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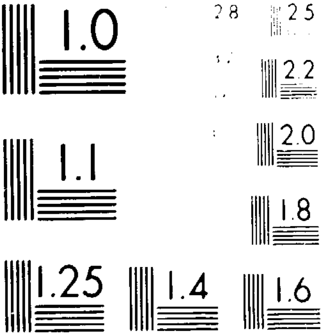
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Distr.
LIMITED

ID/WG.321/8
19 June 1980

ENGLISH

United Nations Industrial Development Organization

Technical Consultations among Developing Countries on Large-Scale Biogas Technology in China

Beijing, China, 4 - 19 July 1980

BIOGAS TECHNOLOGY IN MEXICO *

by

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I. INTRODUCTION

The more advanced contemporary societies of the world have reached a high degree of development, both in the industrial and the agricultural sectors. The well-being this development has brought to urban and rural populations alike, has been possible, in great part, to the availability of energy. In Mexico, roughly half of the population, living in some 400 urban areas of more than 10,000 people where most of the industry is concentrated, have an adquate supply of energy. The other half of the population lives in about 100,000 rural communities, and although a very great effort is being made to increase their productive activities by providing them with energy, there is still a lot to be done.

As an example in the last twenty-six years that Mexico's rural electrification program has been in existence, over 20,000 rural communities have been electrified, serving a total population of 21.5 million. As of 1977, there existed approximately 78,600 non-electrified communities, (Ref.1), half of these being villages of 1 to 30 people, with a total population of 10 million. The high capital cost involved in setting up distribution lines, due to their remote location and large dispersion, makes it highly improbable that the rate of conventional rural electrification will increase. Under such conditions, useful energy could be provided through simple processes of generation based on local renewable energy resources other than those used at present. One of such processes is the production of biogas making use of the organic wastes found locally. On average, in the rural communities,one head of cattle per person is observed. In addition, goats, hogs, and poultry usually roam free in the villages. No fodder is grown to feed confined cattle; the animals are left to roam free and find their own food. Where vegetation is abundant, the animals are brought in at night to the owner's dwelling. In other cases, during the dry season, or where vegetation is scarce, the animals concentrate at night around the watering places and not necessarily in the village. Due to the animal's continuous wandering in search of food, their size and waste production is reduced. A full grown animal produces about 30 kilos per day of waste. The animals could be confined in a communal stable at night to make dung collection easier. Where water is present, a water pumping scheme could be established for irrigating fodder-producing land, in order to be able to confine the cattle and thus increase the amount of dung collected and the capacity of the digester system. The digester sludge would be used to improve the soil. All animal wastes could be used and could also be supplemented with some agricultural residues.

II. RESEARCH ON DIGESTER DESIGN, CONSTRUCTION AND OPERATION

A summary of the research performed at the Instituto de Investigaciones Eléctricas on the production of biogas is presented below.

1. Determination of Operational Parameters.

a). Animal wastes.

The study of the parameters involved in the mesophilic anaerobic digestion of animal manures, was performed at the bench level in batch form, using 200 liter digesters and cow manure as the organic substrate. Each digester was seeded with 20 liters of effluent from another system. Gas production was measured daily and analysis were performed twice a week by gas chromatography. Analysis of the substrate were made before and after fermentation.

i) Total Solids content.

Six different concentrations were studied, from 4 to 13% total solids, to determine the conditions for maximizing gas production and to establish the optimum retention time (Ref. 2). The experiments were conducted in steel drums placed above ground, with a 50 mm asbestos insulation, unheated and without mixing. Ambient temperatures fluctuated between 18°C at night and 30°C in the afternoon.

Figure 1. shows combustible gas production, in liters of gas per dry kilogram of material initially fed to the system, against the concentration. Maximum gas production occured in the range of 4 to 6% total solids. If gas production is plotted as the

total number of liters of gas generated per liter of fermenting broth, a curve with a plateau extending from 6 to 11% total solids concentration is obtained, such as the one shown in Figure 2. This results led us to select a concentration of 7% total solids as one that gave a good digester volume utilization with a high efficiency of gas production per kilogram of waste fed to the system.

ii) Effect of heating

To investigate the possibility of heating the digester in a simple way and to study the effect this would have on the process, two of the steel drums were fitted with a copper coil coupled to a solar water heater working by the thermosiphon effect, with no storage. Another two were insulated on the bottom half only, to simulate a half buried digester, and placed under a plastic hothouse, and the last two drums were left unheated to serve as controls. The experiments were performed as before, with cow manure as a substrate at a concentration of 7% total solids (Ref 3). The internal digester temperatures registered during the experiment appear in Table I. Cummulative combustible gas production per kilogram of dry matter is shown in Figure 3. From this data it is apparent that the intermitent heating provided by solar heaters or by a hothouse did not improve gas production in a significant manner.

b). Agricultural residues.

Mixtures of animal wastes and agricultural residues ground to powder form were studied in 20 liter batch digesters, with no insulation, seeded with 2 liters of effluent. The experiments were conducted at a concentration of 7% total solids and ambient temperature (Ref. 4). Vigorous stirring was provided twice a day. The same analysis were performed as in the case of the animal waste. The materials studied were corn, rice and sorghum residues, and peanut shells, mixed with the necessary quantity of cow manure to achieve a carbon to nitrogen ratio of 30 in the mixture. Figure 4 shows the cummulative production of combustible gas per kilogram of dry organic matter fed originally to the system for each one of the agricultural residues and a control of cow manure with no vegetable addition. The corn stover and manure mixture gave a higher gas production and faster rate than the control. Although the mixture of sorghum residue and manure gave the highest value for gas generation, its production rate was very slow. Both rice straw and peanut shells mixed with manure produced gas at a very slow rate.

Gas composition is presented in Table II, where it may be seen that rice straw and peanut shells produced a gas with a higher methane content than the manure control and the corn stover and sorghum straw gave lower methane content than the control.

2. Family Size Digester

Based on the results of the laboratory experiments, a $10m^3$ continuous (daily load) underground digester was built (Ref. 5) following the designs of the Indian Agricultural Research Institute (Ref. 6). It consist basically of a vertical well 3.6 m deep and 1.9 m in diameter, that serves as the fermentor as is shown in Figure 5. A mixing tank, built higher than the surface of the digester, is connected to the bottom of the well by an inlet pipe to permit the entrance of the load by gravity. As the load enters the digester, an equal volume of sludge is displaced from the surface and leaves the system through a channel in the upper part of the well, flowing to a discharge pit. The gas generated in the process is collected in a 3 m^3 gas holder floating over the top of the digester, its weight compensated by counterweights. To use the gas, a valve is opened and the counterweights are removed and placed on top of the gas holder to provide additional pressure to the gas stream. A stirrer consisting of a rim tied to a steel cable passing through the center of the gas holder and up to a pulley, was installed to permit the evaluation of mixing the reactor contents.

This digester was loaded and seeded with 1 m^3 of sludge, and was operated for more than a year and a half using dairy cow manure as substrate, working at different retention times with and without stirring (Ref. 7). The daily load of manure was mixed with hot water from solar water heaters, to give a concentration around 7% total solids at 32-36°C. The insulation provided by the ground surrounding the digester and the warm loads permitted the internal temperature of the fermenting broth to remain very stable, with values between 27°C (in winter) and 30°C (in summer), for the 80 weeks of operation, with no daily fluctuations. The mean values of gas production at the various retention times studied are shown in Table III. Except for the period where the retention time was 15 days, mixing produced a decrease in gas production, specially during the period where it was performed three times a day. It seems probable that in this type of digester the entrance of the load is enough to cause all the mixing required.

The optimum retention time would be a function of the local needs for gas and the availability of raw matter and labor. This is apparent from the data of Table III, where it is shown that operation at a short residence time produces a a larger volume of gas for a given digester volume than the one produced at the longer residence times, although the gas produced from a given mass of organic matter increases with the residence time. Operation at the short times will imply an increase of the quantity of manure fed daily to the system and of the labor required to handle it. The methane content of the gas varied in the different periods from 51 to 59%. No relation was found of this methane content with the retention time nor with stirring.

The digester was opened after 80 weeks of operation. About 30 cms of scum were found floating on the surface of the mixture and on the bottom a sediment had formed about 40 cms thick. The gas holder showed signs of corrosion, specially in the zones that moved in and out of the liquid phase as the gas holder rised when filled with gas. This seems to indicate that a digester such as this should be opened once a year for scum removal and gas holder maintenance, and emptied every two or three years to get rid of the sediment on the bottom.

3. Communal Digester Module

After the 10 m^3 digester had been operating for about a year, a 40 m^3 reactor was designed and built in an agricultural school, using soil cement as the construction material (Ref. 8).This digester was planned as a module that could be installed in remote and non-electrified villages to make use of the locally available animal residues for the generation of fuel gas to be used in promoting the productive activities of the community. The number of such modules to be installed in a village would depend on their particular needs and the resources available. The system is a horizontal displacement underground digester, 2 m high, 2 m wide and

10 m long, with a fixed dome and loaded by gravity from a mixing tank at one end, as is shown in Figure 6. A man hole was cut for maintenance purposes. Two effluent outlets were provided at the other end, one starting at the bottom of the well and consisting of a 15 cm asbestos pipe and the other at its surface, running along the whole width of the digester. The effluent flows to a discharge pit from where it was collected and evaluated as a soil conditioner by comparison with chemical fertilizers and fresh manure, in a corn field. Preliminary results show that the effect of the effluent compares favourably with both of them. At the discharge pit, the effluent may be passed through a wire screen to separate the solids, the water flowing off to the fields where grain and/or vegetables are grown. The solids are being fed to a compost heap to evaluate their fertilizing value when mixed with sugar cane bagasse.

The gas generated in the process flows out of 5 pipes placed on top of the digester dome, connected to a common header for its use; 6 m^2 of solar collectors were installed to heat the water utilized in the daily load.

This digester has been in operation for 16 months, processing half a ton of dairy cow manure a day at a 7% total solids concentration and a residence time of 30 days. The residence time was selected on the basis of availability of raw material, since there are 25 cows at the school and about 80% of the residues can be collected. The internal temperature has remained stable at 29-31°C during the time of operation. Daily gas production has varied between 28 and 30 m^3 with a mean methane content of 55%. The operation of the system requires 4 man-hours per day, excluding manure collection.

4. Biogas Utilization

a). Gas Purification

The local utilization of biogas in a rural community makes it unnecessary to separate the carbon dioxide present, as there would be no transportation problems involved and very little storage. Also, the volume of gas produced in the proposed units would be too small to make a separation process economic.

The separation of the water vapour carried by the gas is necessary for its efficient utilization. This separation is achieved by passing the gas stream flowing out of the digester through an oil drum placed in the shade to keep it cool, to serve as a condensate trap. The moisture content of the gas leaving the condenser was determined using concentrated sulfuric acid. Results of these tests proved that the gas emerged from the condenser at its saturation humidity. No further drying of the gas was attempted.

Hydrogen sulfide was found in the gas at concentrations of about 0.2% in volume. The elimination of this impurity is necessary when burning the gas in an internal combustion engine, to avoid corrosion problems. A simple scrubber of galvanized iron pipe 15 cm in diameter and 1 m long, packed with 10 kg of oxidized iron filings mixed with sawdust has given very good results for this purpose. No H_2S could be detected by spot tests with lead acetate in the gas leaving the scrubber until 800 m^3 of gas had been treated. The spent iron filings were taken out from the gas scrubber and regenerated by exposure to air for 4 days to convert the ferric sulfide formed, back to ferric oxide.

b). Conversion of Equipment to burn Biogas

To make biogas utilization accessible in most places, existing equipment that runs on bottled gas (liquid propane) was adapted for its use. The appliances modified were a two burners kitchen stove, a gas lamp, a small absorption refrigerator and a 16 kW electric power generator. In order to insure that the same amount of combustible fuel is provided when burning biogas as the equipment received from the bottled gas, the fuel injector area was increased 4 times for the stove and refrigerator, and 6 times for the lamp. The primary air supply was adjusted in each case to avoid yellow points in the flame as well as flame separation or recoil. The electricity generator consisted of a 41 hp internal combustion engine, running on gasoline, that operates at 3600 rpm at all loads, coupled to a 20 kVA, AC generator. Electric current is generated at 220/110 volts, 60 Hz. A subatmospheric system for gas regulation for this motor to permit gas flow into the carburettor was adopted.

c). Performance of the Converted Equipment.

The efficiency of operation of the above mentioned appliances with biogas was evaluated in comparisson with bottled gas (Ref. 9). In the case of the generator, operation efficiency with gasoline was also evaluated. Results are shown in Table IV. From this data, it can be seen that the efficiency of operation of the equipment with biogas does not differ greatly from that obtained with the conventional fuels except in the case of the gas lamp. The luminous intensity of biogas is much lower than that of liquid propane, as the trials with the gas lamp showed, but nevertheless the level of illumination is quit acceptable.

III. OTHER ACTIVITIES IN MEXICO

Activities on biogas technology are relatively recent in Mexico, and therefore its utilization in still very limited. It is estimated that there are about 100 digesters in operation in rural areas, mainly for domestic uses.

The Ministry of Human Settlements is engaged in the construction of 13 small units in rural villages.

The construction of a 20m^3 digester has been completed at a rural development centre, to be operated mainly for demonstration purposes.

A civic association, Proyecto Xochicalli A.C., has promoted the implantation of self constructed digesters.

Research and development work is being performed at several Universities, among them the following:

The Instituto de Investigaciones Metalúrgicas of the University of the State of Michoacán, where a 6m^3 digester has been in operation for several years, using hog residues.

The Universidad Autónoma Metropolitana-Ixtapalapa, in Mexico City, with studies of digester sludge utilization in agriculture. The potential of mixtures of sludge with sugar cane bagasse and molasses to be used as animal feed is also being investigated.

The University of the State of Nuevo León, the Instituto Tecnológico de Estudios Superiores de Occidente in the State of Jalisco, and the Instituto de Investigaciones Bióticas of the State of Veracruz, are also working in this field.

As was mentioned at the beginning of this paper, there are many thousands of small villages where almost the only energy option is fuelwood, and where there is a great need for fertilizers. The contribution biogas could make in these villages is therefore very great, and we will continue to stress the need for a major effort towards the implementation of a biogas program in the country.

ACKNOWLEDGEMENTS

The staff members of the Instituto de Investigaciones Eléctricas that have collaborated in the biogas project beside the author of this paper are: A.Félix, M.I.Mandujano, F.Santander, S.Sánchez and A.Wong. The sludge utilization studies were performed by Dr.G.Viniegra of the Universidad Autónoma Metropolitana-Ixtapalapa. The project has been financially supported by the Gerencia General de Electrificación Rural of the Comisión Federal de Electricidad, México.

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TABLE I

MEAN INTERNAL TEMPERATURE OF DIGESTERS (°C)

	9 AM	12 AM	3 PM
Solar heated	23.1	31.6	35.1
Hot house	26.3	27.2	28.9
Unheated	24.9	26.2	27.2

TABLE II

MEAN GAS COMPOSITION FROM AGRICULTURAL RESIDUES MIXED WITH DAIRY COW MANURE

	% CH_4	% CO_2	% N_2
Corn Stover	53.3	42.1	3.9
Sorghum Straw	56.6	27.8	14.9
Rice Straw	59.2	28.0	11.9
Peanut Shells	58.6	28.0	12.3
Cow Manure	57.7	36.7	5.3

TABLE III

MEAN VALUES OF GAS PRODUCTION IN THE 10 M^3 FAMILY SIZE DIGESTER

RETENTION TIME (days)	MIXING	DAILY PRODUCTION (liters)	CONVERSION (liters of gas/dry kg)	METHANE CONTENT (%)
10	No mixing	14,070	201	56
15	No mixing	9,450	203	59
15	Once a day (very slight)	11,477	246	59
30	No mixing	7,256	311	55
30	Once a day	6,710	288	55
42*	No mixing	6,886	413	51
42*	3 times a day	3,829	230	51
45	No mixing	4,295	276	58

* The digester was fed 5 consecutive days per week and left unloaded for two days.

TABLE IV

OPERATION EFFICIENCIES OF APPLIANCES

	BIOGAS	LIQUID PROPANE	GASOLINE
KITCHEN STOVE	26.9%	28.6 %	-
GAS LAMP	0.3 (Lux/W)	1.31 (Lux/W)	-
REFRIGERATOR*	914 Wh	973 Wh	-
16 kW GENERATOR			
50% LOAD	16.5%	13.9% (39%LOAD)	11.1% (39%LOAD)
75% LOAD	17.0%	15.2%	17.1%
100% LOAD	18.7%	19.3%	19.5%

* Energy consumed to lower the temperature of 300 ml of water from 20°C to 0°C

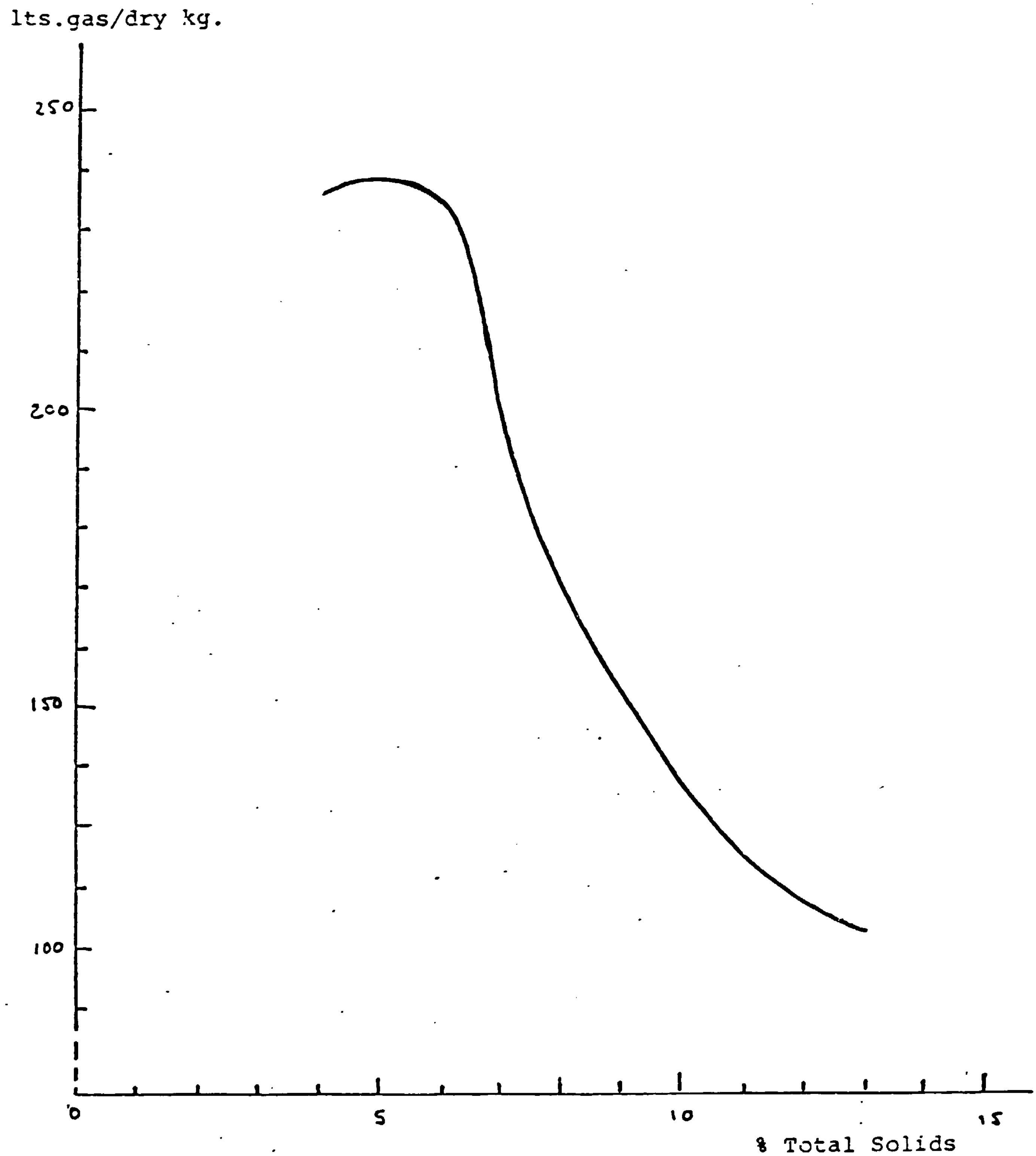

FIGURE 1

GAS PRODUCTION PER UNIT WEIGHT OF DRY INPUT MATERIAL AS A FUNCTION OF SOLIDS CONCENTRATION

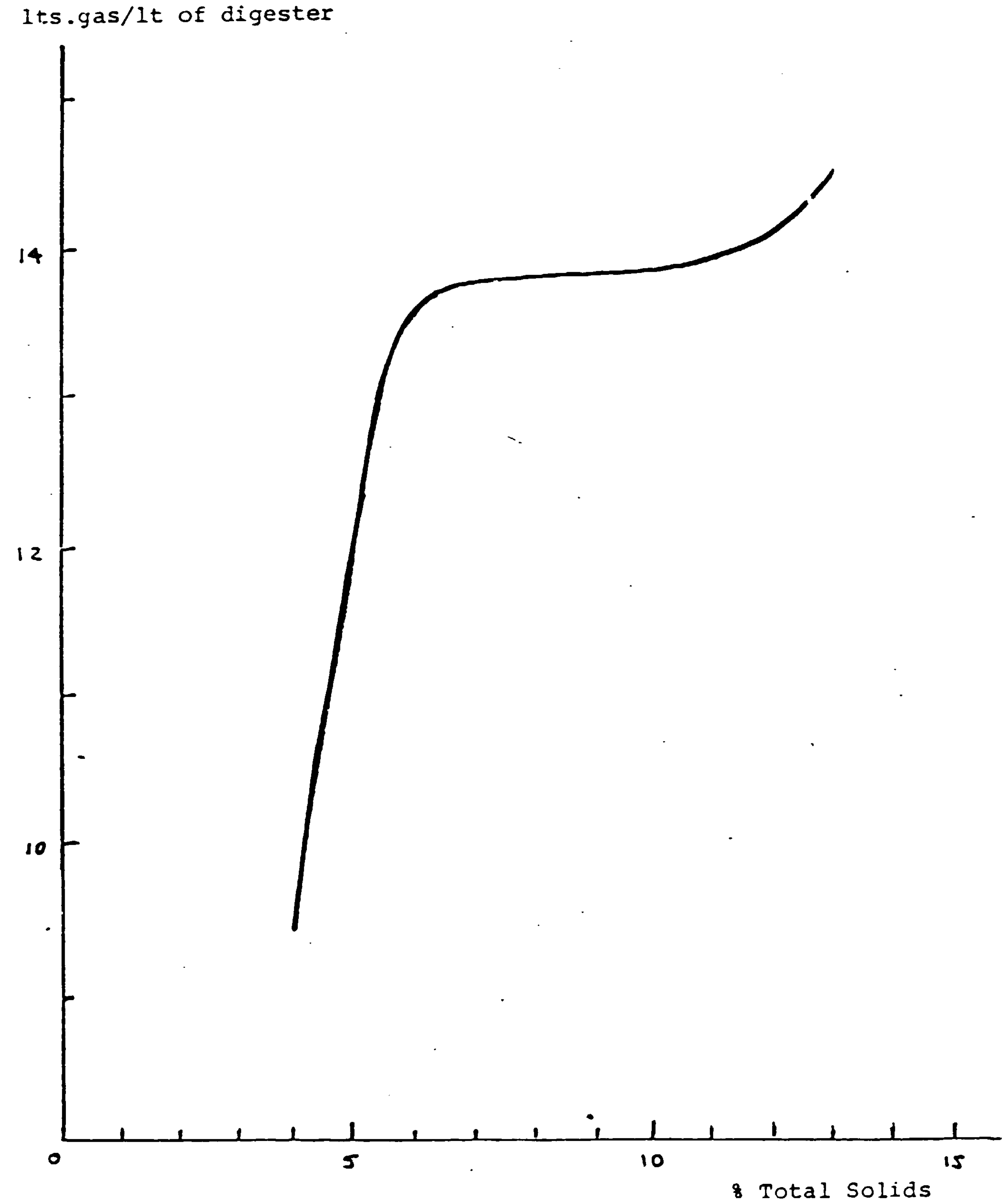

FIGURE 2

GAS PRODUCTION PER UNIT VOLUME OF DIGESTER AS A FUNCTION OF SOLIDS CONCENTRATION

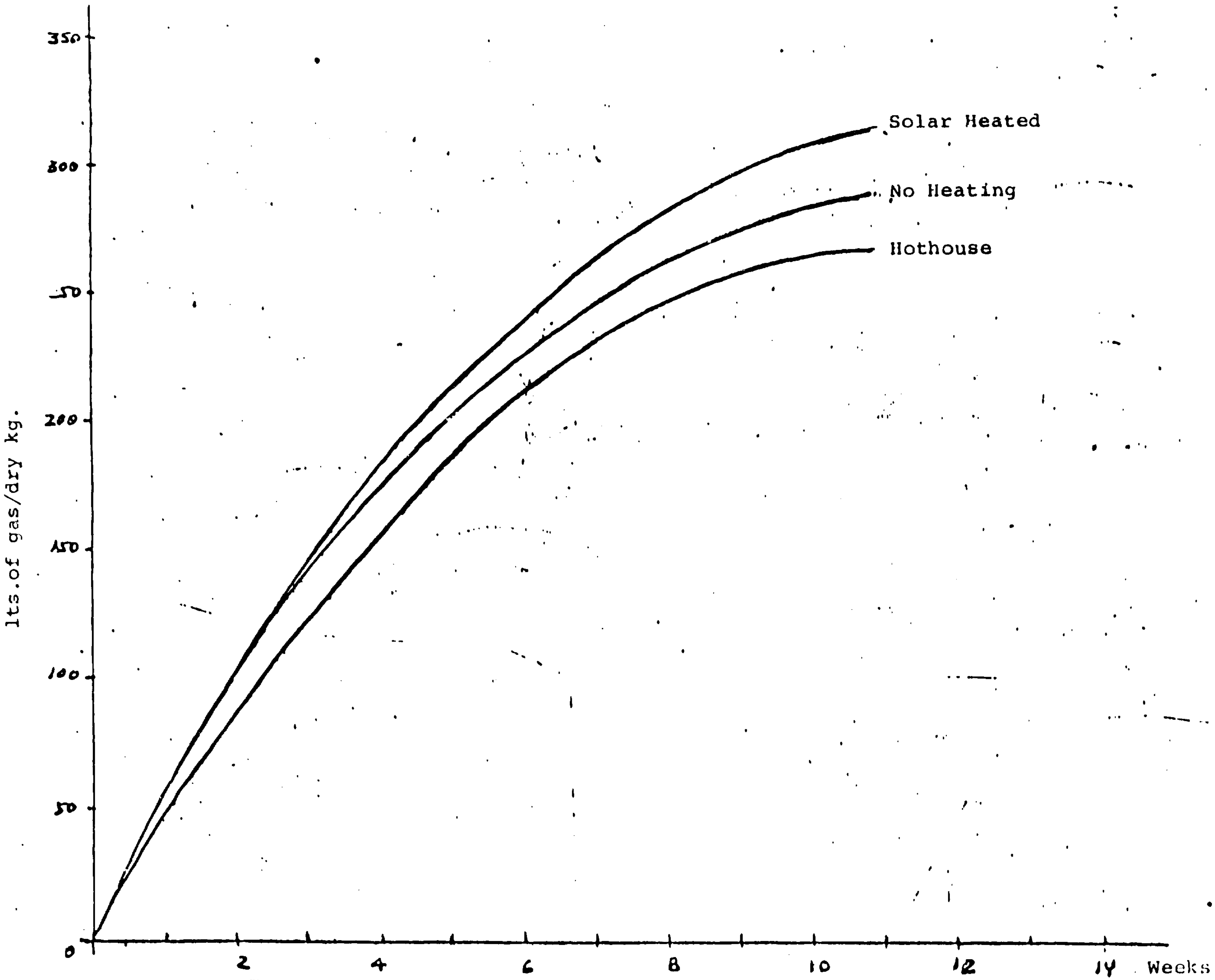

FIGURE 3. EFFECT OF HEATING ON GAS PRODUCTION

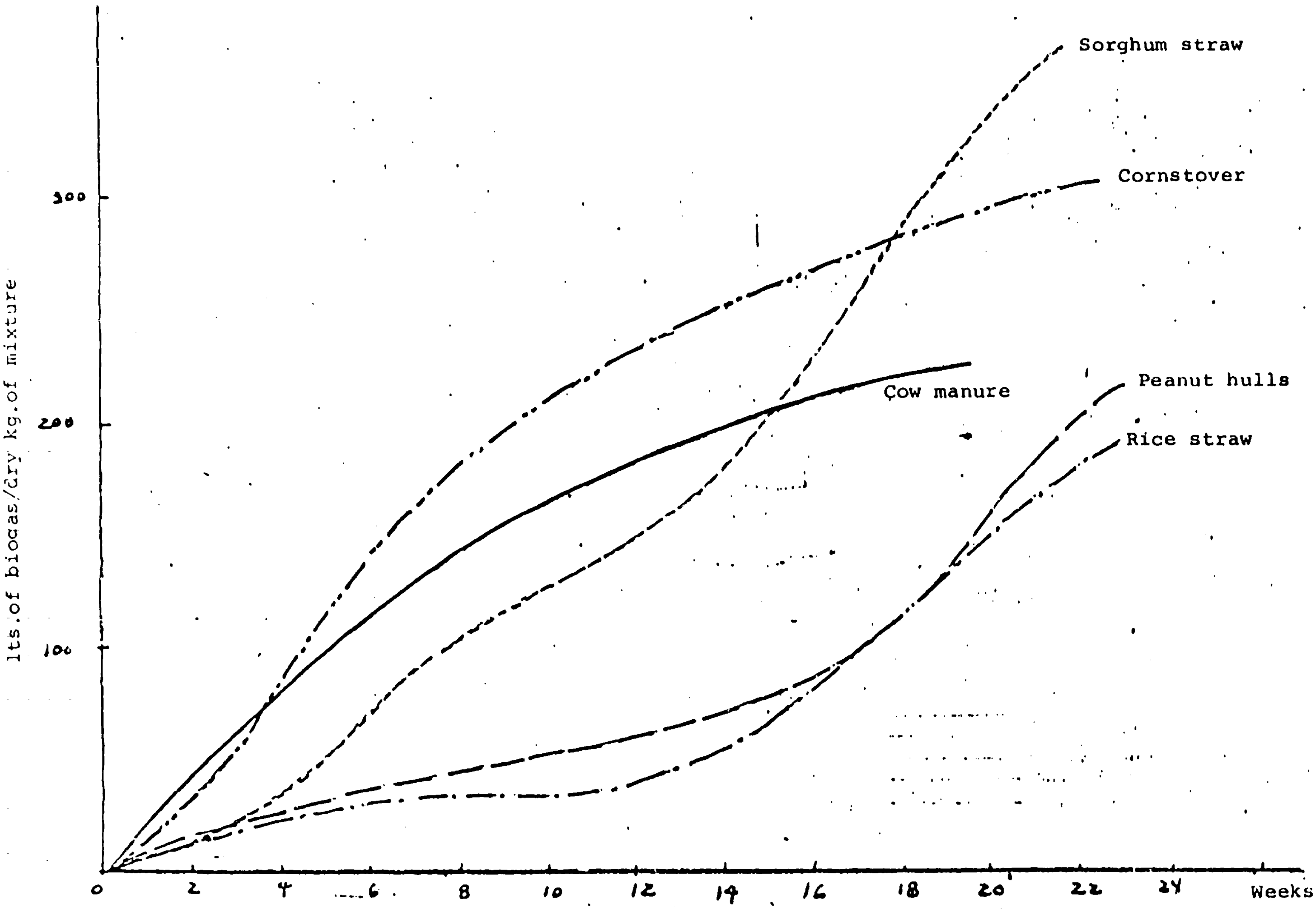

FIGURE 4. GAS PRODUCTION OF MIXTURES OF AGRICULTURAL RESIDUES AND COW MANURE

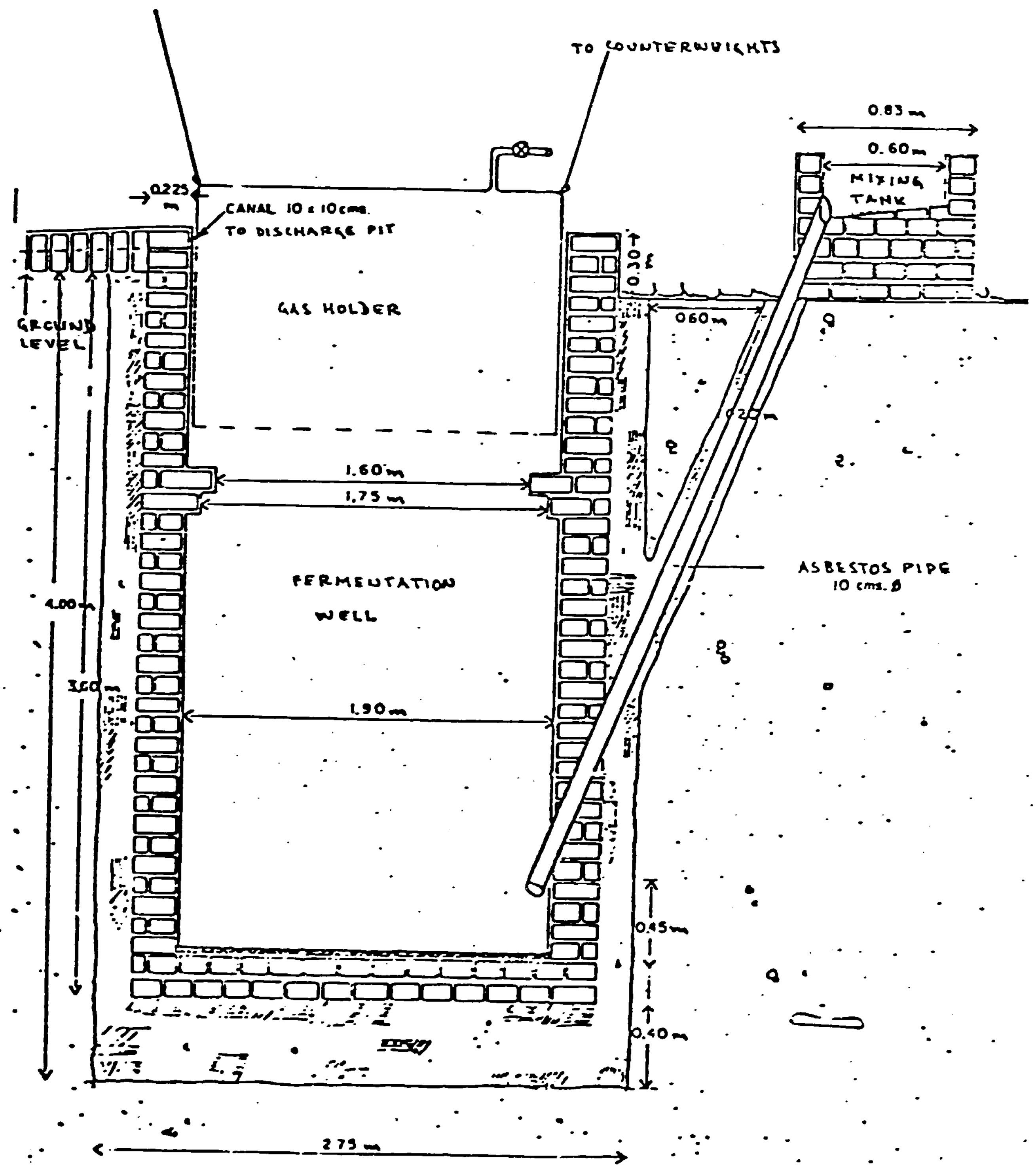

FIGURE 5
FAMILY SIZE DIGESTER

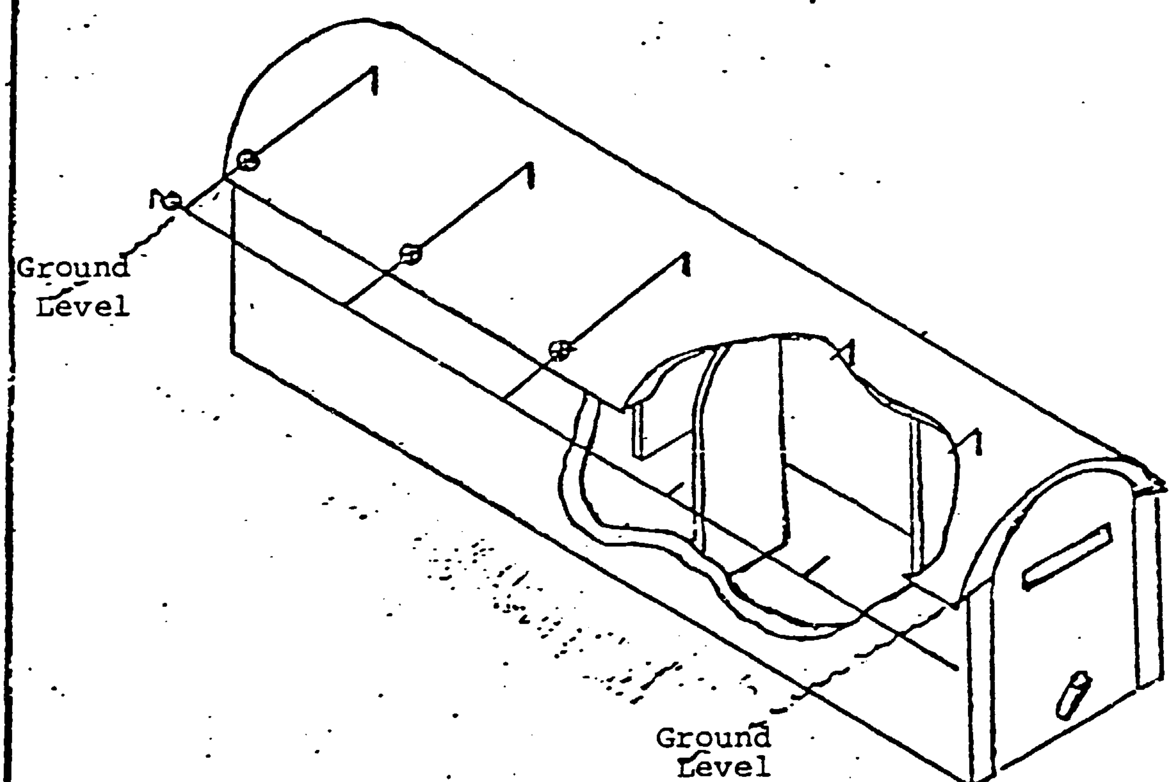

FIGURE 6

COMMUNAL DIGESTER MODULE