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PN-AAN-101
ISN 47584

BIOGAS TECHNOLOGY AND ITS DEVELOPMENT IN THREE AFRICAN COUNTRIES

TRAINING IN ALTERNATIVE ENERGY TECHNOLOGIES (TAET)

NINTH SESSION

FEBRUARY - MAY 1984

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ACKNOWLEDGEMENTS:

We the members of this group would like to extend our sincere thanks to Dr. Martin Bush for his continuous assistance. To Mr. Charles Garretson for his technical support, and the rest of the TAET staff members for their various contributions made to the realization of this project.

Special thanks to the United States Agency for International Development and the University of Florida for granting us the privilege to participate in such a worthy program.

INTRODUCTION

A high percentage of the population of developing countries live in the rural parts. Due to the inavailability of domestic crude and the high cost of transporting imported petroleum products to these rural areas, most of the people rely heavily on fuelwood and charcoal in meeting their domestic energy demands. Consequently, a major problem of deforestration has emerged, and some governments have gone to the extent of banning the use of fuelwood and charcoal. The rural population is now facing an even greater problem in the supply of energy for cooking and illumination. In some rural settings, programs geared towards finding suitable alternatives have been initiated, but up to date, results are still uncertain. What is lacking in these cases, is the technical know-how of the village people and the very high capital cost of the chosen alternatives. One technology that should be given high considerations mainly because it is relatively simple and inexpensive is Biogas. This technology has been proven to work and is in application in many developing countries such as China, India, The Philippines, etc. Though this technology might not replace any significant amount of the country's overall dependence on imported crude, its usage and development can be justified as follows:

1. It provides fuel for lighting and cooking rather inexpensively.

2. It solves the problems of sanitation.
3. It yields a byproduct which is very high in Nitrogen content and can be used for fertilizing purposes.

This document reports studies done on a simple biogas demonstration plant, and gives a case study of its dessimination and development in three african countries. These countries are Liberia, Senegal and The Sudan.

OBJECTIVES

The aim of this experimental project was to do a thorough study of the technology involved in producing methane gas from animal and plant residues. This study should have included the variations of rate determining factors of gas production. These factors are mainly temperature, PH and composition of feedstock. The condition for choosing a particular feedstock was that it should be readily available to at least one country of the members of the project.

This project should also incorporate the building of simple appliances for the utilization of the gas produced, and the comparison of the digester residue (when used as a fertilizer) to that of a commercial fertilizer. From the results of this work, a case study of desseminating or developing this technology in the countries of the group members was to be made so as to make recommendations for biogas usage.

TECHNICAL CONCEPTS

The decay of animals and plants residues in the absence of oxygen yields a combustible gas consisting of about 70% methane and 30% carbon dioxide. The process by which biogas as it is commonly called is produced is termed anaerobic fermentation, which is simply the biological conversaion of complex organic matter in the absence of oxygen to methane and carbon dioxide. This is basically a three stage process (Figure 1) involving the action of a variety of microorganisms (bacteria) on the complex organic or bio resource.

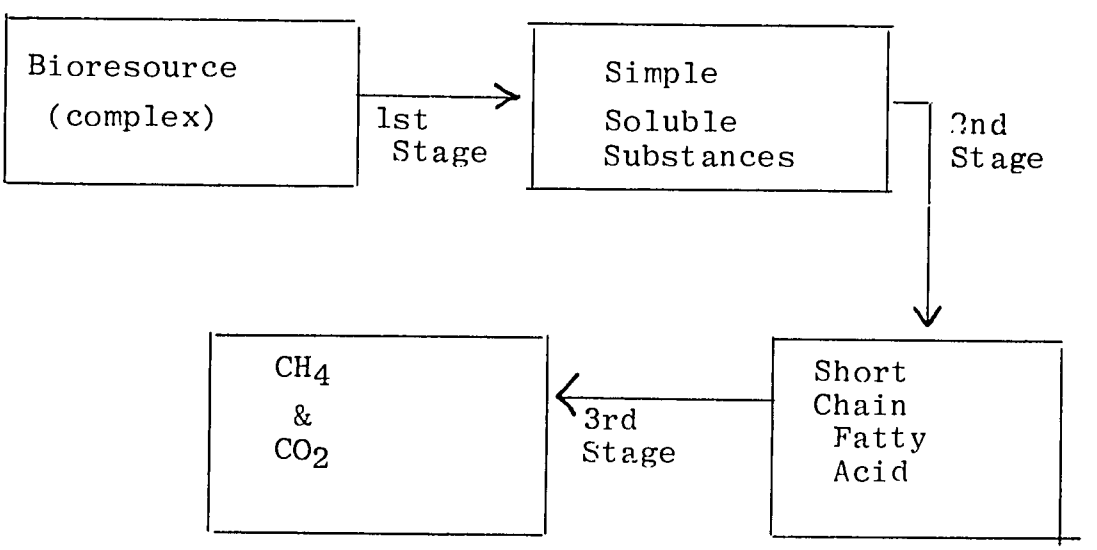
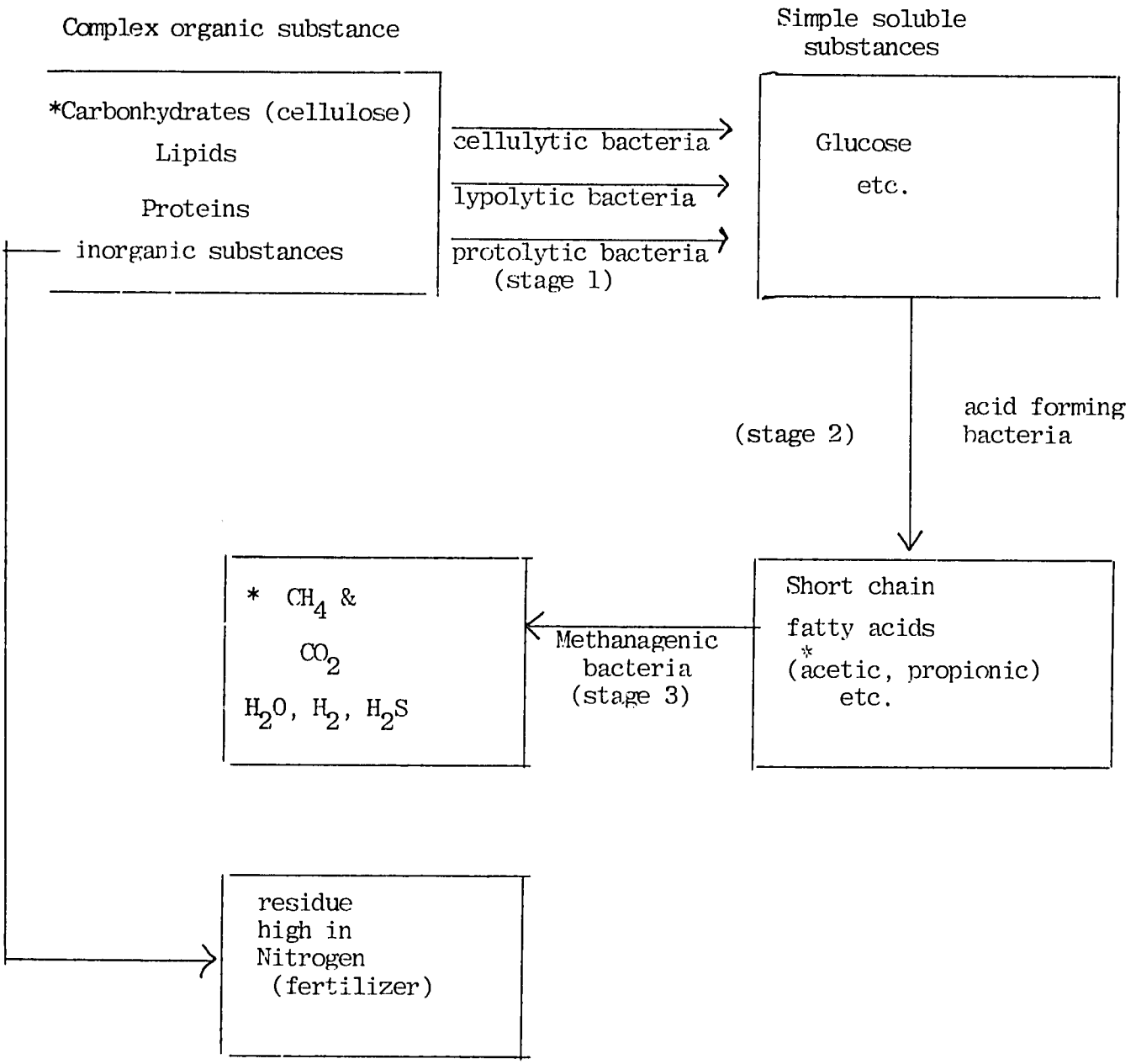


Figure 1: The three stages of anaerobic Fermentation.

In the initial stage of the process the digestable fraction of the complex organic substance, mainly carbohydrates, fats and proteins are converted to simple soluble monomers by a group of bacteria, primarily of a cellulytic nature. This is the rate limiting stage and depends on the growth of the bacteria colony. The product of this stage is used as the substrate of stage 2.

In stage 2, these simple substances are transformed by a group of acid forming bacteria into simple organic acids mainly short chain fatty acids. These acids are then converted to methane and carbon dioxide in the third stage by a group of methanogic bacteria. Figure 2 shows a schematic diagram of the overall process.

Figure 2: The overall anaerobic fermentation process.



* major component

Figure 2: The overall anaerobic fermentation process

The overall gas production depends on the type of raw materials, concentration of bacteria types, and conditions of temperature and pH.

It has been previously determined by other workers in this field that under optimum conditions: 35°c and pH-7 having adequate amounts of bacteria colonies, different animals residues produce different amounts of biogas. Table 1 shows the gas generation of different animals residues.

Table 1: biogas production under optimum conditions

animal residue	biogas production
1. Dairy cattle	30 litres/kg dung
2. Beef cattle	42 litres/kg dung
3. Swine	53 litres/kg dung
4. Poultry	116 litres/kg dung

The residue from the methane gas generators come out to be very rich in nitrogen and can be returned to the soil as a form of fertilizer. This particular residue, lacking the original odor, solves the problem of sanitation and at the same time lessens the risk of insect breeding.

SYSTEM DESCRIPTION

The biogas generator used in this experiment was fabricated with the intention of serving only demonstration purposes. It's a rather small and simple plant which does not allow room for experimentation. The reason why this plant was used was that the group having realized the limitation of time thought it better not to construct a new plant but to use the existing one. This system

being small and very inexpensive served as a model to systems that this project would propose for application in the three countries mentioned earlier. This model biogas generating system can be described as comprising of five main components.

1. The inlet: made of a small drum with a plastic pipe which allows the slurry into the digester.
2. The digester: which is just a fifty-five gallon drum.
3. The stirer: made from the top of the digester and a one inch diameter steel pipe. This serves in keeping the manure in contact with the bacterial colony.
4. The gas holder: this is a smaller drum relative to the digester that floats on the slurry, supported by the stirring rod and the digester.
5. The outlet: simply a plastic elbow.

Figure 3: Shows a diagram of the system.

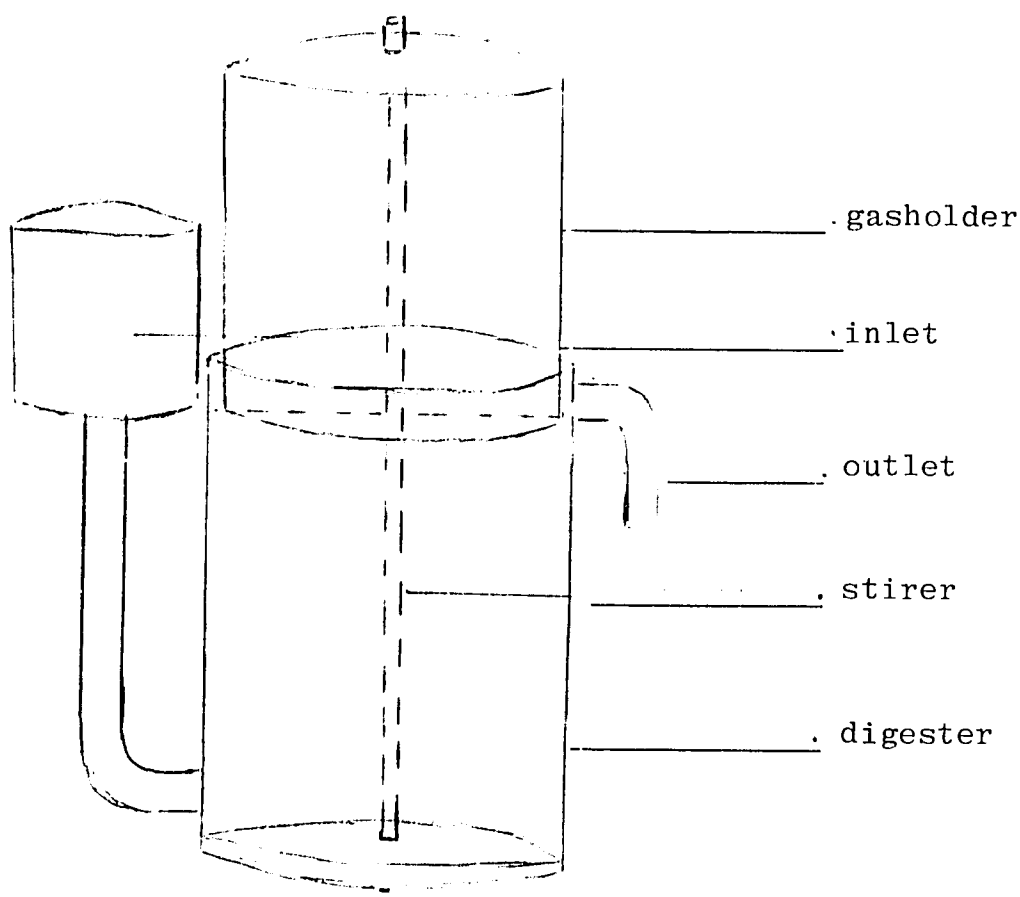


Figure 3: The model biogas generator.

PROCEDURE

Cattle dung was collect d from an experimental farm and was slurred with water in a 1:1 ratio. This slurry was used as a feedstock for the system. The system was charged to its capacity, 52.5 kg of dung (in a one to one ratio with water) and left alone. After about ten days, gas production was observed.

The gas produced was analyzed using a Fisher gas analyzer and the gas components are reported in the results of this report.

We constructed two simple burners of Chinese origin for the testing of gas flamability and utilization. These burners were made from poultry clay and wasted iron.

Figure 4 Shows the basic design of these burners.

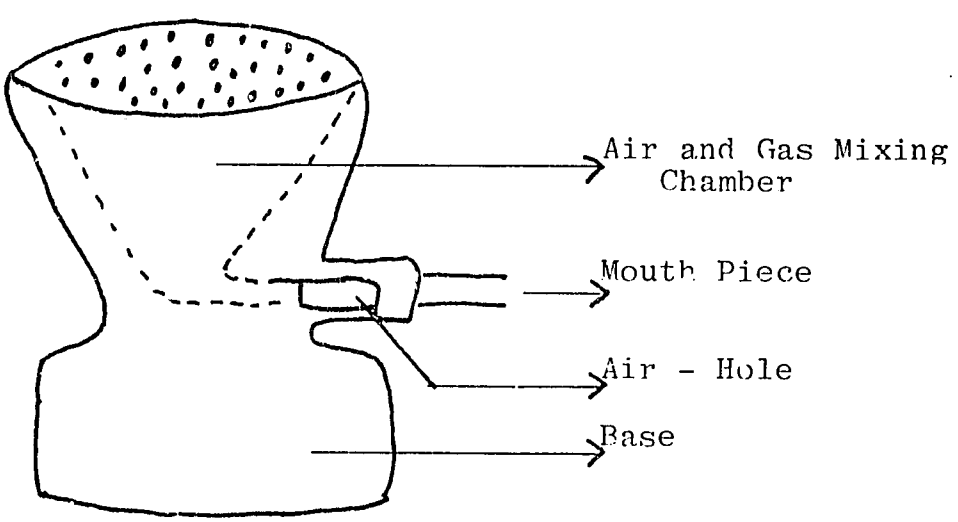


Figure 4: Basic design of biogas burners constructed

For the testing of the residue from the digester as a fertilizer, an experimental garden was planted of carrots, tomatoes and peas. Each plant was grown in three separate ways. One, using 0.12 lbs of a commercial fertilizer. Two, using the same amount of residue from the digester and in the third case, leaving it dependant on the plain soil. These plants were observed and their growth rates are reported in the results of this document. Figure 5 gives a diagram of the garden planted.

Commercial Fertilizer	Digester Residue	Plain Soil
- T	O M A T O E	S -
- C	A R R O T S	-
-	P E A S -	

Figure 5: Experimental garden

Details of gas measurement and analysis can be found in the appendixes.

PROBLEMS ENCOUNTERED

Due to the simplicity of the system, a number of major problem arose that seem to hamper the realization of the aims and objectives of the project. The correction of some of these problems was attempted but most were beyond our control. These problems are listed as follows:

1. We could not test different feedstocks or animal residues because of their inavailability.
2. The cattle dung used contained a large amount of straw which was very difficult to separate. We tried doing a manual separation but it was time consuming and some straw was still introduced into the system, causing it to clog.
3. The system was constantly clogging.
4. The reliance on ambient temperature for heating the system. The average temperature in Gainesville for the months of April and May was about 65°F, whereas the temperature for optimal gas generation is 96°F. This is to say that that system operated on inadequate environmental temperatures.
5. There was no way to determine the pH of the system.

RESULTS:

Table 2 gives a breakdown of the system operation and gas production.

DATE	DUNG LOAD (Kg)	RETENTION TIME (DAYS) ACCUMULATIVE	GAS PRODUCTION (LITERS)	AVERAGE DAILY PRODUCTION (LITERS/DAY)	COMMENTS
Mar. 13	52.5	-	-	-	Initial charge to unit
Apr. 5	1.8	18	99.56	12.45	From observation 10 days before gas production assume 8 days to produce the amount of gas
Apr. 6	1.8	19	16	12.84	Average gas production/day is estimated as the quotient of total gas produce per total number of days of gas production
Apr. 9	3.6	21	50.25	13.82	
Apr. 28	-	-	NA	NA	Gas was used for analysis flamability and testing of burners
May 4	9.144	-	-	-	Unit recharged
May 14	-	31	83.32	11.32	-
May 15	-	32	13.75	11.43	-

I. The total amount of dung fed to the system = 68.844 kg.

Total time of gas production = 23 days

Total amount of gas generated = 262.88 liters

Estimate production rate = 0.166 liters/kg dung/day

From theory, 1 kg of dung under optimum conditions produces 30 - 42 times liters of gas per day. We can estimate that the plant efficiency during operational time was roughly 0.5%.

II. The analysis of the gas shows a composition of 68.82% methane and 17% carbon dioxide. The remaining 15% was undetermined but can be assumed to be other gases such as H_2, air, H_2O, H_2S etc.

III. The burner constructed from poultry clay operated very well and consumed approximately 0.38 m^3 of gas per hour.

IV. The garden planted, showed that the digester residue, was just as good as the commercial fertilizer.

CONCLUSION:

The gas generator used in this study produces very little amounts of gas. In order for such technology to be applicable in developing countries, it must be on a larger scale. Experiments to date suggest that a simple unit capable of serving a family of four to six people can be constructed for about $200 dollars if we assume that labor cost is nil. The initial capital cost per unit of energy may be greater than that of modern electric power systems but the justification of such technology lies in the fact that these modern systems do not reach to the rural population. Therefore, such an alternative seems highly feasible. The potential for such systems could be expressed as follows:

If we assume [1]a system of 10% efficiency, converting 20 lbs of animal dung and other biomass residues daily. 2. One ton of dry biomass = 10-15 MMBTU and 20 lbs = 100-150,000 BTU. With 10% system efficiency, this is equal to 10-15,000 BTU daily. 3 This is equivalent to about 0.08-0.12 gallons of kerosene, which if used for direct illumination is equal to about 2.9 - 4.4 kwh. For example, this amount of energy could be expressed as about 300 - 450 watts of illumination used for 10 hours daily.

This amount of energy seeming very small could be of great benefit to a rural family.

are still not aware of such simple and inexpensive technology.

From an energy assessment undertaken by the Department of Energy, it was proposed that biogas be given high consideration.

If a demonstration project could be set up, to introduce small systems in rural Liberia it is likely that this technology would be a suitable alternative.

Materials are available locally for the fabrication in these systems but what is lacking is the technical know-how of the village people. The Department of Energy needs to initiate programs to teach this technology to village people.

Senegal:

1. Situation and Possibilities

Biogas technology has not yet a great place in the development of renewable energies although the main part of the population lives in rural areas with significant heads of livestock, and a big requirement for energy. The only biogas plants which exist now in the country are in the research centers like ISRA/CNRA, ENSUT or in few villages and built by certain non-governmental organization such as Carritas/Senegal, ENDA tiers monde etc. Many Senegalese farmers have no idea of this simple technology. However, many possibilities and resources exist to introduce biogas plants in rural areas, especially in SYLVO pastoral zone, Senegal oriental and

CASE STUDIES

Liberia:

The imbalance in the economy caused by the dependance on imported crude has caused Liberia, like most developing countries to seek alternative energy resources.

One problem of major concern is to provide electricity to remote areas. A very large portion of the country outside of its capital is not served by the central electrical grid. Considering the present problems of the national economy and domestic priorities, it seems most likely that this grid over the next fifteen years cannot expand its services significantly in the rural areas, consequently, there exist problems of illumination. Presently the major method of illumination in these areas is by the use of kerosene lanterns. But this does not solve the problem because at most times, there is a shortage of kerosene and people would have to return to the open fire for lighting.

Biogas systems have the potential of meeting some of these needs.

Not much work on this technology has been done in this country so as a result the technology has never been put to use. Only a few small systems have been set up and these were strictly for experimental purposes.

The central agriculture research institution has done some research work in this area from a very small system but have never demonstrated biogas technology and people

- the availability of animal and agricultural wastes in these places,
- the problem of wood scarcity which is increasing,
- the desertification problem and the erosion of lands resulting from the clearing of forest for firewood, etc.

2. Dessiminating Technology

As the technology of biogas is proved, before dessiminating it, we need to consider following points:

a) It is necessary to have a structure for the coordination and development of biogas technology. In fact, as we can observe in case of Senegal, the research/development fields are not centralized. Each center or organization has his own program with little consultation with the others. Within the context of a developing country this is a waste of time and money because usually the program are similar. Most of the countries which have more experience on biogas technology have concentrated their efforts and have built efficient infrastructures.

b) The second point is that the country must have a national program where all departments like Energy, Agriculture, Education and Research, Social Development etc., are involved. The important point of this program must be the training of people in building and maintaining of biogas units. Institutions like ENSUT, CNRA, Directors of

Rural Development can train people in a short time. within the framework of the National Program

c) Practical problems: One of these problems is collecting dung. In fact, cattle in Senegal are not mostly on stalling. During the day they graze freely in the fields. However, during the night they are brought together in one place. Collecting dung could be a problem in the first case but usually young people are very organized in the villages and they can maintain such a system.

d) Material and Financial Problems: Most of the countries which are involved in biogas technology use local materials for building the plants. We can notice in Senegal there is availability of unused steel, plenty oil drums which are cheap materials within everyone's reach. On the other hand we can find in some villages, old cement wells which are dry. These wells can be transformed to biogas digestor by a simpler way.

However, there is considerable financial problem concerning biogas technology at the level of the farmer.

Farmers have not enough money to get a biogas plant built with ferro-cement materials, for instance

* ISRA = Institut Senegalais de Recherche Agricole
* CNRA = Centre National De Recherche Agricole
* ENSUT = Ecole National Superieur De Technolgie

because the price of the cement is very high. Maybe by subsidies, as it has been done in India, the Government can slowly dessiminate the technology in rural areas.

The Sudan:

After the rise of petroleum prices in 1973, the energy situation became very critical in Sudan. This particularly in rural areas, where kerosene was used in household and gas oil in pumping of water.

The main fuels used in rural areas are firewood, charcoal and animal and plant wastes. This usage is mainly in the household sector.

It is found that from the surveys done by the National Energy Administration, firewood is collected from far distant places and sometimes it is difficult to acquire. Also the prices of charcoal rise annually. In this situation of scarcity in energy, many rural people (especially in remote areas) burn the animal dungs directly. For these reasons and others (Sudan is one of the largest countries in livestock resources), it is advisable to introduce the biogas technology in rural areas, mainly in the household sector.

Studies and surveys were done by the National Council for Research (Energy Research Council) to produce biogas from water hyacinths which are available in large quantities in White Nile area. An experimental plant was established in Tawila village in the bank of the White Nile.

Also many studies and efforts have been done by the National Energy Administration to find the possibility of introducing this technology by using the animal wastes, to improve the energy output in rural areas.

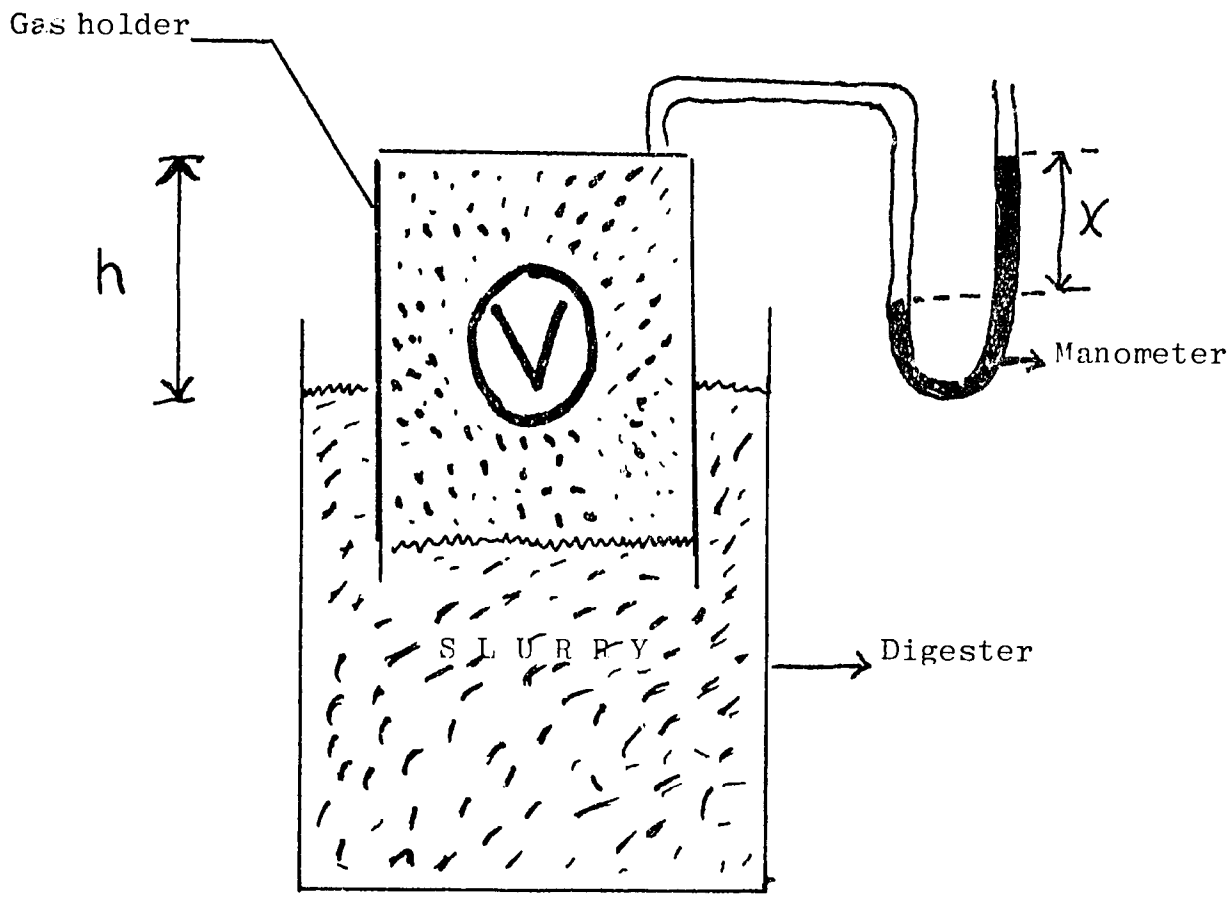
In late 1983, a survey was done by the National Energy Administration to establish a biogas plant in Tute Island near Khartoum. Many farmers in the island will make use of this plant especially in household. The initial cost of this project is about 30,000LS (about 2,307.dollars The civil work in the plant began in early 1984. In fact nearly all the materials needed are available locally. Also there is a sufficient amount of animal waste in the island.

In fact there is a large opportunity of introducing this technology in Sudan. The feedstock is available all over the country (animal dungs) mainly in west, east and south of the country. Also, the water hyacinths can be used. These are available in the White Nile and in the south areas of the country. Also materials for construction are available locally.

The use of this technology will enhance the efforts to stand against the deforestration, desert creeping and in improving health of people (particularly eyes and lungs from using smoky fuels.

APPENDIXES

AP_1: GAS VOLUME MEASUREMENT PROCEDURE



$$V = A \times (h + X)$$

.V - Gas Volume (cubic inch)

.A - Area of gasholder (in^2)

.h - Drum level (Slurry to top of gas drum) (ins)

.X - Gas pressure (ins H_2O)

Note: if we want the Volume in liters the main formula is

$$V + (h + X) \times 4.166$$

AP2 DIGESTER DATA SHEET

DAILY FEED:
3 Litres packed dung
3 litres water

DATE: April 5, 1984 TIME: 3 PM

Drun level (slurry to top of gas drum, h) 20 ins

Gas pressure (p) 3.9 ins H_2O

Gas Temperature _____ °F _____ °C

Slurry Temperature _____ °F _____ °C

Ambient Terperature:

minimum _____ °F _____ °C

maximum 70 °F _____ °C

mean _____ °F _____ °C

Gas Volume = (h + p) x 4.166= 99.56 litres

Gas Used ___yes _x_no

New drum level _____ ins

New gas pressure _____ ins H_2O

New gas volume _____ litres

1 in = 2.54 cm; gas drum area = 1640 cm^2 = 254.5 in^2; 1 in H_2O=0.036
1 cu. ft. = 28.32 litres; 1 gal. = 3.785 litres.

AP3: ANALYSIS PROCEDURE

Note: Apparatus used: Fisher Orsat Gas for more details about the Fisher Orsat Gas refer to manual.

1. CO_2 Percentage determination

The percentage of CO_2 absorbed in the solution of KOH is obtained by passing the biogas through the solution several times.

In our case the volume of sample is:

$V_1 = 41$ ml

After several passes in the solution, this volume decreases to

$V_2 = 33.8$ ml

Therefore, we calculate the percentage of CO_2 absorbed with the following equation.

$$\% CO_2 = \frac{\text{decrease volume}}{\text{volume of sample}} 100 = \frac{V_1 - V_2}{V_1} \times 100$$

$$\text{So, } \% CO_2 = \frac{41-33.8}{41} = 17$$

$CO_2 = 17\%$

2. CH_4 Percentage determination

This has been done by the slow combustion procedure. We know that normal combustion of biogas is given by the

the chemical formula:

$$CH_4 + 2O_2 \xrightarrow{\text{Combustion}} CO_2 + 2H_2O + \text{Heat}$$

As we see, we need twice the volume of oxygen for one unit volume of methane to ensure complete combustion under stochiometric conditions.

In this procedure 17ml of the remaining sample of gas was transferred to the pipet. Then, 82.6 ml of oxygen where added directly to the slow combustion pipet

So, V_1 = 17Ml + 82.6 ml = 99.6 ml

The above described process is repeated several times. Finally, after the combustion, the pipet was cooled down and the gas is returned to the buret and measured. We noticed that the new volume (V_2) of the biogas was:

V_2 = 76.2 ml

So two contraction of Methane = $V_1 - V_2$.

$= 99.6 - 76.2 = 23.4$ ml

Volume of Methane = $\frac{1}{2}$ contraction

$= \frac{23.4}{2} = 11.7$ ml

Therefore the percentage of Methane is:

$\% \ CH_4 = \frac{11.7}{17} = 68.82 \ \%$

So our biogas components are:

Components	%
CH_4	68.82
CO_2	17
Others	14.18

Comparing to the typical percentages, we can conclude that the quality of our biogas is good.

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