# PILOT-PLANT FOR ENERGY RECOVERY FROM TROPICAL WASTE FOOD MATERIALS

by

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**ARSTRACT**
An experimental unit for obtaining gaseous methane from waste food materials is discussed and results are presented for experimental tests with animal wastes and tropical waste food materials. The tropical waste food considered include garri, boiled beans and plantains. As expected, the animal wastes produced higher yields than the vegetable wastes, with boiled beans being the most promising of the vegetable wastes. The results show that it is possible to generate enough gas on a local basis to run such appliances as a .081 $m^3$ (3Cu.ft) gas operated refrigerator or a 1.5 KW (2 hp) parafin engine.

## INTRODUCTION

Declining domestic oil and gas production, coupled with increasing exploration costs, have prompted lots of research efforts in the search for alternative sources of energy. For the poorer nations, particularly the developing countries of Africa and Asia, the consequences are too great to take lightly. The rapid 'development needed to transform agricultural methods, provide adequate shelter and health service and improve the modes of transportation will require a phenomenal increase in the use of energy [1]. This anticipated energy increase cannot now be provided for by the power Authorities in the various countries or by any foreseeable increase in oil production, and even any significant breakthrough in solar energy research cannot carry 'the burden alone.

One other energy source available to all the rural areas is biomass in the form of waste food. Waste food and refuse abound in all communities of Africa and are getting to the point where they constitute health hazards, The amount of waste food materials a community produces is a strong function of its population and level of development. The higher the population the greater the total waste, the lower the level, of development the more the waste because of the lack of food preservation facilities and techniques. A quick survey undertaken for this study at Nsukka estimates that a family of seven produces an average of 2.27 Kg of waste food daily. This gives a daily average of about 46 tonne for a sub-urban community such as Nsukka.

A properly thought-out programme can be worked out to convert this menace to methane or methanol. Such a project will serve the dual purpose of (1) a healthy system for the disposal of waste to products and (2) a bioenergy convertor. Methane when converted to methanol finds a ready use in the transportation industry by using it with gasoline as gasoline - methanol blend. This blend is known for its good knock characteristics because of high octane rating of alcohols. The high octane rating permits engines to be run at high compression ratios thereby realizing high efficiencies. Internal combustion engines run on the gasoline-methanol blends can-be put to use in generating electricity for the rural areas, Pure methane on the other hand will find direct use in the rural areas for lighting, heating and cooking.

A number of researchers [2,6] have looked into the production of energy from biomass and today there are small methanol plants making about 200 gallons per day in the United states, mostly from wood pulp wastes. In India, similar experiments have been done with cowdung and human wastes [7].

There are principally two methods of recovering .energy from waste food materials. One method is through the anaerobic decomposition of waste food which releases 'mash' gas rich in gaseous methane. The second method is by burning the waste food with insufficient air in inceneraters to yield a gaseous mixture rich in carbonmonoxide. The arbonmonoxide is converted into methanol by scrubbing process (reaction with hydrogen) through the reaction

$$CO + 2H_2 \rightarrow CH_3OH$$ •

Considering the low level of technical development in the developing countries, the first method is preferred because of its simplicity. Also; most of the waste food materials will have high water content and would require an initial energy input to dry them before combustion can take place and this makes the second method less efficient than the first [5]. Lastly, the by-product of the anaerobic method is good quality compost which is very valuable as manure.

Even though lots of work seems to have been done on the conversion of biomass to biogas very little experimental data exists on the transient biogas yield of specific biomass materials especially for tropical food materials. The objective of this work is therefore to provide these relevant data for the common Nigerian food materials and to compare the results obtained with those of animal wastes. The food materials so chosen are beans, garri and plantains. Table 8 shows the representative for content of these food materials.

## 2.THE ANAEROBIC (BIOCHEMICAL) PROCESS

Anaerobic digestion is the bacterial decomposition of organic matter in the absence of air or oxygen to produce a gaseous mixture consisting mostly of carbon 'monoxide and methane. Several metabolic pathways have been suggested and studied [9,10,11]. The complex fermentation process was found to be a continuous process which proceeds through several stages to produce simpler and more stable degradation products from organic wastes. The broad sequence of events can be grouped into two stages.-In the first stage, organic materials (waste foods) are used as substrates by organic acid forming bacteria to produce simple organic compounds mainly acids like acetic and propionic acids. Other intermediate compounds formed include hydrogen and formats. This is followed by the second stage in which methane bacteria use up these acids as substrates producing carbonmonoxide and methane by one or more of the following mechanisms.

$$4HCOOH \rightarrow CH_4 + 3CO_2 + 2H_2O$$

$$CH_3COOH \rightarrow CH_4 + CO_2$$

$$2CH_3CH_2OH \rightarrow 3CH_4 + CO_2$$

$$CO_2 + 4H2 \rightarrow CH_4 + 2H_2O$$

A typical gas analysis shows the resultant gas to consist of 40 to 50 percent cabonmonoxide and 50 to 60 percent methane.

The initiation of fermentation depends mostly on the nature and type of substrate available and the prevailing physico-chemical environment. It takes time to initiate and complete these reaction stages and this gives rise to the delay period which is the time between the setup of experiment and initial production of biogas. For some materials the delay period is a couple of hours and for some others it could be as long as five or six weeks. To be able to reduce this waiting period and also increase yield it is necessary to know the optimum conditions under which these reactions occur. These are given [10, 11] as (1)A temperature range between 10 degrees C and 38 degrees C,(2) a pH range of 6.8 to 7.2 (3) a certain amount of Nitrogen.

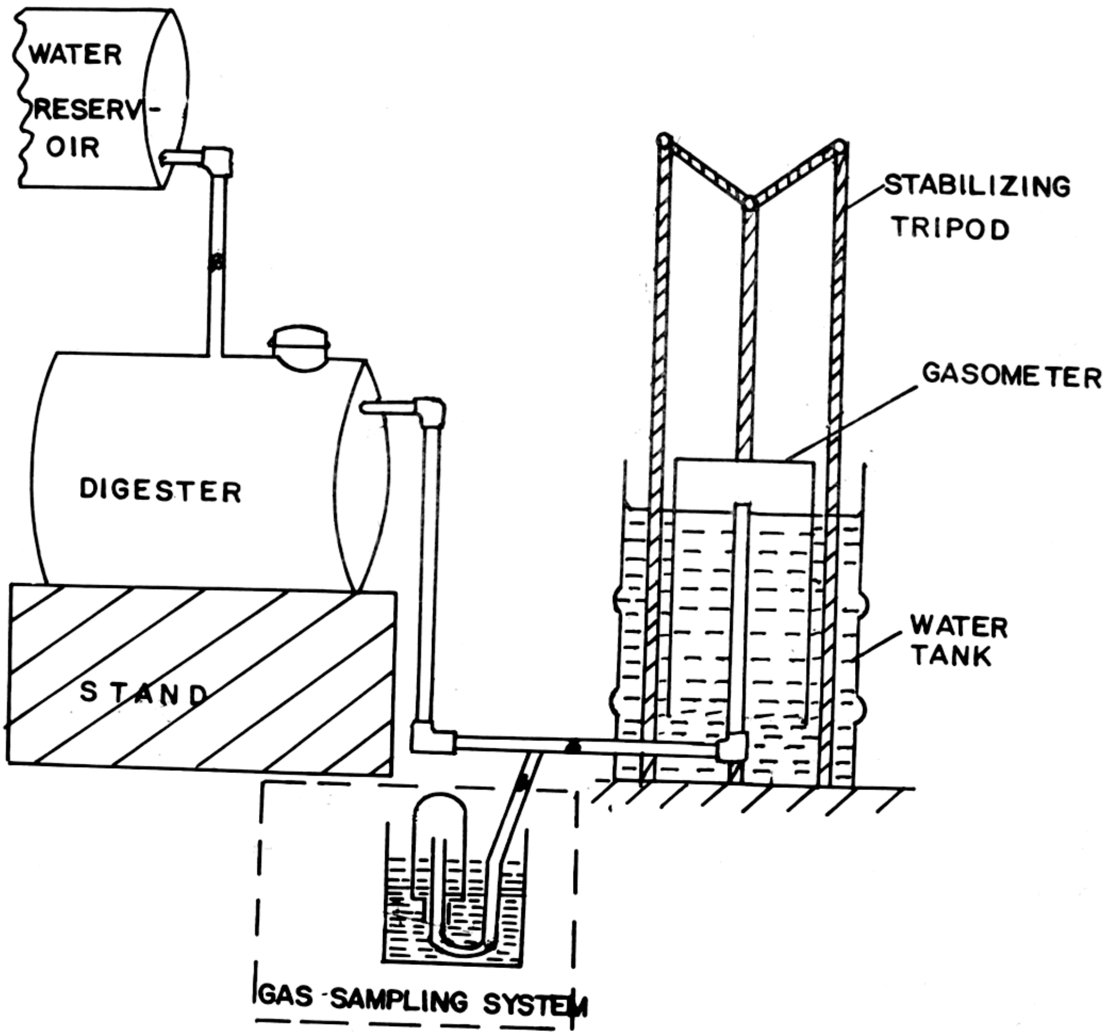


Fig. 1. Schematic of pilot plant.

and (4) complete absence of inhibitors like oxygen and toxic materials. The digestion reaction is characterized by a thermophilic process between 40 degrees C and 60 degrees C and a mesophilic process between 20 degrees C and 37 degrees C. The thermophilic process is faster but has a lower cummulative biogas yield than the mesophilic process. The open air temperature at Nsukka gets up to 65 degrees C whereas the shade temperature fluctuates from a minimum of 17 degrees C to a maximum of 35 degrees C. Mesophilic bacterial action, therefore, can conveniently take place under shade conditions.

**3. EXPERIMENTAL UNIT AND PROCEDURE**

A schematic of the methane producing plant is shown in figure 1 and consists essentially of the digester and the gasometer. The overriding considerations in designing this set up are (1) to minimize costs, and (2) to minimize the level of technology required so as to make it practicable for rural use in developing countries.

The digester is the container (tank) in which fermentation of the waste products takes place. It consists of an empty 167 litres tar drum mounted horizontally as shown. The waste food is fed into the drum through a throat at the top and a side pipe provides outlet for the generated biogas. For anaerobic conditions, the waste foods must be completely covered with water. At certain times of the year (Nov. - Feb.) the weather is very dry and evaporation rates high. A water tank was therefore installed above the digester drum and was used to maintain the level of water above the waste' food in the digester at a fixed level.

The gasometer serves as the gas collection, storage and measuring tank. Because methane is not soluble in water at atmospheric conditions, the gas is collected by the displacement of water in a tar drum. The gasometer consists of the water reservoir, the gas holder and the stabilizing tripod. The water reservoir is made from a 167 litre coal tar drum whose top surface is completely open and is filled with water. The gas holder is made from a: 136 litre coal tar

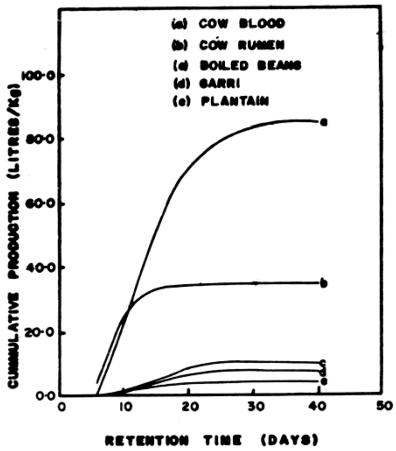


Fig. 2. Cummulative biogas yield from the various waste food materials.

drum of a smaller diameter than the reservoir drum. The gas holder drum rises inside the' reservoir as gas is being collected and this rise gives a measure of the volume of gas inside the gas holder. For easy vertical movements of the gas holder, three rods are connected in a tripod manner to act as guides. Provision is made in the gas line for periodic sampling and analysis of the generated biogas.

The animal and food wastes used in this work are cow blood, cow rumen, boiled beans, garri and plantains. Five different set ups were used for these. Each waste material was first weighed and those in liquid form such as cow blood were then fed into the digester. Those in large chunks such as garri were mashed in a large bowl before being fed into the digester. The wrong type of bacteria may produce gas rich in hydrogen sulphide with a low percent of methane. Methane bacteria were therefore, isolated, cultured and then introduced into the digester. Water was poured into the

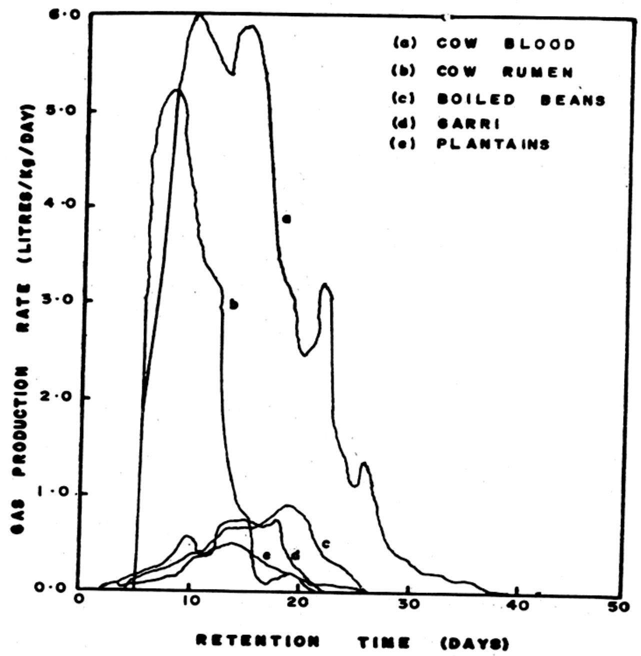


Fig. 3. Biogas production rate from the var10US waste food materials.

digester until the water level was at the root of the digester throat and all the waste food under water. Water was added once a day from the overhead tank to make up for evaporation losses. After the delay period, gas bubbles began to form and at this initial stage can be collected quite easily at the gas sampling end by the displacement of water in a burette. The sample line was then closed as soon as substantial amounts of gas began forming and collection was transferred to the gasometer.

**4. RESULTS AND DISCUSSION**

Figure 2 shows a comparison of the cummulative biogas yield for the various waste food materials used. It is obvious from the curves that animal wastes, because of their high Nitrogen content, 'give the highest yields. This fact has been known for some time and is not the main interest in this work. Interest is more in the results from vegetable waste foods that generally constitute the greater portion of the wastes. The results show that cow blood yielded 84 litres of gas per Kilogram, rumen material yielded 40.5 litres/Kg, boiled beans yielded 10.37 litres/kg, gari yielded 7.16 litres/kg and plantains yielded 4.0 litres/kg. These figures compare favourable with 81 litres/kg. and 27 litres/kg. obtained in the summer and winter months respectively for experiments with cowdung [7].
It has been estimated [2] that a family of three will need about 4050 litres (I50 cu.ft)of gas per day for cooking lighting, while a .081 $m^3$ (3 cu.ft) gas operated refrigerator requires 1350 litres (50 cu.ft) of gas per day and a 1.5 KW (2 hp) parafin engine uses 1485 litres

**TABLE I**

Representative Values per 100 g. of edible portion (from PLATT[8])
COMPOSITION OF FOOD ITEM

| Food Item | Water ml. | Protein g | Ca rbohyd+ rates g | Fat g | Fibre | Calories |
|---|---|---|---|---|---|---|
| Garri | 11-15 | 1.5 | 84 | 0 | 1.5 | 342 |
| Beans | 5-17 | 24.0 | 57 | 1.7 | 4.0 | 339 |
| Plantains | 59-74 | 1.0 | 31 | 0.2 | 0.3 | 128 |
| Rice (lightly milled) | 10-16 | 8.0 | 74 | 1.5 | 0.5 | 354 |

TABLE II

Delay Periods for Various Waste Food Materials DELAY PERIOD (DAYS)

| Waste Food Item | 40kg. of Food | 30kg. of food | 20kg.of food | 10kg. of food |
|---|---|---|---|---|
| Cow Blood | 3 | 3 | 3 | 3 |
| Cow Rumen | 2 | 2 | 2 | 2 |
| Beans | 8 | 8 | 9 | 9 |
| Garri | 18 | 20 | 20 | 28 |
| Plantain | 27 | 27 | 30 | 35 |

(55 cu.ft) of gas per day. These amounts can easily be obtained from what is generally referred to as "backyard" methane generators. This translates to about 17 kgs. of cow blood daily to operate either the refrigerator or the parafin engine and 135 kgs. of bean waste daily to operate each of the two appliances. The requirements on garri and plantains will be 193 kgs. respectively, and will definitely not be very economical. From Table I showing the composition of the various food items, it is reasonable to assume that the high energy yield from beans.

Figure 2 also indicates that for all the curves, there is a substantial delay period before gas generation begins. Results of a separate test conducted to determine this delay for the various materials used, are presented in Table 11. The delay period is less for the animal wastes than for the chunky (large particle) vegetable wastes. Results presented in Table II were obtained without the use of any innoculin. However, by additing cultured bacteria and discharge sludge from previous tests it is possible to drastically reduce the delay period.

The single unit plant as described has a delay period during which there is no gas production and after time T95 when 95% of the maximum yield has been produced, the production rate becomes very slow.
This means that such a unit· if used alone will at best be an intermittent source of energy. For continuous supply of gas, it is necessary to set up a batch unit. This is achieved by a systematized scheduling of a number of digesters connected in series such that while some are in their delay periods, others are in their peak production periods and some others in the medium production periods. For optimum production, each digester is recharged after T95 days with fresh waste.

Figure 3 shows curves of the yield per day for the various wastes. Cow blood and cow rumen have the highest yields per day with the maximum occuring between 5 and 10 days after the beginning of gas production, at a value of 5 litres/kg/day. Vegetable wastes attain their maximum values around the 5th day from beginning of production and remained close to the maximum value for a longer time than was the case for animal wastes. The maximum production rate per day was about 1 litre/kg/day.

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