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INSTALLATION AND OPERATION OF A NIGERIAN ANAEROBIC DIGESTER BASED ON CROP WASTES.

BARRY I WHEATLEY University Industrial Centre, University College, Cardiff.
S E ETHERIDGE Dept. of Microbiology, University College, Cardiff.
DR K ADESOGAN Dept. of Chemistry, University of Ibadan, Nigeria.

INTRODUCTION

The generation of inflammable gases from organic substances by the 'works of nature' has been observed for centuries and many famous names have shown interest in these gases including Volta, Davy and Pasteur. These gases have been known by many names from the strange 'Will-o-wisp' lights sometimes seen over marshland to the more down to earth name of sewer gas often used in the water industry. What ever it is called (I prefer Biogas) the gas which is generated by the anaerobic fermentation of organic material is a mixture,with carbon dioxide and methane as its major components. Table 1 shows the typical analyses of such a gas and the properties of its components.

It has long been the hope of scientists and engineers to harness this natural degradation system to produce a useful fuel while conserving any valuable fertilizer components that exist in the original material. It has only been during periods of crisis that the western world has utilised these systems and during the second world war many 'digesters' were built throughout Europe. With the cheap and readily available fuel of the late 50's and the 60's the interest in small scale energy production units went into a decline.

Table 1. Composition and Properties of Biogas.

Property	CH_4	CO_2	H_2S	Typical biogas
% by volume in typical biogas	54-80	20-45	0.1	100
Energy value (kcal/litre)	9.0	-	-	5.4
Explosive range (% by vol.with air)	5-15	-	4.46	6-12
Density (g/litre) 0°C 760mm	0.72	1.98	1.54	1.22
Specific gravity (relative to air)	0.55	1.5	1.2	0.93
Critical temp. (°C)	-82.5	+31.1	+100.4	
Critical press. (Atm.)	45.8	73.0	88.9	
Odour	None	None	Rotten egg.	

Anaerobic Digesters however, carried on their development along two major routes. Firstly as a pollution control route for sewage and indutrial wastes. Secondly as a means of material and fuel conservation for small village and town units in developing countries. More recently the higher prices being charged for fuel has revived the interest for digesters on European farms and a bewildering range of digester designs are presently available for a farmer's selection.

BASICS OF METHANE FERMENTATION

The generation of methane from organic matter is achieved by the use of naturally occurring (fairly ubiquiteously too) microorganisms. These create one of natures alternative routes to conventional aerobic decay.

Where insufficient air is available to breakdown natures wastes a whole series of anaerobes (bacteria which exist without oxygen) step in. If the temperature is sufficient this degradation can be carried as far as the production of methane.

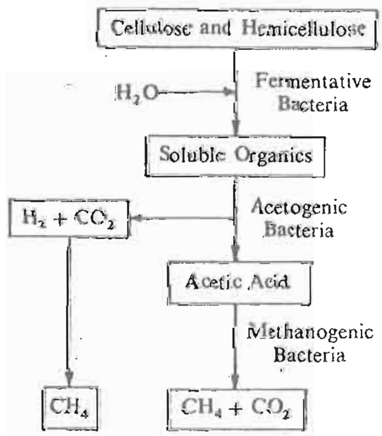


FIG. 1. Anaerobic fermentation of organic solids.

The process is not a simple one and is made up of many differing groups of organisms but can be most simply shown as a three stage process. (see Fig.1). Firstly the cellulose and hemicellulose is broken down to smaller more soluble organics by fermentative bacteria. Next acetogenic bacteria set to work producing acetic acid, other fatty acids plus hydrogen and carbon dioxide. Finally the methanogenic bacteria take both fatty acids and the carbon dioxide/hydrogen mixture and produce methane and carbon dioxide.

Each of these stages is equally important and all the groups of bacteria have to have their needs satisfied otherwise instabilities set in. On the whole each stage satisfies the other so that the only parameters which have to be controlled are temperature and feed rate.

FACTORS AFFECTING METHANE PRODUCTION

In real life many factors affect the production of methane by anaerobic digestion. However usually only a few of the parameters need to be controlled or monitored. The complete breakdown of material anaerobically takes from 10 to 20 days at a temperature of 30°C therefore the flow rate through the digester is an important factor which has to be controlled.

The other factor which has to be controlled is temperature. In normal (mesophillic operation) conditions this means that the temperature has to be maintained between 30 and 40°C. To optimise the gas production it is best that the temperature be controlled to within 1°C at any selected temperature in the above range. Fig. 2 shows the effect of both temperature and retention time upon the gas yields from a digester. In this case the results are for sewage but similar curves are exhibited on most raw materials.

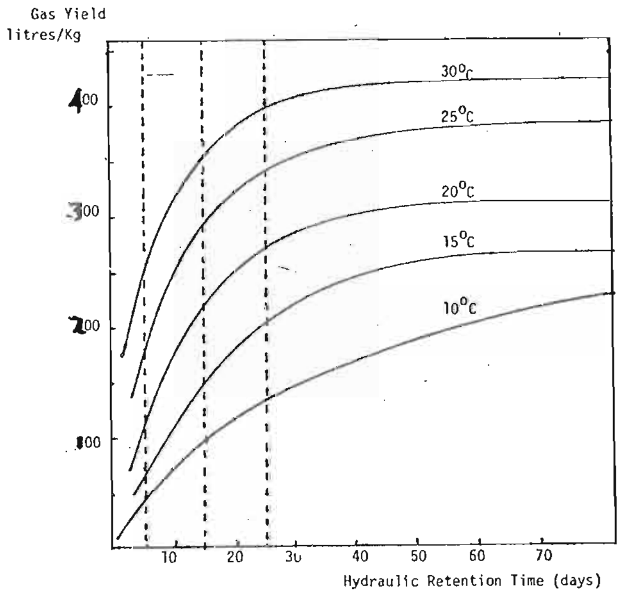


Fig.2. Gas Yields Versus Retention Time.

One parameter which usually cannot be controlled is the raw material. Table 2 shows the typical composition, gas yield and calorific value of biogas produced from the batch digestion of a range of different materials. As can be seen the gas yields can vary quite immensely as can the percentage methane. Some of the plant leaves giving the best results, both in quantity and quality of gas produced.

FERTILIZER VALUE OF THE RESIDUES

Biogas has one major advantage over other forms of fuel production from waste, it does not eliminate nitrogen. All the nitrogen in the original material remains there. Table 3 shows the typical effect of digestion upon a piggery waste.

As can be seen almost 50% of the solids are converted into biogas. Almost 80% of the fatty acids which are to some extent responsible for the bad odours of many wastes are also removed.

Table 2. Gas Yields from Various Substrates.

Organic matter digested	Specific production (litres/kg organic)	% CH in digester gas	Calorific value (MJ/m^3)
Dairy cattle waste	315	80·2	28·8
Cattle waste	342	75·5	27·0
Pig waste	415	80·8	28·9
Wheat straw	367	78·5	28·1
Wheat straw 3 cm	383	80·2	28·8
Wheat straw 0·2 mm	423	81·3	29·1
Clover	445	77·7	27·9
Grass	557	84·0	30·2
Turnip leaves	496	84·0	30·1
Sugar beet leaves	501	84·8	30·3
Potato stems	606	74·7	26·7
Maize stems	514	83·1	29·8

Reference: Rheinhold and Noak.[1]

The Oxygen Demand of the waste whether measured by chemical or biological means is significantly reduced while the nitrogen level does not change. Therefore most suitable organic wastes may be converted into a useful less odorous and less polluting irrigation/fertilizing slurry by anaerobic digestion.

Table 3. Characteristics of Input and Output of Digester.

	Ten-day detention Input	Output	% Reduction
Total Solids (%)	4	2·2	45·0
VFA (ppm)	5226	1113	78·7
NH_3N (ppm)	2122	2171	Nil
BOD (ppm)	21055	5333	74·7
COD (ppm)	72480	41938	42·2
Gas/kg TS added		0·300 m^3	

Table 4. Composition of Input and Output of Digester.

	Input (% DM)	Output (% DM)
Ash	14·0	15·4
Protein N (Protein)	3·2 (20·0)	4·1 (25·6)
NH_3N (NH_3)	2·1 (2·6)	2·7 (3·3)
Fat	13·7	9·4
NDF	45·2	41·3
P_2O_5	3·6	6·0
K_2O	1·1	1·4
ADF	23·6	25·6
Lignin	8·1	11·8

NDF = Neutral detergent fibre. Cellulose, hemi-cellulose and lignin.
ADF = Acid detergent fibre. Cellulose, lignin.

Table 4 shows that there is an increase also in protein content of the solids in the digester effluent. This is being closely investigated around the world as a possible source of animal feed.

Anaerobic digestion has one other 'grace'. The temperature and length of time required to produce methane also reduces the population of many pathogens. See Table 5.

DIGESTER TYPES.

As mentioned earlier there are a staggering variety of digester designs available around the world. It will be useful if I describe three types of digesters which are more numerous than most.

Table 5. Survival of Pathogenic Bacteria during Anaerobic Digestion.

Bacteria	Digestion No.days	Removal %	Remarks.
Endamoeba hystolytica	12	<100	Greatly reduced populations at 20°C.
Salmonella typhosa	20	92	85% reduction in 6 days retention.
Tubercle bacilli	35	85	Digestion cannot be relied upon for complete destruction.
Escherichia coli	49	<100	Greatly reduced populations at 37°C about the same reduction in 14 days at 22°C.

(a) The 'High Rate' Digester:- This is the digester which is most accepted in Western Europe and U.S.A. To be classified as 'High Rate' it requires to be a heated and stirred reactor. Many different designs are available, Figure 2 shows but one. These type of digesters have been built at many thousands of sewage works as secondary sludge treatment units. They are also becoming increasingly popular with large farmers.

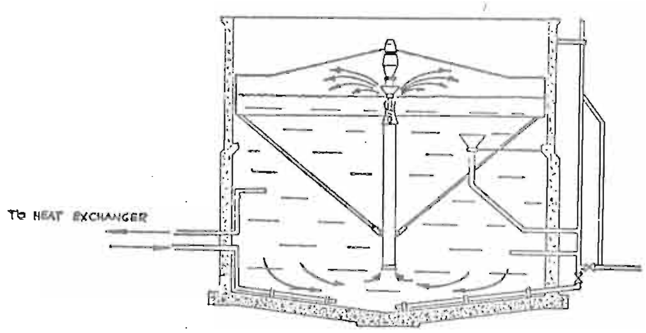
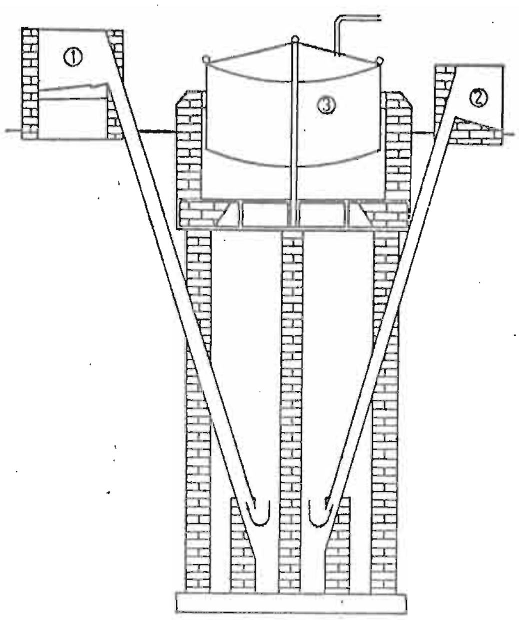


Fig. 2. The 'High Rate' Digester.

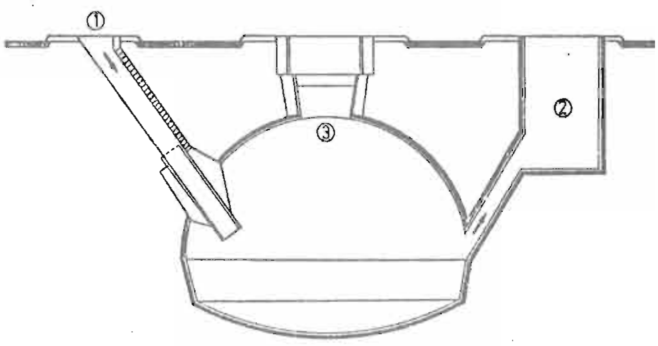
(b) The Gobar Gas Digester:- This type of digester has been designed specifically with rural India in mind (see Fig.3). It is a displacement type digester where cattle waste is added at one side and the effluent overflows at the other. In most of these type of digesters there is an integral gas holder built on top of the digester. Their sizes range from 4m³ to 140m³ and are usually constructed from brick with a metal gas holder. Most are fed with a mixture of cattle dung and night soil. Presently over 70,000 of these plants are reported to be in operation most being backed by government aid, though the plan is seen as a political failure mainly due to the amount of capital required per digester.

Fig. 3. The Gobar Gas Digester.



(c) The Chinese Digester:- These are operated on a semi-continuous basis being fed once a day. The digesters are usually constructed from concrete and bricks. The suspended solids tend to accumulate in the main body of the digester and have to be dug out two or three times per year. It is claimed that there are seven million of these digesters in operation of sizes varying from 6 to 8m³ (see Fig. 4).

Fig. 4. The Chinese Digester.



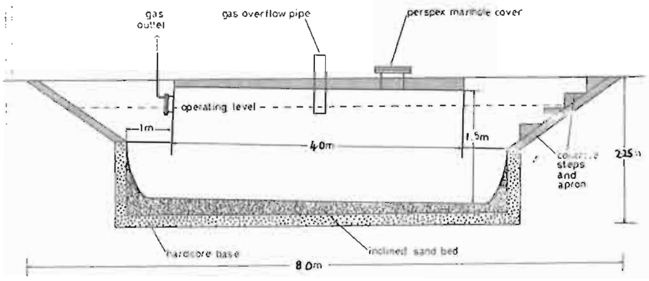
THE DESIGN OF A DIGESTER SUITABLE FOR NIGERIA.

The University of Ibadan decided to build up a University Consultancy Group and one area that this group found to be of particular interest was anaerobic digestion, especially for the production of electricity in rural areas.

The organic feedstocks to be investigated are based upon crop wastes and will be supplemented by night soil and/or animal wastes. In that way local wastes can be converted into fuel and fertilizer while minimizing water losses and assisting with sanitation problems.

The type of feedstock envisaged is likely to be suitable for a digester designed for high solids, i.e. above 10% by weight, therefore the mixing has been minimised. The local high ambient temperature also minimizes the amount of heating required. The daily temperature variation however suggests that insulation could be important. The digester decided upon therefore a horizontal 'plug flow' type of digester as shown in Fig. 4 made of a fibre glass sewer pipe (in this instance but could be made of any local material.)

Fig. 5. The Plug Flow Digester



PLUG FLOW DIGESTER

Mixing and heating will be carried out by means of a mild steel pipework within the digester which can be rotated by chain and pulley whilst hot water is pumped through it. The digester will be installed in the ground so giving natural insulation from daily temperature changes.

The gas will be piped from the digester to a fibreglass gas holder and then through a gas scrubber to remove the CO_2 and on to a small electrical generator.

Three $3m^3$ digesters have been shipped to Ibadan from Cardiff at the time of going to print, and are due to be installed and commissioned during the month of July.

The digesters will work in parallel on different wastes and will hopefully demonstrate the suitability of this type of digester for power generation. The final figure, Fig. 6, gives an artist's impression of the proposed research facility with storage clamps on the right for digester feed solids and fertilizer sludge bays on the far right of the three digesters.

These three digesters when in optimum operation should be able to produce 10 to $20m^3$ of gas per day, i.e. 250 to 500 HJ of energy per day. If converted to electricity at a conversion rate of 30% this will give 2 to 4 Kwh for 1 - 2 hours every day plus 150 to 300 HJ of hot water per day.

Ref 1. Reinhold and Noak)1956)
Methan ans Klarschlamm und mist
Verlag Von Oldenburg. Munich.

Ref. 2. Stafford, Wheatley and Hughes.
Proc. 1st International Symposium on Anaerobic Digestion.
Applied Sciences 1980.

Fig. 6. Arists's Impression of the Anaerobic Digestion Research Facility at Ibadan.