - 40 watt lamps for one hour while the same amount of gas can only light 7 gas lamps for one hour by direct burning (9). Electricity generation will also reduce fire risks.

Electricity generation can be very useful in running isolated healthy clinics out in the country-side. It will provide lighting and be used to run regrigeration facilities for keeping drugs and vaccinations. Preservation of veterinary drugs and vaccines is another interesting area. However, the high cost of the engines and generators might be prohibitive.

5.4 Curing of tobacco

Tobacco is grown and flue-cured mainly by small holders in three areas of Uganda: West Nile, accounting for about 82 % of total production; Middle North, accounting for another 10 % and Kigezi area which make up the balance. In Mubende/Bunyoro area, tobacco is fire cured. Tobacco production has dropped in the recent years from the record production of 5 000 tonnes in 1972 to 2 400 tonnes in 1984.

The industry relies entirely on fuelwood for energy. The total fuelwood requirements for tobacco industry in 1984 are estimated at about 142,000 m^3 for flue-curing and around 30 000 m^3 for fire-curing (4). The efficiency is extremely low especially in the northern part of the country where 106 m^3 of wood per tonne of cured tobacco is needed compared with as low as 20 m^3 achieved in other places. If the present trend continues with the envisaged tobacco production targets, the annual fuelwood demand would be 425 000 m^3 by the year 1989.

These enormous amounts of fuelwood can be saved if biogas is used in tobacco curing instead. In Sichuan province of China, they have succeeded in using biogas to cure tobacco (9). Apart from saving other forms of energy sources, biogas has shown the following advantages :

1) Generally tobacco can be cured to higher grades due to the uniform distribution, rapid rise and flexible regulation of the barn temperature.

2) Manpower saving, when biogas is used. There is no need for anyone to look after the fire, etc.

3) The fire and air temperatures are easier to control using valves in the case of biogas than solid fuels.

4) The barn structures can be simplified, chimneys, furnace chambers and heat exhange structures can be done away with since the burning of biogas is smokeless and clean so that exhaust gases can be blown through the barns without causing harm.

5.5 Safety precautions

It is most important at the commencement of a design of a digester to establish the relevant safety regulations that apply to the situation. Methane is an odourless gas and 5 - 15 % methane in air forms an explosive mixture. Although not poisonous, methane is anaesthetic in a concentration of 1000 ppm (6). Although methane gas is odourless, biogas contains small amounts of impurities which give it a smell. So its presence will usually be detected.

The size of digesters almost entirely precludes them from being placed inside a building, so the normal winds should rapidly dilute and disperse any gas leaking from the digester or gas holder. A floating gas holder will act as a safety valve for overpressure in a digester. In fixed dome digesters a combination of a manometer and a safety valve should be installed, in order to prevent excess pressure build up and to discharge excess gas.

One of the most hazardous times in the operation of digesters is that during startup, the gas produced will mix up with air in the gas holder forming an explosive mixture at some stage. The situation can be made safe by discharging the first gas collected into the air during safe moments for example when there is enough wind to blow it away. Another hazardous moment is during the emptying of a working digester.

Since the poisonous components of biogas i.e. carbon dioxide and hydrogen sulphide are denser than air, they are bound to remain at the bottom of an empty pit. Anybody going down the pit stands the danger of being poisoned. The safety of the pit can be checked, by lowering a chicken in a basket (poor chicken) and letting it stay there for some hours. If it remains alive and active, then the pit is safe otherwise if the poisonous gases have accumulated at the bottom the chicken will die.

A further precaution against explosions is the provision of flame arresters in gas lines. It is commonly placed either just near the digester or just before a gas stove or lamp. It is safer to have one in each place. The flame arrester can be a ball or a roll of fine mesh copper wire inserted into the gas pipe.

6. CONDITIONS FOR THE INTRODUCTION OF BIOGAS IN RURAL UGANDA

6.1 Energy needs

Although no data is available for a complete and reliable assessment of rural energy consumption, attempts have been made by various people to make a rough estimate of these energy needs in order to appreciate the seriousness of the problem. The energy consumed by people depends on its accessibility.

Talking to Elidali Bujeli, a 65 years old man at Kamongoli market in Tororo district, one could clearly see the pattern of development in the field of energy supply for the last fifty years or so. The old man said that at the time he was a young man there was pleanty of forest and the population was so low that villages were two kilometers or more apart. Fuelwood was plenty during those days. It wasn't until the late 1940s and early 1950s with the coming of the railway steam engines that he saw massive cutting of forests to supply fuel to the railway. Urbanization was also taking root during this period which necessitated the cutting of trees for fuel and building in towns. Trees started being owned by individuals in the 1950s after land registration which resulted in private ownership of land as opposed to communal ownership before then but there still remained the traditional free collection of firewood from other people's land. The continued diminishing of forests led to a situation where since the early 1980s one cannot freely collect firewood from other people's land. People now have to pay for fuelwood when there is scarcity, even in the rural areas. One clearly sees a steady commercialisation of fuelwood which is the main domestic energy source in the rural households.

The poor rural households turn to crop residues, the consequence of which will be a quicker depletion of the farming land. The tendency is for the poorer household to start using crop residue and subsequently cow-dung while the more affluent households tend to shift away from non-commercial forms of energy to more efficient and cleaner ones like gas and hydro-electric power.

While land resource conservation and elimination of environmental pollution demand that the current energy consumption from firewood be either replaced by another or be met from vigorous afforestation programmes, there does not exist easy solutions to meet either of the two alternatives. Afforestation programmes in areas experiencing woodfuel shortages are already experiencing difficulties because of land demand for agriculture. Any possible afforestation programmes are unlikely to meet the long-term charcoal requirements for urban use and wood for construction in both rural and urban areas let alone firewood for the rural households. Biogas production may play a part in meeting energy requirements in rural households.

6.2 Availability of technical know-how

Biogas technology is substantial and well published but most of it is still too expensive and therefore, does not render itself to widespread adoption. More research is required to develop cheap digesters that can be easily afforded by rural households. The masonary skills are bound to be a limitation.

The collection of digester inputs, farm wastes and cow-dung can present a problem. Simple wood wheelbarrows could be constructed for the purpose. Such a simple mechanization has been seen to involve men in jobs which were traditionally left to women.

The question of appliances is not bound to present a big problem since initially the gas will mostly be used for cooking and lighting. There are already locally made metallic gas cookers in use in the country although the question of price might limit its adoption among the rural poor. Cookers and lamps made of clay could be a very viable alternative in this case since the raw material is readily available to the rural people at a very low price if not free, and the people themselves can be taught to make them.

6.3 Availability of building materials

Digesters and associated masonry work can be made out of any of the usual building materials except unfired bricks and mud mortar. Choice is normally a matter of what is available at the lowest cost. Materials usually needed for the Chinese fixed-dome type of digester are from the following items: fired-bricks, sand, cement, gravel and water. The following materials could also be used if they are available and at reasonable prices: lime concrete, lime clay, precast concrete rings, precast concrete section and ferrocement. Metallic material will be needed for the Indian design with a floating gas-holder. Due to low cement production in the country, there will not be enough of it in the near future for a large scale biogas project. Due to its shortage and the high demand, the price is so high that it is a limiting factor. But there are large lime deposits in various parts of the country which can be used instead. Here it must be observed that the use of a cheap material can cause serious problems like frequent operational failures and short lifetime, two factors that will not augur very well for the popularization of the programme.

For the appliances, clay lamps and stove could be used. The technique of making them has to be introduced so that the people can make them, themselves.

In China, bamboo tubes are used in some places. They are normally coated with some protective material e.g. pigsblood plaster and connected with pieces of rubber hoses. Outdoor hoses are protected by a casing of bamboo tubing or any other suitable material available. Junctions are normally made of glass, metal or plastic tubes (1). This technique can be tried out in Uganda in places where bamboo is available or other tubing materials available locally can be experimented with for example, elephant grass and the tubes used in traditional beer drinking .

If floating gas holder type of digesters are built, then one needs more expensive construction material for gas holders. The materials generally used are mild steel, galvanized iron, ferrocement, bamboocement and plastic.

Mild steel is used in most countries because of its low cost. However, it rusts, especially on the outside, where it dips in and out of the digester content. Usually, the rust on the steel is removed by sandpaper and wire brush prior to painting. The life of the gas holder would extend greatly if paint is used regularly or whenever rust appears.

Galvanized iron could be used if available at reasonable prices. Life expectancy for this kind of gas holder is said to be about five years (if not painted). If properly painted and maintained, it should give many years of good service (6).

Ferrocement and bamboocement are another category of gas holders. Ferrocement is a composite material consisting of thin wire mesh impregnated with rich cement mortar. Ferrocement can be cast into sections as thin as 1 cm., and suitable for precast products because of the resulting low weight of the components.

In bamboocement holders, the bamboo mesh is used instead of wire mesh. This is even lighter, cheaper and easily available in some rural areas. Suitable coating should be applied to the inside and outside surface of both ferro and bamboo cement gas holders to improve their impermeability to gas. Both ferrocement and bamboocement gas holders are cheaper than mild steel gas holders, have lower thermal conductivity and high resistance to corrosion.

Many types of plastics such as polyethelene, high density polyethelene (HDPF) and PVC are used. They are not recommended, however, since their exposure to the sun causes crack and consequential gas leaks.

Floating gas holder type of digesters would not be recommended for various reasons:

(a) They are bound to be more expensive to build due to the expensive material involved.

(b) They will be more difficult to construct since the gas holders will need more skilled labour which is not available in the Ugandan country-side.

(c) They are more complicated mechanisms due to the moving parts which will make it difficult the rural people to maintain.

6.4 Availability of Digester Materials

In Uganda, like many other developing countries, available sources of organic material suitable for gas generation at village level are basically animal wastes and agricultural residue. Taboos stand in the way for the use of human waste (night soil). The existing digesters in the country use animal waste (cow-dung) as the only raw material for gas production. One cow produces about 10 kg. of dung but since the animals are only confined at night, the amount that can be collected is much less. It has been estimated that one needs five livestock units for a family unit.

Crop residues are very important raw materials for gas production. They have been shown to yield more gas than animal wastes (see Fig. 2). Assuming that annual crops in small holder farming can yield approximately 24 tonnes of dry matter per hectare per year, 10 % of which is consumed as human food, leaves about 20 tonnes per hectare per year to be used in digesters for gas production (8). This will reduce dependance on cow-dung and therefore make it possible for families with less than five livestock units to run a digester.

Water is another crucial element for fermentation and must be plentifully available. In some parts of Uganda, water is scarce and the value of its use for biogas must be weighed against alternative uses. The problem could be partly solved during the rain periods by collecting rain water but the best approach would be to integrate the development of biogas, pumped water and the development in other fields of rural life.

7. CHINESE PILOT PROJECT

During the past 30 years or so, China has developed a highly successful national biogas programme but it took them more than 20 years and yet there are still problems to be solved. A national biogas programme was first published in 1958 when Mao called on local communities to produce and make use of the biogas. This was part of the movement to establish rural organisation through collectivising land and labour and to step up the pace of development throughout the economy by making use of all potential resources.

It was not until 1970, however, and only in the mountainous province of Sichian that biogas plants were built at a rapid rate. By the mid-1970s the technique was spreading to other provinces so that the total number for the whole country had reached roughly 7.2 million units by 1985, ranging from individual family units only a few m^3 in volume to communal plants of 100 m^3.

In Uganda, non-governmental organisations such as church of Uganda, had been involved in biogas production and utilization a few years ago in Mbarara and in Kumi Leprosy centre, but they seem to have had problems with the type of digesters used. The cost of setting up a digester was prohibitive at that time and it was a new technology unknown to the people so only a few wealthy farmers and institutions constructed them.

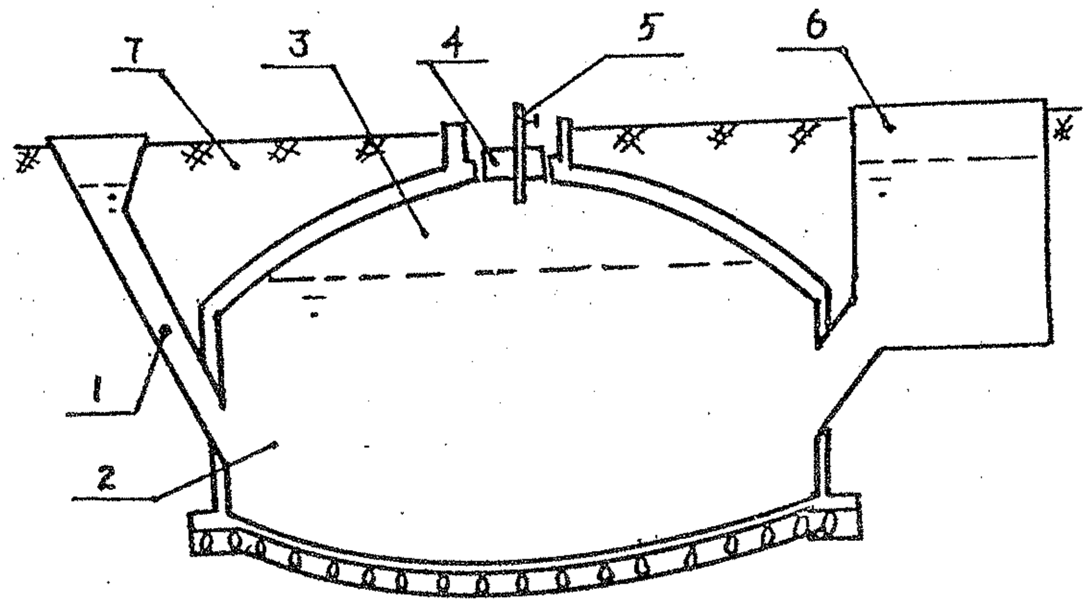
In 1985, a biogas pilot project was started in Uganda partly funded by the government of the People's Republic of China through a 59 000 pound sterling (590 000 S Kr) loan advanced under the agreement for economic and technical co-operation between the two countries.

The Chinese experts in biogas technology arrived in the country early 1985 and carried out a two week feasibility study. After a tour around the country which included visits to government farms, private farm and communal projects, Eastern and Northern Regions were chosen for the demonstration plants.

The reasons were that these were areas that experienced fuel shortages due to the low rainfall (500 - 1000 mm per year) and have a fairly rapid population growth which has put pressure on the areas' vegetation. The areas were also chosen because the people there have a cattle keeping tradition and cow-dung was to be the main digester material to be used. When political instability cropped up in the Northern region, it was decided to carry out the project in the Eastern region. Seven digesters were built.

7.1 Types and technical parameters of the digesters

Circular semi continuous digesters with fixed dome concrete gas storages were built (see Fig. 7).



1. feed hole 2. fermentation tank 3. gas holder 4. movable lid 5. pipe for gas outlet 6. tank for used materials 7. backfill

Fig. 7. Side view of a circular digester (6).

The underground circular digester is said to have the advantages of having a rational distribution of stress, being easy to build and saving labour, material and money. But there are problems of tackling the problem of groundwater if the unit is built in a place with a high water table.

The sizes of digesters are 6, 7, and 8 cubic metres and the following parameters were considered and adapted during the design and construction; the ground surface permits loading of 300 kg/m^2. During the period of normal gas production in the digester, the gas pressure to the structure was to be 550 kg/m^2 maximum 650 kg/m^2. The water level had to be more than 1.0 meter below the ground level. The bearing capacity of the foundation was found to be greater than 8.0 t/m^2. The designed gas generating capacity; 0.15 m^3/m^3/day with fermentation at a natural air temperature; 1.0 m^3/m^3/day with thermophilic fermentation. The design gas storage capacity is 50 per cent of the gas produced daily.

Static pressure on the circular digester

A circular biogas digester which is built underground bears such axial symmetric loads as its own weight, the perpendicular and horizontal pressure of earth, live load on the ground, the reaction of the foundation, hydrostatic pressure and bouyancy (given ground water), the hydraulic pressure of the compost and the pressure of the biogas inside the digester. The distribution of these axial symmetric loads is shown in Fig. 8.

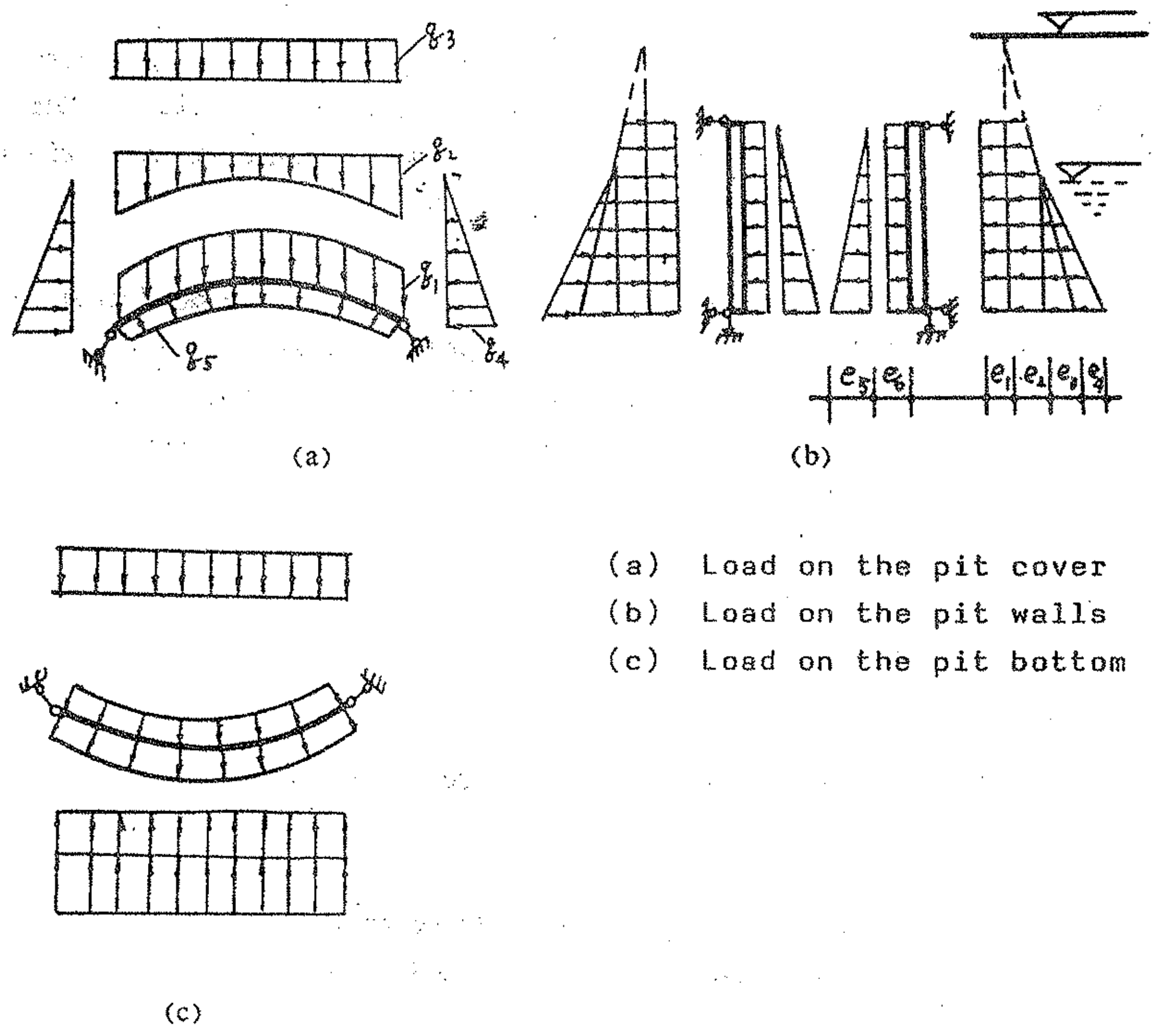


Fig. 8. Diagrams showing loads on different parts of a circular digester (11).

In view of the fact that the circular digester is a sealed shell-like structure, it is more practical to calculate the horizontal side pressure of earth in terms of the static pressure of earth. Calculation and analysis shows that the cover and bottom are in most unfavourable situation when the digester is empty, while its cylindrical walls are in the most unfavourable situation when it is in use. Structural tests of a model digester show that the above mentioned assumptions tally fairly well with the results of the tests.

7.2 Construction of the digester

A circular digester can be build by two different technical processes, the prefabricated block method and the integral construction method. It is said that practice shows that the first method, which is more widely used in China, has the following advantages:

1) Standard blocks provide favourable conditions for standardizing the shape of the digester. Blocks can be prefabricated in one factory or produced separately. Factory production of blocks, supply of comprehensive sets of parts and assembly on the spot ensures quality and reduces costs.

2) A good deal of timber is saved

3) Construciton is simple and easy.

4) It can be applied to areas with different water tables and geological conditions.

This method couldn't be used in Uganda since only a small number of digesters was built. Below are the principal stages of construciton:

(1) Site selection

While overall consideration is given to the supply of the inputs, higher ground is more desirable for digester location, because it makes possible use of gravitation flow to move the discharged manure. At the same time, due consideration should be given to the distance to the end use point of the gas.

(2) Excavation of digester hole

The site should be marked out for excavation. The hole should be as round as possible to enable an easy construction of the digester wall. If there is groundwater, effective measures are adopted to drain it off, and construction work to be done quickly so that it is not affected by heavy rain.

(3) Laying of digester floor

Gravel is laid and packed solid after the foundation is tamped, then mortar is poured and a top layer of concrete applied which is shaken down and smoothed out to a finish.

(4) Building of digester walls

The following points are considered:

a) All blocks are soaked in water beforehand so that they are dry outside and wet inside at the time of laying.

b) Blocks are laid level and straight with plenty of mortar.

c) After laying, the blocks are moistened from time to time so as to avoid the premature drying of the mortar.

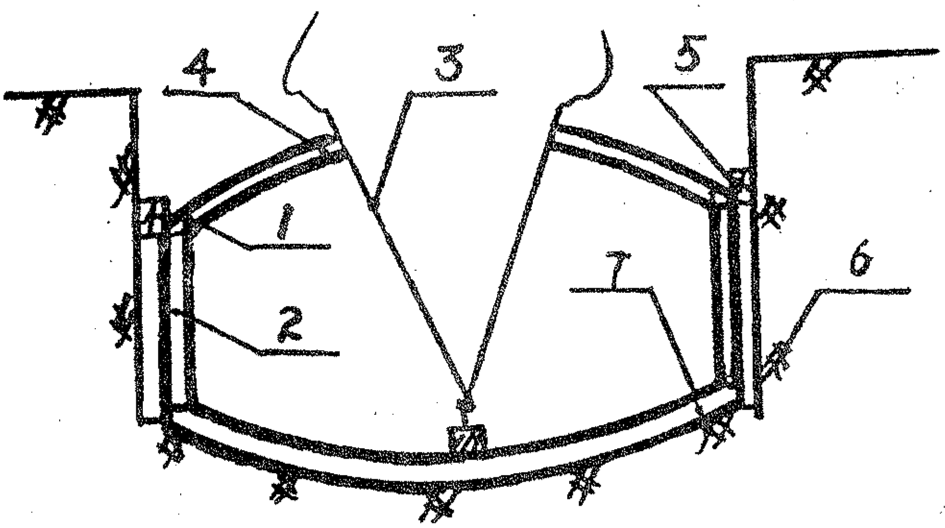
The filling of earth around the digester walls is important. The fill must have a moisture content somewhere between 20 and 25 %. It is better if blended with 30 % gravel or brick fragments. The fill is spread in uniformly thin layers and evenly tamped. Work on the feed and discharge tanks and the back filling round them should proceed at the same time and same level with the main digester.

(5) The concrete collar beam work

The mortar is spread evenly on top of the finished pit wall before fixing the steel cage of the concrete collar. Arched timber forms are used and the casting done section by section with low plastic concrete, which is rammed and smoothed out into the inclined plane as required.

(6) Digester cover work

Work on the digester cover may start when the concrete collar reaches 70 % of its final strength. The cover can be constructed with small concrete blocks or common clay bricks by the fast and economical method of formless suspension setting without using arch supports or braced forms (see Fig. 9).



1. Concrete collar beam
2. Digester wall
3. Radius of curvature
4. Digester cover
5. Bolster
6. Backfill
7. Digester floor

Fig. 9. Digester cover construction by the formless suspension-setting method (9).

(7) Inner seal course work

Seal course work is plastered on inner-lining of the digester, the tank and the movable cover. This is to ensure against water and gas leakage, which merits full attention. The finish is a coating of straight cement applied in thin uniform coating on the dried digester walls so as to increase its resistance to water seepage and gas leak.

7.3 Operations and maintenance of digesters

The following instructions are given for the maintenance and operation of the digesters:

1) Add new materials three times a week. Each time put about 50 kg. (one wheel-barrow) of cow-dung into the feed tank, add 40 litres of water, mix thoroughly with a stick into even paste and then remove the plug to let the paste rush into the digester.

2) During each feeding time, agitate the mixture in the digester by moving the specially made stick up and down at least 40 times.

3) Add water on the water-sealing-cover quite often to avoid gas leakage.

4) Examine the gas-conveying tubes quite often to ensure that there is no gas leakage. If there is a leakage, take immediate measures to rectify the situation.

5) Once a month, remove water from the filter and clean it. This is often done when all the gas has been used up, i.e. when the pressure gauge reads zero, pull out the tubes connecting the filter, empty it, clean it and join the tubes again to the filter.

6) Replace the material at least once a year. Remove the cover and leave the digester open for some time, preferably over-night, to let the gases escape before removing the spent material.

The users are further cautioned about the fire risks in the course of using the gas. Instructions are given on how to use the gas safely for lighting and cooking. The gas conveying tubes are to be kept away from fire and should not be pressed by heavy things.

The big problem has been that it has been difficult to get backup help and expertise when things go wrong. The engineer who was in charge of the construction has since left the Ministry of Animal Industry and Fisheries which has the direct responsibility for the project. The masonry is said to have been done by seven Ugandan masons who were trained and supervised by three Chinese biogas technology experts.

The seven masons do not work with the project anymore. The extension staff in the Ministry of Animal Industry and Fisheries and the Ministry of Agriculture who are in daily contact with the people in the rural areas have no knowledge at all about biogas production. Courses and seminars should have been held for the extension workers so that they could be able to discuss with and answer the peasants'questions about biogas production.

7.4 Performance of the digesters

The units were inspected by Mr. Khakosi, I.W.C. in November of 1985, a few months after they had been completed. The report says that the units were producing at their expected levels. Gas production for all units was taken and the results are shown in the table 3.

By the time of Mr. Khakosi's inspection, the digesters were producing gas at the expected rate. It should be remembered that at this time there was still full attention paid to the units, the Chinese experts were still around and the initial loadings were done under their supervision.

One year later when the author of this report went round to look at the digesters, the bad management practices clearly showed their results. Jami 1 had produced no gas at all for the previous six months while Jami 2 had had terrible leaks for three months. Efforts to get hold of the people to rectify the faults were unsuccessful. One unit that was working very well then, was the one on Tororo Mix Farm. The trend was that the digesters where the owners stayed on the farm and managed the systems themselves, were working well but those owned by the so called telephone farmers (i.e. people who work and stay away from the farm and employ other people to run the farm), had problems. One reason is that farm employees do not show the same responsibility for the farm property as the owner especially when they are underpaid. A second reason is that the frequent changing of the farm employees means that people do not stay long enough to learn how to run the systems properly.

TABLE 3. Capacity of gas production of the digesters (5)

Biogas unit		Capacity digester (m^3)	Date of initial feeding	Avarage gas product-ion m^3/day	Remarks
Mulatsi	1	8	28.05.85	1.12	poor management fed digester only 32 instead of 61 times
Mulatsi	2	7	01.06.85	1.19	fair management
Jami	1	7	29.08.85	1.35	good management
Kumi		7	31.08.85	1.45	fair management
Jami	2	6	22.10.85	1.10	good management
Kalaha estates		7	05.11.85	1.05	good management production expected to increase
Tororo Mix Farm		7	08.11.85	0.82	good management, but digester had just been fed with fresh manure. Normal production is expected.

There was not much data collected about the performance of the digesters. The purpose of the pilot project apart from demonstration, should have been to collect information which will be useful if a large scale biogas project is undertaken. There should be a team which on fulltime basis follows the performance of the project. This team should collect data on the technical performance, social effects and the overall viability of biogas production in the rural areas. In collaboration with other institutions like Makerere University, the team should design and try out other types or modifications with the aim of reducing costs and improving performance. The performance of the digesters in terms of gas production and as a pilot project leaves much to be desired.

Mrs. Mary Ocheng of Tororo Mix Farm lives on the farm with her husband, nine children and three dependants. Before the digester was installed, she walked two to three kilometres to collect firewood and it took up to two hours and more. The firewood collected would last two days unless more than one member of the family had been involved in the collection. On the other hand, the digester has to be loaded twice a week. The cow-dung has to be moved only a few metres from the cattle stall to the digester. Water has to be collected from half a kilometre away since the home's water supply system has broken down. Every loading needs 40 litres of water according to the recommendations, but Mrs. Ocheng says she normally needs up to 80 litres which means she has to make four trips to collect the water since she can only carry one 20 litre container at a go. The loading itself takes about half an hour.

The gas produced from Mrs Ocheng's pit does not cover the family's cooking and lighting needs. The fuelwood requirement is reduced to about one half of the previous requirement and paraffin for lighting is reduced to about one quarter the previous requirement. Mrs Ocheng says that biogas is very convenient when it comes to preparation of children's food, it is easy to keep the utensils clean, easy and quick to light up and it is not like fuelwood which one lights and leaves to burn to waste after cooking a small meal for the children. For these reasons, she says the gas is left almost exclusively for cooking breakfast and children's food and, of course, tea for visitors like the author. One clearly saw the sort of prestige she derived from her unit and with that, one is left in no doubt that it is a status symbol. This can be very helpful when introducing biogas on large scale because people will tend to accept it even if it involves higher labour input as can be seen in Mrs Ocheng's case.

Ocheng's family has sixteen livestock units and there is excessive cow-dung so that it is possible for them to operate a larger unit that will cover the family's household energy requirement not considering the fact that there is plenty of crop residue which can also be used. Crop residues could be used in the existing unit and may increase the gas production.

Jami 1 and Jami 2 which are situated on Jami Mixed Farm, had technical problems as mentioned before. The owner, Dr. Kinani, Permanent Secretary, Ministry of Health, says that the type of digesters constructed can not be managed in the villages. He says they are expensive, difficult to maintain and gas lines get easily blocked. He recommends that better designs should be sought. He finds the digesters inadequate, the light is faint and the gas is not sufficient for cooking family meals.

Dr. Kanani's view point is right but then even the better designed digesters will have to be combined with good management for good performance.

7.5 Safety precautions

One risk area observed on the pilot plants is that the safety valves discharge excess gas into the houses. There can be an accumulation of excessive gas in the houses to an explosive mixture which could result in an explosion when an attempt is made to light one of the appliances. This could be solved by making a connection so that the excessive gas is discharged outside the houses.

The absence of technical follow-up also constitutes a risk in that the rural people will try to carry out repairs which are potentially dangerous like emptying of the pits.

7.6 Technology transfer

It is bound to be difficult to transfer an apparently successful technology in China to Uganda. Certain distinctively Chinese features have made the development of biogas technology a downhill path:

a) Pattern of land tenure, density and organisation of the population and social security were probably the most potent factors that worked in Chinas favour during the early days of biogas development in the country. All land was collectively owned except for the private garden plots; and the communal land was intensively farmed and populated so that the location of resources was known and exploited to its utmost. The population was relatively static and highly structured. There was no option other than the common goal. Once that goal was agreed, construction and maintaining the necessary equipment posed no problem. All this was immensely aided by the existence of collective financing, central planning, political discipline and emphasis on rural development.

b) Manure was plentiful and accessible. The pigs which were confined and numerous, were called miniature fertiliser factories. Most of them lived in pens and fed on a variety of vegetable wastes. There was also this long tradition of using human waste in agriculture. The introduction of the waste into biogas pits did not therefore, go against social taboos, on the contrary, it was useful in breaking the epidemical cycle of various diseases.

Initial development of biogas was thus facilitated by a high degree of organisation in rural China and its operation was perpetuated by the ease of material collection and by a tradition of concentrating agricultural wastes for disposal and recycling.

Comparing Uganda with China, most of these factors are absent but this by no means suggests that there are no physical and social factors in Uganda that are advantageous to the development of biogas technology:

a) The rural population lacks the hierarchical, tightly organised structures of the Chinese communes and is scattered over large areas. Their annual incomes and the capacity to invest is extremely restricted.

b) The field grazing of cattle during the day makes the collection of manure complicated. On the contrary however, the resulting manure concentration does still seem to be sufficient to permit collection for biogas production in most households. The limiting factors could be labour requirement and the amount of microbiological action that will already have taken place before the manure reaches the pit.

c) In Uganda, the use of human waste is not practised in agriculture and there is likely to be insurmountable difficulties in utilising it for gas production. But it is not critically essential in biogas production and this is not bound to be the best way of dealing with water-borne cyclical diseases.

7.7 Cost analysis (5)

The following cost analysis of the digesters was carried out in early 1985 and hence the prices used are for that period. It should be known that prices have gone up since that time and the recent currency reform with the large devaluation has not made the situation any easier.

Materials	Amount Ushs.
1000 clay bricks at 45/- each	45 000
20 bags cement at 20 000/- each	400 000
3 tonnes of course aggregated at 10 000/- per tonne	30 000
3 tonnes fine aggregate (sand) at 10 000/- per tonne	30 000
1 6.35 mm x 12.2 m iron bar at 20 000/- each	20 000
2 1 m x 1 m wiremesh at 10 000/- each	20 000
Sub-Total	545 000

Equipment

The equipment was brought from China so its price was directly converted from the Chinese Yuan to the Uganda Shilling without considering the taxes involved and the transport costs. That would have been difficult to determine accurately.

Equipment	Amount Ushs.
2 stoves 5 000/- each	10 000
30 m of tubing material 10 000/- per metre	300 000
4 sets of biogas lamps 5 000/- each	20 000
5 valves 1 000/- each	5 000
1 pressure gauge 1 000/- each	1 000
Sub-Total	336 000

Transport

The cost of hiring a lorry for 30 km was 30 000/- and the lorry had to make an avarage of 90 km. So the transport costs were 90 000/-.

Labour

It is estimated that 3 masons and 5 casual workers could complete the construction of a unit in 15 days. The government salaries of 6 000/-per day for a mason and 3 000/- per day for a casual worker used. These then bring the cost of labour to:

$$(3 \times 6\ 000 \times 15) + (5 \times 3\ 000 \times 15) = 495\ 000/-$$

Contingencies

The contingencies are calculated at a rate of 10 % of the total cost which gives 147 000/+

This brings us to a total cost of 1 613 000/-

At the official exchange rate, this was equivalent to US$ 877 (S Kr. 6 140).

8. LIKELY EFFECTS OF BIOGAS SYSTEMS IN RURAL UGANDA

8.1 Labour distribution

In many societies in Uganda, sexual division of labour is very well defined so that the introduction of a new technology is bound to have different impacts on men and women.

8.1.1 Women

Women are the main producers in traditional agricultural societies and Uganda is no exception. In a lot of cases, the introduction of new technology have had the effect of increasing the work load on them. The introduction of ox-ploughs and tractors have enabled men to plough up larger fields thus increasing the work of planting, weeding and harvesting which are mostly women's jobs.

Biogas technology introduction could just increase the women's work load if it is not incorporated into other developments like water supply system as it could be seen in Mrs Ocheng's case. A well co-ordinated introduction of biogas technology in the rural areas especially where there is a shortage of domestic fuel would reduce the work load on women. The long time required to collect fuelwood will be reduced to feeding the digester. New technologies also tend to break the traditional sexual division of labour for example, it is much easier to get men cooking on electric and gas cookers than on the traditional three stone open fire. In other words, it will be easier to get men involved in domestic energy supply, a field traditionally left to women.

8.1.2 Men

The work load on the men is likely to increase because it is mostly men who will be involved in the construction of the digesters and major repairs that might be needed. This is not to say that women cannot do it, but the way things are now, it is going to take a bit of time to get a substantial number of women in the fields of masonry and building.

This situation is going to be strengthened even more when the constructions and repairs are to be undertaken at professional level with monetary exchanges involved. It has been observed that men move into the womens' traditional work when it gets commercialised. Among the children, it will be easier to engage the boys also in domestic energy supply unlike in fuelwood collection when only the girls would follow their mothers into the woods.

8.2 Health conditions

Domestic energy shortage is quite often accompanied by a deterioration in the health of the members of the societies. There are various explanations for this. One is that the meals are not prepared as frequently as they could be otherwise and this takes its toll especially among the children who have smaller stomachs and therefore need to eat small quantities but more frequently. Another is that the women would spend more time and energy collecting fuel so that little time will be left to take care of the nutrition of the families. The production of minor crops which are important components of the family food supply is bound to suffer.

The introduction of biogas digesters therefore, will have the effect of relieving family labour so that it can be used in other areas like food production and preparation. This will have the effect of improving the family members' health. The gas is particularly convenient in the preparation of children's food. It is quick and easy to light and cooks faster. The risk of feeding children on cold contaminated food will be reduced. All these will have an overall effect on improving childrens' health. The digesters will also have the effect of improving the sanitary conditions around the villages, hence better the people's health.

8.3 Environmental conservation

Deforestation, particularly when accompanied with fuelwood shortage affects many aspects of rural life. The deforestation of watersheds and areas with sensitive soils can lead to soil erosion and loss of soil fertility, increased flood damage and downstream sedimentation of water reservoir. A lot of agricultural land is threatened with soil erosion as the result of increased population and livestock pressure leading to land clearing for agriculture, over-grazing of upland range and forest areas and over-cutting for fuelwood. The scarcity of fuelwood because of deforestation often results in the use of crop and livestock residue for fuel thus reducing their availability as fertilizer and thereby lowering crop yields. In addition, the use of more human labour to procure the necessary household energy supplies reduces the labour available for more productive activities and often perpetuates the cycle of rural poverty and further dependance upon the resources being depleted.

Biogas production will have the effect of saving the forests and the soil and its productivity. Deforestation also exposes the soil to wind erosion and high evapotranspiration which leads to low watertable. The continuing importance of biomass use for energy production is indisputable, as are the threats posed in many parts of the world by deforestation and inappropriate fuelwood collection practices. Without effective measures to curb deforestation and provide environmentally sound domestic energy alternatives like biogas and others, the ecological and social consequences could be severe, as is already evident in several of the most severely affected areas.

8.4 Potential problems with a biogas programme

Before biogas is adopted in large scale, there are a number of political, administrative and technical problems that need to be resolved at both the national and the village level. As shown by past experiences with rural development projects, the peasants are going to make an attempt to bend biogas installations to their own purposes if the policy makers ignore the human factor. Examples of this have been seen where peasants turn the improved chicken house into dwelling places and use the agricultural credit to marry second wives.

The general administrative problems likely to be encountered are those typical of any new rural development programmes. These include co-ordination of finance, production, distribution and political activities together with assuring adequate numbers and competence of staff to carry forward the assigned tasks. A well built and functioning political structure would make this a little easier and this should be one explanation why the biogas technology did better in China than India despite the fact that the state spends more money for the programme in India per unit than in China.

Any massive diffusion of technology depends upon the dissemination of information, guidance of production and distribution by co-operation between technicians and the population and adequate provision of maintenance. For a biogas programme to succeed, it must be based on a technically sound plant which can function under a wide range of operating conditions. This is where a lot of research will be needed to adopt the foreign designs to improve efficiency, to come up with a good handling technique for sludge output to conserve nutrients and in the operations of plants in areas with limited water supply. Any breakdown in administration, maintenance or technical components during the initial stages of the programme can discourage the very people it is intended to serve.

There is also the danger of the plants being sited in villages that are close to roads, towns, power lines or even end up in homes of the more affluent members of the society as was the case of all the units in the Chinese pilot project in Eastern Uganda which ended up in the farms of Senior Civil Servants in the Ministry of Animal Industry and Fisheries. This pattern tend to result from ease of access for construction, maintenance, monitoring and influence at decision making level. Yet these are the sites where biogas power production offers little or no cost advantage and least needed for that matter.

The project is bound to work in disfavour of the poor and the landless who have no cattle. Cow-dung which has been free could be commercialised as a result of the new value added to it. The wealthier cattle owners are bound to increase their power and status. The losers in this case will be the poorer members of the society who will continue to suffer the fuel shortage and therefore continue with the old habit of environmental destruction.

9. ECONOMIC ANALYSIS

The economic viability of a biogas generation programme depends on local conditions. Although the major item appears to be the capital cost of the equipment, maintenance charges can be high and in some areas the availability of water can also be a crucial factor. The competitiveness of the fuel will, of course, also depend on the opportunity costs of the alternative fuels. For example, in an area with considerable supplies of wood and other forest products at close to zero cost, the programme may be unattractive. On the other hand if fuel are in short supply and the price of wood is high as a measure of ecological protection, then the programme will be more attractive.

Digester prices vary widely around the world, it would be interesting to look at these price variations here. It has been shown in Chapter 6 that the Chinese pilot project digesters in Uganda cost about US$ 880 in 1985. Plants marketed in Kenya by the Hutchinson Tunnel Company, of Indian design are constructed out of corrugated metal. They cost between US$ 100 and US$ 200 including piping and some other accessories. The plant sizes range from 4 to 16 m^3. The Chinese designs are said to be even cheaper. In Arusha, Tanzania, the cost of a 3 m^3 Indian design unit was reduced to about US$ 140 by using opened-out oil drums as the main source of steel. An even simpler design was achieved by fastening seven oil drums in a hexagonal pattern to serve as the floating gas holder. The cost of such a unit was quoted at about US$ 50 but this design presented the problem of mosquito breeding in the exposed part of the sludge which contributed positively to the spread of malaria. The prices are from 1979 (pyle, D.L.). In India, a family size plant of 2.8 m^3 capacity required an initial investment of about US$ 200 (1977 prices) (11). Larger units are bound to be more expensive. In China, the family size digester cost about 200 Yuan (US$ 120) in 1985.

The above prices reflect more the different currency policies in those countries rather than the true costs of biogas digesters. But all the same it can clearly be seen that the digesters in the Chinese pilot project in Uganda were exceptionally expensive. One reason is that the Ugandan Shilling was highly over-valuated at that particular time. There have been questions raised about the utilisation of the money, according to the Weekly Topic (Ugandan Newspaper), of July 23, 1986, the seven units should have cost £ 9,212 (Pound Sterling) out of the £ 54,00 (Pound) loan. It is not clear what happened to the rest of money, about £ 45 000 (Pound Sterling). Whether this could be part of an explanation for the high cost of the units, is anybody's guess.

The availability of funds to cover the capital cost of digesters is the most important constraint that would face a large scale household biogas programme. The peasants poor economic situation will not make matters any easier. Everything is going to depend on the will of state powers as to what use to put the surplus value produced by the sweat of peasants and workers of Uganda. In China there has been heavy state subsidies to get the biogas programme off the ground. In India there have been loans and subsidies for the programme although there have been some complaints for subsidizing a technology too costly and labour intensive for any but the wealthiest farmers. But costly as it may be, societies have to pay to solve their problems and if it is not done now, the future generations might have to pay more.

10. RECOMMENDATIONS AND CONCLUSIONS

Biomass and in particular fuelwood is the major source of energy in Uganda and this is going to continue for years to come. Rural households have been having access to wood as a free commodity but slowly wood is acquiring a monetary value in rural areas where it is scarce. A factor contributing to the scarcity and increasing commercialization of wood is the rapid population growth. Capital problems compounded by political problems have hindered the construction and distribution in the rural areas of other forms of energy. Even if this was done, few households in the rural areas could afford it. The rural population is the most important woodfuel consuming group, accounting for well over 95 % of the national wood energy consumption. There are signs that with the increasing scarcity of woodfuel people burn more and more agricultural residue. One can predict that cow-dung will in the future be burned as fuel. A change in eating habits is already visible, in terms of reduction in the number of cooked meals and change to less nutritious foods that requires little cooking. The burning of agricultural residues will have a negative effect on the soil of steadily reducing its carrying capacity and increasing the erosion rate. A change in cooking and eating habits could have the effect of reducing the working capacity of the people and negatively affect their health.

In order to avoid the downward spiral, there is a strong need for programmes to increase the fuelwood supply, increase the efficiency in utilization of fuelwood and develop alternative energy sources. The fuelwood supply can be increased through a tree planting programme but here one should bear in mind the increasing demand for agricultural land for food production due to rapid population increases. Care should also be taken when it comes to the choice of trees to be planted. There has been a strong emphasis on eucalyptus in the past but there has been criticism expressed from different parts of the world that eucalyptus is environmentally disastrous and that it, reduces soil fertility, water retention capacity and lowers the water-table. It is a commercial tree which quickly attracts the eye of builders and industrialists, benefits the big farmers and industries but not the rural poor. There should be a mixed type of forestry which takes into account all the needs: commercial, social, recreational, fodder, fuel, etc. For fuelwood, one can investigate the quick growing trees of which there are many types that can do well in the tropics.

The commendable job being done by various institutions, organizations and individuals in search of improved cooking stoves should continue and be intensified. There is progress made in increasing the efficiency of wood and charcoal cooking stoves but the focus has been mostly on the urban households who can pay for the innovations. There should be more effort directed to rural households. Care should be taken when dealing with this field of rural life. Traditional cooking stoves or fire places are inefficient simple technologies, but their functions in rural societies are highly multifaceted and may be intimately linked to social and cultural aspects of life. From the users point of view, a high efficiency may not be the first priority, any other feature or features for example: cooking speed, convenience, versatility and status could be more important. If the new stoves are going to cost money when the traditional ones are free, then it is going to be difficult to have them accepted by the people.

On the question of alternative energy sources, there are many options open and these include: coal, geothermal, wind power,small hydro, solar, biogas, etc. Different options will need different levels of capital investment and they should be investigated to establish their viability because different alternatives could be suitable in different parts of the country and for different purposes.

Biogas generation is not as easy as the simplicity of its equipment might suggest. The temperature and chemical sensitivity of the methanogenic bacteria requires careful management. Digesters must be fed according to schedule with material of the proper liquidity, Ph and carbon/nitrogen ratio. A change in the chemical or biological composition of the digester contents may halt gas production for a long time.

There is considerable scope for improving on existing knowledge of biogas technology, relevant to Uganda's conditions. This means that a programme of co-ordinated indigenous research, development and field experimentations should be undertaken and fully supported by the government. Existing institutions should be examined for their adequacy in technical support and education.

Work should be done on the use of different fermentation materials in Uganda to produce gas and to recycle the organic nutrients to the soil. Whereas the gas can be valued with a fair degree of precision, information on the value of the slurry is scanty. Experiments should be carried out to measure the yield of crops grown with slurry, as compared to those grown otherwise. A solution should be sought for the transport of the slurry from the digester to the fields.

There is need for the state to create and guarantee essential technical support in the forms of teams of technicians in a biogas extension service, to teach the methods, supervise construction to be available for assistance when problems arise. The lack of technical support for operation and maintenance is a problem of existing biogas units in the country.

In conclusion, energy resources availability plays a significant role on human welfare. In Uganda and other developing countries, renewable energy plays a major role in the overall energy picture. The development and utilisation of renewable energy resources as a part of total energy supply requires considerable amount of activities in:

a) Social science type of research to understand and define the problem and to provide proper orientation for selection of a given technical option;

b) Resources assessment, field equipment testing design and engineering to justify the selection of appropriate technology and;

c) Formulation of a medium-term and long-term plan of action to implement the adopted policies. Provision should be made to collect new information as they become available regarding adopted technologies. Policies should be continually reviewed and when necessary, altered to reflect the effect of collected information or changing conditions.

Biogas as a new source of energy is a viable candidate for consideration in energy resource planning and policy making. From a technical standpoint, it is a feasible option and easily transferable technology. Its level of sophistication can accommodate site-specific requirements, i.e. it can be selected to rely on local material resources and available skilled manpower.

Economically, apart from the direct benefits of gas production and enriched manure, biogas technology offers indirect benefits. They include controlling deforestation and soil erosion, improving health, better sanitation and general ecological balance. It reduces dependence on imported fuel and can provide energy where it is needed and therefore, does away with the distribution and transportation system.

Perhaps, in recognising the important role of technology for development, we have come to expect too much of technology, to perceive problems as technological, when the real problems are structural, political, social and economic. It remains to be seen whether the two objectives of easing the commercial energy problem by using local renewable resources and provision of energy to the rural poor, can be solved simultaneously. The solution is to give the rural peasants the political and economic power to decide on their own future.

11. SUMMARY

In Uganda, the energy sector like the rest of the economy has suffered severe setback during the 1970s and 1980s, the years of political problems in that country. It has been seen that middle class households and even the upper class are reverting from the more efficient and cleaner fuels i.e. electricity and gas, to woodfuel in form of charcoal due partly to the unrealiability of the clean fuels and partly to their high prices and that of the appliances required in their utilisation. This report is a result of a Minor Field Study to evaluate the energy situation in Uganda with the aim of establishing the possibilities of introducing biogas systems in the countryside.

It came out during the study that the country faces fuel shortage in the urban areas and some parts of the rural areas and the situation is deteriorating with time. Factors contributing to this situation include inefficient use of fuelwood and charcoal, the rapid population increase without corresponding technological development, rapid growth of the urban areas and the intensive exploitation without replanting of forest products for other purposes.

The report gives a general description of biogas production, its characteristics, and its use for cooking, lighting, heating, driving of engines, generating of electricity and curing of tobacco. There is an outline of safety precautions during the production and use of the gas. Conditions for the introduction of biogas systems in the rural areas of Uganda are also outlined and these include, energy needs, availability of technical know-how, availability of building material and availability of organic materials for biogas production. It is pointed out in the report that all these conditions are fairly satisfactorily fulfilled as it concerns the Ugandan situation.

The Chinese Pilot Project consisting of seven plants in the eastern part of Uganda is examined. Some plants have managerial problems but the biggest problem is that the project has no technical backup in terms of repairs and servicing, whenever problems arise. There is hardly any data being collected from the plants and no visible follow-up. The local extension staff do not have knowledge about the functioning of the units and therefore they are not useful to the unit owners in terms of advice and repairs. Some differences in basic conditions as relates to biogas technology transfer are briefly examined. It turns out that the pilot plants are very expensive.

There is an observation on the likely effects of introducing biogas systems in rural Uganda. It is likely that if care is not taken, the project can increase the labour burden on some members of the society. The health conditions in the society should improve and the environment conservated. There then comes an economic analysis which points out that research is needed to produce a cheaper design.

REFERENCES

1. Ariane Van Buren, 1979. A Chinese Biogas Manual. Intermediate technology publications Limited. London, UK.

2. Bagabo, Samuel, 1987. Improved Cookstoves Promotion in Urban Areas. A Paper Prepared for the National Workshop on Improved Cookstoves at Mukono DFI, March 1987, Kampala, Uganda.

3. Barnett, Andrew et al 1978. Biogas Technology in the Third World. International Development Research Centre, Ottawa, Canada.

4. Joint UNDP/World Bank Report 1985. Energy Sector Management Assistance Programme, Uganda. Energy Efficiency in Tobacco Curing Sector, Kampala, Uganda.

5. Khakosi, I.W.C., 1985. Inpection Report of the Chinese Biogas Pilot Project, Kampala, Uganda.

6. Kormi, Iraj, 1985. United Nations Development Programme, Energy Office, Biogas Report, Kampala, Uganda.

7. Ministry of Planning and Economic Development, Background to Budget 1986/1987. The Republic of Uganda. Kampala, Uganda.

8. Muchiri, G. 1980. Rural Energy Needs and Alternative Sources. Proceedings of International Workshop on Energy and Environment in East Africa, Nairobi, Kenya.

9. National Office for Biogas Development and Extension, Peoples Republic of China, Biogas in China. Report at the Technical Consultation on Large-scale Biogas Technology.

10. Pfeffer, J.T. 1979. Anaerobic Digestion Process. Proceedings of the First International Symposium on Anaerobic Digestion held at University College, Cardiff, Wales, September, 1979.

11. Stafford, D.A., Hawkes, D.L. and Horton, 1980. Methane Production From Waste Organic Matter CRC Press Inc., BOCA Roton, Florida, USA.

12. Stewart, D.J. 1979. Energy Crops to Methane. Proceedings of the First International Symposium on Anaerobic Digestion held at University College Cardiff, Wales, September, 1979.

13. Turyareeba, Patience, J. 1987. Wood Energy Conservation. Paper Prepared for the National Workshop on Improved Cookstoves at Mukono DFI, March 1987, Kampala, Uganda.

APPENDIX 1.

Ayieko Singoro
Uppsala 1986-09-17

Study proposal for a minor field study in Uganda

Aim of the study

The main task is to carry out a study of the energy utilization by Ugandan peasants with the aim of trying to establish the possibilities of introducing biogas systems in the countryside.

Information sort:

1. Family size.
2. Income.
3. Type of agriculture.
4. Level of mechanization.
5. An estimate of the amount of energy used by each family.
6. Lookout for any biogas systems constructed in the country before and how they have been running - technically and socially.
7. The level of technological know-how in the rural areas and at different levels of government administration that can construct, maintain and run biogas systems.
8. Try to evaluate the effect of the technology on the lives of the people; work loads on women, children and men.
9. Find out the availability of materials for building and running biogas systems:
   - building materials - cement, pipes (metal and/or plastic)
   - raw materials for running the system - biomass, water, etc.
10. The availability and/or the possibility of locally producing the appliances for the utilization of the gas produced - burners, lamps, etc.
11. Last but not least a general survey of the expected cost of a family unit to provide enough or suppliment the families energy requirements.

Methods to be used

Most of the study will be carried out through personal interviews with family members, administrators at different levels and professional people working in the field of rural development, agriculture, forestry and energy utilization in general. Some measurements to estimate different quantities e.g. energy utilization, shall be carried out. Collecting of any available literature on the subject and talking to people in the training institutions like Makerere University, Kampala.

Purpose of the study

The study shall be done as the project work for the Master of Science degree course I am pursuing at the Swedish University of Agricultural Sciences, Department of Agricultural Engineering.

Supervisor: Dr. Anders Almquist, Department of Agricultural Engineering.

With the help of: Lennart Thyselius, Swedish Institute of Agricultural Engineering.

Personal conducts in Uganda

Head of Agricultural Engineering Department, Makerere University, Kampala, who shall be my supervisor in Uganda.

I am also in touch with the Ministry of Energy under whose auspices the project will be carried out.

Time needed

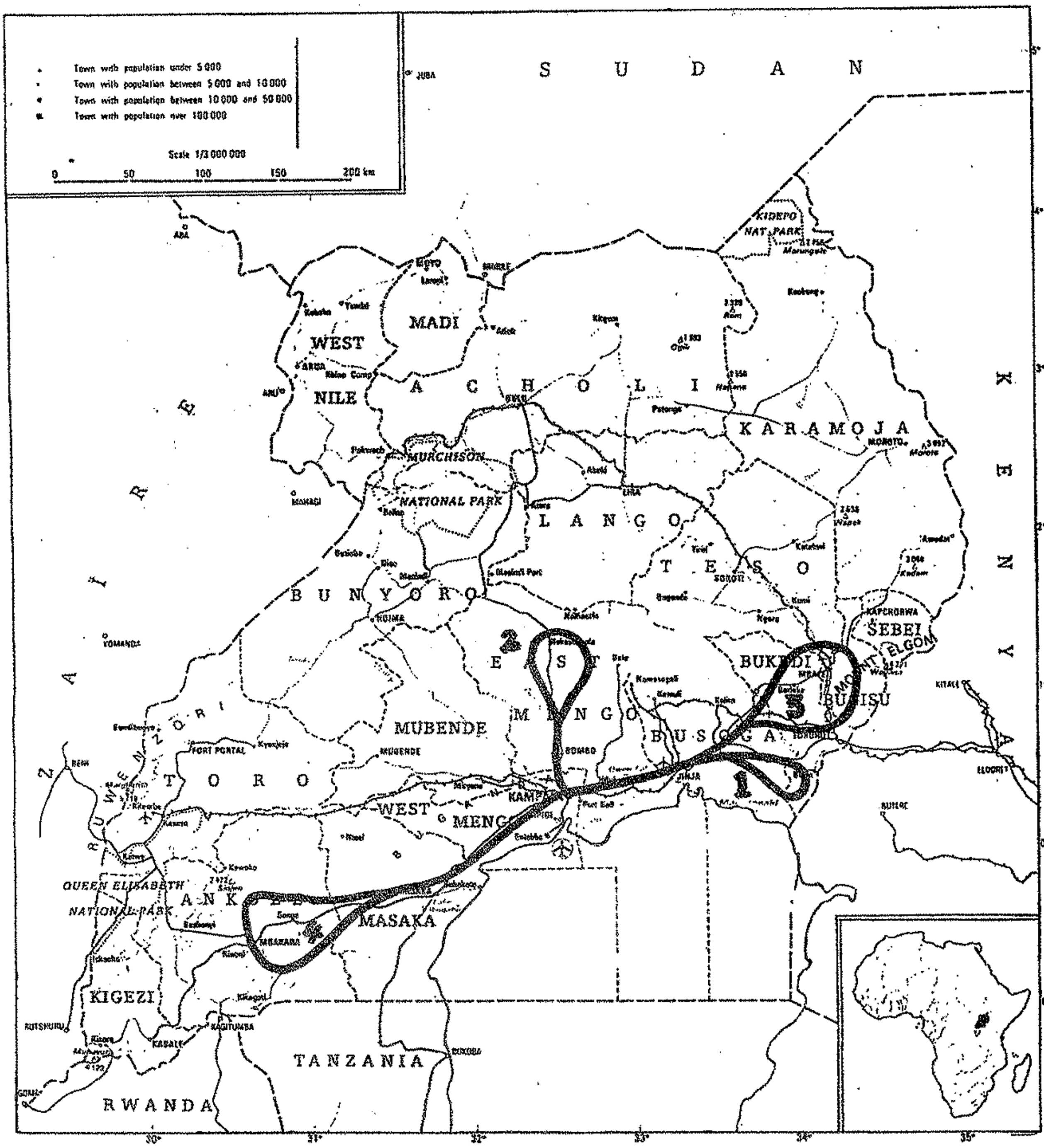
The time needed shall be about three months starting from the middle of October, 1986.

Costs

The expected costs are as follows:
Return airticket Stockholm-Kampala. Transport costs in Uganda. Little material needed for the study and upkeeping for about three months.

APPENDIX 2.

Travel around the country



Trip 1. 12/12 - 20/12 - 86

Travelled from Kampala to Busia. It was difficult to get hold of the District Administrators. Interviewed people in the countryside.

27/12-86 - 15/2-87 Sick (hospitalised)

Trip 2. 17/2 - 20/2 -87

A trip to Nakasongola. Interviewed people in the countryside.

Trip 3. 26/2 - 10/3 -87

Trip to Mbale, Tororo and part of Bukedi District. Visited all the biogas plants (Chinese Pilot Project) except Kumi in Kumi District, for security reasons. Interviewed Administrators and rural people.

Trip 4. 13/3 - 17/3 - 87

Trip to Mbarara. Visited a biogas plant built by the Uganda Church, but it was not in production. Talked to rural people.

APPENDIX 3.

List of people interviewed during the study and institutions visited

Rural People

	Family size	Economy
Busia area		
Egesa, S.W.	5	BA
Lucho, W.	8	A
Muse, O.	10	AA
Ogola, P.	12	A
Okwara, N.	5	BA
Omala, J.M.	11	BA
Owenda, O.S.	5	A
Wamala, G.	13	A
Wango, J.P.	5	BA
Waswa, S.	9	AA
Wele, N.	4	BA
Tororo area		
Akuto, M.	6	A
Amoti, S.P.	5	BA
Bujeli, E.	15	BA
Echaku, J:S:	10	A
Ocheng, M.	14	A
Omaka, S.	10	AA
Mulabi, P.	4	A
Otang, J.	15	BA
Mbale area		
Nasimolo, E.	7	BA
Waliakho, J.	10	A
Mwandu, S.w.	9	A
Mwembe, B	4	AA
Nakholo, W.M.	15	A
Waluukha, P.	5	BA
Wasimu	14	BA

Nakasongola area

Ajjudde, P.	10	AA
Kaddu, P.N.	8	A
Kiwanuka, M	12	A
Kiyita, S.	4	BA
Nagawa, C	15	A
Nakabugu, W.	9	AA

Mbarara area

Kaggwa, L.	12	A
Kato, S.	9	A
Katu, R.	15	BA
Muzila, P.	7	AA
Tukahirwa, J.	10	A
Tumusiime G.	3	A
Twesiime, M.	7	AA

A - Average
AA - Above average
BA - Below average

Administrators, Field Workers and Researchers interviewed

Andrua, H.	Forest Officer/Planning Forestry Department, Ministry of Agriculture & Forestry, ENTEBBE.
Bazigah, S.	Statistician, Ministry of Energy, KAMPALA.
Butoni, C. (Dr.)	Regional Veterinary Officer, Eastern Region, MBALE.
Byaruhanga, S.	Chief Housing Officer, Ministry of Housing, KAMPALA.
Chapaa, K.K.	Engineering Consultant, 69, Nasser Road, KAMPALA.
Chiwezi, P.	Ministry of Agriculture & Forestry, KAMPALA.
Illukor, J.(Proff.)	Researcher (Biogas), Makerere University, Physics Department, KAMPALA.
Kapampara, P.	Senior Assistant Secretary, Ministry of Energy, KAMPALA.

Khakosi, I.W.C. (Agric.Eng.)	Prisons Headquarters, Ministry of Internal Affairs, KAMPALA.
Kibira, G.	Librarian, University Library, Makerere University, KAMPALA.
Kiwanuka, S. (Agric.Eng.)	Agricultural Mechanization Research Centre, NAMALELE.
Lugemwa, A.	Y.M.C.A. - KAMPALA.
Lutaya, H.	Statistics Department, Ministry of Planning & Economic Dev., ENTEBBE.
Madaya, P.	Chief Research Co-ordinator, National Research Council, Ministry of Planning & Economic Dev., KAMPALA.
Makumbi, S.	Secretary, Joint Energy & Environment Project (JEEP), KAMPALA.
Musana, C.	Veterinary Field Staff, Ministry of Animal Industries & Fisheries, TORORO.
Nalwanga, M.	Assistant Agricultrual Officer/ Statistics, Ministry of Agriculture & Forestry, ENTEBBE.

Namono, D. (Dr.)	District Veterinary Officer, Ministry of Animal Industries & Fisheries, MBALE.
Sewanywa, P.	Forest Officer/Energy, Nakawa Forest Research Centre, Forest Department, Ministry of Agriculture & Forestry, ENTEBBE.
Sizoma, G.	Chairman, Joint Energy & Environmental Project (JEEP), KAMPALA.
Turyareeba, P.	Forest Officer/Energy, Nakawa Forest Research Centre, Forest Department, Ministry of Agriculture & Forestry, ENTEBBE.
Wabudeya, N.B. (Dr.)	District Veterinary Officer, Ministry of Animal Industry & Fisheries MBALE.

Institutions visited

Agricultrual Mechanization Research Centre,
Namalele.

Kyambogo Technical Institute,
Kyambogo, Kampala.

Makerere University,
Kampala.

Ministries of :

- Agriculture & Forestry
- Animal Industry & Fisheries
- Energy
- Environmental Protection
- Health
- Works & Housing

Nakawa Forest Research Centre,
Kampala.