PN-AAU-632
44160

DYNATECH R/D COMPANY

PROCEEDINGS

INTERNATIONAL WORKSHOP ON
BIOENERGY RECOVERY AND CONSERVATION

Topic:

"Low Capital Cost Fuel Gas Production
from Combined Organic Residues"

October 31, November 1-2, 1984

Held at:

The Museum of Science,
Boston, Massachusetts, U.S.A.

Sponsored by:

The U.S. Agency for International Development
Under Contract DPE-5542-C-00-3050-00
To Dynatech R/D Company,
99 Erie Street, Cambridge, MA 02139, U.S.A.

a division of DYNATECH CORPORATION

SUMMARY

PROCEEDINGS:

INTERNATIONAL WORKSHOP
ON BIOENERGY RECOVERY AND CONSERVATION

The International Workshop on Bioenergy Recovery and Conservation, including presentation of projects under sponsorship of the U.S. Agency for International Development, was held in Boston, Massachusetts, October 31, November 1, and 2, 1984. The major focus of the workshop was on the topic of low capital cost fuel gas production from combined organic residues. Presentations were on laboratory evaluations of the anaerobic digestion of agricultural residues, industrial wastes, and municipal solid wastes. This present document is a compilation of the reports presented at this workshop and, therefore, constitute the proceedings of this international meeting. The reports of the workshop in these proceedings are by alphabetical order by the presentor.

INTERNATIONAL WORKSHOP
OF BIOENERGY RECOVERY AND CONSERVATION

Tuesday, October 30, 1984

Individual arrival at:

The Charles River Motel
1800 Soldiers Field Road
Brighton, MA 02135
Tel. (617) 254-0200

Wednesday, October 31, 1984:

08:00 AM	Bus departs from the Charles River Motel to the Museum of Science (Workshop will be in the Morse Auditorium.). Coffee and danish will be available at the Workshop.	
09:00	Introduction	Mr. Alfred P. Leuschner Workshop Moderator Dynatech R/D Company
09:15	Welcome	Mr. Robert G. Kispert President Dynatech R/D Company
09:30	Overview of A.I.D. Programs from the Office of the Science Advisor	Dr. Irwin Asher U.S. Agency for International Development
10:00	A.I.D. Project in Guatemala	Dr. Carlos Rolz Central American Research Institute for Industry
10:45	Break	
11:15	A.I.D. Project in Portugal	Dr. Antonio V. Xavier New University of Lisbon
12:00	Lunch (in Morse Auditorium)	

INTERNATIONAL WORKSHOP
OF BIOENERGY RECOVERY AND CONSERVATION

Wednesday, October 31, 1984 (cont'd):

02:00 PM	A.I.D. Project in Thailand	Ms. Napha Lotong Kasetsart University
02:45	Overview of A.I.D. Programs in Energy Recovery	Dr. Paul Weatherly U.S. Agency for International Development
03:15	Break	
03:45	Bioenergy Recovery and Conservation in Singapore	Dr. Kee Kean Chin National University of Singapore
04:30	Bioenergy Recovery and Conservation in India	Prof. V.V. Modi University of Baroda
05:15	Cocktail Hour (in Skyline Room, 6th Floor)	
06:15	Banquet (Welcome)	Donald L. Wise, Ph.D. Vice President Dynatech R/D Company
09:00	Bus returns to the Charles River Motel.	

NOTE: All technical presentations are scheduled for 45 minutes and will consist of a 30 minute presentation followed by a 15 minutes question and answer period.

INTERNATIONAL WORKSHOP
OF BIOENERGY RECOVERY AND CONSERVATION

Thursday, November 1, 1984

08:00 AM	Bus departs from the Charles River Motel to the Museum of Science Coffee and danish will be available at the Workshop.	
09:00	Bioenergy Recovery and Conservation in Indonesia	Dr. Suhirman Jakarta, Indonesia
09:45	Bioenergy Recovery and Conseration in Hong Kong	Dr. M.H. Wong The Chinese University of Hong Kong
10:30	Break	
11:00	Bioenergy Recovery and Conservation in the Philippines	Dr. William G. Padolina University of the Philippines at Los Banos
11:45	Lunch (in Morse Auditorium)	
	Overview of Pertinent International Meetings, including AD'85	Mr. Ralph L. Wentworth (Vice Chairman of AD'85 to be held in China) Dynatech R/D Company
02:00 PM	Bioenergy Recovery and Conservation in Israel	Dr. Uri Marchaim
02:45	Bioenergy Recovery and Conservation in Egypt	Dr. M. Nabil Alaa El-Din Agricultural Research Center
03:30	Break	
04:00	Bioenergy Recovery and Conservation in Spain	Dr. Joan Mata Universidad de Barcelona
06:00	Cocktails and dinner at Engineering Club, Prudential Building, Boston, Massachusetts (access to "Skywalk" atop Prudential Building)	
09:00	Free evening in Boston or bus from Prudential to Charles River Motel.	

INTERNATIONAL WORKSHOP
OF BIOENERGY RECOVERY AND CONSERVATION

Friday, November 2, 1984

08:00 AM	Bus departs from the Charles River Motel to the Museum of Science. Coffee and danish will be available at the Workshop.	
09:00	Anaerobic Digestion Experiments in Guatemala	Mr. Jose Francisco Calzada Central American Research Institute for Industry
09:45	Bioenergy Recovery and Conservation in Peru	Dr. Javier Verastegui Lima, Peru
10:30	Break	
11:00	Bioenergy Recovery from Municipal Solid Waste in the United States	Alfred P. Leuschner Dynatech R/D Company
	Engineering Analysis	Mostafa A. Sharaf, Ph.D. Dynatech R/D Company
12:00	Lunch (in Morse Auditorium)	
	Review List of Discussion Topics)	
02:00 PM	Discussion/Conclusion/Implementation	Group Discussion
04:00	Closure	
	Individual Departures	

INTERNATIONAL WORKSHOP

OF BIOENERGY RECOVERY AND CONSERVATION

PRESENTORS

Dr. M. Nabil Alaa El-Din
Head of Research Microbiology
National Director, Biogas Project
Agricultural Research Center
Giza, Egypt

Dr. Kee Kean Chin
Professor, Department of Civil Engineering
National University of Singapore
Faculty of Engineering
12 B Patterson Hill
Singapore 9

Ms. Napha Lotong
Assistant Professor
Department of Microbiology
Kasetsart University, Bangkok
c/o E.J. Briskey
USAID, Box 47
A.P.O. San Francisco, CA 96346, U.S.A.

Dr. Uri Marchaim
Project Director
MIGAL
South Industrial Area
Kiryat - Shmona 12-210
ISRAEL

Dr. Joan Mata
Senior Lecturer
Universidad de Barcelona
Facultad de Quimica
Diagonal 647
Barcelona 28
Spain

Dr. V.V. Modi
Professor and Head
Department of Microbiology
The Maharaja Sayajirao University of Baroda
Baroda - 390 002
India

Dr. William Padolina
Department of Chemistry
University of the Philippines at Los Banos
College, Laguna 3720
Philippines

RE: International Workshop on
Bioenergy Recovery and Conservation
PRESENTORS (cont'd)

Dr. Carlos Rolz
Head, Applied Research Division
Investigacion y Technologia Industrial
Avenida La Reforma 4-47
Zona 10 - Guatemala

Mr. Jose Francisco Calzada
Central American Research Institute for Industry
Avenida La Reforma 4-47
Zona 10 - Guatemala

Dr. Suhirman
Head, Microbilogy Laboratory
Kantor/Office
Lembaga Biologi Nasional
J.L. IR.H. Juanda 18, Bogor
Indonesia

Dr. Antonio V. Xavier
Department of Chemistry and Biotechnology
Universidade Nova de Lisboa
Quinta da Torre, 2825 Monte da Caparica
Portugal

Dr. Javier Verastegui
Jr. Morelli 2da. cda.-esquina av. de las Artes
(altura duadra 21 av. Javier Prade Este)
San Borja - Surquillo, Lima 34
apartado 145, Lima, Peru

Dr. M.H. Wong
Senior Lecturer
Department of Biology
University Science Center
The Chinese University of Hong Kong
Shatin, NT
Hong Kong

Alfred P. Leuschner
Manager, Environmental Engineering
Dynatech R/D Company
99 Erie Street
Cambridge, Massachusetts 02139, U.S.A.
(Mr. Leuschner will be Workshop Moderator)

RE: International Workshop on
Bioenergy Recovery and Conservation
PRESENTORS (cont'd)

Dr. Paul Weatherly
U.S. Agency for International Development
Washington, D.C. 20523, U.S.A.

Dr. Irwin Asher
U.S. Agency for Internatial Development
Washington, D.C. 20523, U.S.A.

Dr. Donald L. Wise
Vice President
Dynatech R/D Company
99 Erie Street
Cambridge, Massachusetts 02139, U.S.A.

Mr. Robert G. Kispert
President
Dynatech R/D Company
99 Erie Street
Cambridge, Massachusetts 02139, U.S.A.

Mr. Ralph L. Wentworth
Vice President
Dynatech R/D Company
99 Erie Street
Cambridge, Massachusetts 02139, U.S.A.

Mr. Rui F. Afonso
Senior Staff Engineer
Dynatech R/D Company
99 Erie Street
Cambridge, Massachusetts 02139, U.S.A.

Mostafa A. Sharaf
Senior Staff Engineer
Dynatech R/D Company
99 Erie Street
Cambridge, Massachusetts 02139, U.S.A.

Mr. Ford A. Daley
Marketing Representative
Dynatech R/D Company
99 Erie Street
Cambridge, Massachusetts 02139, U.S.A.

"AGRICULTURAL WASTES"

Report Presented By:

Dr. Joan Mata
Senior Lecturer
Universidad de Barcelona
Facultad de Quimica
Diagonal 647
Barcelona 28,
SPAIN

UNIVERSITAT DE BARCELONA
CENTRE DE CALCUL

INTRODUCTION

BEST AVAILABLE

AGRICULTURAL WASTES

There are large quantities of biomass available in crop residues in Spain. Nevertheless, it is rather difficult to know accurately the characteristics of each type of them, their volume, uses, etc.. The reasons are that some of them are used without being identified and that they are spread all over the country. When compared with the whole volume of wastes they represent more than 50%, as shown in table 1.1.(Enseñat, 1980)

Among crop residues, cereal straws are the most significant and among them, barley straw is the most important, with an average production of 6.200.000 Ton per year (see table 1.2).

In Spain, the agricultural area used for production of the main cereals (barley, wheat and oats) amounts to 6.6 millions hectares. The output of straw comes to around 10.5 million tons, with an average straw-to-grain ratio of 0.78 for wheat, 0.80 for oats and 0.86 for barley. Thus the average density, of harvestable straw for dry and irrigated land is about 1.59 tons per hectare (see table 1.3)

Although it is the most significant crop residue, there are no accurate figures for the use of straw. Nevertheles, when compared with Italy and France, with similar levels of productions, as shown in table 1.4, harvested straw in Spain, probably represent about 70% of total straw production, the remainder - at least 30% - being burnt or buried on the spot.

Harvested straw is used for different purposes as shown in table 1.5.Although the amounts are not available, its use for animal feeding - especially legominous straw due to its high protein content - and bedding for animals are the most significant.

Upgrading for direct energetic uses is still marginal, even today mainly because of economic reasons. However, anaerobic digestion appears to be the most feasible, the major reason being its fairly low investment costs.

BEST
AVAILABLE

ANAEROBIC DIGESTION OF AGRICULTURAL RESIDUES

Anaerobic digestion appears to be a feasible solution for a direct energetic use of crop residues, especially for those with a high water content (i.e., corn stover, sun-flower stalks, etc.) Although, as mentioned before, some of them can be used as animal feed or as a fertilizer, sometimes they occur in too large quantities, which can cause environmental problems. Moreover, in many areas, surpluses of straw occur, and if the price is not high enough the farmer could decide not to collect it. Non harvested straw can only be either chopped up and ploughed back into the soil (with an extra cost and problems with heavy soils which do not allow the straw to decay to a sufficient extent) or burnt on field (with the disadvantages of environmental hazards and the destruction of the existing humus) As pointed out in table 1.4 this surplus represents an average of 3.3 million Tons per year. Mean composition of straw is shown in table 1.6. In accordance with these figures this residual straw represents a potential of 600.000.000 of Nm3 methane per year, that is, 6.000.000.000 ther. per year.

All these wastes, straws and crop residues in general, either on their own or combined with manures, are perfectly digested in the old well known batch system. This technique, commonly known as "dry fermentation", is ideal to minimize handling and digestion control, and has been used on a practical scale by farmers in Europe. This type of digestion was first studied by Buswell (Buswell and Hatfield, 1936) but with no information on the kinetic aspects. Further expansion of the technology occured during the late 1950' (Keefer, 1947 and Schulze, 1958), and, especially during the 70's, due to the studies of Golueke dealing with solid wastes management (Golueke and McGauhen, 1970 and Golueke, 1974). Other valuable work was carried out by Pfeffer. The subject of his study was primarily devoted to municipal solid wastes (Pfeffer,1974 and Pfeffer and Liebman,1974). More recently, Wise and co-workers have done a comprehensible study on combined organic residues (Wise et al., 1981), and Jewell and co-workers at the Cornell University have also studied the dry fermentation process of straw (Jewell, 1981,1982)

In Spain there have been some studies on this concept carried out in a semi-technical scale by Mata (Mata, 1984). The general aim of study was to develop a low cost approach to digest solid waste, i.e., crop residues that do not have free water in void spaces. This kind of system should have two main characteristics:

First of all a very low capital investment is required; therefor efforts were concentrated on developing a cheap digester similar to that shown in figure 1.5. In fact this

BEST AVAILABLE

CENTRE DE CÀLCUL

reactor is designed to be made by the farmer himself, with the aid of his own tractor. Thus, the cost and the definite shape of it will be strongly influenced by the specific characteristics of the soil and the possible shapes of the site. As can be seen in figure 1.1 this system uses the concept of leachate recycle which has proved to be very effective in biogas enhancement (Wise, 1983).

According to Klink and Yuen (1981) the reasons for the increase of gas production rates from leachate movement are most probably due to one or more of the following effects:

Maintenance of desirable humidity levels through the reactor.

Maintenance of a suitable pH value throughout the digester and with a greater uniformity.

A better distribution of buffer and nutrients

A dilution of inhibitory and/or toxic substances

A better distribution of enzymes

A better distribution of methane formers.

Secondly, the system should be designed in such a way as to minimize handling and residue pretreatment (both chemical or mechanical). The idea would be to load the reactor only seasonly, in order to keep labor requirements to a minimum level.

The study of Mata was part of an international program entitled "Low Capital Fuel Gas Production From Combined Organic Residues". The program was supported by the A.I.D. and coordinated by D.L. Wise. As barley straw is the main agricultural waste in Spain, it was mainly devoted to this particular crop residue. The rest of the communication is devoted to this work.

UNIVERSITAT DE BARCELONA

CENTRE DE CÀLCUL

BEST AVAILABLE

AIM OF THE STUDY

The aim of the study was to assess the possibilities of a very simple system to obtain reasonably good biogas yields. The attainment of optimal operational conditions was also pursued in order to scale up the process to a real situation. In this respect, the need and influence of nutrient and buffer addition was tested. For design purposes a kinetic study was also done. These data are used in the assessment of the economic feasibility of the project. Finally technological problems (i.e. liquid distribution, frequency of recycling, piping clogging, etc.) were also evaluated

UNIVERSITAT DE BARCELONA

BEST AVAILABLE

EXPERIMENTAL STUDY

EXPERIMENTAL DEVICE

Four digesters were built for this study. Each of them was made from 200 liter drums and modified specifically for this study. Figure 2.1 sketches one of this reactors. A cement base was installed into the bottom of each reactor sloping down to leachate drain. A 5 liter bottle was provided to collect the leachtate so as to prevent the recycling pump from running without load. Over the cement base, crushed stone was installed to allow the leachate to freely flow out of the reactor through the drain. An additional inlet for nutrient and/or buffer addition was also provided. Barley straw was placed in each reactor without any kind of compaction.

REACTOR LOADINGS

Each reactor was filled with barley straw. Fresh cow manure was added as inoculum of hidrolitic bacteria as well as digested pig manure as a source of methanogenic bacteria and nitrogen. Both manures are readily available to the farmer. The proportion of digested slurry was that so as to balance the ratio C|N to about 1|25-30. Finally water was added to bring the digester to a reasonable level of moisture. As stated in different studies the total water content should not be less that 70% (De Walle et al. 1979) As the pH of digested pig manure was over 8 no attempt was made to provide the digesters with buffer, at least during the firsts stages of the digestion. The only factor tested in this study was the level of cow inoculum, as hydrolitic inoculum. Table 2.1 shows the initial content of each digester whereas table 2.2 shows the average composition of the initial biomass.

OPERATIONAL METHODS

Each reactor was operated with leachate collection and recycled by means of a pump (figure 2.1). As mentioned before This system has proved to be very effective in enhancing gas production, when tested with municipal solid waste digestion in landfills. The recirculation of the liquid took place 5 times a day for 20 seconds. This time allowed 4 liters to be recirculated. The digesters were placed in a thermostated room. The temperature was controlled at 35 C.

UNIVERSITAT DE BARCELONA

BEST AVAILABLE

CENTRE DE RECURS

Gas measurement was achieved by means of a simple water displacement system.

ANALYTICAL PROCEDURES

On a regular basis, solids, leachtate and gases were analysed to asses the performance of the digesters. Table 2.3 presents a summary of the parameters measured and the frequency of their measurements. The straw and inoculum were analysed prior to placement into the reactors. These parameters included Total Solids (TS), Total Volatile Solids (TVS), Chemical Oxigen Demand (COD), Total Kjendhal Nitrogen (TKN), Total Phosphorus (TOT.P) and Fibers (cellulose, hemicellulose and lignine - CEL, HEMCEL, LIGN -).

The leachtate from the digesters was regularly analysed. On a weekly basis Alkalinity, pH, Total Volatile Acids, (TVA) Ammonia Nitrogen (N), TS, TVS from leachate and gas composition were determined. The gas evolved was measured daily during routine operations of maintenance.

UNIVERSITAT DE BARCELONA

CENTRE DE CÀLCUL

BEST AVAILABLE

RESULTS

Before starting the experiment, straw, cow inoculum, plus the added water were placed together in the digester for four days. Liquid recirculation was provided in order to homogenize the contents. The digestion period lasted about 100 days. After that point biogas production was very low. Gas production started almost immediately, as a result of the methanogenic inoculum introduced in the reactors. The particular behavior of each digester was as follows:

Digester D1

Digester D1 achieved its maximum gas production on day 27. On day 50 this digesterr received two liters, in order to bring the moisture level of all the reactors to the same level (that expressed in table 2.1). As a result the gas production rate dropped dramatically, but, after a few days it increased again, reaching the levels that could be expected. Figure 3.1 presents daily methane production. (Table A-1 of Appendix shows the data from which it was constructed). Mean biogas composition was 51%. The quality of the leachate produced is presented in figures 3.9 to 3.12 (data used for their construction are in tables A-2 to A-6 in Appendix A). As can be seen Alkalinity dropped around day 50 as a consequence of water addition. Nevertheless it soon went up again because of the high pH. (See table A-6 in Appendix A). TS and TVA (figures 3.9 and 3.12) experimented a regular reduction without being significantly affected by the addition of water. This could be explained because of the limiting effect of the hidrolilic step. (After day 50-55 their levels remained fairly constant). The percentage of VS in leachate was gradually decreasing as the percentage of inert components was increasing (Figure 3.10). The accumulated methane production on day 110 was 220 liters (STP).

Digester D2

Digester D2 showed a more homogeneous behavior. From the start of the operation this digester achieved a high level of methane production (figure 3.2). This level was maintained during the first 30-37 days. Water addition to this digester did not affect it to the same extent as in digester D1. The reasons for this are that a smaller quantity of water (2 liters) was used and, also, the lower rate of biogas production at that moment. Leachate quality in digester D2

BEST AVAILABLE

is presented, as before, in figures 3.9 to 3.12 (Appendix tables A-2 to A-4). Nothing special can be stated except that the leachate of this digester, together with that of digester D1, exhibited the highest level of alkalinity. This could be explained by the higher content of inoculum. The accumulated methane production on day 110 was 000 liters (STP). The average percentage of methane was about 50%.

Digester D3

Digester D3 exhibited a similar behavior to digester D2. Daily methane production is presented in figure 3.3. Figure 3.7 shows the accumulated production (see table A-4 for details). The percentage of methane, as in the other reactors, reached 50% shortly after gas production started and remained between 50 and 55%. The pH of the leachate was relatively high as in the other cases (see table A-6). This was caused by the high pH of the manure used as inoculum (see table 2.2). Leachate quality data is again presented in figures 3.9 to 3.12. As can be seen a sharp drop in alkalinity occurred around day 50. This was due to the gradual addition during 4 days of 1 liter of 1N hydrochloric acid in order to reduce the pH value, and in this way to achieve an improvement in the bacterial environment. No effect was observed on biogas production, due to the high buffered medium. The pH stayed around the same values and, after a few days alkalinity reached its usual values. The rest of the observed parameters exhibited a behavior similar to the other digesters. The accumulated methane production on day 110 reached 157 liters at STP. The average percentage of methane was about 50-53%.

Digester D4

Digester D4 like the others was operated with leachate recycle but with no water addition. Figures 3.4 and 3.8 present data on daily and accumulated methane production respectively. The behavior is quite similar to that of digester D3, except for the sudden increase in methane production which occurred on day 90. A possible explanation for this increase is given in the discussion of the results. The leachate quality over time is presented in figures 3.9 to 3.12. The only noteworthy thing is that the alkalinity level did not drop because no liquid addition was made. Nevertheless an increase in alkalinity was observed about day 70-75, that is, a little before the sudden increase on biogas production mentioned earlier.

BEST AVAILABLE

CENTRE DE CÀLCUL

DISCUSSION OF THE RESULTS

A first evaluation of the data presented in the previous section is the estimation of B0, the ultimate methane yield of the organic mixtures. The units of this parameter are m3 of methane (STP) per kg of VS added to the digester. B0 constitutes a good measure of the biodegradability of a particular waste. There are several methods to evaluate B0. In this study it was achieved directly from experimental results by plotting the accumulated gas production B per unit VS added against the reciprocal of batch fermentation time (figures 3.13 to 3.16) and extrapolating the resulting straight line (Hashimoto, 1983).

The resulting values are presented in table 3.1, where the initial content of cow manure, and the ratio of dry matter of both components are also shown. Plotting these B0 values against cow manure content the value of B0 decreases as the fraction of VS of straw in the mixture increases (figure 3.17).

Similar results were obtained by Hashimoto during the batch fermentation of mixtures straw-cow manure at thermophilic temperatures in a laboratory scale (Hashimoto, 1982). Hashimotos's B0 values for pure wheat straw was about 260 l/kg VS, and about 380 for cow manure. Nevertheless, the observed values for the straw in the present study, could be a little underestimated. This is because when the digesters were opened, some of the initial straw appeared undegraded. This straw was right in the leachate non-accesible places, and, of course, this circumstance affects to some extent the B0 calculations.

Jewell worked on a similar system but with a 100 m3 digester. The employed mixture consisted of 8150 Kg Vs from wheat straw and 1760 Kg from digested dairy cow manure, added as inoculum (Jewell, 1982). The cumulative methane production was 1226 m3, that is, 128 liters per kg VS added. This yield is similar to that obtained in the present study (D1, 208; D2, 200; D3, 150 and D4, 190), but even considering all the differential factors, the yield is smaller. The same happens when comparing the own yields obtained by Jewell on a laboratory scale (140 l/Kg VS added) after 100 daysse.

After considereing the results of Hashimoto and Jewell, and those of the present study, it appears that smaller yields are obtained when the scale of operation is greater. This is, of course, a general phenomena, but with this type of "dry fermentation" systems it could be strongly influenced by the design of the leachate recycle distribution grid.

UNIVERSITAT DE BARCELONA

BEST AVAILABLE

Kinetic study

Quantifying reactor performance can be accomplished by mathematically modeling the results of each reactor. Each reactor was operated as a batch system, thus it is assumed that the rate of substrate disappearance and consequently methane formation will follow the laws of first order batch kinetics (Jewell, 1980, Wise, 1982).

The rate equation for first order kinetics is given by

$$dS/dt = -kS$$

where S is the available substrate concentration. The remaining substrate concentration S is related to methane production by the Hashimoto approach (Hashimoto, 1982)

$$(B0-B)/B0 = S/S0$$

where $S0$ is the initial quantity of biodegradable substrate, $B0$, the ultimate methane yield and B the accumulated methane production. Thus, the integrated equation, becomes:

$$B = B0\ (1 - \exp(-kt)\ )$$

where k is the substrate decay rate coefficient (1/days) and t, time (days).

The higher the value of k, the more rapid the degradation and thus the greater the quantity of methane being produced with time.

By plotting (B0 - B)/B0 against time on a semi log graph, the rate of substrate degradation k can be determined. The following are the resultant values:

D1	k=0.0084	r=0.994
D2	k=0.0111	r=0.995
D3	k=0.0100	r=0.999
D4	k=0.0127	r=0.998

This values are within the range of those obtained by Jewell for wheat straw in the above mentioned work (Jewell, 1982).

As the cow manure added as inoculum was the only differential factor between the 4 digesters, the different decay rates obtained should quantify the resulting enhancement effect. But, after examining the obtained coefficients, no clear conclusion can be reached.

UNIVERSITAT DE BARCELONA

BEST AVAILABLE

CENTRE DE CÀLCUL

The higher value of the decay rate observed in digester D4 is related to the sudden increase in biogas production achieved on day 86, as previously mentioned. The explanation given is that a non degraded portion of organic mixture fell down to a zone where the liquid could effectively leach out the soluble components, and, as a result, the methane production rate increased. This effect is related to the increase of alkalinity achieved some days before.

On the other hand digester D1 with the highest cow manure ratio (0.17 as dry matter) exhibits the lower decay coefficient. As the mean value of k=0.0106 and the differences are about 20% this could only be explained by homogeneity problems of the mixture. As a consequence no net effects can be concluded about cow manure addition, that is to say, the level of the cow inoculum does not affect gas production.

BEST AVAILABLE

CONCLUSIONS

This study documents the effects of recycling on biogas enhancement. Enhancement is a new technology for landfill gas recovery, while applicable to combined organic mixtures digestion. The results of this work clearly show the need for a good leachate distribution, if not mechanical equipment - even a very simple one - is used.

The moisture level should be kept above 70%, but higher values have similar effects, as comparing the results of different authors. In this study a level of 90% was used, but the limiting factor was the liquid needed to be pumped.

Using digested pig slurry as fresh cow manure as inoculum, there is no need for buffer nor for nutrient addition, when digesting cereal straw. Similar results were found by Jewell (Jewell, 1982).

For the design of a full scale unit, a decay rate coefficient of k=0.0106 can be used. Thus for a small digester to that show in figure 1.1, with a load of 2000 Kg of straw (an hectare of dry land produces 1.4 tons of barley straw, as shown in table 1.3), the following energetic yield would be obtained.

Load every 2 months: 14,400 therms/year

Load every 3 months: 11,800 therms/year

Load every 4 months: 10,600 therms/year

with respective biodegradabel VS reductions of 37, 41 and 72%. The need for cow manure would be about 350 Kg. Water and digested pig manure would be added only the first time, as the methanogenic inoculum would remain in the liquid. This liquid would be used subsequently and additions would be made to replace the leachate removed in the digested mixture. This removal of retained leachate in the digested straw could act as a drain for inert compounds. First time a total amount of 5 m3 of liquid would be needed (3 m3 would be digested pig manure). A variable quantity of water would also be necessary to assure the correct working of the pump.

UNIVERSITAT DE BARCELONA

CENTRE DE CÀLCUL

BEST AVAILABLE

REFERENCES

Buswell, A.M. and Hatfield, W.D. (1936)
State Water Survey Bulletin 32, Urbana, Il

Enseñat, A. (1980)
(In spanish) Seminario sobre la recuperacion de los recursos
de los residuos, Soria.

Golueke, C.G. (1971)
3rd. Annual Report, E.P.A., Whashington D.C.

Golueke, C.G. and McGauhen, P.H. (1970)
1st and 2nd Annual Report, E.P.A., Whashington D.C.

Hashimoto, A.G. (1982)
Biotech. and Bioeng., 25, pp 185-200

Jewell, W.J. et al. (1981)
2nd Int. Symp. on Anaerobic Digestion, Travemunde.

Jewell, W.J. (1982)
Semin. sobre Dig. Anaerobia. Mexico City.

Keefer, C.E. (1947)
Sewage Works Journal, 19

Mata, J. (1984)
"Low Capital Cost Fuel Gas Production From Combined Organic Residues", Dynatech Project AID-1

Pfeffer, J.T. (1974)
Final Report, E.P.A., Whashington, D.C.

Pfeffer, J.T. and Liebman, J.C. (1974)
Annual Progress Report, N.S.F., Whashington D.C.

Requillart, V. (1984)
Biomas News Int., 1.

Schulze, K.L. (1958)
Sewage and Industrial Wastes

Wise D.L. et al (1981)
Resources and Conservation, 6, 275-294

Wise D.L. et (1983)
Personal Communication

SOLID WASTES IN SPAIN		
	(10^6 Tons per year)	
Crop and cattle wastes	116	58%
Municipal waste water treatment plants residues	4	2%
Municipal Solid Wastes	8	4%
Other residues different from domestic refuse	6	3%
Mining wastes	54	27%
Inert industrial wastes	10	5%
Toxic industrial wastes	2	1%

TABLE 1.1

SPANISH PRODUCTION OF STRAWS

Cereals	G/S	1978	1979	1980	1981	1982	1983	1984	media
Wheat	0,78	4028	3038	4612	3087	3374	3377(*)	4680(*)	3742
Barley	0,86	6831	5374	7619	4083	4696	5651(*)	9141(*)	6200
Oats	0,80	458	392	512	371	347	376(*)	664(*)	446
Legominous									
B.Bean	1,00	118	91	98	80	46	41	63	77
F.Bean	1,02	103	98	80	81	74	73	--	85
Chickpea	0,90	68	58	54	31	39	48	57	51
Lentil	1,03	64	53	60	21	28	38	50	45

TABLE 1.2

HARVESTABLE STRAW IN SPAIN

(Average values)

Area used (10^6 ha)	Wheat	2.6
	Barley	3.6
	Oats	0.4

Average grain yields (Ton/ha)

	Dry land	Irr. land
Wheat	1.4	3.6
Barley	1.4	3.2
Oats	1.1	2.3

Harvestable straws (Cereal straws) 10^6 Ton 10.5

Density of harvestable straw (Ton/ha) 1.59

TABLE 1.3

NON HARVESTED STRAW IN 6 EUROPEAN COUNTRIES			
	Straw product.	Non harvested straw	%
Denmark	6.5	2.0	31
Italy	7.5	2.3	31
England/Wales	12.5	7.5	60
Ellas	4.0	2.0	50
France	26.0	8.0	31
Spain(o)	10.5	3.3	31

Data from Requillard,1984
(o) Estimated

TABLE 1.4

USES OF HARVESTED STRAW

Non direct energetic uses

FODDER (Treated or untreated)

BEDDING FOR ANIMALS

ORGANIC FERTILIZERS

PAPER INDUSTRY

Direct energetic uses

COMBUSTION

PIROLISIS

GASIFICATION

ALCOHOLIC FERMENTATION

ANAEROBIC DIGESTION

TABLE 1.5

AVERAGE COMPOSITION OF BARLEY STRAW

TS	92%
VS	78.7% (TS)
COD (g/g TS)	1.1
N/Kj	0.3% (TS)
Hemicel.	43.6%
Cellul.	34.7%
Lignine	6.8%

TABLE 1.6

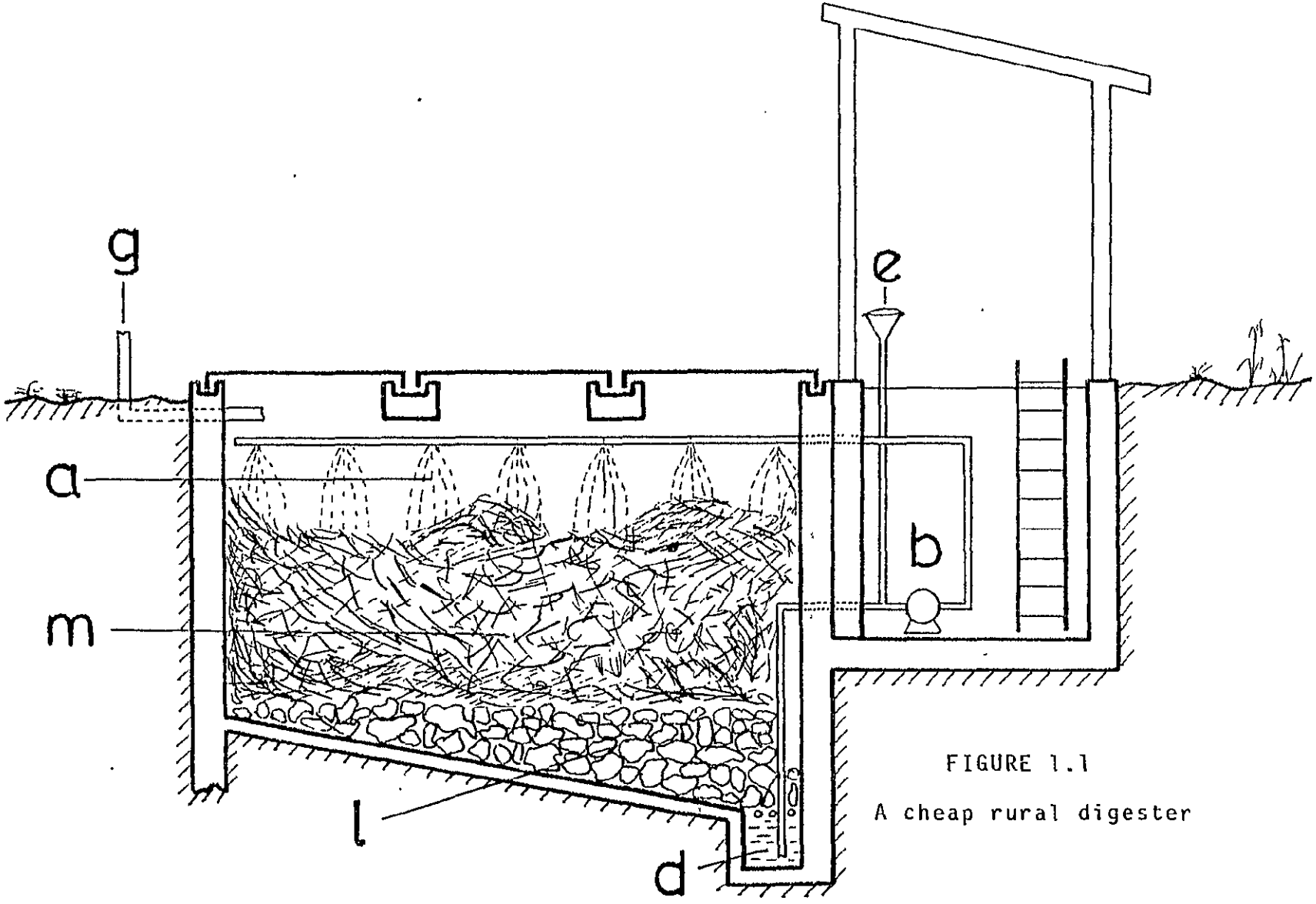


FIGURE 1.1

A cheap rural digester

SKETCH OF THE LABORATORY DIGESTER

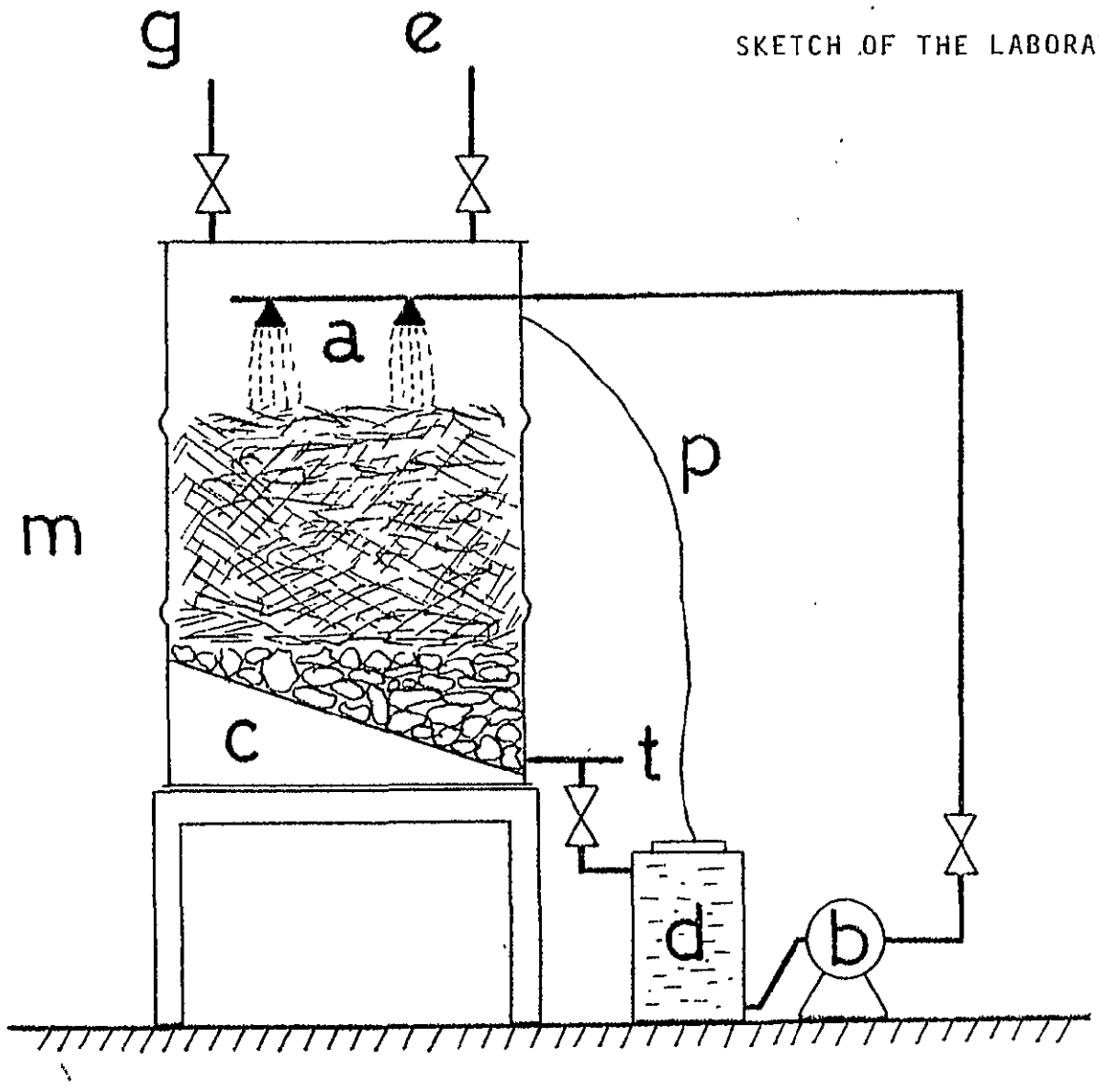


FIGURE 2.1

INITIAL BIOMASS IN DIGESTERS

DIGESTER	Barley straw(Kg)	Fresh cow manure	INOCUL. DIG.(l.)	TS	VS	Dry matter ratio
D1	2,70	1.596,2	4,20	12%	93%	0,17
D2	2,70	678,0	4,25	12%	93%	0,09
D3	2,70	304,0	4,30	12%	94%	0,05
D4	2,70	112,2	4,35	11%	94%	0,03

TABLE 2.1

INITIAL BIOMASS COMPOSITION

BARLEY STRAW

* TS = 93,13%
  VS = 95,10%
  N/Kj = 1,39%

COW INOCULUM

* TS = 22,78%
  VS = 82,85%
  N/NH_3 = 0,08%
  N/Kj.= 3,25%

DIGESTED PIG SLURRY

* pH = 8,10
  TS = 1,43%
  VS = 55,09%
  N/NH_3 = 3600 ppm
  N/Kj.= 4075 ppm
  d = 1,01 kg/lit

TABLE 2.2

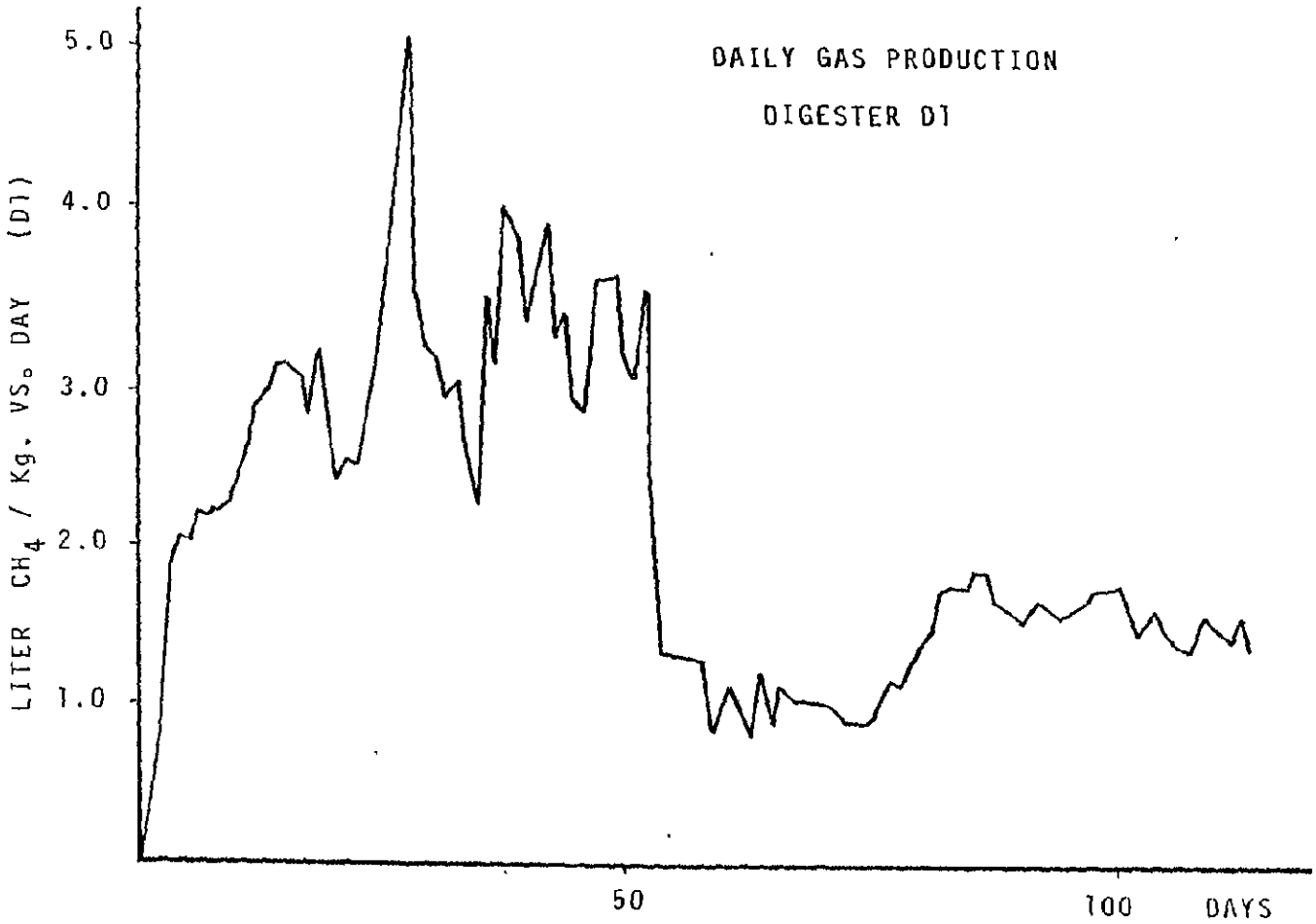

DAILY GAS PRODUCTION
DIGESTER D1
LITER CH_4 / Kg. VS_o DAY (D1)
5.0
4.0
3.0
2.0
1.0
50
100
DAYS

Figure 3.1

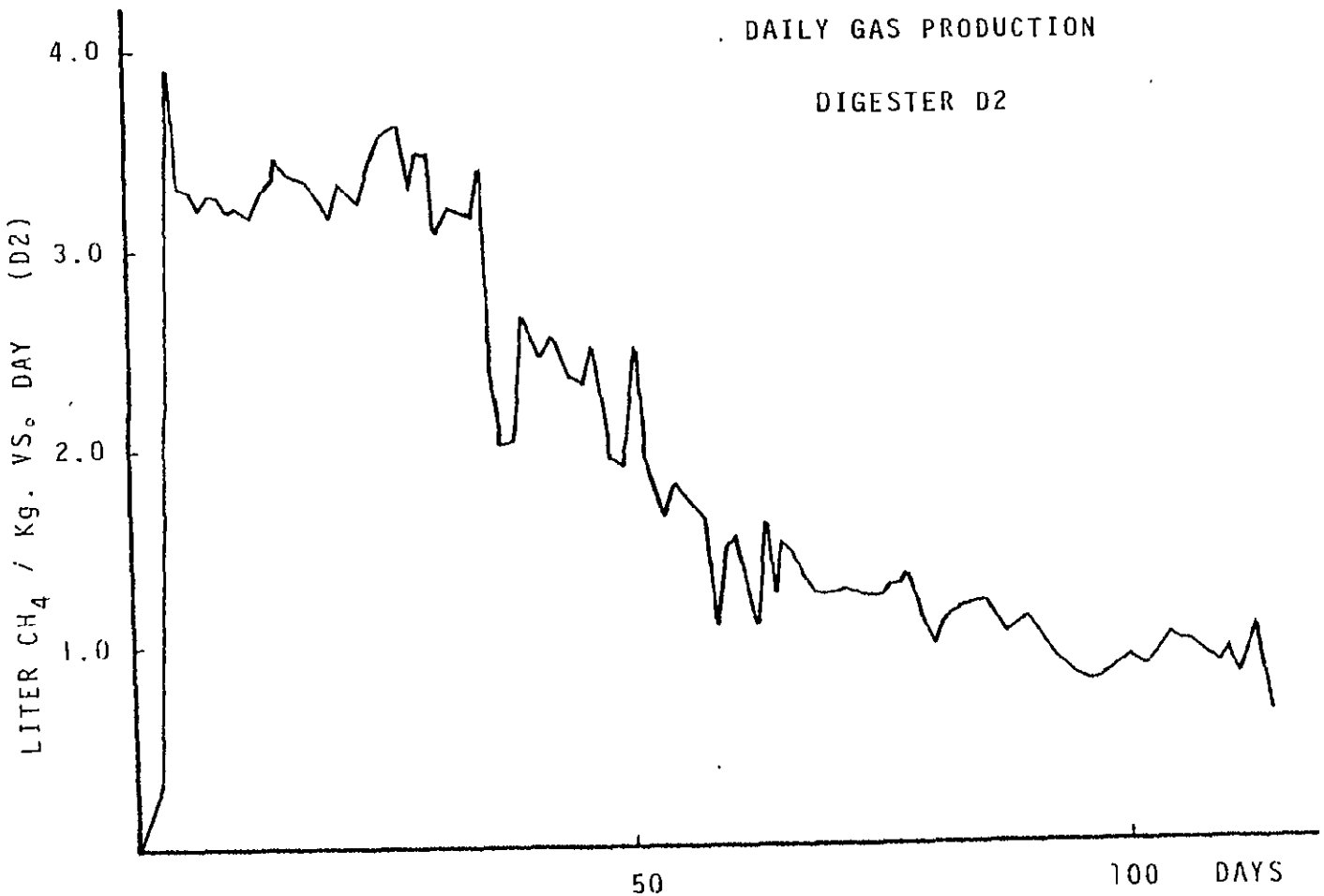

DAILY GAS PRODUCTION
DIGESTER D2
LITER CH_4 / Kg. VS_o DAY (D2)
4.0
3.0
2.0
1.0
50
100
DAYS

Figure 3.2

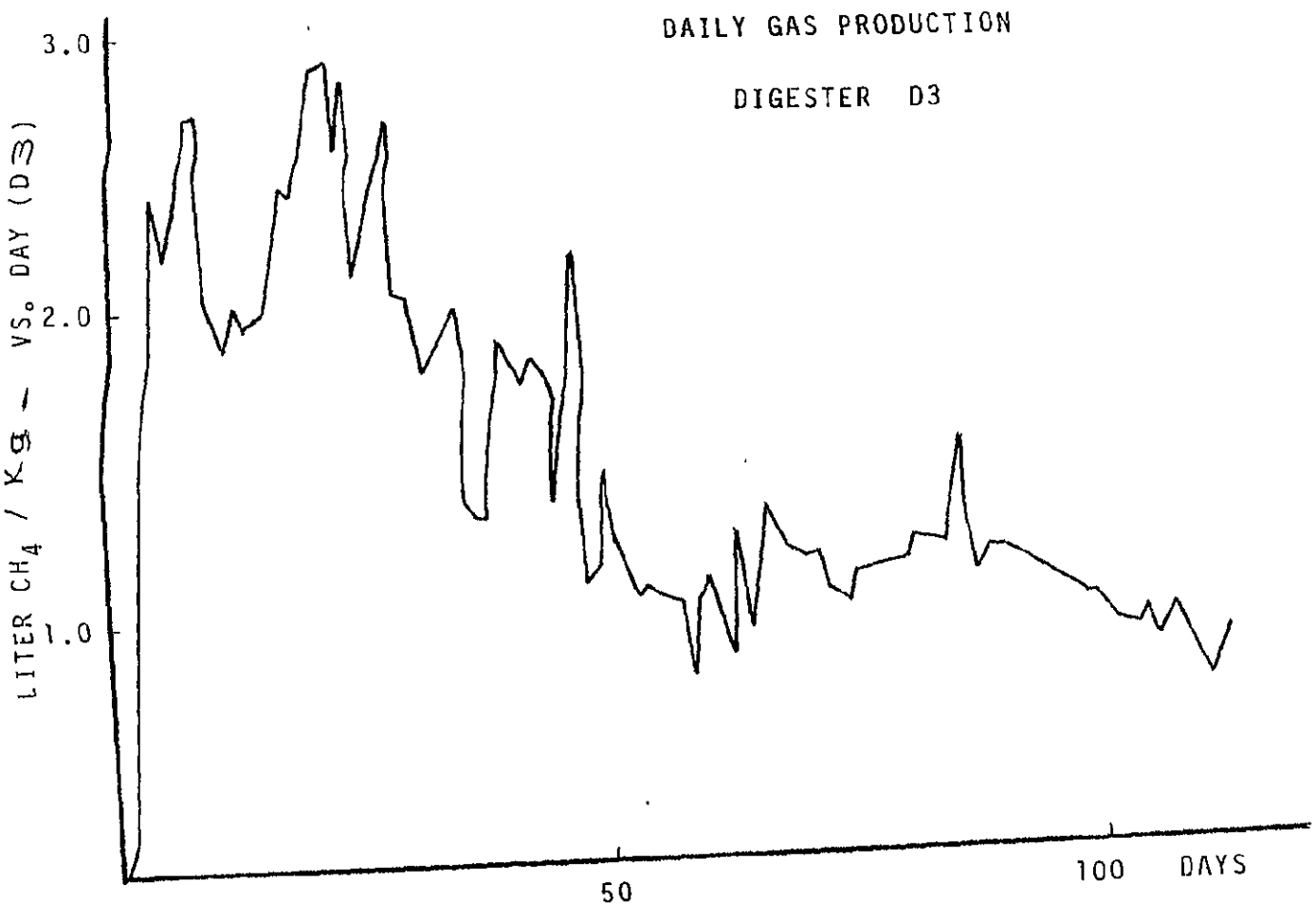

DAILY GAS PRODUCTION
DIGESTER D3
LITER CH_4 / Kg - VS_o DAY (D3)
3.0
2.0
1.0
50
100
DAYS

Figure 3.3

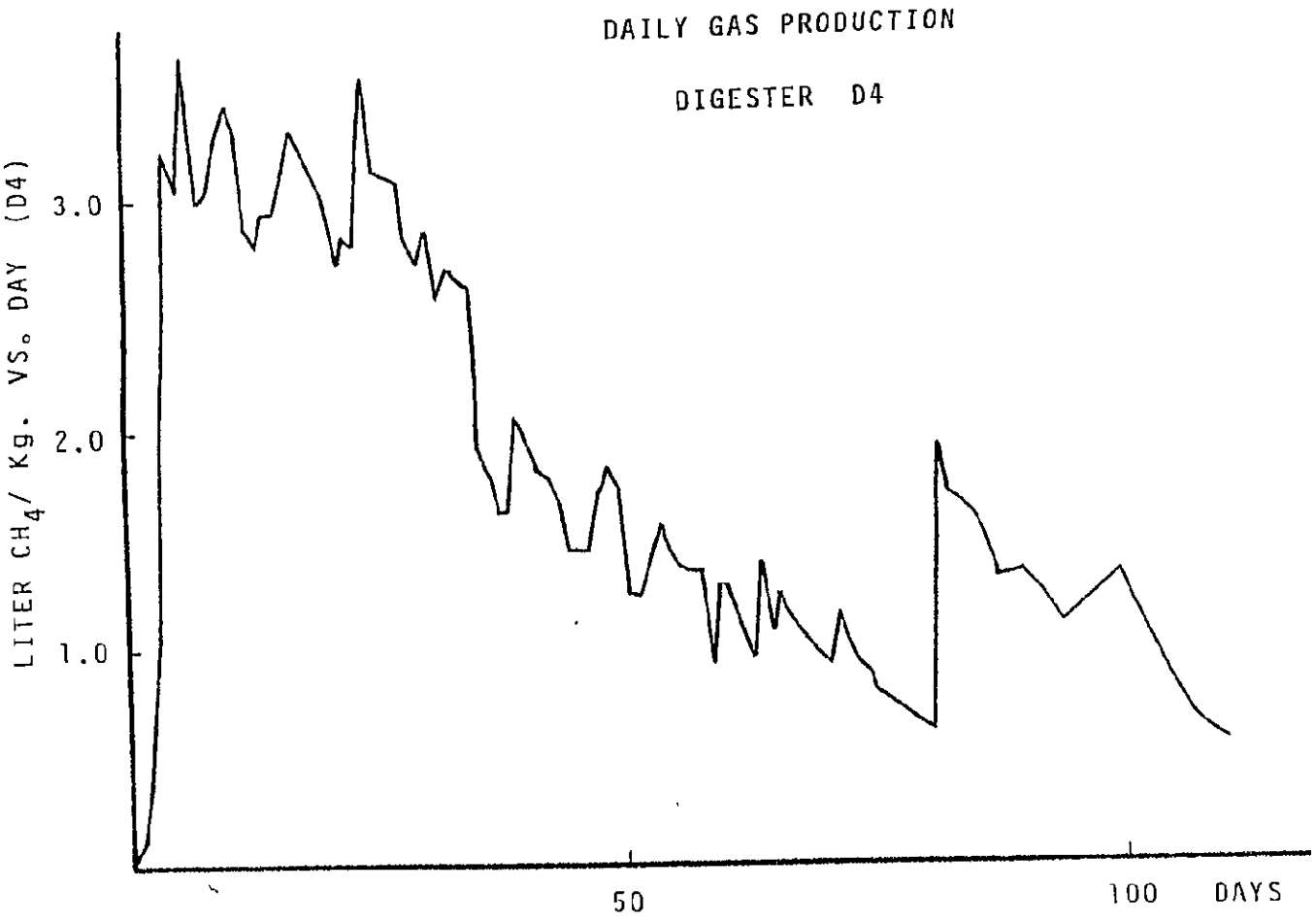

DAILY GAS PRODUCTION
DIGESTER D4
LITER CH_4/ Kg. VS. DAY (D4)
3.0
2.0
1.0
50
100
DAYS

Figure 3.4

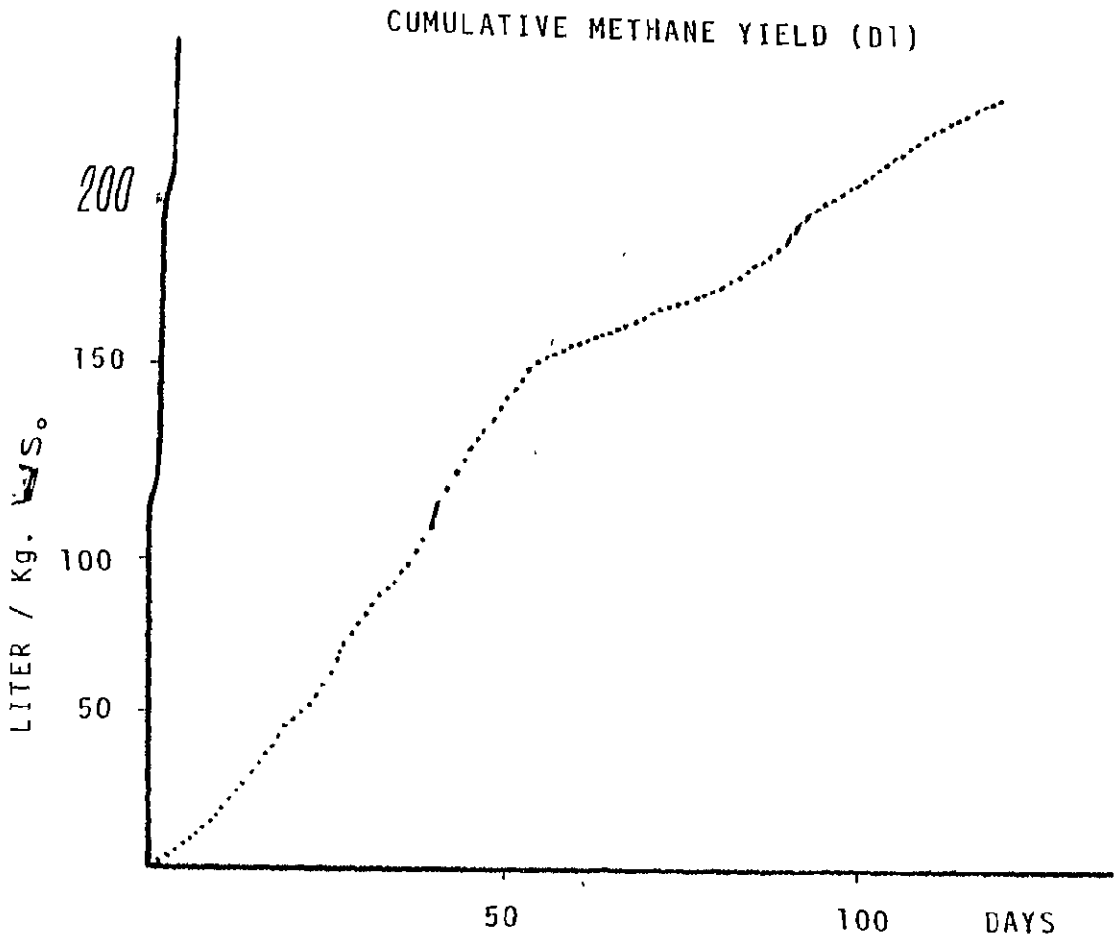

CUMULATIVE METHANE YIELD (D1)
LITER / Kg. VS°
200
150
100
50
50
100
DAYS

Figure 3.5

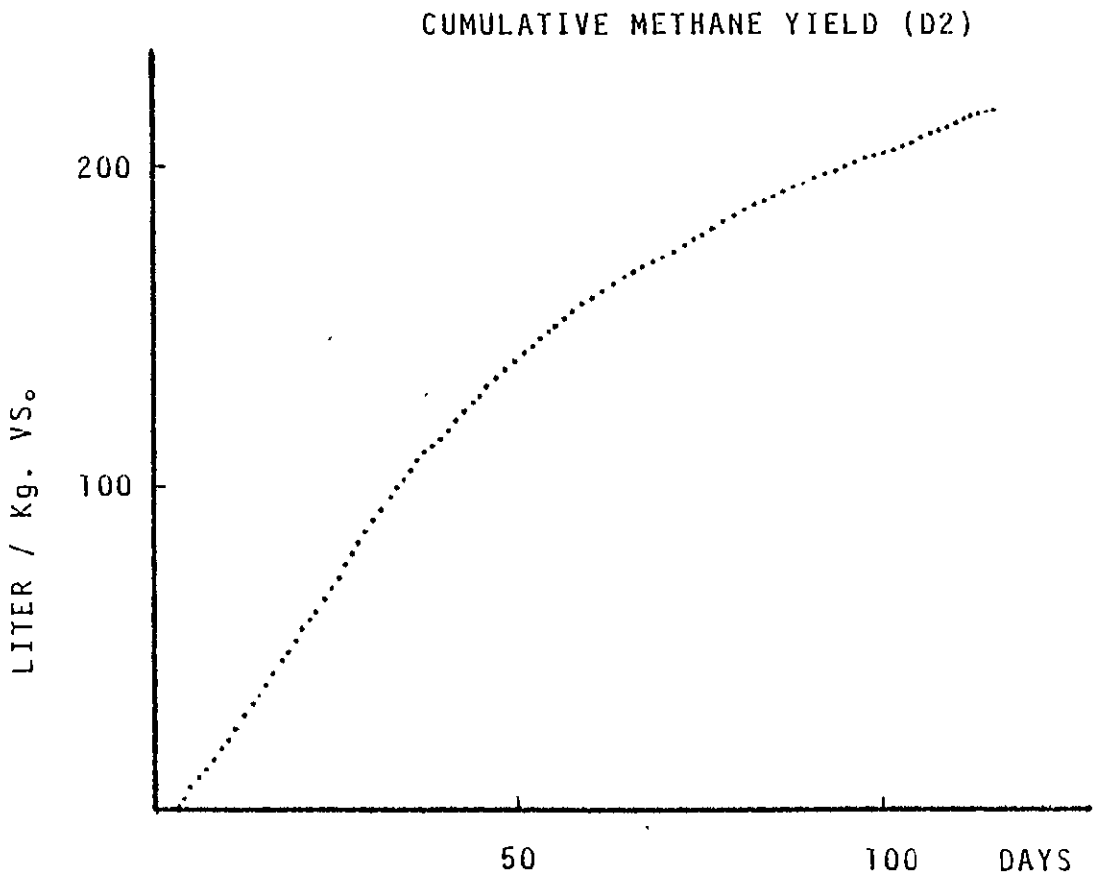


Figure 3.6

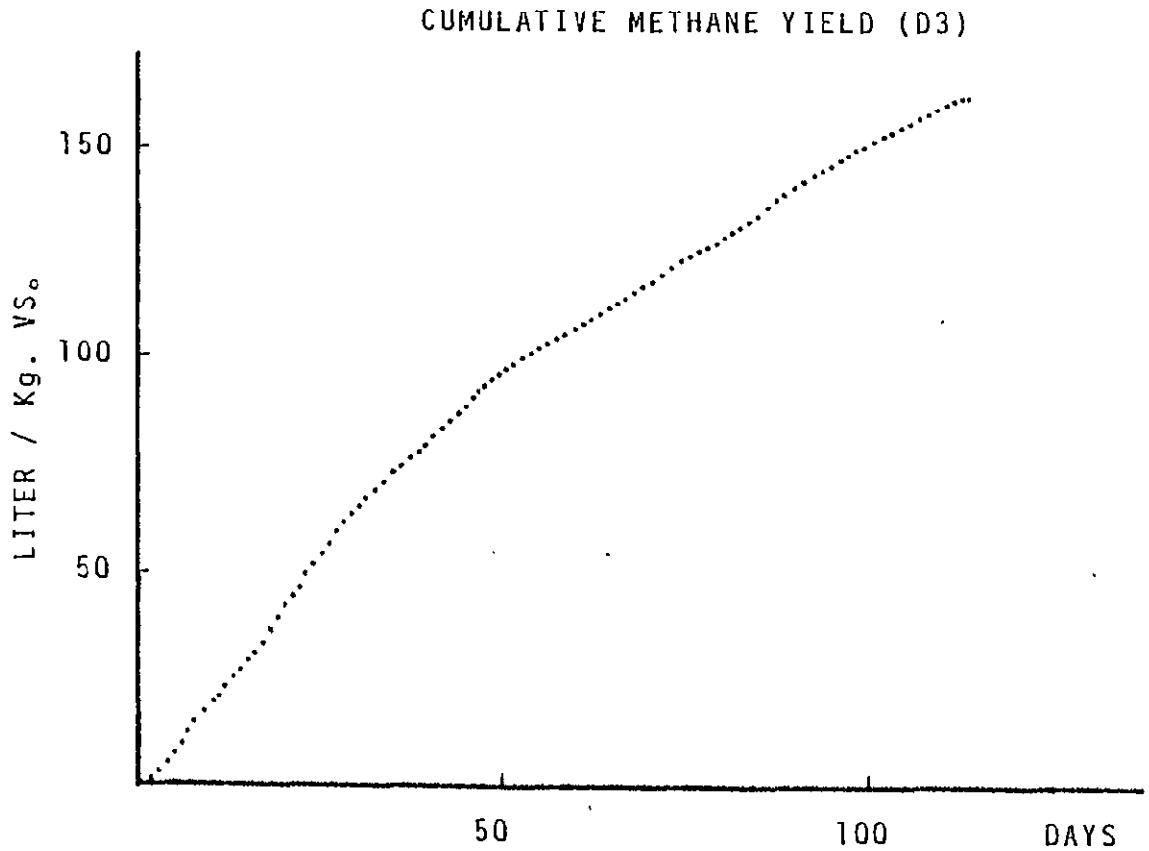

CUMULATIVE METHANE YIELD (D3)
LITER / Kg. VS₀
150
100
50
50
100
DAYS

Figure 3.7

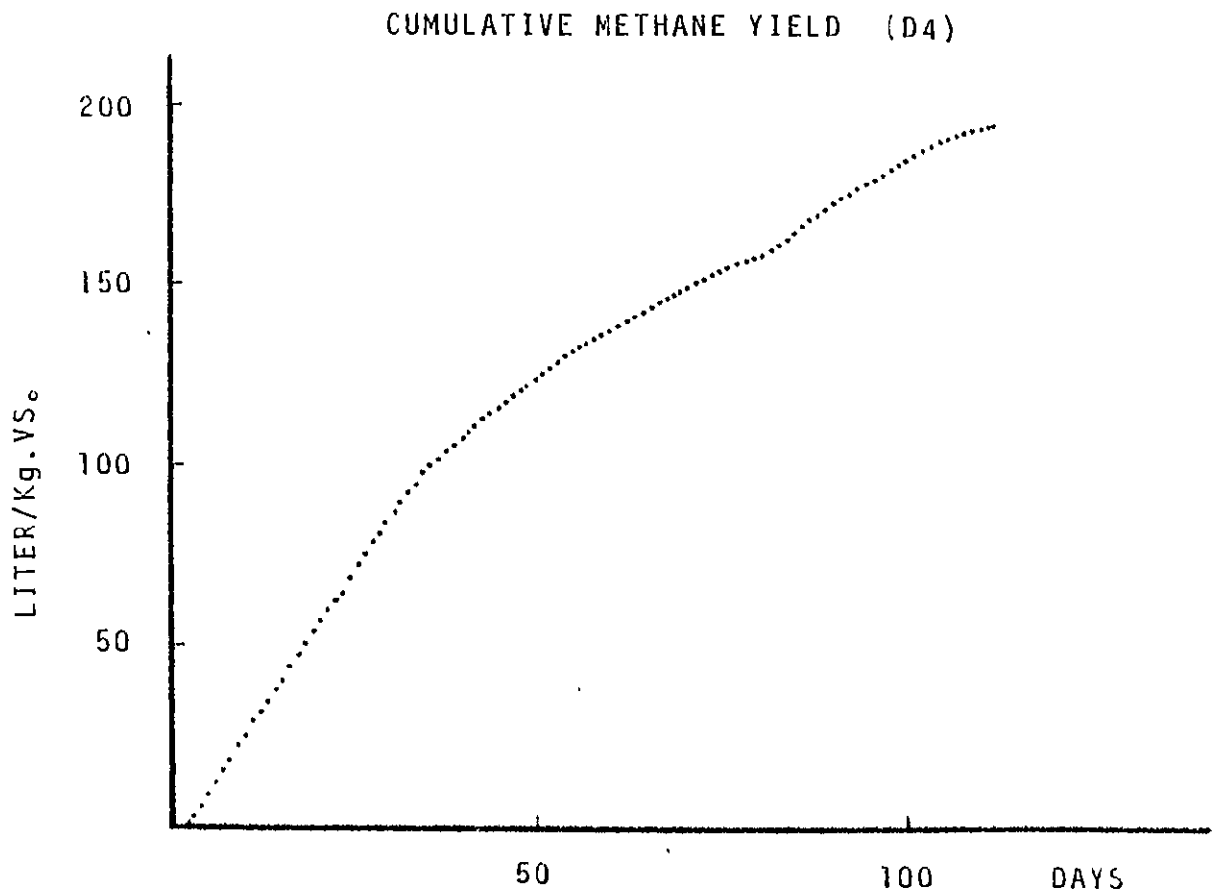

CUMULATIVE METHANE YIELD (D4)
200
150
100
50
LITER/Kg.VS₀
50
100
DAYS

Figure 3.8

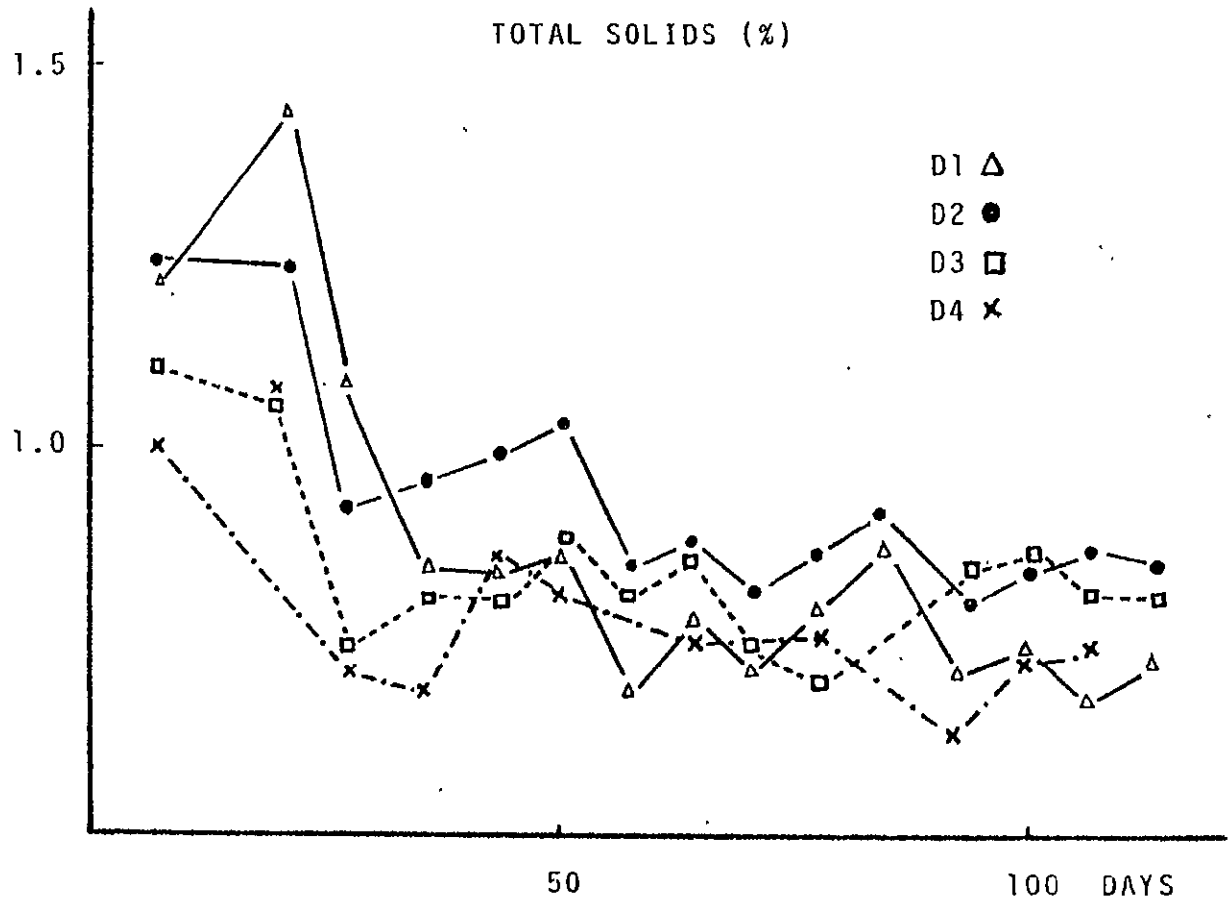


Figure 3.9

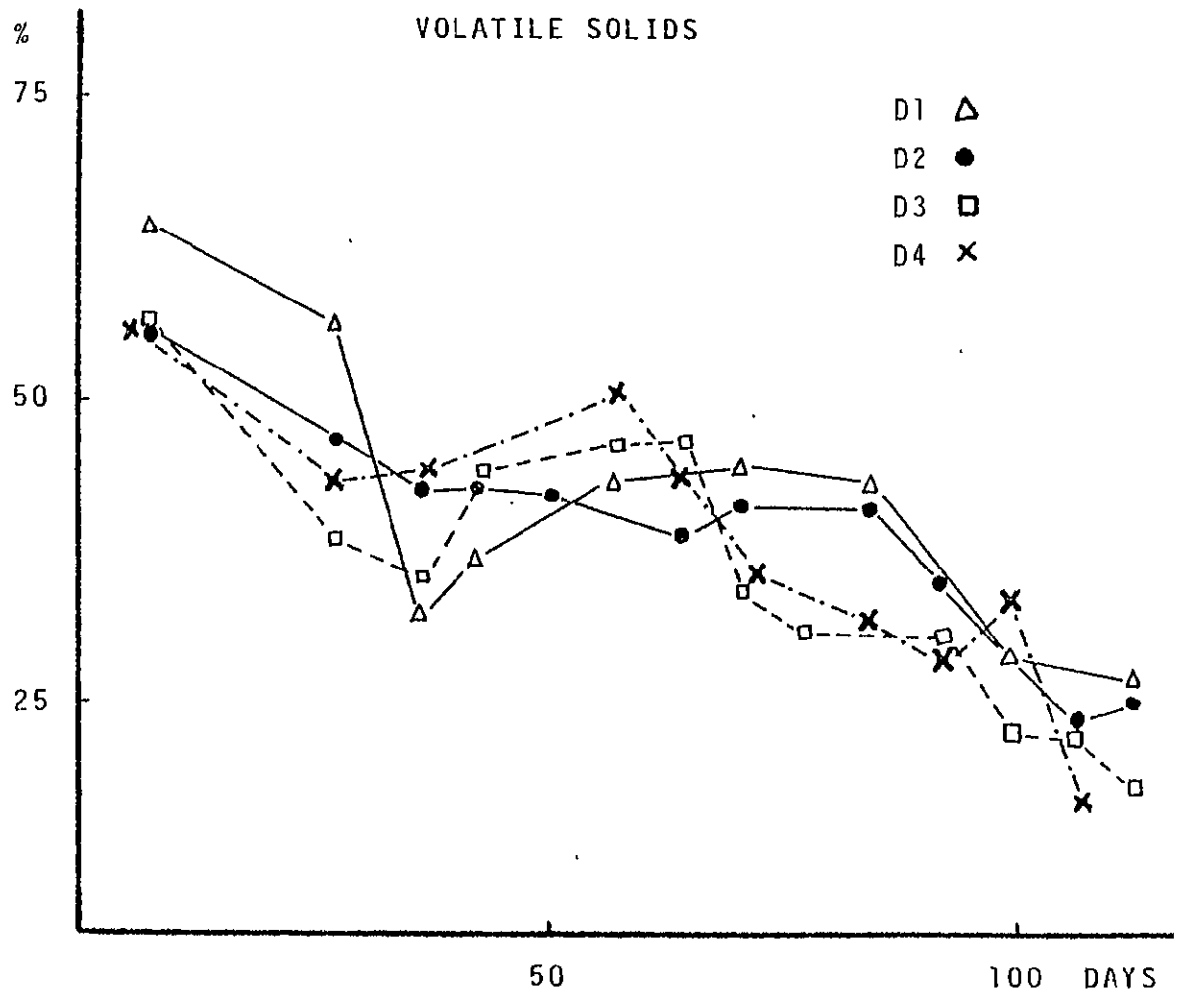


Figure 3.10

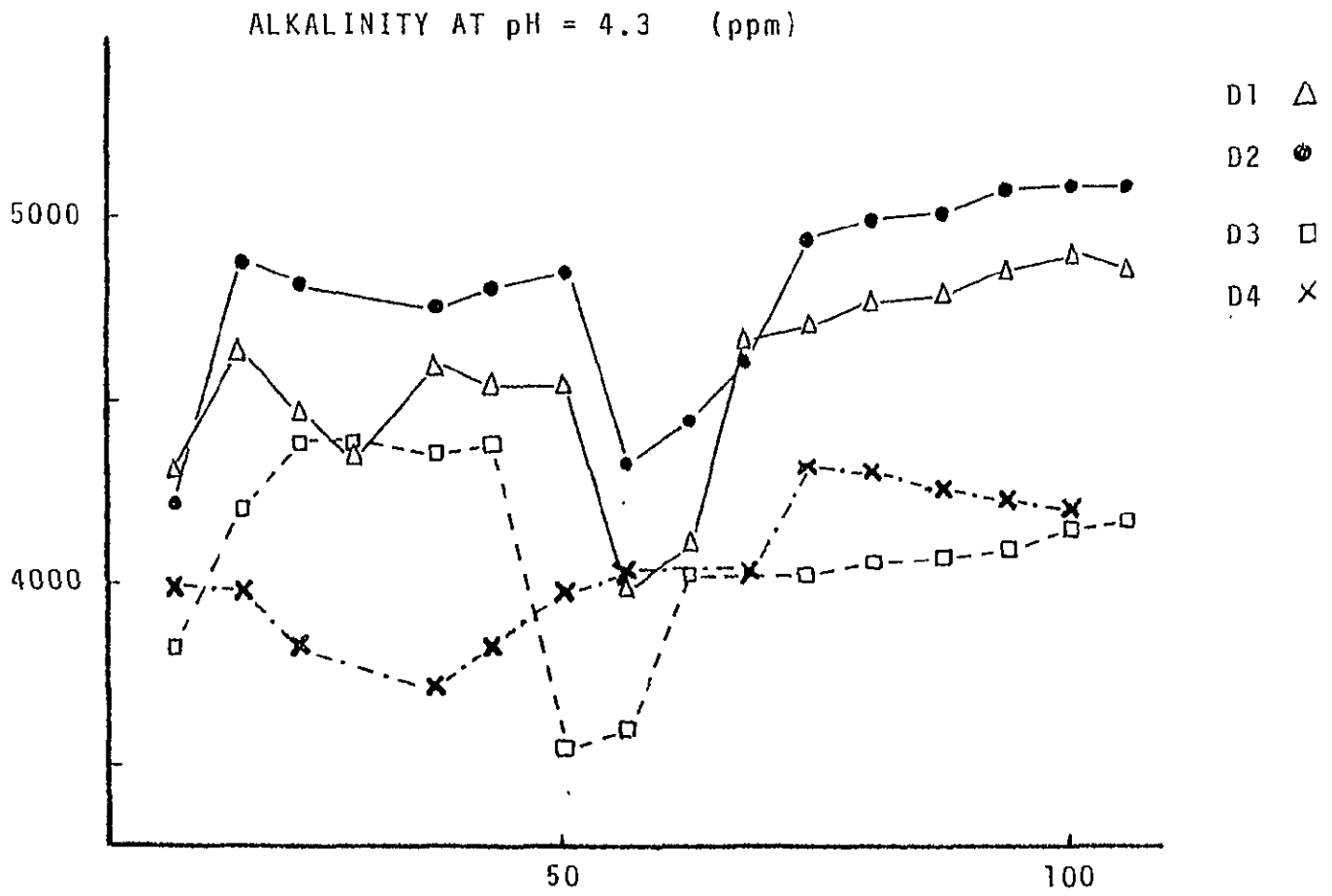


Figure 3.11

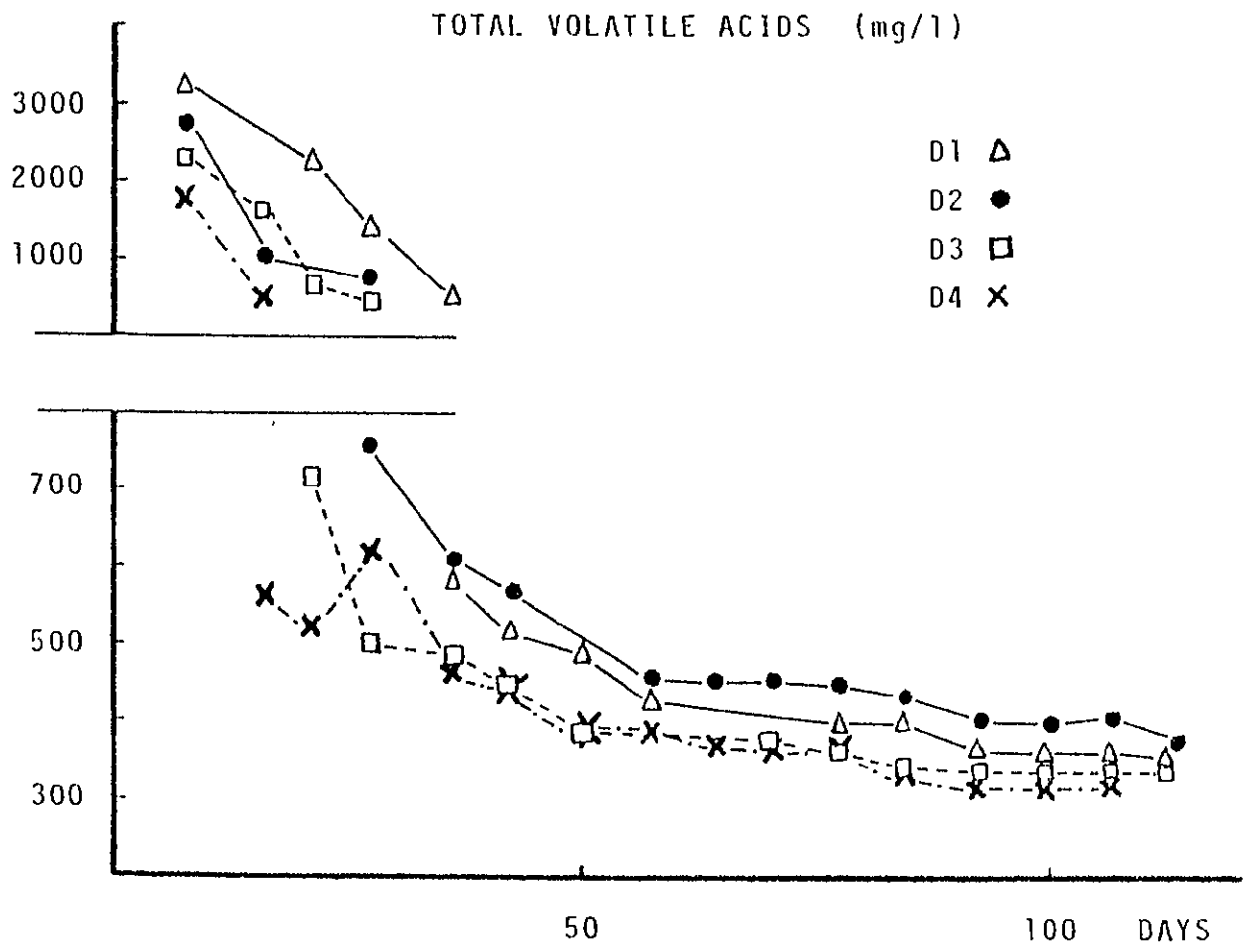

TOTAL VOLATILE ACIDS (mg/l)
3000
2000
1000
700
500
300
D1
D2
D3
D4
50
100
DAYS

Figure 3.12

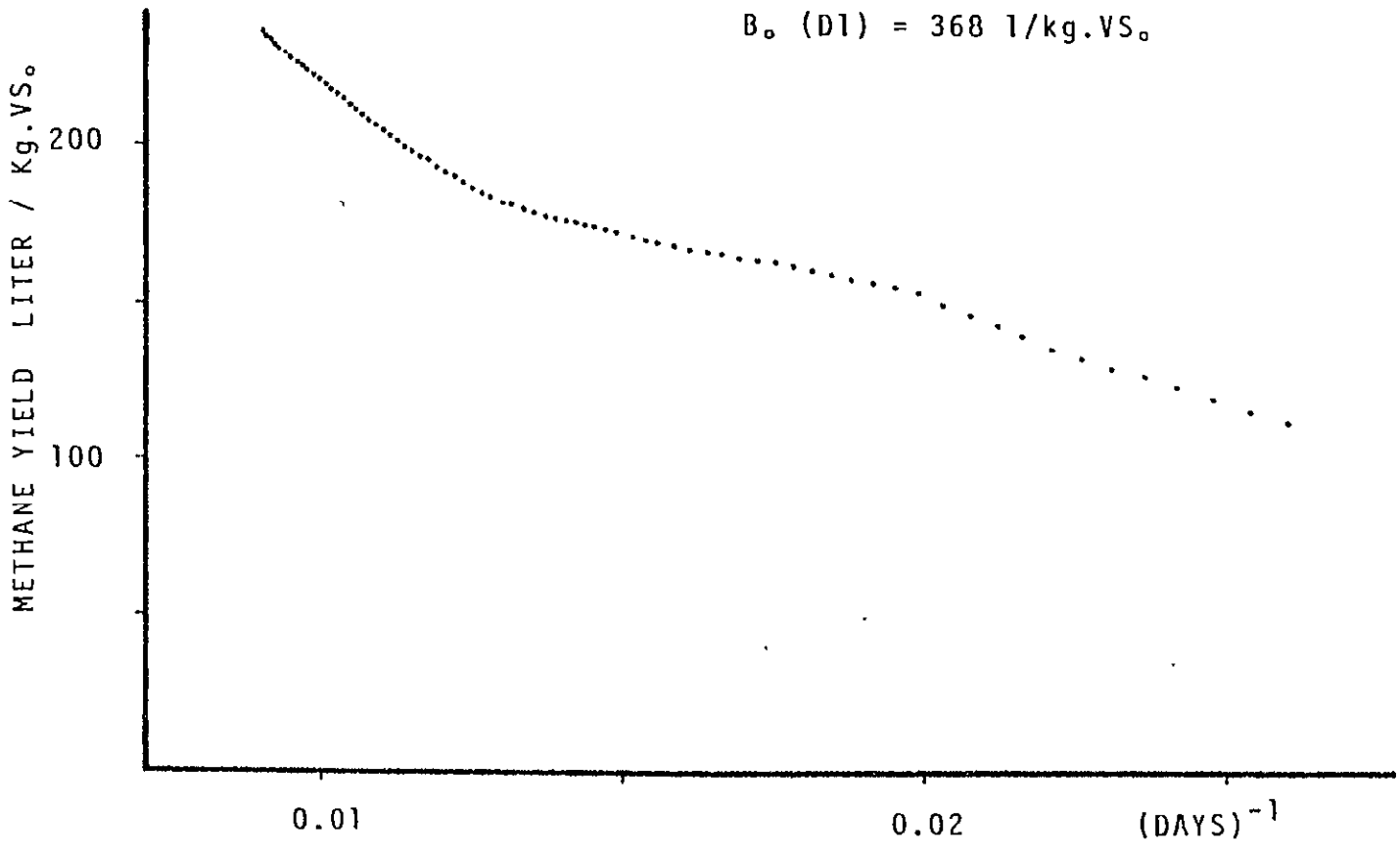

B_o (D1) = 368 l/kg.VS_o
METHANE YIELD LITER / Kg.VS_o
200
100
0.01
0.02
$(DAYS)^{-1}$

Figure 3.13

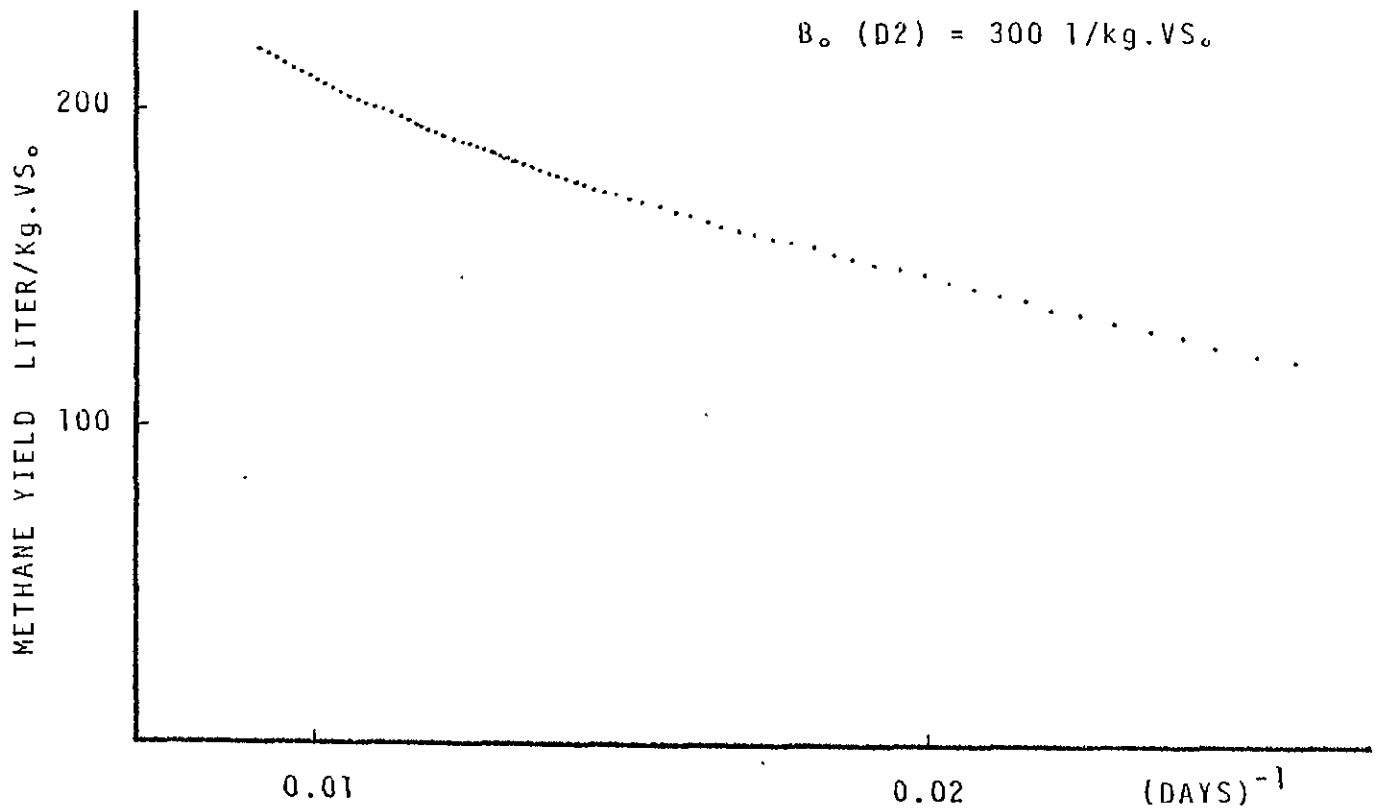

B_o (D2) = 300 l/kg.VS_o
METHANE YIELD LITER/Kg.VS_o
200
100
0.01
0.02
$(DAYS)^{-1}$

Figure 3.14

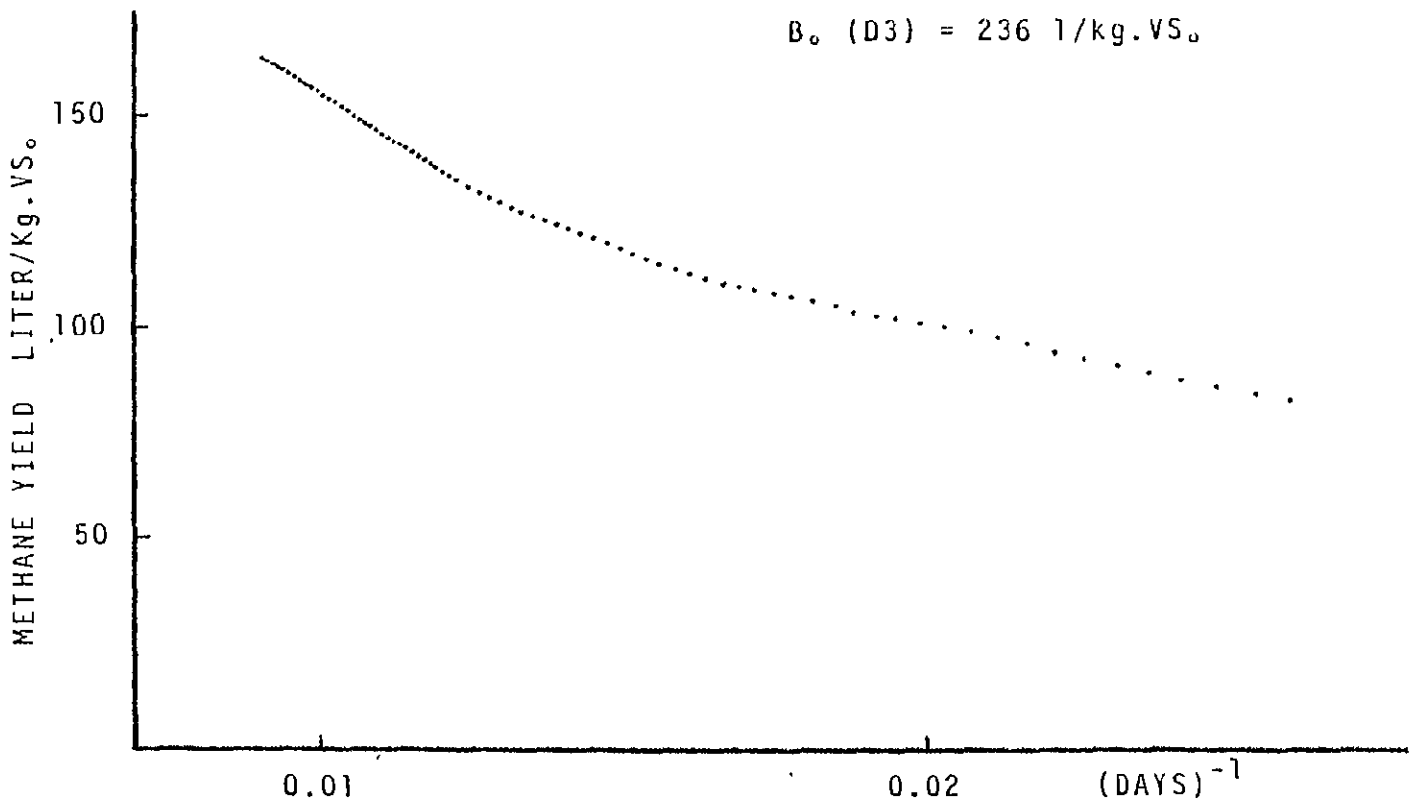

B_o (D3) = 236 l/kg.VS_o
METHANE YIELD LITER/Kg.VS_o
150
100
50
0.01
0.02
$(DAYS)^{-1}$

Figure 3.15

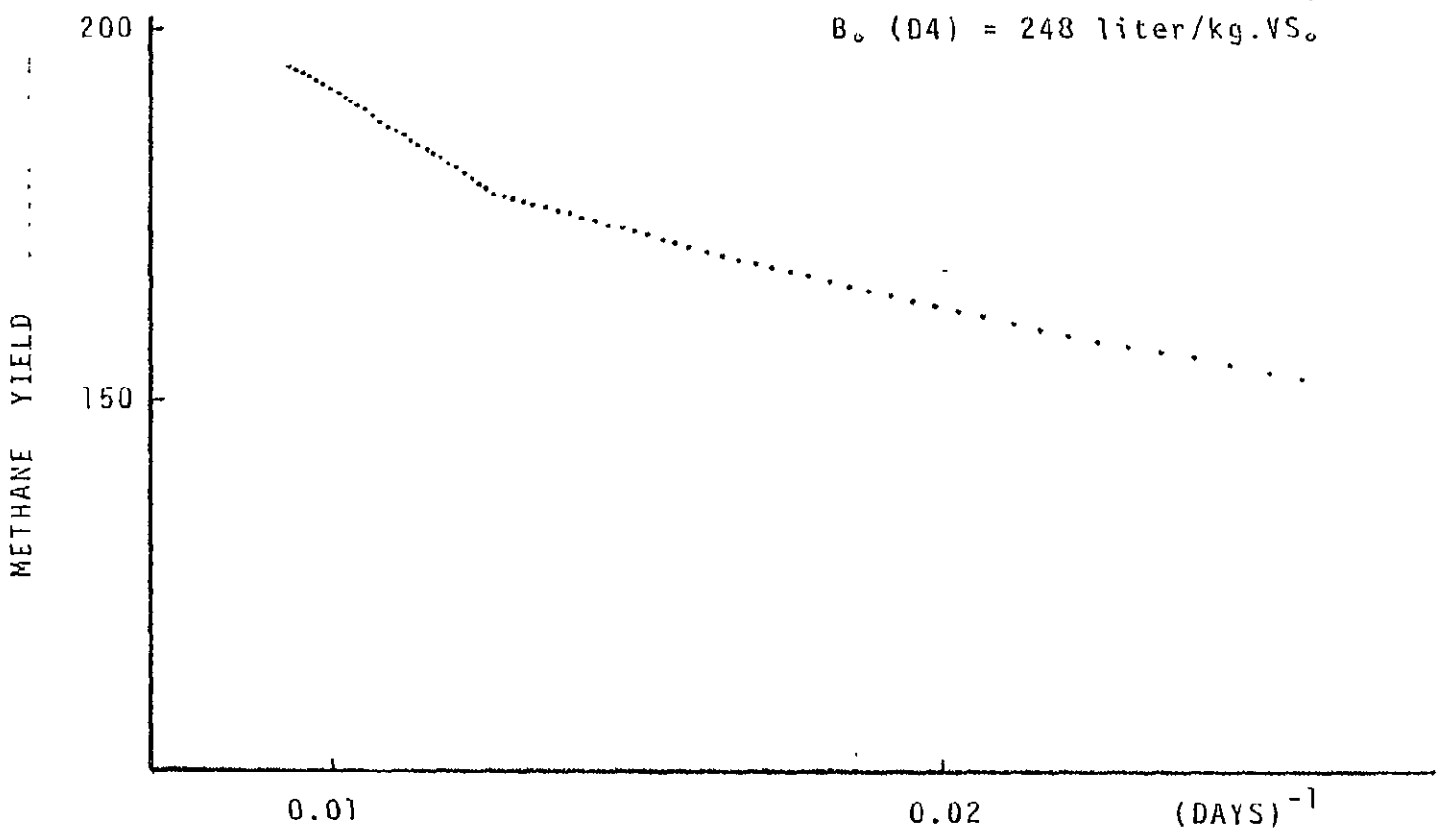


Figure 3.16

EFFECT OF COW MANURE CONTENT ON
ULTIMATE METHANE YIELD

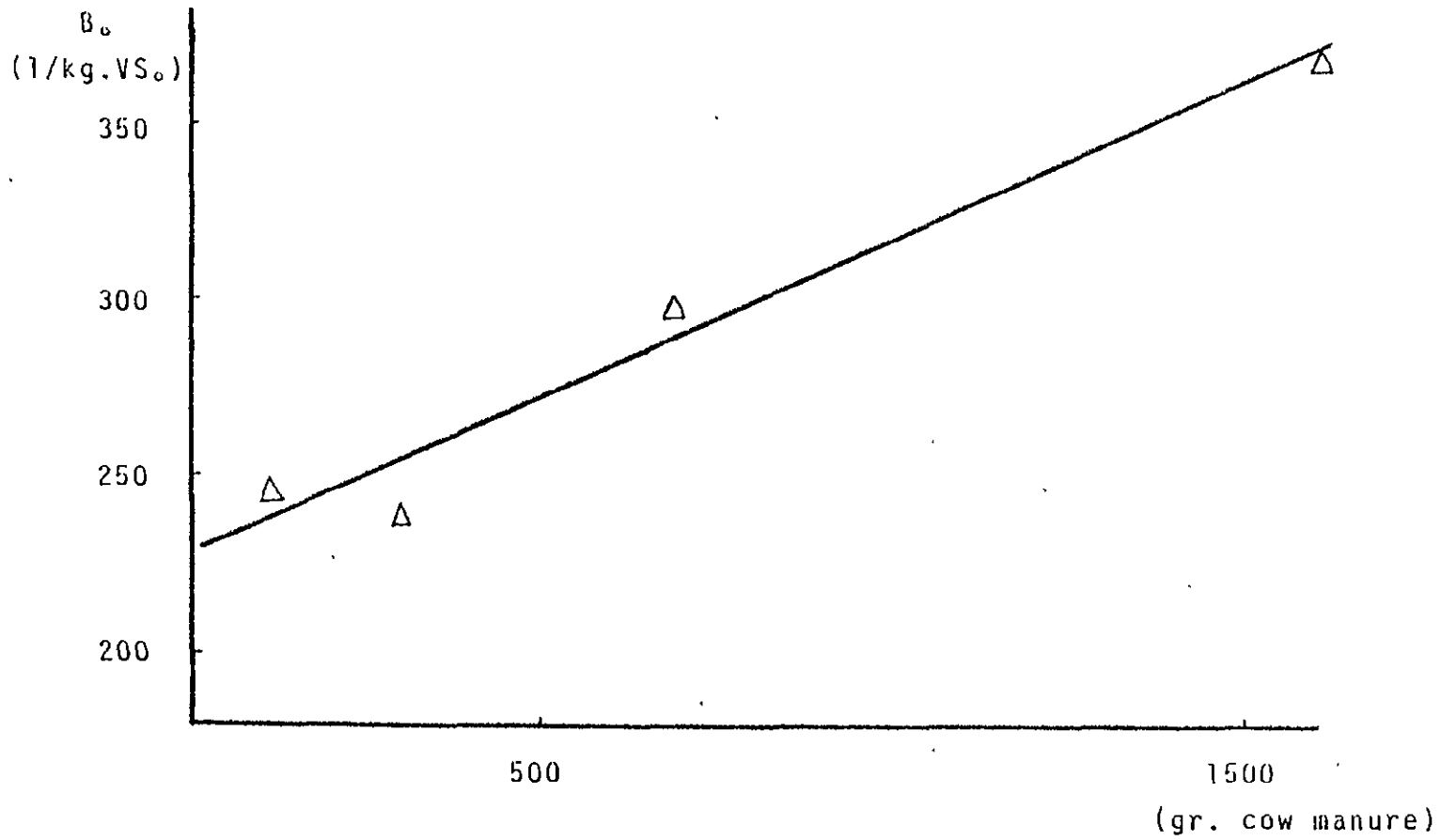


Figure 3.17

RELATION BETWEEN BO and COW MANURE INOCULUM

DIGESTER	B_o (l/Kg.VS_o)	Cow manure content (g)	Dry matter ratio
D1	368	1.596,2	0,17
D2	300	678,0	0,09
D3	236	304,0	0,05
D4	248	112,2	0,03

TABLE 3.1

ANALYSIS SCHEDULE

MATERIAL	PARAMETER	ANALYSIS FREQUENCY
Straw	TS	Initial
	TVS	Initial
	TKN	Initial
	Tot.P	Initial
	CEL	Initial
	HEMCEL	Initial
	LIGN	Initial
Leachate	TS	Weekly
	TVS	Weekly
	ALK	Weekly
	pH	Weekly
	TVA	Weekly
Gas	Quantity	Daily
	Composit.	Weekly

TABLE 2.3

APPENDIX

CUMULATIVE METHANE PRODUCTION

day	D1	D2	D3	D4
1	0,17	0,20	0,10	0,10
2	1,01	0,32	0,83	0,70
3	2,78	1,90	2,22	1,73
4	4,72	5,73	4,61	4,94
5	6,64	9,00	6,77	7,96
6	8,75	12,23	9,16	11,61
7	10,81	15,38	11,81	14,58
8	12,94	18,58	14,46	17,59
9	15,09	21,79	16,47	20,81
10	17,03	24,92	18,40	24,24
11	19,92	28,07	20,18	27,54
12	22,67	31,19	22,14	30,41
13	25,54	34,40	24,01	33,16
14	28,57	37,71	25,90	36,09
15	31,60	41,11	27,84	39,00
16	34,58	44,46	30,00	42,17
17	37,31	47,74	32,42	45,48
18	40,39	51,00	34,82	48,66
19	43,10	54,18	37,43	51,75
20	45,42	57,28	40,25	54,74
21	47,84	60,52	43,09	57,42
22	50,24	63,71	45,61	60,27
23	52,95	66,87	48,37	63,02
24	55,96	70,23	50,45	66,59
25	59,70	73,73	52,69	69,69
26	64,08	77,25	55,12	72,77
27	69,09	80,78	57,74	75,83
28	72,52	84,03	59,75	78,65
29	75,65	87,43	61,75	81,33
30	78,71	90,83	63,66	84,16

Table A-1

day	D1	D2	D3	D4
31	81,53	93,86	65,36	86,68
32	84,42	96,98	67,14	89,34
33	86,94	100,09	69,01	91,96
34	89,09	103,18	70,96	94,53
35	92,53	106,49	72,73	96,44
36	95,59	108,86	74,13	98,26
37	99,47	110,84	75,46	99,86
38	103,32	112,82	76,81	101,47
39	106,60	115,34	78,61	103,48
40	110,20	117,78	80,35	105,42
41	114,12	120,11	82,01	107,24
42	117,32	122,58	83,75	108,99
43	120,64	124,95	85,43	110,63
44	123,45	127,21	87,07	112,06
45	126,15	129,45	88,46	113,48
46	129,69	131,99	90,61	114,89
47	133,24	134,03	92,22	116,61
48	136,81	135,89	93,30	118,44
49	139,87	137,75	94,42	120,16
50	142,78	140,16	95,90	121,38
51	146,16	142,08	97,11	122,60
52	148,47	143,84	98,22	123,98
53	149,71	145,43	99,23	125,53
54	150,54	147,16	100,26	126,92
55	152,17	148,86	101,27	128,27
56	153,39	150,51	102,27	129,57
57	154,58	152,06	103,24	130,89
58	155,36	153,11	103,92	131,80
59	156,18	154,55	104,90	133,05
60	157,24	156,05	105,97	134,34

Table A-1 (cont.)

day	D1	D2	D3	D4
61	158,15	157,33	106,88	135,44
62	158,90	158,39	107,65	136,37
63	160,02	159,97	108,91	137,76
64	160,85	161,15	109,78	138,84
65	161,89	162,59	110,91	140,05
66	162,86	163,98	112,26	141,14
67	163,81	165,27	113,51	142,17
68	164,74	166,46	114,67	143,14
69	165,68	167,65	115,81	144,07
70	166,60	168,85	116,93	144,97
71	167,49	170,08	118,08	146,11
72	168,31	171,29	119,09	147,10
73	169,12	172,48	120,07	148,01
74	169,93	173,65	121,03	148,86
75	170,86	174,87	122,09	149,63
76	171,96	176,12	123,17	150,35
77	172,98	177,41	124,26	151,04
78	174,16	178,56	125,37	151,71
79	175,45	179,61	126,49	152,32
80	176,84	180,55	127,60	152,90
81	178,43	181,63	128,79	154,79
82	180,08	182,74	129,98	156,48
83	181,73	183,87	131,16	158,14
84	183,37	185,02	132,33	159,76
85	185,12	186,17	133,76	161,29
86	186,85	187,25	135,01	162,73
87	188,40	188,23	136,07	164,02
88	189,89	189,26	137,18	165,33
89	191,32	190,31	138,33	166,67
90	192,82	191,31	139,47	167,95

Table A-1 (cont.)

day	D1	D2	D3	D4
91	194,40	192,25	140,59	169,18
92	195,93	193,12	141,70	170,34
93	197,40	193,93	142,78	171,42
94	198,90	194,71	143,83	172,54
95	200,43	195,47	144,85	173,70
96	202,00	196,21	145,85	174,89
97	203,62	197,00	146,83	176,14
98	205,26	197,84	147,79	177,42
99	206,93	198,73	148,73	178,73
100	208,44	199,59	149,63	179,93
101	209,78	200,40	150,46	180,99
102	211,22	201,30	151,29	182,00
103	212,72	202,26	152,11	182,94
104	214,10	203,21	152,91	183,79
105	215,41	204,15	153,68	184,54
106	216,66	205,06	154,50	185,21
107	218,02	205,95	155,38	185,82
108	219,49	206,80	156,17	186,39
109	220,88	207,61	156,87	186,94
110	222,22	208,39	157,48	187,46
111	223,52	209,33	158,19	--
112	225,07	210,42	158,99	--
113	226,33	210,96	--	--

Table A-1 (cont.)

TOTAL SOLIDS IN THE LEACHATE

DAY	D1	D2	D3	D4
7	1,22	1,25	1,11	1,00
21	1,44	1,24	1,07	1,06
27	1,09	0,93	0,74	0,71
36	0,84	0,96	0,82	0,68
42	0,83	1,00	0,81	0,87
50	0,86	1,04	0,88	0,81
57	0,67	0,85	0,80	0,69
64	0,79	0,88	0,88	0,76
70	0,70	0,81	0,67	0,67
77	0,80	0,87	0,69	0,76
84	0,88	--	0,93	0,90
92	0,69	0,79	0,86	0,63
99	0,75	0,84	0,84	0,73
106	0,66	--	0,81	0,75
112	0,76	0,86	0,80	--

Table A-2

VOLATILE SOLIDS IN THE LEACHATE (%VS)

DAY	D1	D2	D3	D4
7	61,6	53,9	54,9	55,6
21	45,1	34,4	35,5	34,0
27	55,1	47,3	40,5	45,1
36	35,7	43,8	36,6	44,1
42	39,8	44,0	44,4	43,7
50	36,0	43,3	31,8	38,3
57	44,8	47,1	47,5	50,7
64	54,4	42,0	47,7	44,7
70	45,7	43,2	37,3	37,3
77	60,0	50,6	34,8	52,6
84	44,3	43,0	32,3	35,6
92	53,6	38,2	34,9	34,9
99	33,3	41,7	28,6	37,0
106	25,8	29,0	28,4	22,7
112	31,8	30,4	24,3	--

Table A-3

ALKALINITY AT pH 4.30 IN THE LEACHATE (as ppm $CaCO_3$)

DAY	D1	D2	D3	D4
7	4316	4230	3825	4022
15	4659	4880	4218	3997
21	4488	4819	4402	3850
27	4267	4536	4387	3642
36	4598	4757	4365	3740
42	4561	4806	4402	3850
50	4561	4855	3556	3997
57	3997	4340	3617	3948
64	4120	4463	4046	3948
70	4684	4610	3862	4022
77	4723	4951	4041	4335
84	4790	5004	4068	4322
92	4804	5031	4094	4282
99	4857	5085	4121	4255
106	4911	5111	4175	4228
112	4871	5085	4202	--

Table A-4

VOLATILE ACIDS IN THE LEACHATE (as ppm Acetic A.)

DAY	D1	D2	D3	D4
7	3328	2741	2241	1844
15	2010	1029	1604	556
21	2361	--	720	516
27	1454	758	502	612
36	584	612	486	454
42	519	570	452	441
50	496	482	384	387
57	428	458	363	387
64	404	452	404	357
70	441	458	377	357
77	408	438	367	363
84	404	428	340	336
92	374	401	336	312
99	390	394	340	312
106	374	411	340	319
112	357	394	340	-

Table A-5

pH IN THE LEACHATE

DAY				
7	7,00	7,25	7,40	7,45
15	7,10	7,40	7,40	7,20
21	7,40	7,70	7,55	7,50
27	7,45	7,90	7,80	7,80
36	7,55	7,55	7,60	7,70
42	7,40	7,65	7,70	7,80
50	7,60	7,75	7,65	7,75
57	7,70	7,70	7,75	7,85
64	7,60	7,80	7,75	7,80
70	7,23	7,33	7,18	7,40
77	7,35	7,30	7,55	7,60
79	7,25	7,35	7,20	7,35
84	7,30	7,40	7,40	7,60
91	7,35	7,35	7,35	7,45
92	7,20	7,20	7,15	7,30
99	7,20	7,30	7,25	7,50
106	7,30	7,20	7,30	7,35
112	7,15	7,30	7,30	--

Table A-6

"BIOENERGY RECOVERY AND CONSERVATION IN EGYPT"

Report Presented By:

Dr. M. Nabil Alaa El-Din
Head of Research, Microbiology
National Director, Biogas Project
Agricultural Research Center
Giza,
EGYPT

BIOENERGY RECOVERY AND CONSERVATION IN EGYPT[1]

M.N. Alaa El-Din,[2] S.A. El-Shimi,[3] M.H. Mohmoud,[3]
I. Abdel-Azia,[3] and M. El-Ghetani[4]

ABSTRACT

In Egypt the cultivated area remain unchanged during the last three decades, while the population increased from about 19 million in 1952 to about 46 million inhabitants in 1982. The cultivated area per capita decreased therefore reaching by 0.13 acre (0.06 ha) the lowest world figure. Intensive cultivation by crop index higher than 2 crops/year and extensive utilization of biomass available are the main features of agriculture. The first puts a heavy load on soil fertility and thus burning biomass to gain energy is not appreciated. Recycling of organic residues is therefore highly appreciated.

In the present study energy sources available and energy demands as well as the technology status available are demonstrated. Biomass sources, their present uses and the potential energy release using appropriate biogas technology are discussed.

A detailed survey of resources and uses of biomass for energy in 4 villages is carried out and energy balances and fertilizer nutrient recycling are estimated. Energy consumption and the cost of 1000 K cal net energy was calculated and found to be much higher for cow dung cakes and crop residues than for kerosine and bottled gas.

---

[1]Paper presented at the "International Workshop on Bioenergy Recovery and Conservation," October 31-Nov. 2, 1984, Boston, Massachusetts, USA.

[2]Head of Research and National Director of Biogas Project, Soils and Water Research Institute, Agric. Res. Center, Giza, Egypt.

[3]Researchers, Soils and Water Res. Inst. Agric. Res. Center, Giza, Egypt.

[4]Director of Research, International Center for Rural Development, Maruit, Egypt.

1. Introduction

The fast increase of population in Egypt (about 1.2 million/year) presents the major problem as the area cultivated to provide biomass remain unchanged for many years. Intensive cultivation became a necessity and put heavy load on soil fertility. This situation has therefore developed a kind of balance between man, animal and soil as competitors for agricultural residues, which in other countries may present a problem to get rid of. Crop residues are highly considered as animal feed, burning material and as organic manures to sustain fertility of old land and to improve it in newly reclaimed soils.

As biomass resources are limited the order of priorities is towards animal feed utilization, burning in open fires and in poor quality ovens to bake bread and finally to prepare organic manures. The amounts of biomass available for each of the utilization forms is much lower than needed. The traditional technologies developed along many thousands of years is fairly stable and hardly to interfere with, but simple technologies which can improve feeding value of residues, energy release and/or increase the amounts of organic manures and their quality are highly appreciated by both farmers and government.

The purpose of the present study is to throw light on the present energy resources and demand in Egypt with special emphasis on biomass. Identification of actual resources and pattern of use of biomass for energy in rural Egypt and the possibilities to maximize energy and fertilizer return through biogas technology.

2 Energy Demand

2.1. Present Energy Demand

The commercial primary energy demand in Egypt has increased during the period 1952-1981 from nearly 3 million tons of oil (with no hydropower) to nearly 17 million tons of oil equivalent (TOE), with hydropower accounting for nearly 20%[7].

Out of the 80% share of petroleum, nearly 16% goes to thermal electricity generation, thus bringing the total share of electricity to 36%. A rough estimate of present non-commercial energy sources is in the range of 3 million TOE, thus bringing the gross total primary energy demand in 1981 to about 20 million TOE.

One of the most alarming aspects in recent years has been the fast growing rate of energy consumption of electricity and petroleum products as indicated by the figures in Tables 1 and 2.

For the period 1975-1981, the average annual consumption growth rate has exceeded 11% for petroleum and 14% for electricity. As two thirds of the Nile's ultimate hydropower potential is already developed and utilized, thermal power generation has been growing in recent years at an annual rate of nearly 21%.

2.2 Future Demand Forecast

Several efforts have been made during the past few years to assess energy demand up to the year 2000. Two of these studies have already been published. The first was undertaken in 1976 by the Specialized National Councils and the second was completed in 1978 by a joint Egypt-USA group[8]. A third study is still in progress and is being carried out by one of the working groups of the Supreme Council of Energy. Currently, Egypt is trying to establish adequate capabilities to help, improve and update these studies.

TABLE 1. 1952-1981 domestic consumption of petroleum products (,000 metric tons).

Year	Natural gas	Butagas	Gasoline	Kerosene	Gas oil	Fuel oil	Lubricants and Asphalt	Total
1952	-	4	252	665	343	1754	39	3057
1960	-	20	262	736	786	2783	158	4745
1965	-	59	287	928	1124	2974	209	5581
1970	-	108	444	820	1176	3005	297	5850
1975	33	179	656	1188	1335	3639	231	7261
1979	862	339	1041	1486	2040	4840	541	11139
1980	1810	408	1219	1555	2714	2495	924	14125
1981	2500	435	1400	1750	2847	5512	1065	15509.

Source: Ministry of Petroleum, ARE 1) Abdallah (1982)

TABLE 2. 1952-1981 domestic consumption of electric power

Year	Power consumption (million Kwh)			Peak Load (Mw)
	Thermal	Hydro	Total	
1952	929	-	929	110
1960	2829	250	3097	533
1965	3262	1738	5000	750
1970	2225	4690	6915	1100
1975	3009	6790	9799	1733
1980	9377	9905	19282	3260
1981	11458	9925	21383	3665

Source: Ministry of Petroleum, ARE 1) Abdallah (1982)

In this area international cooperation is expected in the near future.

Total projected demand for primary commercial energy by the year 2000 is tentatively estimated at nearly 65 million tons of oil equivalent[1]. This would be almost 3.6 times the current primary commercial energy consumption, or an average growth rate in consumption of nearly 7.5% per annum during the period 1980-2000. A rough breakdown of the 65 million TOE is as follow:

- demand for electricity is expected to reach nearly 105 billion KW based on the assumption that the per capita share will increase from its current level of 450 KW to the world average of 1600 KW. Expressed in terms of primary energy requirements this may range between 28-30 million TOE.

- new and renewable sources of energy (NRSE), other than hydro and non-commercial, are expected to provide nearly one million TOE by the year 2000. Including the above mentioned 1.5 million TOE of new hydropower, the total commercial new and renewable sources of energy will account for about 1% by the year 2000.

- direct consumption of oil and natural gas is expected to be of the order of 34-36 million TOE. Adding thermal electricity generation, the primary demand of which is estimated at nearly 13-15 million TOE the total oil and natural gas requirements would amount to nearly 50 million TOE.

3. Energy Resources

The principal indigenous energy resources are petroleum, natural gas and hydropower; small coal deposits also exist in the Sinai. No conventional deposits of low-cost uranium ore have been discovered so far. In the long run solar energy may be another important source, but it has not been tapped because present knowledge and technology are limited. Non commercial fuels, in form of animal and vegetable wastes, are another significant energy source in rural areas.

3.1. Oil

Exploration activities have been intensified since 1973, and a number of new discoveries have added nearly 2.5 billion barrels to proven reserves. More than 1.4 billion dollars has been spent on oil exploration from 1973 to 1981. Production of oil and natural gas has increased during the period 1973-1982 from 8.5 million tons to 35 millions tons. However, as previously mentioned, domestic consumption during the same period has grownth from 6.5 million tons to nearly 15.5 million tons.

3.2. Natural Gas

Recent exploration activities have resulted in the discovery of several fields of natural gas. A pipeline is already under construction to gather and utilize associated gas which has been increasing with growing oil production. Hence, the amount of natural gas produced and utilized has rapidly increased from 33 thousand tons in 1975 to nearly 2.5 million tons in 1982. It is anticipated that natural gas will play an important role in the energy mix. To accelerate this role, the Egyptian concession terms have been recently modified to allow for greater incentives to encourage foreign companies to explore for natural gas.

3.3. Hydropower

The main conventional hydropower resources are on the Nile and have been largely developed. The principal hydropower stations are at the Aswan Dam, which was commissioned in 1960-61, and the Aswan High Dam, which came into service in 1967-70. Installed capacities are 345 MW and 2100 MW respectively, but total available capacity varies from about 800 MW in winter mounths to about 1.400 MW in summer. Although the reservoir was filled in 1976, the maximum effective capacity in 1977 was only 1.300 MW because of transmission limitations. Improvements are expected to raise this figure to 1.800 MW by the near future.[1)]

Ongoing plans aim at the construction of a second station at Aswan and the utilization of several mini-hydro sites along the river. A pumped-storage project at Suez it being studied with a view to meet peak loads, and the planned Qattara Depression Project may provide additional capacity of nearly 600 MW before the year 2000.[1)]

Electric power subsector.

Electricity was first introduced in Egypt in 1895. Isolated diesel and some oil-fire steam units were installed in major population centers by various government, private and municipal organizations. The supply in Cairo was in the hands of the privately owned Lebon Company until 1949, when the government owned Cairo Electric and Gas Department took over the responsibility. In Alexandria, the assets of the Lebon Company were nationalized in 1961 and a government corporation, the Alexandria Electric and Gas Authority, took control.

In 1964 the Ministry of Electricity and Energy (MEE) was formed to consolidate all electricity organizations under state ownership. In 1965 the General Egyptian Electricity corporation (GEEC) was established to own, operate and expand the public power system. In 1971 the General Rural Electrification Authority (GREA) was created to plan and supervise the construction of rural electrification projects.[1)]

Early in 1976 the sector was reorganized through the establishment of four new authorities: the Egyptian Electricity Authority (EEA), replacing GEEC, the Rural Electrification Authority (REA), the Nuclear Power Plant Authority (NPPA), and Qattara Depression Authority.

Since 1970 all important hydro and thermal-generating stations in Egypt have operated through EEA's unified power system. The system has a total installed generating capacity of 2.445 MW of hydro in the South and 1.370 MW of steam and gas-turbine units, mostly in the Delta. A 500 KVolt, double-circuit transmission line, 838 Km long, connects the Aswan station to the Delta region and is the backbone of the interconnected system.

Excessive outages experienced during early operation of the 500 KVolt system caused EEA to impose unusually severe restrictions on the maximum load assigned to the hydro stations. This limitation on the power transmitted from Aswan to the large load centers in the Delta has delayed full utilization of available High Dam generation. Although load growth averaged 17% annually during 1974-1981 and is estimated at 13% annually for 1981-1985, existing capacity and committed construction are ample to serve the short-term needs if expected improvements in system operation are realized.[1]

3.4 Nuclear Energy

Being cheaper to generate electricity by nuclear reactors than by oil-fired stations, Egypt plans to build nuclear reactors, with a total capacity of nearly 8.000 MW by the year 2000. These would provide nearly 40% of the country's demand for electric power.

Agreements for bilateral cooperation in the field of peaceful uses of nuclear power have recently been concluded with France and the United States.

Legislative measures are being taken to allocate nearly 500 million dollars per annum from oil revenues to help finance the nuclear reactors programme whose financial requirements may exceed 20 billion dollars during the period 1980-2000.

Uranium, thorium and other radioactive materials have been discovered in Egypt, but a great deal of effort is needed to eveluate the techno-economic feasibility of such deposits and the exploration of new ones. A special Authority for nuclear materials is being established under the chairmanship of the Minister of Industry to accelerate such activities.[1]

3.5 Coal

Few coal deposits were discovered in Egypt with estimated reserves in the range of 80 million tons. Al-Maghara coal mine in Sinai is being studied for immediate development and utilization (with nearly 35 million tons reserves). A programme for coal exploration in several areas is underway, and Egypt may soon be exploiting coal for electricity generation.

Coal is already used as a feedstock for steel industry in amounts totalling one million tons at present and are expected to reach 5.5 million tons by the year 2000.[1]

3.6. New and Renewable Sources of Energy

Several Ministries and Companies, public as well as private, are undertaking the responsibility of demonstration and commercialization activities in the field of NRSE.

The most important among these institutions is the Ministry of Electricity which established several bodies to handle various aspects of these responsibilities. This Ministry established a Council headed by the Minister to deal with policy matters, an Authority to monitor implementations and a Company to manufacture equipments.

More recently, with the financial support of the EEC, the Ministry of Electricity is undertaking a Feasibility Study to examine the establishment of an independent body for NRSE and a grant by USAID in the amount of 5.3 million dollars has been ratified to allow for field testing of new and renewable equipments.

In a recent joint Egyptian-USAID assessment of renewable energy resources and priorities[8], some areas with good prospects for application in Egypt were identified as follows:

- Solar domestic water heating;
- Solar collectors for industrial heat;
- Solar desalination;
- Rural biogas digesters;
- Photovoltaics for remote area applications;
- Passive solar architecture for new settlements;
- Solar flat plate collectors for refrigeration;
- Wind systems for water pumping and electricity generation.

3.6.1. Solar Energy

Egypt has an extensive research and development programme basically in the solar energy laboratory of the NRC in addition to the Universities and the Ministry of Electricity and with the cooperation of Germany, USA, Canada and France.

At present the use of energy produced by solar radiation is still under experimentation, but several demonstration projects have been executed in order to enhance the public awareness, train technical personnel and above all to assess the technical and socio-economic feasibility of the new technologies under actual egyptian conditions.[1)]

3.6.2 Wind Energy

The Ministry of Energy and Electricity with the support of USAID has conducted a research programme to measure wind speed and duration in Egypt. Several areas have an average daily and annual wind speed high enough to be considered for the development of wind-power generators. Basic studies concerning design performance of different wind mills and generators suitable for electricity generation are underway at the NRC and at Cairo, Alexandria and Helwan Universities.[1)]

3.6.3 Biomass

The cultivated area in Egypt remained unchanged during the last three decades while the population increased from about 19 million in 1952 to about 46 million in 1982.[10)]

The cultivated area per head decreased therefore from 0.134 hectares in 1952 to 0.059 ha in 1980 (-56.3%). The cropped area, however, increased from 3.78 to 4.57 million ha during the same period (+20.1%). The intensified cultivation of the limited area increased the need for organic manuring to conserve soil fertility.[2)]

The organic matter content in egyptian soils ranged from 0 to 2%, a level which is considered very poor and needs annual ammendment especially after erecting the Aswan High Dam which deprives the soil of a major part of the annual supply of suspended matter. In addition, projects for expanding the cultivated area by reclamation of desert sandy soils presents an addi-

tional increasing demand for organic manures.[2]

The importance of organic manures in egyptian agriculture has been repeatedly proved especially in long term field experiments such as those conducted at Bahteem since 1919 until now.

As shown on Table 3, organic manuring could replace nitrogen and phosphate fertilizers and increase the yields of cereals, fiber and forage crops by 16-172%, as compared to optimal chemical fertilization treatments.[11] Soil chemical properties due to their contents of plant nutrients and soil pH were also favoured by the organic manuring (see Table 4).

In Egypt's rural areas, the current energy use pattern can be characterized by the utilization of non-commercial energy sources. In 1975, crop residues provided 172×10^{15} joules or one third of the energy consumed in Egypt. Animal wastes provided some 43×10^{15} joules of energy for cooking and baking in the same year. Crop residues and animal droppings are therefore extensively used as fuel.[8]

The area cultivated for different crops, the crop residues produced, the energy equivalents and plant nutrients losses due to burning as well as their selling values[2] are presented in Table 5. Those of animal droppings are given in Table 6.

As shown on Table 5 and 6, residues made available through harvesting of different crops were about 22.6 million tons out of which about 3.6 million tons are used for direct burning (60%). Animal droppings, principally cow and buffalo, are used as organic manure or as fuel for rural cooking. Generally, manure is mixed with straw and/or stalks, which are stored on the roofs together with other crop residues for additional drying.

Removal of these nutrient rich resources from the fields deprives the farmer of much needed fertilizers, and their replacement often means the use of chemical fertilizers at a severe financial and energy cost.[4] In 1977, for example, the fertilizer values of crop

TABLE 3. Effect of prolonged application of chemical fertilizers and organic manures on crop yields (Evaluation of results 1919-1955; values are given as % of the control).

Crop	Control	Mineral fertilizers		Organic manuring
		Nitrogen	Nitrogen + Phosphorus	
Cotton	100	143	188	181
Wheat	100	147	192	264
Maize	100	155	229	245
Clover	100	100	265	437

Source: (11) Taha et al (1966)

TABLE 4. Effect of prolonged application of chemical fertilizers and organic manures on crop yields and the soil contents of plant nutrients (average values of 43 years evaluation of permanent experiment of Bahteem).

		Control	Chemical fertilizers			Organic manure
			N x	NP x	NPK x	
Crop yield % (1959-1962)		100	151	165	143	212.50
Organic matter	%	1.08	1.16	1.17	1.17	2.51
Total nitrogen	%	0.07	0.07	0.07	0.07	0.15
NH^+_4 —N	ppm	4.20	5.10	4.20	5.10	9.20
NO^-_3 —N	ppm	16.90	17.20	17.00	17.70	29.40
P_2O_5	ppm	56.10	51.20	104.40	101.60	313.20
pH		8.20	8.40	8.30	8.30	7.60

x N = Nitrogen; NP = Nitrogen + Phosphorus; NPK = Nitrogen + Phosphorus + Potassium

Source: (4) Taha et al (1966)

TABLE 5. Crop residues, quantities, their content of plant nutrients, selling value and utilization for fuel and fodder (status 1978).

Crop	Area 000 acres	Residues 000 Ton/ year	Fertilizer Nutrients Quantities 000 Ton/year N	P_2O_5	K_2O	Value million L.E./year	Selling value million L.E./year
Wheat:	1374						
Straw		2845	19.1	2.0	25.6	4.31	105.58
Mill		490	9.8	0.3	4.4	1.65	24.50
Barley	101	177	1.3	0.2	2.9	0.36	4.96
Broad bean	238	283	3.5	0.4	4.7	0.79	6.17
Fenugreek	21	17	0.4	0.1	0.2	0.07	0.33
Chickpea	14	28	0.6	0.1	0.3	0.11	0.95
Lentils	34	13	0.3	-	0.1	0.05	0.37
Clover green	2850	-	-	-	-	-	-
Clover seeds	233	201	4.5	0.4	2.0	0.85	2.74
Cotton	1177	1782	31.2	4.0	33.0	6.63	12.97
Rice:	1019						
Straw		2472	12.1	1.8	23.3	3.16	11.59
Husks		583	-	-	-	-	-
Bran		233	-	-	-	-	11.65
Sorghum	435	1526	16.5	2.3	20.1	3.67	16.97
Maize:	1877						
Stalks		3474	29.8	4.8	35.7	6.64	20.46
Cobs		500	5.4	0.8	6.6	1.20	7.50
Sugar cane:	250						
Green tops		2900	18.5	2.5	9.6	3.41	18.60
Bagasses		1393	12.3	1.6	23.7	0.58	5.00
Dry leaves		250	2.2	0.3	4.3		
Peanut	31	39	0.6	0.1	0.5	12.00	0.20
Sesame	23	31	0.3	0.1	0.5	0.08	0.16
Flax	59	-	-	-	-	-	-
Sunflower	4	10	0.1	-	0.2	0.02	-
Soybean	82	81	1.8	0.2	0.8	3.22	1.23
Vegetables	922	931	14.0	2.2	14.0	2.03	4.66
Horticultures	321	321	6.3	1.0	6.3	1.34	1.61
TOTAL	10505	22588	190.6	26.0	218.7	40.52	258.34
Used as fuel		13608	136.3	19.5	172.1	30.68	87.00
% from total		60.2	71.5	75.2	78.7	75.70	33.70
Used as fodder		6963	59.4	5.6	46.7	10.86	171.10
New sources for fodder		9279	86.5	12.9	109.1	19.51	-

Source: (2) - Alaa El-Din (1980)

TABLE 6. Farm animals' production of organic manure; losses of fertilizers and organic matter through the use of animal droppings for fuel purposes and their values.

Animals	Number (,000)	Manure (million c.m/year)	Losses (%) Total	For fuel	Manure net production (million c.m/year)
Cows	2048	71.68	30.0	30.0	50.2
Buffaloes	2266	79.31	30.0	30.0	55.2
Sheep	1821	9.11	35.0	-	5.9
Goats	1375	6.88	35.0	-	4.5
Camels	97	1.46	80.0	-	0.2
Pigs	15	0.08	35.0	-	0.05
Donkeys, horses and mules	1257	18.86	80.0	-	2.8
Poultry	38081	0.25	-	100.0	-
TOTAL	46960	187.63	-	-	119.2

Source (2) Alaa El-Din (1980)

(cont.)

TABLE 6. (cont.)

Animals	Fertilizer Nutrients (,000 Ton/year)								Organic Matter used as fuel	
	Production				Losses				Quantity	Organic manure equiv
	N	P_2O_5	K_2O	Value x	N	P_2O_5	K_2O	Value x	(,000 Ton/year)	(million c.m/year)
Cows) Buffaloes)	156.4	54.4	181.2	37.8	46.9	16.3	54.4	11.2	1767	44.1
Sheep) Goats)	15.5	4.6	16.2	3.5	5.4	1.6	5.7	1.2	224	5.6
Camels	-	-	-	-	-	-	-	-	-	-
Pigs	-	-	-	-	-	-	-	-	-	-
Donkeys, horses and mules	27.1	5.6	27.7	5.9	21.7	4.5	22.2	6.0	650	16.3
Poultry	2.3	4.5	0.6	-	-	-	-	-	-	-
TOTAL	201.5	68.9	225.7	47.2	74.0	22.4	82.3	18.4	2641	66.0

x Million L.E./year. 3)

residues and animal excreta were 30.68 and 47.84 million L.E. for their content of plant nutrients; and 13.23 and 8 million L.E. for their organic matter respectively (total fertilizer values were 43.52 and 55.84 million L.E.). Out of these values 75.7% and 23.7% were lost by burning crop residues and cow dung 3).

The direct combustion of these valuable residues takes place in devices of low efficiency. Efficiencies ranging between 5-10%, depend on whether an open fire (kanon) is used or a clay unit (furn), generally attached to the wall of the house without a chimney for air circulation. These systems have numerous disadvatanges.

The large quantities of smoke produced through burning cow dung not only pollutes the environment but creates a high risk of eye irritation and disease. Cooking becomes an inefficiently time consuming task as the cooking process is very slow and a significant part of daily house work is taken up in the preparation of cow dung cakes and crop residues to be used as fuel. In addition, storage and handling fresh residues directly, allow the dissemination of disease and parasites from animal to man. Fire is also a continuous threat to villages due to the exposure of crop residues and cow dung cakes stored on the roofs.

The utilization of crop residues for fuel purposes in rural Egypt leads, in addition to the great loss in energy (90%), to the loss of a large quantity of crop residues suitable as fed for farm animals. The residues of field, horticulture and vegetable crops (22.6 million tons/year) currently provide about 7 million tons/year for feeding farm animals. A great part of crop residues presently used for fuel could be utilized efficiently as an additional fed source for farm animals. These amount to about 9.3 million tons/year.

Utilization of this additional source can provide the animal production sector with 2.4 million tons starch equivalent/year 3) or 3.7 million tons/year of a total digestable nutrients (see Table 7). This can help to cover the shortage in feed which is estimated at 1.8-2.0 million tons starch value and thus bring into the market 5.25 million tons starch value by

TABLE 7. Present uses of crop residues in Egypt and their possible saving for feed purposes.

Uses of the residues	Quantity ,000 Ton/Year	Starch equivalent ,000 Ton/Year	Digestible material ,000 Ton/Year	Selling value million L.E./Year
Fodder	6963	1789	2785	171.1
Fuel	13608	-	-	78.0
TOTAL	20571	-	-	258.1
New sources as fodder	9279	2385	3712	288.0

Source (3) Alaa El-Din (1981)

the year 2000 enabling the egyptian economy to satisfy 18 grammes animal protein/capita/day.

The present national production of meat amounts to less than 1/3rd of the minimum human requirement of animal protein (30 grm/capita/day). This is due to the lack of feed which is largely composed of filling materials (crop residues and straws). Saving these amounts of crop residues from burning would allow an increase in the number of fattened animals by 1.3 million, enough to produce about 300.000 tons of red meat annually.

In addition, the drain of about 30% of animal dung (4.3 million cow and buffalo) and the burnign of it as fuel for baking and cooking leads to the loss of 44 million cubic meters of manure (Table 6).

The night soil in rural areas is not longer in common use in soil fertilization as it was the case in the past. Their residues are now either dumped into water streams or at the outskirts of villages which in either case act as microbial and chemical pollutants to the environment.

4. Available Raw Materials and Energy Production Potential

A survey was carried out to evaluate the raw materials generated in the area and utilized for energy production to satisfy domestic needs and/or to provide land with fertilizer, which in turn is considered as indirect energy (see map).

The survey included 4 villages namely: AHAMED ORABI, AL-GAZAER, PALESTINE and ALOLA AL GHARBIA as well as 11 animal farms belonging to Mariut Company and 2 other Companies in the area. A lengthy questionnaire was applied in the present study. The questionnaire was previously used by the Biogas Research Team of the Ministry of Agriculture (MOA) to evaluate energy resources, uses and budgets at 9 Governorates (460 families)7).

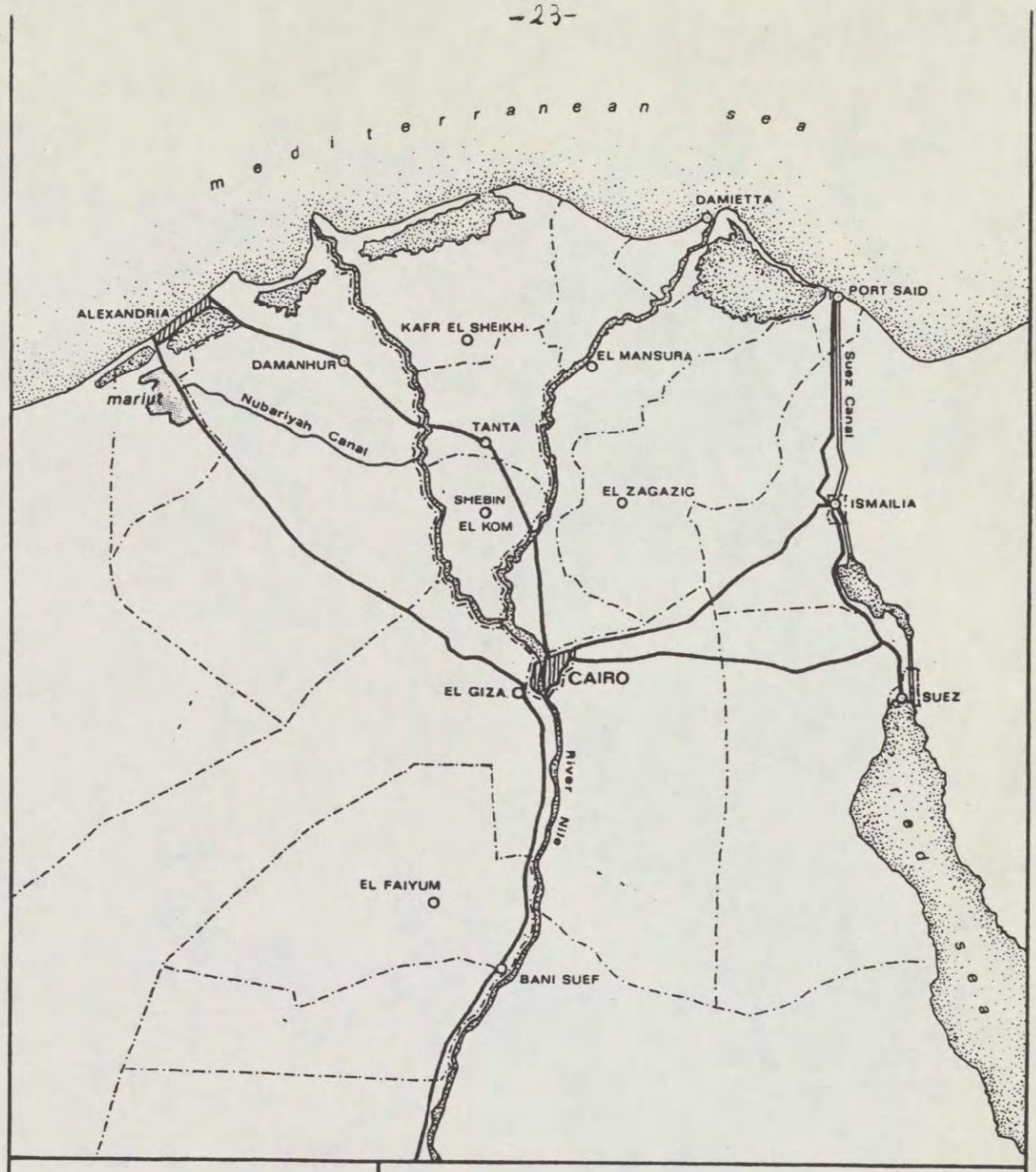
The survey was carried out with the help of some agriculture engineers of both the Biogas Research Team (ARC) and the Mariut Center under the supervision of the Team Leader.

Analysis on non-conventional energy sources (crop residues and animal droppings) to evaluate potential production of biogas and gross energy, were carried out at the laboratories of the Biogas Project, Soils and Water Research Institute of the ARC (MOA). The data were subjected to analysis and revealed the following:

4.1. Domestic Wastes

The settlements of the Project Area are not equipped with sewer networks, although sewer facilities are planned for future centers. At present, cesspools are used. Obviously, sewer systems are required to concentrate enough raw materials for biogas production on medium scale.

Therefore, biogas plants of a size above 500 cu.m



— LEGEND —

Governatorate Boundary

Main Roads

Main Towns

Project Area

LOCATION MAP
— Lower Egypt —

SCALE 1:2,000,000

based on the treatment of human wastes can only be envisaged for the settlements to be planned in the future.

Suitable layout criteria should therefore be adopted by town planners in the event that sizeable biogas facilities are to be adopted for centralized power supply in the local settlements.

4. 2. Agricultural Wastes

The average value for production of crop residues was found to be 1.929 Kg of crop residues/family/year and 1.3 tons cattle dung cakes/family/year. The residues are entirely used for energy although not all families are producers. The major crops bearing residues for energy are from maize, cotton and rice. The share of each crop into the residues used for energy is given in Table 8 .

The distribution of crop residue producers and those who buy or get the residues free of charge is given in Table 9 . As shown in the Table, there was some difference percentage wise between the villages where families produce crop residues for energy.

Average values, however, indicate that 2/3rd of the families produce more that enough while 6.4% produce less than needed and therefore must buy crop residues to cover some of their needs. 26.3% are not producers and about half of them buy crop residues while the others get their needs free of charge. The later group might have to pay in the form of work; i.e. clear cotton fields from cotton stalks in proper time in order to get their fuel.

The crop residues were used for different purposes and the major application was for baking bread. Of the families interviewed, 89% used crop residues for baking, 33% for cooking, roasting and heating water and less than 10% for making tea and coffee. 13.4% used crop residues for the purpose of shunning mosquitoes (see Table 10).

TABLE 8 Crop residues used for energy in Mariut area (Kg/family/year)

Village	Maize stalks	Corn cobs	Cotton stalks	Rice straws	Dems feeds x	Tree branches	Total
Ahamed Orabi	765.4	130.45	-	-	936.15	73.0	2205.0
Al-Gazaer	719.0	124.00	-	47.3	955.00	16.4	1861.7
Palestine	686.0	162.00	-	-	347.00	43.5	1238.5
Alola Al-Gharbia	944.0	273.53	39.2	400.0	545.80	211.2	2413.7
TOTAL	3114.4	689.95	39.2	447.3	2783.95	644.1	7718.9
Average	778.6	172.49	39.2	223.6	695.99	161.0	1929.7

x Waste stuff.

TABLE 9 . Sources of securing the needs of crop residues for domestic energy uses in Mariut area (% of total consumption).

Village	Produced	Bought	Produced + bought	Getting as gift
Ahamed Orabi	46.0	13.0	6.0	20.0
Al-Gazaer	67.0	10.0	6.6	10.0
Palestine	67.0	20.0	6.6	13.0
Alola Al-Gharbia	90.0	5.0	-	-
Average	67.5	12.0	6.4	14.3

TABLE 10. Household uses of crop residues as energy source in Mariut area (% of total consumers).

Village	Baking bread	Cooking	Rosting	Space heating	Water pipe	Water heating	Shuning of mosquitoes	Coffee and tea
Ahamed Orabi	73.0	13.0	13.0	73.0	-	7.0	7.0	-
Al-Gazaer	87.0	20.0	13.6	7.0	10.0	20.0	6.6	3.5
Palestine	100.0	40.0	20.0	20.0	20.0	13.0	20.0	13.0
Alola Al-Gharbia	95.0	50.0	55.0	40.0	55.0	45.0	20.0	10.0
Average	88.7	30.7	25.2	35.0	28.3	21.2	13.4	8.8

Animal droppings are usually collected, mixed with fine crop residues and formed to cakes of different sizes. The cakes are then dried in the sun and stored on the roofs until used as fuel. The production rates of dung cakes and their uses are given in Table 11.

The consumption of different energy sources for domestic purposes has also been evaluated for the four villages under investigation. The rates of consumption and the expenditure are given in Tables 12 and 13.

Average consumption of electricity was not investigated as there were no meters in the farmer houses, so the average consumption was calculated from the total production of electricity in the area and the amount devoted to the domestic use. A figure of 400 Kwh was given as being the annual consumption rate for each family in the area. The per capita consumption was therefore 50 Kwh/year.

Expenditure for electricity was calculated, although there is no charge for electricity in Mariut area for the moment, but calculations were made for comparison with other sources of energy.

Butagas is commonly used in Mariut area, where the average consumption was found to be about 95 Kg/family/-year or 11.9 Kg/capita/year, while expenditure in local prices is 17.6 L.E./family/year or 2.3 L.E./capita/year. The average consumption was found to be much higher than in other rural areas of Egypt (2.7 Kg butagas/capita/year).

Kerosene was consumed by 100% of the families at the rate of 189 litres/family/year being only about 37% of the consumption in other villages in Egypt. This might be due to the high consumption of butagas averaging 50.7 L.E./family/year due to the higher living standard of the families in Mariut area and/or the higher education level of pioneer families.

Alcohol was consumed in minor quantities and mainly for making tea and coffee and in some cases for starting kerosene stoves.

TABLE 11. Production of dung cakes and its uses in Mariut area.

Village	Average number of animals			Cattle dung produced		% of total consumers				
	Cows	Buffaloes	Total	Kg/day	Kg/year	Baking bread	Cooking	Rosting	Space heating	Water heating
Ahamed Orabi	1	1	2	4.94	1 803	40.0	7.0	13.0	7.0	7.0
Al-Gazaer	1	1	2	5.04	1 840	40.0	7.0	3.5	3.5	-
Palestine	1.5	1	2.5	5.4	1 971	40.0	20.0	13.0	6.7	13.0
Alola Al-Gharbia	2	1	3	6.0	2 190	100.0	40.0	35.0	20.0	40.0
Average	1.38	1	2.38	5.35	1 951	55.0	18.5	16.13	9.3	20

TABLE 12. Consumption of conventional sources of energy for domestic use in Mariut area.

Village	Consumers (%)	Consumption Unit/year		Expenditure L.E./year	
		Family	Capita*	Family	Capita*
Electricity (KWh)**					
Ahamed Orabi	-	-	-	-	-
Al-Gazaer	52.0	400	50	9.60	1.20
Palestine	53.0	400	50	9.60	1.20
Alola Al-Gharbia	60.0	400	50	9.60	1.20
Average	55.0	400	50	9.60	1.20
Butagas (Kg)					
Ahamed Orabi	27.0	138.2	17.3	24.00	3.00
Al-Gazaer	20.0	87.8	11.0	15.25	1.91
Palestine	20.0	105.1	13.1	17.10	2.14
Alola Al-Gharbia	15.0	48.6	6.1	17.00	2.13
Average	20.5	94.9	11.9	17.59	2.29
Kerosene (liter)					
Ahamed Orabi	100	205.2	25.6	7.89	0.99
Al-Gazaer	100	182.4	22.8	6.77	0.82
Palestine	100	205.2	25.6	8.35	1.04
Alola Al-Gharbia	100	164.4	20.5	6.58	0.82
Average	100	189.3	23.7	7.40	0.93
Alcohol (liter)					
Ahamed Orabi	26.7	8.4	1.0	2.52	0.32
Al-Gazaer	-	-	-	-	-
Palestine	7.0	6.0	0.7	1.80	0.23
Alola Al-Gharbia	40.0	10.8	1.3	3.32	0.42
Average	24.6	8.4	1.1	2.31	0.32
Batteries (unit)					
Ahamed Orabi	53.0	141.6	17.7	35.28	4.41
Al-Gazaer	43.0	82.3	10.3	15.84	1.98
Palestine	47.0	82.3	10.3	23.28	2.91
Alola Al-Gharbia	70.0	142.0	17.7	37.32	4.67
Average	48.7	112.0	14.0	27.93	2.49
Total expenditure				64.83	8.23

* Average household size: 8 persons. ** No meters to evaluate households consumption.

TABLE 13. Consumption of non-conventional sources of energy for domestic uses in Mariut area.

Village	Consumers %	Consumption Kg/year		Value L.E./year	
		Family	Capita	Family	Capita
1. Dung cakes x					
Ahamed Orabi	60	1439.0	179.88	50.36	6.30
Al-Gazaer	40	1234.0	154.25	43.19	5.40
Palestine	40	1111.5	138.94	38.90	4.86
Alola Al-Gharbia	100	1334.4	166.75	46.70	5.84
Average	60	1279.73	159.96	44.79	5.60
2. Crop residues					
Ahamed Orabi	73	2205.0	275.63	54.89	6.86
Al-Gazaer	87	1861.7	232.71	35.96	4.50
Palestine	100	1238.5	154.81	37.43	4.68
Alola Al-Gharbia	95	2414.0	301.75	61.40	7.68
Average	89	1929.8	241.23	47.42	5.93
TOTAL		3209.5	401.19	92.21	11.53

x One Kg of dung cakes equivalent 3.5 Piastres.

1 £E = 100 piastres

Dry batteries are used for operating radios, cassette recorders and pocket lamps. The rate of consumption is much higher than in traditional villages. The expenditure reached 28 L.E./family/year and presented the highest expenditure among the non-conventional sources of energy.

Total expenditure for conventional sources was about 65 L.E./family/year and 8.2 L.E./capita/year. Table 13 shows that these figures were much lower than those recorded for non-conventional sources.

Rural families in the Project Area consumed dung cakes and crop residues to the value of about 45 L.E. and 47 L.E./family/year totalling about 92 L.E./family/year. The cost of energy, however, depends on efficiency; therefore, gross energy, net energy and the cost of 1000 Kcal net energy were estimated. For this purpose, laboratory experiments were carried out, the results of which are discussed below.

The gross energy used in Mariut area for domestic purposes is shown in Table 14. Conventional sources ranged between 2.43-3.41 million Kcal/family/year and non-conventional sources ranged between 10.31-16.46 million Kcal/family/year.

There were some differences between the villages under investigation, showing lower consumption in Palestine and about 50% higher consumption in Ahamed Orabi village. The major difference was due to the higher consumption of cattle dung and crop residues.

The net energy consumption for domestic use, shown on Table 15, was much lower as the efficiency of energy utilization varied between 11% for crop residues and 70% for electricity. The average net energy consumption was 1.745 million Kcal/family/year from conventional sources and 1.55 million Kcal/family/year from non-conventional fuels. The total net energy consumption was 3.295 million Kcal/family/year.

The net energy consumption per capita, ranged between 0.375 and 0.452 million Kcal/year. The average value

TABLE 14. Gross energy consumption for domestic purposes in Mariut area.

Source of energy	million Kcal/family/year					million Kcal/capita/year				
	Ahamed Orabi	Al-Gazaer	Palestine	Alola Al-Gharbia	Average	Ahamed Orabi	Al-Gazaer	Palestine	Alola Al-Gharbia	Average
Conventional										
Electricity	-	0.344	0.344	0.344	0.344	-	0.043	0.043	0.043	0.043
Butagas	1.49	0.950	1.140	0.530	1.030	0.190	0.120	0.140	0.070	0.130
Kerosene	1.87	1.660	1.870	1.500	1.730	0.230	0.210	0.230	0.190	0.220
Alcohol	0.05	-	0.003	0.060	0.038	0.006	-	-	0.007	0.004
Batteries	-	-	-	-	-	-	-	-	-	-
Subtotal	3.41	2.954	3.357	2.434	3.142	0.426	0.373	0.413	0.310	0.397
Non-conventional										
Cattle dung	6.30	5.400	4.860	5.840	5.600	0.790	0.680	0.610	0.730	0.700
Crop residues	9.70	8.190	5.450	10.620	8.490	1.210	1.020	0.680	1.330	1.060
Subtotal	16.00	13.590	10.310	16.460	14.090	2.000	1.700	1.290	2.060	1.760
TOTAL	19.41	16.544	13.667	18.894	17.232	2.426	2.073	1.703	2.370	2.157

Calorific value: Electricity = 860 Kcal/Kwh; Butagas = 10800 Kcal/Kg; Kerosene = 9122 Kcal/liter; Alcohol = 5340 Kcal/liter
Cattle dung = 4376 Kcal/Kg dry matter; Crop residues = 4400 Kcal/Kg dry matter.

TABLE 15. Net energy consumed for domestic purposes in Mariut area.

Source of energy	Million/Kcal/family/year					Million/Kcal/capita/year				
	Ahamed Orabi	Al-Gazaer	Palestine	Alola Al-Gharbia	Average	Ahamed Orabi	Al-Gazaer	Palestine	Alola Al-Gharbia	Average
Conventional										
Electricity	-	0.241	0.241	0.241	0.241	-	0.030	0.030	0.030	0.030
Butagas	0.894	0.570	0.684	0.318	0.618	0.112	0.071	0.086	0.040	0.077
Alcohol	0.025	-	0.002	0.036	0.023	0.003	-	-	0.005	0.003
Batteries	-	-	-	-	-	-	-	-	-	-
Kerosene	0.935	0.830	0.935	0.750	0.863	0.117	0.100	0.117	0.094	0.108
Subtotal	1.854	1.641	1.862	1.345	1.745	0.232	0.201	0.233	0.169	0.218
Non-conventional										
Cattle dung	0.693	0.594	0.535	0.642	0.616	0.087	0.074	0.067	0.080	0.077
Crop residues	1.067	0.901	0.600	1.168	0.934	0.133	0.113	0.075	0.146	0.117
Subtotal	1.760	1.495	1.135	1.810	1.550	0.220	0.187	0.142	0.226	0.194
TOTAL	3.614	3.136	2.997	3.155	3.295	0.452	0.388	0.375	0.395	0.412

Efficiency: Electricity = 70%; Kerosene = 50%; Butagas = 60%; Alcohol = 60%.
Cattle dung = 11%; Crop residues = 11%.

was about 0.412 million Kcal/year (very close to the net energy consumption of 0.387 million Kcal/year in other developing countries) and much lower than the consumption recorded in other rural areas of Egypt at 0.778 million Kcal/year.[7]

The relative satisfaction of gross energy consumed from different sources are given in Table 16 and those for net energy in Table 17.

18.2% of the total gross energy consumption was covered by conventional sources (butagas, electricity, kerosene and alcohol), while 81.2% was provided by cattle dung and crop residues. These figures change dramatically when dealing with net energy, as conventional sources satisfied 52.1% of the needs, while the rest was covered by non-conventional sources.

Table 18 shows that there were no major differences between the villages under investigation, with the exception of Palestine, which depends more on conventional than on non-conventional sources of energy.

The actual cost of obtaining 1.000 Kcal net energy in Mariut is indicated in Table 19, showing crop residues and cattle dung to be a much more expensive source of energy than butagas and kerosene when considering local prices. This amount of net energy will cost Mariut farmers 5.1 piastres (Pt.) when burning crop residues and 7.3 Pt. in the case of cattle dung. The same amount of net energy will cost 3 Pt. when butagas is the source and 0.9 Pt. if kerosene is used.

When considering the world prices of butagas and kerosene, the cost of cattle dung will amount to almost the same as butagas and about the double of kerosene in order to obtain 1.000 Kcal net energy. These figures do not include the fertilizer nutrient contained in the crop residues and cattle dung.

The losses of plant nutrients and organic matter through burning of crop residues and cattle dung cakes in the Project Area were estimated, and are presented in Tables 20 and 21.

TABLE 16. Relative satisfaction of gross energy consumed from different sources (% of total).

Village	Conventional						Non-conventional		
	Electricity	Butagas	Kerosene	Alcohol	Batteries	Subtotal	Cattle dung	Crop residues	Subtotal
Ahamed Orabi	-	7.67	9.63	0.260	-	17.56	32.45	49.96	82.40
Al-Gazaer	2.08	5.74	11.29	-	-	17.84	32.62	49.47	82.08
Palestine	2.52	8.34	13.69	0.022	-	24.57	35.58	39.89	75.47
Alola Al-Gharbia	1.82	2.80	7.94	0.317	-	12.88	30.89	56.18	87.07
Average	2.14	6.14	10.64	0.200	-	18.21	32.89	48.88	81.76

TABLE 18. Gross and net energy consumption from conventional and non-conventional sources in Mariut area.

Village	Gross energy (%)		Net energy (%)	
	Conventional	Non-conventional	Conventional	Non-conventional
Ahamed Orabi	17.57	82.40	51.30	48.70
Al-Gazaer	17.84	82.08	52.33	47.68
Palestine	24.57	75.47	62.13	37.87
Alola Al-Gharbia	12.88	87.07	42.64	57.38
Average	18.22	81.76	52.10	47.91

TABLE 19. Annual per capita consumption, expenditure and cost of 1000 Kcal net energy in Mariut area.

Source of energy	Quantity	Net energy Kcal x 10	Expenditure Piastre	Cost of 1000 Kcal net energy (P.T.)	
				Local	World
Conventional					
Electricity (KWh)	50.00	30	120	4.0	10.83
Butagas (Kg)	11.87	77	229	3.0	7.40
Kerosene (Liter)	23.66	108	93	0.9	4.60
Alcohol (Liter)	1.05	3	32	10.7	10.70
Batteries (Unit)	14.01	-	249	-	-
Subtotal	-	218	723	-	-
Non-conventional					
Crop residues (Kg)	241	117	593	5.1	-
Cattle dung (Kg)	160	77	560	7.3	-
Subtotal	401	194	1153	-	-
TOTAL	-	412	1876	-	-

TABLE 20. Losses of plant nutrient and organic matter through burning of crop residues at Mariut area.

	Kg nutrient ($N+P_2O_5+K_2O$)/family/year				
	Ahmed Orabi	Al-Gazaer	Palestine	Alola Al-Gharbia	Average
Loss of nutrients:					
Maize stalks	17.3	16.3	14.5	21.3	17.4
Maize cobs	3.3	3.2	42.0	7.0	13.9
Cotton stalks	-	-	-	2.0	0.5
Rice strow	-	0.7	-	6.0	1.7
Dems	21.2	21.6	7.8	12.3	15.7
Tree branches	1.7	0.4	1.4	4.8	2.1
Subtotal (Kg nutrient)	42.8	41.6	27.9	53.4	41.4
Value (L.E.)	17.8	13.0	7.3	17.9	14.0
Losses of organic matter: x					
Amount (Kg)	1498	1257	837	1630	1305.5
Value (L.E.)	20.0	16.8	11.2	21.7	17.4
Total value of losses:					
L.E./family/year	37.8	29.8	18.5	39.6	31.4
L.E./capital/year	4.7	3.7	2.3	4.9	3.9

x Calculated on the basis of the amounts of crop residues burned and the content of 10% moisture and 75% of organic matter in the residues.

TABLE 21. Lossess of plant nutrient and organic matter through burning of cattle dung in Mariut area.

	Kg nutrient ($N+P_2O_5+K_2O$)/family/year				
	Ahamed Orabi	Al-Gazaer	Palestine	Alola A-Gharbia	Average
Losses of nutrients					
Amount (Kg)	73.20	62.60	80.00	88.90	76.20
Value (L.E.)	29.90	19.70	20.70	29.90	25.10
Losses of organic matter x					
Amount (Kg)	1217	1242	1330	1478	1317
Value (L.E.)	16.20	16.60	17.70	19.70	17.60
Total value of losses					
L.E./family/year	46.10	36.30	38.40	49.60	42.60
L.E./capita/year	5.76	4.54	4.80	6.20	5.35

x Calculated on the basis of the amounts of cattle dung burned and the content of 10% moisture and 75% of organic matter in the dung cakes.

The losses of fertilizer nutrients ranged between 28-53 Kg $N+P_2O_5+K_2O$/family/year with the average of 41.4 Kg. The value of these nutrients calculated on the basis of the present price in Mariut area (a mixture of official and black market prices) ranged between 7.3 and 17.9 L.E./family/year with the average of 14.0 L.E.

The losses of organic matter through burning of crop residues ranged between 837 and 1.630 Kg organic matter /family/year and their value based on the common prices of organic manure ranged between 11.2 and 21.7 L.E./family/year, with an average of 17.4 L.E.

The total value of losses due to burning of crop residues averaged 31.4 L.E./family/year or 3.93 L.E./capita/year.

The losses of nutrients by burning cattle dung shown on Table 21, ranged between 62.6 and 88.9 Kg $N+P_2O_5+K_2O$-/family/year with an average of 76.2 L.E. The value of these nutrients averaged 25.0 L.E./family/year.

The loss of organic matter through cattle dung burning ranged between 1.217 and 1.478 Kg/family/year valued at an average of 17.6 L.E./family/year. The total value of these losses gives an average breakdown of 62.6 L.E./family/year or 5.35 L.E./capita/year.

When considering the above mentioned facts, the actual cost of obtaining net energy from crop residues and cattle dung becomes much higher than estimated in Table 19. This is simply due to the loss of fertilizer nutrients and organic matter which are badly needed for the production and sustaining of soil fertility in old land and for building up fertility in newly reclaimed areas like Mariut.

Table 22 gives our suggestion for the cost of 1.000 Kcal net energy in Mariut as compared to butagas and kerosene, evaluated on the basis of local prices as well as world prices. The results show energy costs from crop residues to be about nine times that of kerosene and three times that of butagas (when conside-

TABLE 22. Local and world cost of 1000 Kcal of net energy from different sources of energy and its ratio with kerosene.

Source	Price, Piastres/1000 Kcal net energy			
	Local	%	World	%
Kerosene	0.9	100	4.60	100
Butagas	3.0	333	7.40	161
Crop residues	8.4	933	8.40	183
Cattle dung	14.2	1577	14.20	309

Note: Electricity and alcohol were excluded as the first is not in common use for cooking and the second is not in common use.

ring the subsidized local prices of kerosene and butagas), and 83% higher than kerosene and about 10% higher than butagas when considering the world prices for petroleum fuels.

Cattle dung cakes showed worthwhile figures in terms of the cost of the same amount of net energy it can realize, which was around sixteen times higher than kerosene, five times higher than butagas supplied at local prices, and about three times higher than kerosene and two times higher than butagas when considering world prices.

The amount of fertilizer nutrient lost through burning crop residues and cattle dung (N, P_2O_5 and K_2O) totalling 116.7, 104.2, 107.9 and 142.3 Kg for Ahamed Orabi, Al-Gazaer, Palestine and Alola Al-Gharbia respectively, represented 21-32% of total annual fertilizer nutrients applied to the holdings of each family (see Table 23).

In other words, burning crop residues and cattle dung deprives the soil of about 1/3rd of the nutrients needed.

A technology which can provide energy without losing fertilizer nutrients and the organic matter in the residues, will not only improve the energy balance but also reduce fertilizer consumption and thus save the energy utilized for their manufacturing.

TABLE 23. Quantity and price of fertilizer yearly applied to crops grown in Mariut area by household (Kilograms and L.E.).

	Ahamed Orabi		Al-Gazaer		Palestine		Alola Al-Gharbia	
Type and amount of fertilizer applied:	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Ammonium Nitrate (33.5% N)	562	68	400	41	330	30	725	80
Ammonium Sulphate (20.6% N)	500	30	390	30	740	42	300	30
Urea (46% N)	100	16	50	6	200	24	120	18
Super Phosphate (15.5% P_2O_5)	550	26	550	27	650	26	760	38
Triple Phosphate (45% P_2O_5)	100	9	25	2	70	7	40	4
Potassium Sulphate (48% K_2O)	-	-	28	2	50	3	30	2
Total fertilizer applied:								
N	234	114	237	78	355	97	360	128
P_2O_5	130	35	96	30	132	33	136	42
K_2O	-	-	13	2	24	3	14	2
Total Nutrient	365	149	347	109	511	132	510	172

5. Economic Parameters of Biogas Production in Rural Areas of Egypt

Biogas as fuel contains an efficiency of 60-70% with a heating value of 18.7 MJ/cu.m.[9] If the biogas is burned in appropriately designed burners (as those available for butagas in Egypt), a combustion efficiency of 30% could easily be achieved. This is far in excess of what could be achieved by direct burning, which is limited to less than 10%.

The estimate for the quantity of biogas needed to cover the daily demand in rural areas of Egypt has been reported to be 0.2-0.3 cu.m/capita/day for cooking, and 0.07 to 0.08 cu.m/mantel lamp/hour.[5]

To replace kerosene with biogas about 1.3-1.8 cu.m biogas/litre kerosene is required. To replace one litre diesel fuel, 1.5-2.0 cu.m biogas are required.[5]

Calculations (see Table 24) of heat energy return, feed and plant nutrients through the application of biogas technology can be summarized as follows:[3]

two to three times more efficient energy for cooking, lighting, etc.; increase in efficient energy from 1.060 to 2.070-3.030 million litres kerosene equivalent, or from 739 to 1.440-2.110 thousand tons butagas equivalent;

more than a doubling of animal feed; saving 9.3 million tons/year dry matter of a crop residues suitable as animal feed, i.e. an increase of 133% of what is presently available (7 million tons/year);

more than a doubling of plant nutrients returned to the soil; increase in the amount of plant nutrient (NPK) returned into soil from 312.000 tons/year to 726.000 tons/year;

almost three times the available organic manure; increase in the amount of organic manure from 107 million cu.m/year to 300 million cu.m/year (280%) which will cover the need for organic manure which is estimated at 120 million cu.m/year; and

the utilization of poultry droppings and human wastes

TABLE 24. Energy released from burning crop residues and animal droppings in rural Egypt, their equivalent as kerosene and butagas, their economic value as energy source and the economic value of fodder and manure.

Residues and uses	Energy released from residues equivalents to:				Selling value of energy compared with: (million L.E./year)			
	Kerosene (million l/year)		Butagas (,000 ton/year)		Kerosene **		Butagas ***	
	Present	After biogas x	Present	After biogas x	Present	After biogas x	Present	After biogas x
Crop residues (presently used as fuel)	856	272	597	190	175	57	263	84
Dung cakes (presently used as fuel)	204	708-867	142	494-605	42	145-178	63	217-266
Dung of animals raised on crop residues saved from burning	-	821-1005	-	573-702	-	168-206	-	202-308
Poultry droppings (presently used as fertilizer)	-	102-193	-	71-134	-	21-40	-	31-59
Human excrete (presently not in use)	-	164-691	-	115-482	-	34-142	-	51-212
TOTAL	1060	2067-3027	739	1443-2113	217	425-623	326	635-929

x Considering the minimum and maximum potential of biogas production.
** World price of kerosene 0.205 L.E. and net energy 4561 Kcal/liter.
*** World price of butagas 0.440 L.E. and net energy 6480 Kcal/Kg.

(cont.)

TABLE 24. (cont.)

Residues and uses	Selling value (million L.E./year)				Economic return compared with: (million L.E./year)			
	Meat produced from excess fodder xxxx		Fertilizers		Kerosene		Butagas	
	Present	After biogas	Present	After biogas	Present	After biogas	Present	After biogas
Crop residues (presently used as fuel)	-	750	9.0	2.9	184.0	810	272.0	737
Dung cakes (presently used as fuel)	-	-	8.0	35.2	50.0	180-213	71.0	252-301
Dung of animals raised on crop residues saved from burning	-	-	-	40.8	-	209-247	-	292-349
Poultry droppings (presently used as fertilizer)	-	-	2.3	2.3	2.3	23-42	2.3	33-61
Human excrete (presently not in use)	-	-	-	18.7	-	53-61	-	70-300
TOTAL	-	750	19.3	99.9	236.3	1275-1473	345.3	1384-1848

xxxx Fodder gained from saved crop residues is about 9.3 million Ton/year and contains 3.4 million Ton/starch equivalent. It can produce 300 000 Tons of red meat at the value of 2500 L.E./Ton.

Source: (3) Alaa El-Din (1981)

in the production of biogas and organic manure, will reduce their pollutant potential.

The economic value of energy, feed and fertilizers as produced today and after application of biogas technology are illustrated in Table 24 according to the 1980 prices.

The comparative economic return of biogas energy when replacing kerosene will increase from 217 million L.E./year to 425-623 million L.E./year and from 326 million L.E./year to 635-929 million L.E./year when replacing butagas.

The economic return of saving 9.3 million tons feed/year will amount to 750 million L.E., equivalent to the value of 300.000 tons red meat added to the local production.

A significant increase in the value of nutrients and organic matter returned to the soil through biogas technology will be observed as it will increase from 19.3 million L.E. to 99.9 million L.E./year.

In general, the economic return of farm residues when utilized for biogas production will increase from 236.3 million L.E./year to 1.257-1.473 million L.E./-year as compared with kerosene or from 345.3 million L.E./year to 1.384-1.848 million L.E./year compared with butagas.

6. Past and Current Developments of Biogas Techniques in Egypt

The first trail biogas plant constructed in Egypt dates back to 1938, when the municipality of Cairo city established a 750 cu.m digester run on sewage sludge from the El-Gabel El-Asfar farm sewage treatment plant. The digester was connected with a separate movable gasholder (1.500 cu.m). The plant, however, has been out of operation for many decades[5].

The process of biogas generation from crop residues, animal droppings and human wastes (kitchen refuse, night soil), attracted the interest of egyptian scientists as well as those of developed and developing countries because of the numerous benefits realized from it.

Biogas technology provides a clean and convenient fuel for cooking. Manure obtained after biogas is higher in quantity, richer in nitrogen content and more free from pathogens and parasites as compared with the traditionally prepared manures.

Biogas conserves local fuel, i.e. kerosene. Vegetable refuse which would otherwise be burned inefficiently, animal and human wastes which might otherwise be a serious threat to health, crop stalks and straw which are otherwise burned as fuel are saved for use as fodder and for silage making. Finally, biogas reduces cooking time and thus reduces the housekeeping load for women.

Realizing the above mentioned facts, the scientists of the Ministry of Agriculture started a research programme on biogas in the fifties. The experimental work, however, was limited to laboratory investigation until 1977.

After a study tour organized by FAO in the People's Republic of China in 1977, the experts of MOA constructed the first household biogas digester at the Faculty of Agriculture, Cairo University at Fayum.

In 1981 the Ministry of Agriculture, with the technical and financial support of the FAO, started the project "Biogas for Rural Population". The aim of this project was to introduce the technology of biogas production and use into rural Egypt. The following has been achieved up to October 1984:6.

Implementation of biogas digesters.

35 biogas field units were constructed at 18 locations in 8 Governorates (see Table 25), FAO, USAID, MOA

A survey of energy resources and uses in egyptian villages was conducted to investigate the social and economic implications of introducing small-scale biogas digesters into egyptian agricultural communities (IDRC, MOA and USAID)

Research.

Several laboratory experiments were carried out to evaluate the rate of biogas generation from agricultural and city wastes under different operational conditions using different technologies.

Analyses were conducted on microbes present in biogas digesters, as well as the survival of pathogenic microbs during the biogas process.

Identification of the nutrient cycle under traditional conditions and after introduction of biogas technology to the rural ecosystem.

Greenhouse experiments with biogas fermenters to evaluate biogas and manure production from different agricultural and city wastes.

Evaluation of the manurial value of biogas effluent for field crops, maize, wheat, rice, cotton and vegetables. Economical evaluation of biogas manure in the production cycle.

Evaluation of residual effects of biogas manure in the soil (USAID)

Growing Azolla and Algae on biogas effluent as feed for poultry and as green manure (FAO)

Investigating the possibilities for biogas generation from landfills of city garbage (USAID)

TABLE 25. Biogas field units constructed by the Ministry of Agriculture (status 1984).

No	Locality	Beneficiary	Year of construction	Size c.m	Type
	Fayum Governorate				
1	Cairo	Fac. of Agric.	1978	10	Chinese
2	El-Salhiah	Private	1983	7	Indian
	Kalyubia Governorate				
3	Moshtohour	Animal farm	1980	45	Chinese
4	Moshtohour	Chcken farm	1980	10	Indian
5	Moshtohour	Private	1980	8	Indian
6	Moshtohour	Private	1980	6	Indian
7	Moshtohour	Chicken farm	1981	38	Indian
8	Moshtohour	Hospital	1982	13	Chinese
9	Moshtohour	Hospital	1983	20	PVC
10	El-Hessa	Private	1981	8	Indian
11	El-Hessa	Private	1981	7	Indian
12	El-Hessa	Private	1981	8	Indian
13	Mogowl	Chicken farm	1981	200	Taiwanese
	Giza Governorate				
14	Wardan	Private	1981	10	Chinese
15	Wardan	Chicken farm	1981	20	Indian
16	Wardan	Chicken farm	1981	17	Indian
17	Wardan	Private	1981	10	Indian
18	Giza	Fac. of Agric.	1982	8	Chinese
19	Giza	MOA	1982	8	Indian
20	Giza	Biogas Train.	1983	8	Chinese
21	Giza	Center, MOA	1983	8	Indian
	Behera Governorate				
22	El-Kadi	Private	1981	8	Indian
23	Tahrir South	Private	1982	15	Indian
24	Tahrir South	Private	1983	12	Indian
	Gharbia Governorate				
25	Shobra Tana	Private	1982	10	Indian
26	Shobra Tana	Private	1983	13	Indian
27	Tlbantkisar	Private	1983	12	Indian
	Sharkia Governorate				
28	Basaisa	Private	1982	12	Indian
29	Basaisa	Private	1982	10	Indian
30	Basaisa	Tech. Center	1982	10	Chinese

(cont.)

TABLE 25. (cont.)

No	Locality	Beneficiary	Year of construction	Size c.m	Type
	Alexandria Governorate				
31	Fac. of Agric. Alex. Univ.	MOA and Fac. of Agric.	1981	8	Indian
	North Sinai Governorate				
32	El-Arish	Private	1983	10	Indian
33	El-Arish	Private	1983	10	Indian
	Army Forces				
34	Army Forces		1983	180	Taiwanese
	Others				
35	Kafr Tohourmus	Scout Camp	1983	6	Indian

The National Research Center (NRC) has been interested in developing the biogas technology since 1975. In 1978 a national biogas research and development programme was started at the Academy of Scientific Research and Technology (ASRT), financially supported by USAID.

The project started with a fact-finding phase, a central library was established and a study tour to India, China and Thailand undertaken. Socio-economic surveys of typical egyptian villages were conducted and two villages, one traditional and one newly planned, were selected for field demonstrations. The NRC group has constructed and operated five biogas digesters to date; these are indicated in Table 26 .

The scientists of the Faculty of Agriculture at Fayum became interested in the biogas research when the first digester was constructed at their faculty by experts from MOA in 1977-1978. They constructed a similar unit at Abo-Ghandeer in 1981. The unit, however, did not operate properly. The same group is now working in collaboration with engineering scientists of Cairo University to combine wind energy for mixing digesting material in biogas unit. The work is still underway.

Some laboratory experiments are being carried out at the Faculty of Agriculture, Minia University in Upper Egypt. The work is still in the initial stage.

On the whole, 35 plants have been established by the Agricultural Research Center and 5 plants by the National Research Center; their capacities range between 6 and 200 cu.m. This indicates that development of biogas industry in Egypt is still at its primary stage and that only small units are operating to date. The technology adopted for the existing plants are either of the Chinese, Indian, Taiwanese or Plastic types.

TABLE 26 . Biogas plants constructed by National Research Center.

N°	Type	Locality	Volume m
1	Indian	El-Manawat, Giza	10
2	Chinese	idem	10
3	idem	Cairo	6
4	idem	idem	12
5	Indian	idem	7

Source: 1983 Biogas survey.

REFERENCES

1. Abdallah, H. (1982): The energy situation in Egypt. Ministry of Petroleum, Egypt.

2. Alaa El-Din, M.N. (1980): Biogas for rural Egypt. Egyptian-French Seminar on "Valorization of Agricultural by - Products in Egypt", Cairo, May 5-8, 1980.

3. Alaa El-Din, M.N. (1981): Production of energy, feed and organic fertilizers through the popularization of Biogas technology using the human and animal wastes and crop residues in the Egyptian village. A feasibility study presented to the Supreme Council of Energy of Egypt (in Arabic).

4. Alaa El-Din, M.N., Abu Talib and Fritz, J. (1980): Biomass energy potential in Egypt: a realistic appraisal. Bioenergy 80 World Congress, Atlanta, Georgia, U.S.A., April 21-24 1980.

5. Alaa El-Din, M.N., El-Shimi, S.A., Mahmoud, M.H. and Abdel-Aziz, I.M. (1983): Biogas for rural Egypt; energy, manure, fodder. The Egyptian experience. (in Arabic), Giza, Egypt, March 1983.

6. Alaa El-Din, M.N., El-Shimi, S.A., Mahmoud, H.M., Abdel-Aziz, I.M., Ali, B.E., Mohamed, M.E. and Anton, G.G. (1982): Progress report on the activities of the FAO/MOA Project TCP/EGY 003 (mi) Biogas for Rural Population. Jan. 1982.

7. Alaa El-Din, M.N. Rizk, I., Ellakkani, H., Abdel-Tawab, S., El-Shimi, S.A. and El-Sabbah, M. (1984): Rural energy in Egypt: a domestic needs and resources. Final report of IDRC Study.

8. DOE/GOE. (1979): Joint Egypt/US Report on Egypt/US Cooperative Energy Assessment, April 1979.

9. Smil, V. (1977): Intermediate energy production. China Bulletin of Atomic Scientists, Feb. 1977.

10. Statistic Yearbook (1979): Statistic Yearbook of ARE for 1979.

11. Taha, S.M., Mahmoud, S.Z., El-Damaty, A. and Ibrohim, A.N. (1966): Effect of prolonged use of fertilizers on chemical and microbiological properties of soil. J. Microbiol. UAR. Vol. 1, No. 2.

"BIOENERGY RECOVERY AND CONSERVATION IN INDIA"

Report Presented By:

Dr. V.V. Modi
Professor and Head
Department of Microbiology
The Maharaja Sayajirao University of Baroda
Baroda - 390 002,
INDIA

V.V. MODI

Bio ENERGY
~~BIOENGINEERING~~ RECOVERY AND CONSERVATION IN INDIA

India with vast cattle and human resources, and with adequate sunshine can hope to utilise the animal, human and agricultural waste for production of energy in the form of Bio-Gas. The real start of Bio-Gas plant in this country was made in 1951 with the introduction of the semicontinous plant containing the gas holder and digester in one unit. It will be interesting to note the historical background of bio-gas technology. The presence of combustible gas from decaying vegetable matter was discovered by Volta (1776); a century later gas digester was set up at, Bombay. With the energy crisis, the idea of recycling waste recovering the energy in the form of Methane was intensively investigated. India already has developed empirically the Gobar Gas Plant for supporting rural energy purposes and pollution reduction. These designs have been somewhat modified and the Chinese designs (fixed dome) super imposed. The substrate be not only of Gobar but also other plant and animal residues and acquatic biomass.

Specially developed thermophylic organism have given increased gas production per unit substrate and the quality of gas (Methane content). The residence time is reduced in this improved design to only 10 to 15 days from maximum gas production continuous fermentation system are also being introduced for the demonstration units.

Based on the logical idea of separation of acidogens and methenogens a two stage bioreactor with up and down flow systems have been used for large scale effluents from food and distillary industry. This produces greater part of the energy for this industry and also valuable nitrogen fertilizer as a co-product. Among the improved materials of construction light resinous materials or the so called polycement are being tried in demonstration units. The bio-gas system not only provides the

recovery of energy but also contributes subsequently for pollution control. The department of additional resources of energy is subsidizing small 2 to 10 cubic ft. units and establishing large community multipurpose demonstration units in several parts of the country. In addition to this a TV system (Training and Visit system) educating and maintaining the units is also proposed. About 70000 units were installed by the end of the 5th plan. An-other 150000 units were expected to be completed by the end of 6th plan all over the country. A total of 1.5 million bio-gas plants are proposed to be installed during the seventh plan period. This programme is likely to cost 5 million dollars. Materials of construction, designs and substrates are also modified to fulfill the special requirement of several different ecological areas. For instance in the colder areas of the country like those grew Himalayan mountains installation system and solar energy activited heating system have been added to the basic design.

Further advance on the system is envisaged with other recycling systems like Wind Power for Pumping, developing acquatic biomass and fishpond to use waste materials from the bio-gas unit in other words to make bio-gas the centre of the total village activity releasing the Man hours spend in collecting fuel and thereby contributing to the total welfare of the community.

The constituents of the latex bearing plants like Euphorbia sp. and other milk weeds have been successfully converted to fuels and chemicals by chemical means. A hydrocarbon degrading strain of Aspergillus japonicus isolated in our laboratory could utilise 4 ./. v/v and 1 ./. v/v latex of Calotropis gigantia and Euphorbia

nerifolia as a sole source of carbon. G.L.C. analysis of hydrocarbons from the hexane fraction of C. gigantia latex showed the presence of a C_{24} hydrocarbon whereas C_{29} and C_{30} peaks were observed in E. nerifolia latex. IR spectra of high molecular weight hydrocarbons extracted in benzene showed presence of waxes and polyrsoprenes in both the latices. Degradation of these complex components by A. japonicus required casamino acids as a nitrogen source in the transformation medium. Transmission electron micrographs of A. japonicus degrading these latices showed the uptake and accumulation of osmophillic material in the cells.

"BIOENERGY RECOVERY AND CONSERVATION IN ISRAELI AGRICULTURE"

Report Presented By:

Dr. Uri Marchaim
Project Director
MIGAL
South Industrial Area
Kiryat - Shmona 12-210
ISRAEL

BIOENERGY RECOVERY AND CONSERVATION IN ISRAELI AGRICULTURE

ANAEROBIC DIGESTION OF COTTON STALKS

Prepared by:

Dr. Uri Marchaim and Eng. Carlos Dozoretz

MIGAL LABORATORIES

South Industrial Area, Kiryat Shemona 10200, ISRAEL

INTRODUCTION

Modern agriculture is highly dependent on other sectors of the economy for most of its inputs. Agricultural development in the last years shows that the rate of dependency of agriculture on other sectors is increasing. This is noted especially in the growing demand for fossil fuel energy. Modern agriculture can not greatly reduce its demand for energy without a major reduction in output.

Israeli agriculture is probably one of the most energy-intensive industries in Israel and in World agriculture. Its increasing productivity and development had involved increased energy use. In a recent study by Dvoskin[1], the impact of rising energy prices on various agricultural sectors was evaluated. They found that if energy prices will continue rising the agricultural economic situation deteriorates faster than the industrial sector.

Despite its energy intensity Israel has managed to utilize its natural resources for agriculture. For instance, the "NEFAH"[2] project - the utilization of agricultural wastes and biomass for production of energy (biogas), animal food supplement, substrates for crops and plants and industrial products (fiber boards) by the anaerobic digestion process - is unique in its comprehensive approach and begin to be widely used in Israeli kibbutzim.

In Israel over 10% of the total national energy consumption is used for agricultural production, and only about 2.5% in the form of direct energy input[3]. The profitability of many crops depends very much on the prices of

fuel and it availability. The high enegy intensity of Israeli agriculture is mainly due to its water needs and the constant growing of the agricultural production for export, mainly to the Europe market. Therefore, reduction in energy consumption, and use of alternative energy sources are in very intensive development in Israel.

Two ways to ensure that agriculture has the energy that it needs are:

- substitution of plentiful energy agricultural users with other energy sources.
- conservation and more efficient energy management.

A brief description of the main efforts in Israel will be described in this paper with a deeper description on our specific work with cotton stalks.

CONSERVATION OF ENERGY IN GREEN-HOUSES

Air shipment, greenhouses heating, artifical lighting and fertilizers makes this exported crops very energy dependent. More than one half of the production cost of cut flowers is for energy. Therefore, reduction in energy consumption and use of alternative cheaper energy sources are of main goals in the Israeli agriculture.

In a Symposium held on March 1984 in the Volcani Center at Beit-Dagan Israel, the energetic aspects of growing plants under covers (green-houses and plastic covers) were discussed and summerized.[4] This followed a survey of green-houses heating systems in Israel done by Heshev.[5]

It is clear that the plant does not need energy at night. We heat the green-house since the loses to the environment is high because of the green-house structure which is a compromise with the flowers' needs during the day and summer times. During the summer days we even need to lower the temperature in the green-houses. Therefore most new technologies for new structures of green-houses or new ways of heating are based on insulating the green-house, collecting the surplus heat during the day and release it during the night or even during some of the winter days.

In Israel, several new technologies are examined now[4] including closed green-houses in which air changes are limited, uses of hygroscopic salts, developing heat exchanger light/air on the roof and the hydrosolaric green-house system. In all those directions a very intensive research and development is done and results are implemented in many places even before final results are published.

CONSERVATION OF ENERGY IN ANIMAL HUSBANDARY

Until a few years ago not much was done by Israeli agricultural section to reduce the negative impact of energy soaring prices on the farming community. However, in the last few years, more and more farmers have been taking an interest in solving their energy problem. The government is helping in financing some of those efforts.

Because of the special nature of the energy consumption pattern of Israeli animal husbandry, not much direct energy can be saved. Most energy saved will be achieved through better use of inputs. The following are some examples of energy saving: (1) instruments for better control of the temperature inside poultry houses, and using the heat of the chickens themselves in a more efficient way; (2) reducing energy use by better design of equipment; (3) reducing energy demands for hot water by using waste heat from compressures of the milking system; (4) reducing energy use for water pumping which is the main sector consuming energy in Israeli agriculture; (5) reducing energy consumption in fish ponds by reducing airation and (6) reducing indirect energy of fertilizers, pesticides and irrigation system operations.

ENERGY RECYCLING IN ANIMAL PRODUCTION BY IMPROVING FEED DIGESTIBILITY.

Food for cattle and poultry has to be looked at as metabolic energy, when dealing with energy conservation and better utilization. It is important to pay attention to processes preparing the feed and uses of the animal wastes as materials for refeeding. If animal feed is considered as metabolic energy, improving digestibility of organic materials will have an important role in energy conservation and utilization. This will also decrease agricultural inputs by using less water, fertilizers and direct energy.

In the last few years, more and more farmers and researchers have been taking an interest to find alternative waste materials for feeding animals. It is a common procedure in most Israeli animal husbandary to use a computer program that has the ability to price the feed based on the nutritional data provided according to a least cost gain and profit projection program. This program can compare the waste provided to the existing value of other conventional energy and protien feedstuffs and determine the amount that can be used. Different waste materials like cirtus peels, cotton seeds, grain-dust, whey etc., are widely used in Israel. Other organic wastes are specially treated.

Cellulose is, as might be expected, one of the principal sources of energy in ruminant nutrition due to its fermentation in the rumen by cellulolytic microflora. Notwithstanding, the diet of a highly productive ruminant, under intensive conditions, is characterized by a high content of readily fermentable carbohydrates and is low in cellulose. This dietary regime should be maintained in order to keep the high level of production of the ruminant industry. However, as the prices of the starchy feeds are high and increasing continuously, the time has come to consider the conversion of cellulosic materials into readily fermentable feeds. In considering prospective uses for cellulose, this direction appears to be particularly attractive, from both the economic and technological points of view, since the modest objective (according to this concept) is to produce a crude fermentable mixture.

Ben-Ghedalia et al[6] examined the effect of combined chemical and enzyme treatments on the saccharification and in vivo digestion rate of wheat straw. Wheat straw was pretreated with sodium hydroxide, ozone, and sulfur dioxide, and subsequently treated with four sources of cellulases. The effect of the combined chemical + enzyme treatments on the extent of saccharification and on the digestion rate by rumen microorganisms was studied. The in vitro organic matter digestibility was affected significantly only by the chemical pretreatments, whereas the effect of the cellulases was expressed mainly in increasing the fermentability of the hydrolyzed straw. The in vitro digestion pattern of the saccharified straw was found to be typical of a highly fermentable feed comparable to a starchy mixture such as used in concentrate ruminant diets.

Ben-Ghedalia, et al[6] also examined the effect of ozone and ammonium hydroxide treatments on composition and in vitro digestibility of cotton straw. In vitro organic matter digestibility was significantly increased by more than 100% by the ozone treatments, as a result of the partial conversion of cell walls into cell contents and the increased degradation of the cell wall. Ozone treatments increased the initial rate of in vitro organic matter digestibility.

Those treatments are still under intensive research and are not widely used. Work done with the feeding of raw cow manure[7] is also examined but not used. On the other hand poultry manure (after silage for cattle or as is for fish) is a common feed in Israel and was examined for years by Tagari[8] and colleagues of the Faculty of Agriculture in Rehovot.

AGRICULTURAL WASTE UTILIZATION IS ISRAEL

Plants transform solar energy into chemical energy or biomass, which can then be harvested and converted into usable energy products. The biomass resources of residues and terrestrial and aquatic plants are renewable; they can potentially supply significant amounts of the future energy requirements.

In the historical pattern of agriculture, crop residues went back to the land, by ploughing it back to the soil.

Since about 1970, many countries in the world has undertaken an extensive research program to develop processes for converting agricultural, foresty, and municipal wastes into fuels and chemicals. This program has involved studies on both old and new processes for Biomass conversion. Many of the older processes of Biomass conversion, such as acid hydrolysis and fermentation to ethanol and to biogas, are being reinvestigated using newer technologies.

These resources can be converted by a number of technologies into liquid transportation fuels, gaseous energy products, and other forms of energy. The present availability of biomass residues (field corp residues, animal manures, and forest and mill residues) is estimated to be 100 million dry tons, with a theoretical maximum of 427 million dry tons.[9] Biomass residues are currently being used in animal feeds, fiberboard products, fertilizer, soil tilth, and as soil conditioners.

The cost of biomass residues varies greatly according to type, application, region and location with respect to potential users. Field crop residues vary in the U.S. from $4.00 per ton for wheat and other small grain straws to $15 per ton for corn stover. Manure residues range from $0.50 per ton for cattle manure to $17 per ton for poultry manure. The cost associated with collecting, reducing, and transporting forest residues is estimated to range from $25 to $60 per ton, depending on location.

Many processing options can be applied to the conversion of biomass to energy or chemicals. These processes range in their stage of development from laboratory scale to commercially proven processes. Commercial combustion facilities have been used for many years, and anaerobic digestion facilities for feedlot manures are operating now. Fermentation to produce ethanol and petrochemical substitues, gasification to produce ammonia, SNG, hydrogen and methyl fuel, and liquefaction to produce fuel oil are technically feasible but not yet economically competitive. Photochemical processes are being pursued on a long-term, low-emphasis basis.

Some biomass materials may require pretreatment, which usually consists of drying or further volume reduction. After suitable preparation, biomass can theoretically be processed using any of a number of proven technologies. However, the chemical composition of any biomass feedstock will dictate the probable conversion process and path for utilization. For example, direct combusion or gasification is the most likely alternative for low-moisture content biomass, while anaerobic digestion and fermentation are more adaptable to high-moisture biomass materials.

There are three major sources of residual agricultural Biomass in Israel: Manure, Crop waste and agro-industrial wastes. The relative amounts of each type of Biomass were published earlier[10] and are summerized in Table 1. In a survey published by Marchaim and Criden[10] and a survey published by Rimon and Wienstein[11] it was found that over 870,000 tons of dry matter of organic crop wastes are generated every year in Israel. The largest part of this waste is generated at the cotton fields - over 260,000 tons of dry weight a year. The other main waste is the wheat straw (250,000 tons). In another survey conducted by TAHAL Engineering Co.[12] the amounts differ slightly and an economical evaluation of some technologies to produce energy from Biomass are presented.

Most, if not all, of the cotton waste is not utilized yet. The main reasons for that are: (a) problems in storage of this waste, which is generated in high quantities in a very short period, (b) the high moisture (50-65%) which require drying or special storage, in order to stop biochemical processes, (c) lignification on storage which lower its quality for feeding, and (d) its very low quality as animal food without special pretreatment, which is expensive. Another concern is the high levels of chemicals used during the growing season. A preliminary study, done by us a few years ago,[13] examined the possibility of using cotton stalks as raw material for growing yeasts with a high methionin content, as animal feed. The study examined the distribution of cotton stalks in Israel and the availability of this waste. It was found that in some parts of Israel the process can be economical feasible.

It has been estimated[14] that waste's Biomass could replace 5 to 10 percent of the petroleum need in the U.S., and we estimated[10] that in Israel 8 to 10 percent of the current used energy could probably be replaced.

Much activity in biotechnology has been directed toward the use of renewable plant resources for production of fuels and energy. Another important use could be for production of industrial chemicals. A route of great potential for basic chemical production from plant Biomass is via hydrolysis of the carbohydrates of sugars. Simple carbohydrate and structual polymers represent over 80% of forage Biomass.[15]

The depolimerization products of fiber components must be separated from one another in order to convert them selectively to a mixture of simple organic compounds. Hemicellulose sugars are released following mild acid hydrolysis. The more resistant cellulose can then be hydrolyzed to glucose by more severe acid hydrolysis conditions. Structual polysaccharides from mature crops needs high-temperature steam treatment which are very costly although not very effective.

The discussion to follow will not dwell on hydrolyzion processes, which have been recently reviewed by several authors in the CRC SERIES IN BIOENERGY SYSTEMS[16], but will concentrate on the anaerobic digestion of crops to produce BIOGAS and other useful products.

COMPOSITION OF PLANT MATERIALS

Most plant materials contains three major components: Cellulose, Hemicellulose and Lignin. Cellulose is generally the major component, making up 25 to 61% of all plant materials.[17]

The other components, Hemicellulose and Lignin, differ in their structure, depending on the plant material. The relative abundance of these components in various biomass materials is shown in Table 2, (taken from 17).

The structure, origins, and potential applications of lignin are considered in the light of the chance that lignocellulose materials may one day emerge as significant sources of biomass-based energy production. If the cellulosic portion of such materials are used to produce energy, than the utilization of the remaining lignin assumes an important role and has related economic implications.

Cellulose is the single most abundant renewable resource on earth. It has been estimated that as much at $22x10^9$ tons of cellulose are produced annually world-wide through the photosynthetic fixation of CO_2 and that as much as $4x10^9$ ton/year could be available for processing. In nature, cellulose, a polymer of β-D 1,4-linked anhydrous glucose units, comprise 40 to 60 percent of the cell wall material of trees and plants. The individual cellulose molecules are linked together to form elementary fibrils, 30 to 40 Angstroms. These fibrils are aggregated, via intermolecular hydrogen bonding, into larger subunit structues reffered to as microfibrils. Of essentially infinite length and approximately 250 Angstroms width, these microfibrils contain alternating sequences of highly ordered (or crystalline) and randomly oriented (or amorphous) phases and are imbedded in a matrix of hemicellulose.

This latter carbohydrate component, Hemicellulose, comprising 20 to 50 percents of the plant dry weight, is a branched ploymer of pentose sugars. The composition of a specific hemicellulose of hardwoods differs from that of softwoods, and those will probably be completely different from the cotton stalks hemicellulose.

In mature plants, the cellulosic and hemicellulosic fractions are encrusted in an amorphous lay of Lignin. This latter component, which accounts for the remaining 10 to 20 percents of the plant material, is a complex three-dimensional ploymer formed by carbon-carbon or either bonds between phenylpropane units. It is the intricate nature of the association of cellulose with hemicellulose and lignin and of the intermolecular hydrogen bonding of cellulose itself which simultaneously supplies structural integraty to the plant and hinders the access of degrading agents to the cellulosic portion of the biomass. Native biomass can be roughly thought of as similar to reinforced concrete with crystalline cellulose fibers (analogous to reinforcing roods) imbedded in a matrix of lignin (analogous to the concrete). The lignin also serves to seal the cellulose, forming a barrier which protect the fiber from attack by hydrolytic agents.

Effective utilization of this renewable resource depends in part on its efficient hydrolysis to yield glucose. Cellulose is resistant to hydrolysis either by acid or enzymes. Furthermore, cellulose naturally occurs in association with hemicellulose and lignin. Recently, a number of pretreatments have been proposed to disassociate the lignocellulose complex (the Iotech process of steam explosion, enzymes or acids and a pretreatment by Ozone). Commercialization of such systems to produce glucose syrups is envisaged.

Acid hydrolysis of cellulose, though rapid, has a number of disadvantages which include: high capital costs, low overall conversion efficiency (65 to 72%), degradation of product (glucose) to yield toxic impurities, and equipment corrosion. On the other hand, enzymatic hydrolysis of cellulose yields pure glucose syrups devoid of degradation products and only requires low temperature and pressures. It is far more efficient in terms of percentage conversion (95%). However, the enzymatic process is slow. The lignin is almost not degraded in the regular enzymatic process, but interfere in the penetration of the enzymes.

The high amount of the cotton stalks waste, containing high percentage of lignocellulose complex, is a target for many chemcial as well as biochemical treatments in addtion to the direct use for burning (a project now in final stage of eraction at Sha'ar Hanegev, Israel).

The chemical procedures are used in many cases as pretreatment for the biochemical processes. It was examined in the U.S. by several researches and is also examined now in Israel[13], for a process of growing SCP (Single Cell Proteins). Those processes showed, until recently, no economical profit and in our work we are looking for a process that will avoid the pretreatment. One of the possibilities is the thermophilic anaerobic digestion that already showed some advantage in degrading fibers[19].

CHEMICAL COMPOSITION OF COTTON STALKS

We define the cotton waste material as this part of the plant that remain in the field after the picking of the cotton, and the cutting down of the stalks.

A stalk of approximately 10 cm. is left and the roots are not uprooted. The stalk waste was found to be composed of 50% main stalk, 30% small stems, 6-10% leaves and 10% cotton fibers.[20] In several laboratories it was found that the cotton stalk differs from wheat straw in same chemical features:

1. The Lignin percentage ranges between 12 to 22 percent in cotton compared to 9-12 percent in straw. The Ligno-cellulose is also more complex and harder to break.

2. The Hemicellulose in cotton ranges around 13% while it is approximately 25% in straw. This means a lower portion of degraded organic matter after hydrolysis in the cotton stalks.

3. The cotton stalks contain approximately 4-7% Pectin compounds which are neglectable in straw.

4. The cotton stalk contains 20-30% intracellular soluble materials while the straw contains only around 13%. This difference shows the potential of cotton stalks as a source for extracting of plant metabolites, many of which with biological activities.

It was found[18] that the composition of the cotton stalks depends on the quality of the soil it was grown on. Specifically in the Hula Valley fields with the high water levels and high organic matter, it was found that the water content is much higher in the cotton stalks than in other parts of Israel.

A more detailed information on the components of the cotton stalks in several parts of Israel can be found in the work published by Ben-Gedalia et al[6] and Shefet[20] of the Volcani Institute.

It was found in the work we did earlier in Migal laboratory that the chemical composition of cotton stalks harvested on September, dried in the fields and than kept for few months in a closed container of 1 cubic meter is not constant. Since there is an effect of heterogenity and the material collected from the field consist of the stalks, leaves and some cotton left, the exact composition depend on the specific material in a specific location. It also depend on the period of storage and the longer the storage the higher the lignin. Results are given in Table 3.

ANAEROBIC DIGESTION

Anaerobic digestion of organic matter has been implemented and recommended for many years as a practical process for disposal or energy recovery, mostly for sewage treatment. Intensive utilization of the technology as a source of energy has not yet occurred. Now, the increasing value of fuels and the impending shortage of the more convenient fuels, notably natural gas, creates a climate in which anaerobic digestion becomes of strong interest. Evidence of this interest is work carried out in the last few years to provide the technical basis for generating fuel gas by the anaerobic digestion of municipal solid waste.[22] Another resource for fuel gas generation is the residue from intensive animal raising operations such as beef cattle feedlots and dairying.[10]

The publication of Buswell[23] and his co-workers at the University of Illinois deserve recognition as landmarks in anaerobic digestion technology. The agricultural residues of chief concern to Buswell were plant materials; he studied the digestion of pure cellulose as well as many other representative pure compounds in order to understand what ultimate performance might be attained in digesting residues and to determine how well cornstalks could be digested. It was determined that all the water soluble consituents are removed in digestion and that the chief water insoluble material attached was cellulose. The experiments showed that some lignin was attacked, but in other work he demonstrated that isolated lignin does not digest and, in fact, suppresses the digestion of cellulosic materials through the recovery of fibers for papermaking.

Anaerobic digestion is a process wherein complex organic compounds are broken down to produce Biogas (consisting of methane and carbon dioxide). It takes place in the absence of air and in the presence of suitable population of microorganisms. Temperature is a basic parameter, and the speed of the reaction can be increased by raising the temperature. Two optimum temperature ranges - mesophilic (30-40°C) and thermophilic (50-60°C) are usually used, which differ in their bacterial population. Important environmental factors in digester management include temperture, pH, nitrient supply, absence of oxygen and toxic materials. During the anaerobic digestion process the biodegradable fraction of the organic matter fed to the digester is attacked by the microorganisms and the degraded matter is converted to Biogas which can be used as a fuel. The undergradable matter (the percent of which depends on the digestion process and condition as well as on the fraction of cellulose and lignin) consists mainly of the fibers.

The functioning and management of anaerobic digesters can be appraoched from standpoints which differ in level of detail. The most general outlook is an engineering approach, establishing good operating principles. A more detailed approach deals with the extracellular chemistry of the digester. This focusses on the more readily measureable chemical characteristics of the system. At the most detailed level, the fundamental microbiology of anaerobic digetion is considered. This approach has the promise of yielding the broadest understanding, but the scope of information available is not yet complete enought to provide an easy basis for digester manipulation. A number of reviews of anaerobic digestion technology are available based on approaches of this kind. As examples, there may be cited the practical summaries by Buswell[24]. McCarty[25] represents the chemical approach. The review by Hobson et al[26] stresses the metabolic mechanisms.

The anaerobic conversion of a substrate to methane is commonly referred to as occurring in two stages, acid formation and methanogenesis. Two groups of microorganisms mediate these two stages of digestion.

ANAEROBIC DIGESTION OF COTTON STALKS

Many different organic wastes can be used as biomass sources for feeding anaerobic digesters. The integrative approach to the subject of biomass production and utilization raises the demand to reconsider the introduction of biomass from sources which were previously neglected. With this appraoch, the collection of different wastes (especially plant residues) which were formerly abandoned and even cultivation of biomass as energy crops to increase the amount of substrate of the process, may become feasible.[27]

Choosing the optimal biomass souce for an integrative project is a complex task requiring a comprehensive survey of agroeconomic factors, e.g. plant growth rates, land, water, and fertilizer demands and availability, etc. Anaerobic biodegradability factors should be considered, as well as the quality of digested products for further potential utilizations at the specific locality.

A potential benefit of using biomass from different sources is the possibility of controlling the chemical composition of the digester feed. Of special importance to the digestion efficiency is the balanced ratio of N, P and C, but some other elements also play an important role in maintaining an effective digestion process. Organic matter of plant origin is often characterized by the C:N ratio, which is too high for anaerobic digestion, whereas the ratio of these same elements in municipal sewage sludge and in livestock wastes (especially swine and poultry manures) typically is low.

Cotton stalks alone were not examined for anaerobic digestion since it is known from our experiments in the past and from work done by others that this waste needs some other organic material to be mixed with in order to initiate any anaerobic digestion activity.

The advantages of using the thermophilic anaerobic digestion for the breakdown of crop waste was presented by Marchaim et al.[19] recently. It suggested that when agricultural wastes, and especially crop wastes, are used as raw materials, the thermophilic digestion has an advantage. The main reason for that assumption is the different quality of the digested material left after the anaerobic process which became the main product of the process, and is called "Cabutz".

"Cabutz" is the solid phase of the slurry left after the thermophilic anaerobic digestion. It consists mainly on the lignocellulose complex of the organic material charged to the anaerobic digestion system, which was degraded to a limited extent. It was shown that the Cabutz is a growth substrate for house plants and can replace peat-moss in greenhouses[28] and the mushroom industry.[29] This material is now used in many places in Israel and has proved to produce high yields of plants; it probably contains some growth factors. In the 'NEFAH' process, developed in Israel, the thermophilic anaerobic digestion of cow manure not only broke down the ligno-cellulose complex to achieve the porosity needed for air penetration and water - holding capacity, but also eliminated most pathogenic bacteria present in the manure[30] and most moulds.[29] The Cabutz therefore has some advantages over peat-moss when used in the integrative farm, since it is less likely to become contaminated.

The anaerobic digestion was performed in an erlenmyer of 3 Liters, containing up to 2 Liters of water in which cotton stalks were imersed and digested anaerobically in a water bath heated by thermostate of 53°C. The material in the vessel was stirred with a magnetic stirrer (which sometimes, especially with high solids content, did not work properly). The gas was measured by water displacement. Cotton stalks of the last harvesting period were collected in the field after trimming and kept in a closed container (Table 3). The stalks were grounded and mixed with water to the proper solid concentration.

Another digester used for the anaerobic digestion of cotton stalks was a perspex vessel of 6.5 Liters with mechanical stirring at 60 rpm in a water bath of 53°C. There was a 2.5 cm. outlet at the bottom of the vessel for slurry withdrawing and two 1 cm pipe openings for feeding and for biogas. The main problem in this system was not in feeding the materials through the 1 cm pipe but the withdrawing of the representative sample from the 2.5 cm. outlet. Although the stirrer was in operation, only the liquid fraction was withdrawn, and accumulation of the fibrous fraction was noted in the digester. Therefore results of this experiment are only an indication.

The gas production rates in both experiments are given in Fig. 1, 2 and 3.

The pH of digestion was around 7.6 and voltaile acids concentration was lower than 2 grams per Kg. No results of the chemical composition of the withdrawn slurry during the experiment is included since the material withdrawn was not representative.

During the accumulation of solids in the digester, the growing levels of the volatile acids probably affected the pH and souring of the system began.

At the end of the experiment in the 4 Liters working volume digester (6.5 Liters total volume) samples from the upper, middle and lower parts were collected and analysed. Results are given in Table 4.

The low pH explains the low gas production, and the differences in solids concentration between the different layers-the problem in mixing and in gas production.

THERMOPHILIC ANAEROBIC DIGESTION - ADVANCE EXPERIMENTS

In a work done by Kimchie of the Haifa-Technion group,[31] as part of the "NEFAH" project, the contribution to gas production of cotton stalks in mixture with cow manure in a 12% solids concentration in the digester was examined. The percentage of the cotton stalks dry matter in the mixture with cow manure was changed from 20-60%. The retention time in the first experiment was 10 days and in the others 20 days. The thermophilic digestion in 55°C was chosen first.

The results of the experiments showed that the higher the percentage of cotton stalks in the mixture, the lower the gas production. Based on calculation of digestion efficiency of the mixture of cotton stalks and cow manure (Table 5) it can be concluded that the efficiency of the digestion of the cotton stalks is nearly zero even after a long retention time.

MESOPHILIC ANAEROBIC DIGESTION - SIMPLE BATCH DIGESTION.

We are now operating two sets of digesters. One set of mesophilic 4 L digesters with cotton stalks mixed with low percentage of cow manure (5% of the cotton solids) with and without addition of Nitrogen, and inocculated with digested slurry. The other experiment is a 15 Liters vessel with 2.8 Kg cotton stalks and 12 Liters of liquids (water and inocculum) which are circulated for 2 min. every 20 minutes through the solid fraction. The gas produced in each vessel is recorded separately. Fig. 4 and 5 show the set-up.

Cotton stalks of this years harvesting were first chopped in the Hubbert blender dry. Then water was added up to approximately 9% and the mixture was blended again for half hour and kept in refrigerator overnight. To the mixture of 12 Kg, 475 gr of fresh manure (12% solids) from the cowbarn were added and mixed for another half hour. 3,640 Kg were put in 5 liters plastic containers and 350 gr of active mesophilic inocculum of anaerobic digestion of slaughter-house waste material was added to each vessel. Samples were taken for chemical composition. 0.5 gr of ammonium nitrate in water were added to three of the six digesters.

All digesters were put in a thermostatic water bath with circulated water at 35°C without stirring or mixing. Outlets were connected to simple water displacement gas meter and gas production was measured for 150 days. Samples of Biogas were taken during the experiment for gas analysis in the Varian Gas Chromotogram.

RESULTS AND DISCUSSION

1. After 150 days of anaerobic digestion there is still a slow gas production in the 3 digesters with added nitrogen but almost no gas production in those without nitrogen.
2. Gas production rates were quite stable during the first 1 1/2 months - 60 Liters for 45 days or 1.33 L/day/4 liter working volume or 0.33 L/L/day, in the digesters with added nitrogen.
3. Gas production rates were also stable during the first 1 1/2 months in the control without added nitrogen, but lower, 55-60L for 45 days or 0.30 L/L/day.
4. There is no significant difference in accumulated gas production with and without added nitrogen.
5. Destruction of organic matter during the 150 days of the mesophilic anaerobic digestion of cotton stalks was almost 50% which is much higher than expected and reported elsewhere! It may be the result of the special conditions of growing cotton in the Hula Valley (18), the very long digestion time and the constant mesophilic conditions. Since gas production rate is starting without lag and is quite stable for 45 days it may also be the result of using adapted culture of microorganisms from our experiments with slaughter-house wastes, which has high percentage of straw in it!
6. Gas composition of both treatments is similar in both samples at the end of the experiment and during the experiment. It has a high methane (CH_4) content.
7. The pH of the reaction is 7.5 (higher a bit in the digesters with nitrogen) and similar to the pH of mesophilic digestion we are operating with slaughter-house wastes.

8. The initial solid concentration was 9.7% and dropped down during the 150 days of experiments to 4.07% with nitrogen and 4.62% without nitrogen. This slight difference is in correlation to the lower gas production in the 3 digesters without nitrogen.

9. There is similiar ash content in all digesters.

10. Nitrogen concentration is higher in 0.1 g/L in the digesters to which ammonium nitrate was added than in controls, while ammonia concentration is much higher than in controls. (0.183 g/L in comparison to 0.09 g/L). Part of the nitrogen probably evaporated with the biogas. This nitrogen concentration and ammonia concentration has no inhibition effect on the process and improved a little the performance of the digestion, but is not essential for farm applications!

11. There is no phosphate differences between treatments, as expected.

12. Total volatile acids is very low in all digesters (0.05 g/L) at the end of the experiment. Almost no difference between treatments.

13. Electrical conductivity is slightly higher in digesters with added nitrogen, as expected (8.85 compared to 7.51). This shows a high content of salts. We expected a higher ash content in the slurry.

14. The digestion process was performed without any mixing or liquid circulation. This is quit surprising since no lag was noted, and may be the result of using a good inocculum. The experiment with circulating the liquid every 20 min for 2 min gave similiar initial gas production. Since all cotton stalks were immersed completely in the liquid of the digestion mixture it is not different from results we reported earlier (10) with cow manure. If higher concentration of solid will be used, or cotton stalks will not be chopped so intensively, results may change.

8. The initial solid concentration was 9.7% and dropped down during the 150 days of experiments to 4.07% with nitrogen and 4.62% without nitrogen. This slight difference is in correlation to the lower gas production in the 3 digesters without nitrogen.

9. There is similiar ash content in all digesters.

10. Nitrogen concentration is higher in 0.1 g/L in the digesters to which ammonium nitrate was added than in controls, while ammonia concentration is much higher than in controls. (0.183 g/L in comparison to 0.09 g/L). Part of the nitrogen probably evaporated with the biogas. This nitrogen concentration and ammonia concentration has no inhibition effect on the process and improved a little the performance of the digestion, but is not essential for farm applications!

11. There is no phosphate differences between treatments, as expected.

12. Total volatile acids is very low in all digesters (0.05 g/L) at the end of the experiment. Almost no difference between treatments.

13. Electrical conductivity is slightly higher in digesters with added nitrogen, as expected (8.85 compared to 7.51). This shows a high content of salts. We expected a higher ash content in the slurry.

14. The digestion process was performed without any mixing or liquid circulation. This is quit surprising since no lag was noted, and may be the result of using a good inocculum. The experiment with circulating the liquid every 20 min for 2 min gave similiar initial gas production. Since all cotton stalks were immersed completely in the liquid of the digestion mixture it is not different from results we reported earlier (10) with cow manure. If higher concentration of solid will be used, or cotton stalks will not be chopped so intensively, results may change.

15. The gas production was much higher than expected. Results from the literature (31) and our results in the past were much lower. We never examined such a long digestion period but even initial gas production was high.

    We can attribute this gas production and organic destruction to the special cotton stalks grown in the Hula Valley (18) or to the specific inocculum. The results of this experiment must be examined in a pilot plant in order to confirm results. It is also important to calculate the most economical efficiency period of digestion since after 2.5 months over 85% of the biogas was produced.

16. It is important to examine other nitrogen content compound as an additive to the reaction and to used the cheapest nitrogen salt. We are not sure that we will recommend any nitrogen addition to farmers. It will be very important to examine cotton stalks in other parts of Israel and the world to determine the best C:N ratio.

17. We have not examined the effect of herbicides and insecticides sprays on the reaction, but from our experiments no effect was noted.

18. In Israel and other countries the amount of cotton stalks produced every year is high, and in some countries even the highest organic waste material. If this renewable organic material can be used for energy production and soil-conditioning it may be of very significant impact on world agriculture!

FIG. 1: Biogas production rate in thermophilic anaerobic digester (of 2 L working volume) of cotton stalks.

FIG. 2: Biogas production rate in thermophilic anaerobic digester (of 2 L working volume) of cotton stalks, with stirring.

FIG. 3: Biogas production rate in thermophilic anaerobic digester (of 3 L working volume) of cotton stalks, with mechanical stirring. The digester was charged continuously once a day with powdered cotton stalks immersed in water.

FIG. 4: The batch mesophilic anaerobic digestion system (of 3 L working volume) of cotton stalks.

FIG. 5: The batch mesophilic anaerobic digestion system (of 15 L volume) of cotton stalks, in which the liquids are circulated.

FIG. 6: Accumulated gas production of the batch mesophilic anaerobic digestion of cotton stalks (without added ammonia) during 150 days.

FIG. 7: Accumulated gas production of the batch mesophilic anaerobic digestion of cotton stalks with 0.5 gr added ammonium nitrate during 150 days.

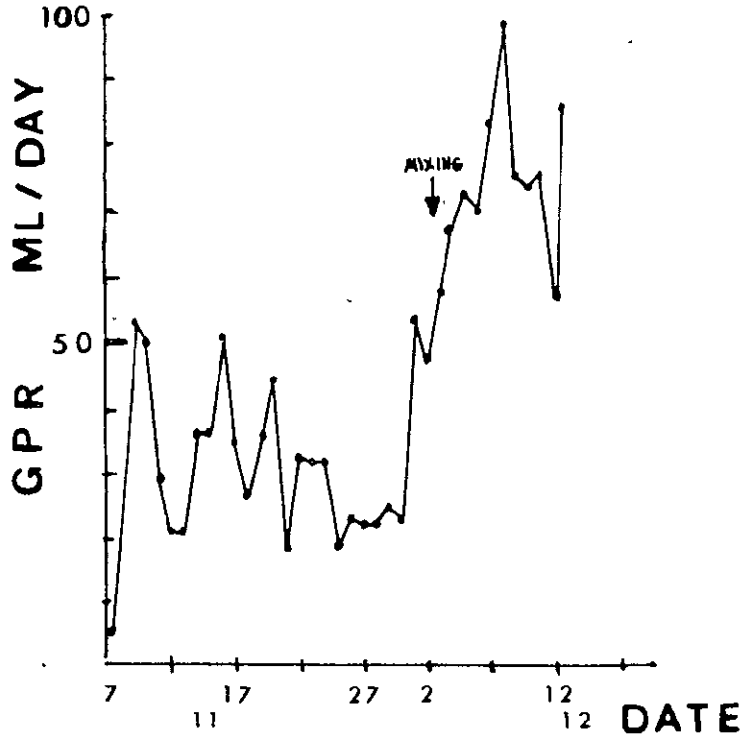


FIG. 1) Biogas production rate in thermophilic anaerobic digester (of 2 L working volume) of cotton stalks.

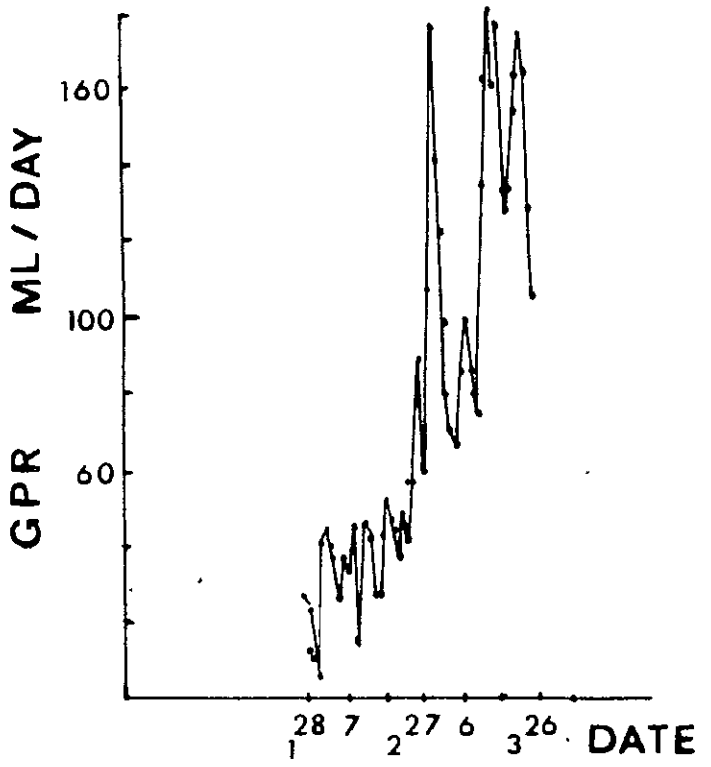


FIG. 2) Biogas production rate in thermophilic anaerobic digester (of 2 L working volume) of cotton stalks, with stirring.

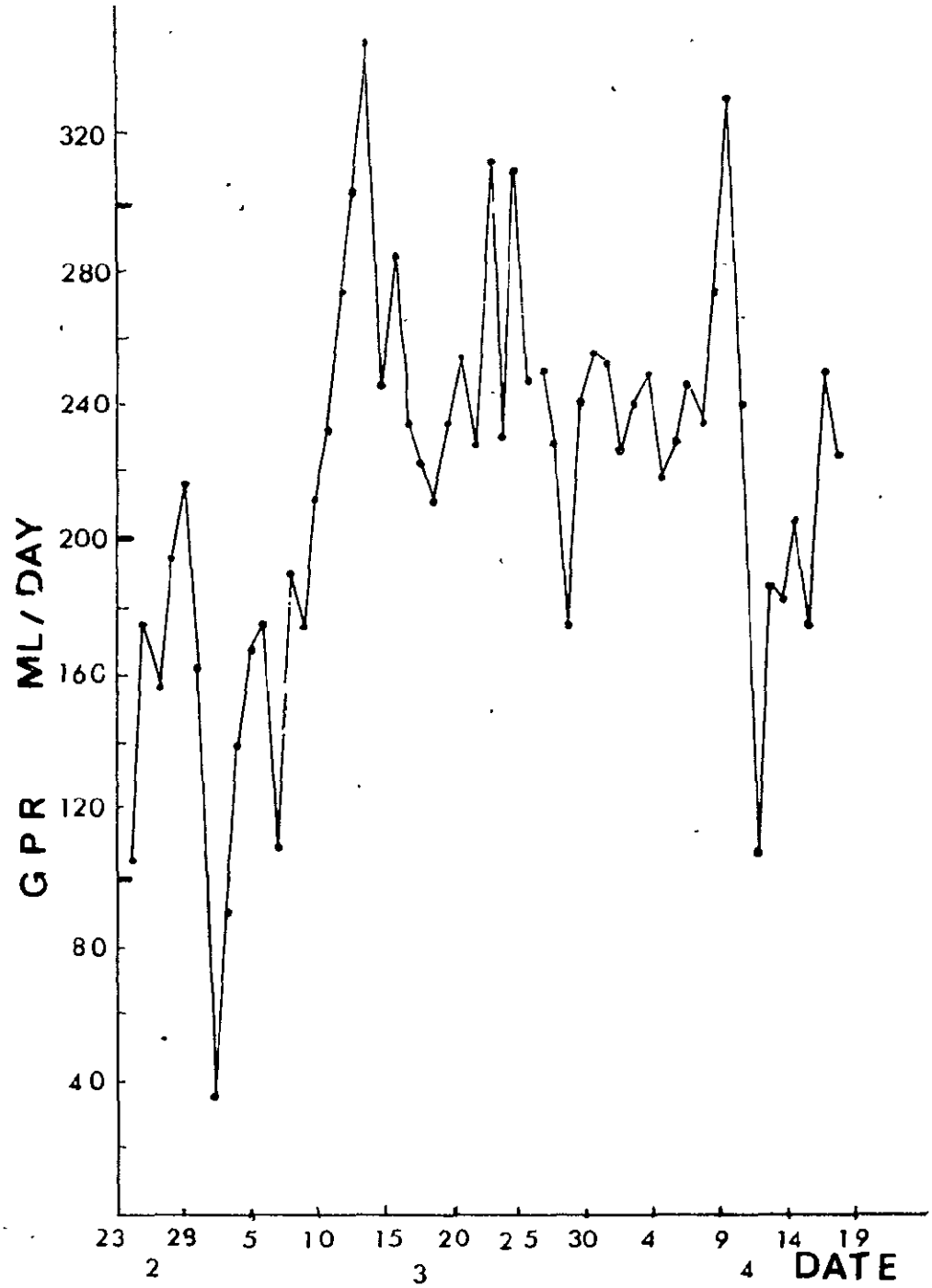
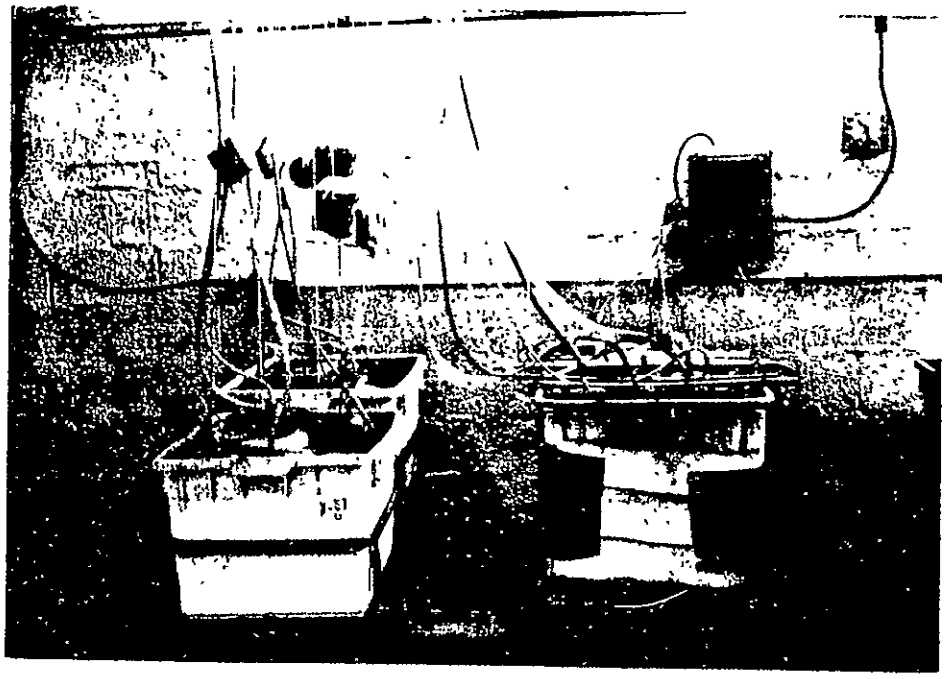
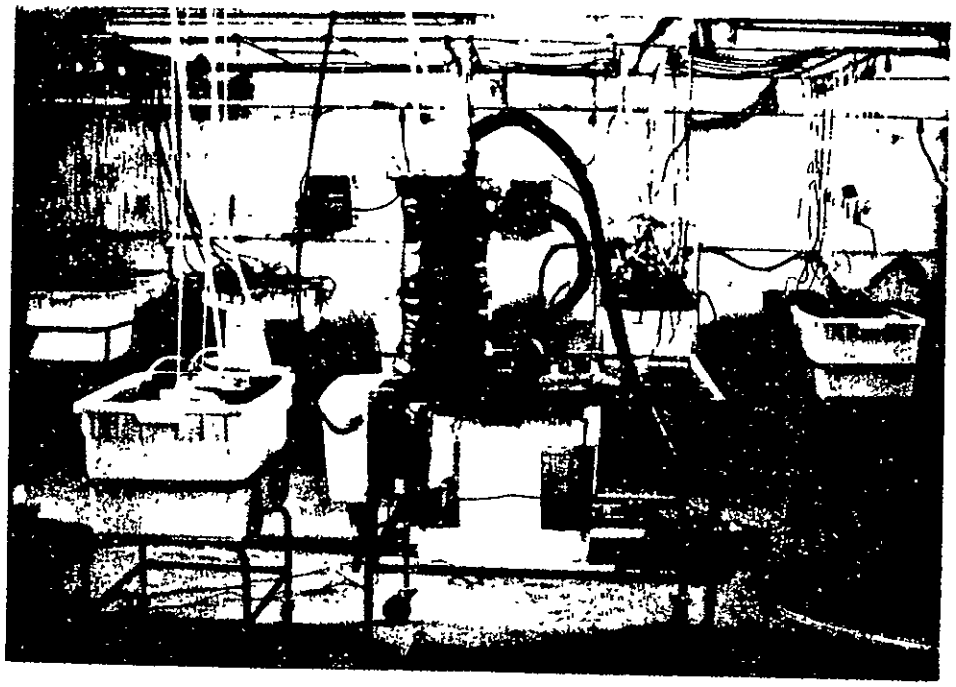


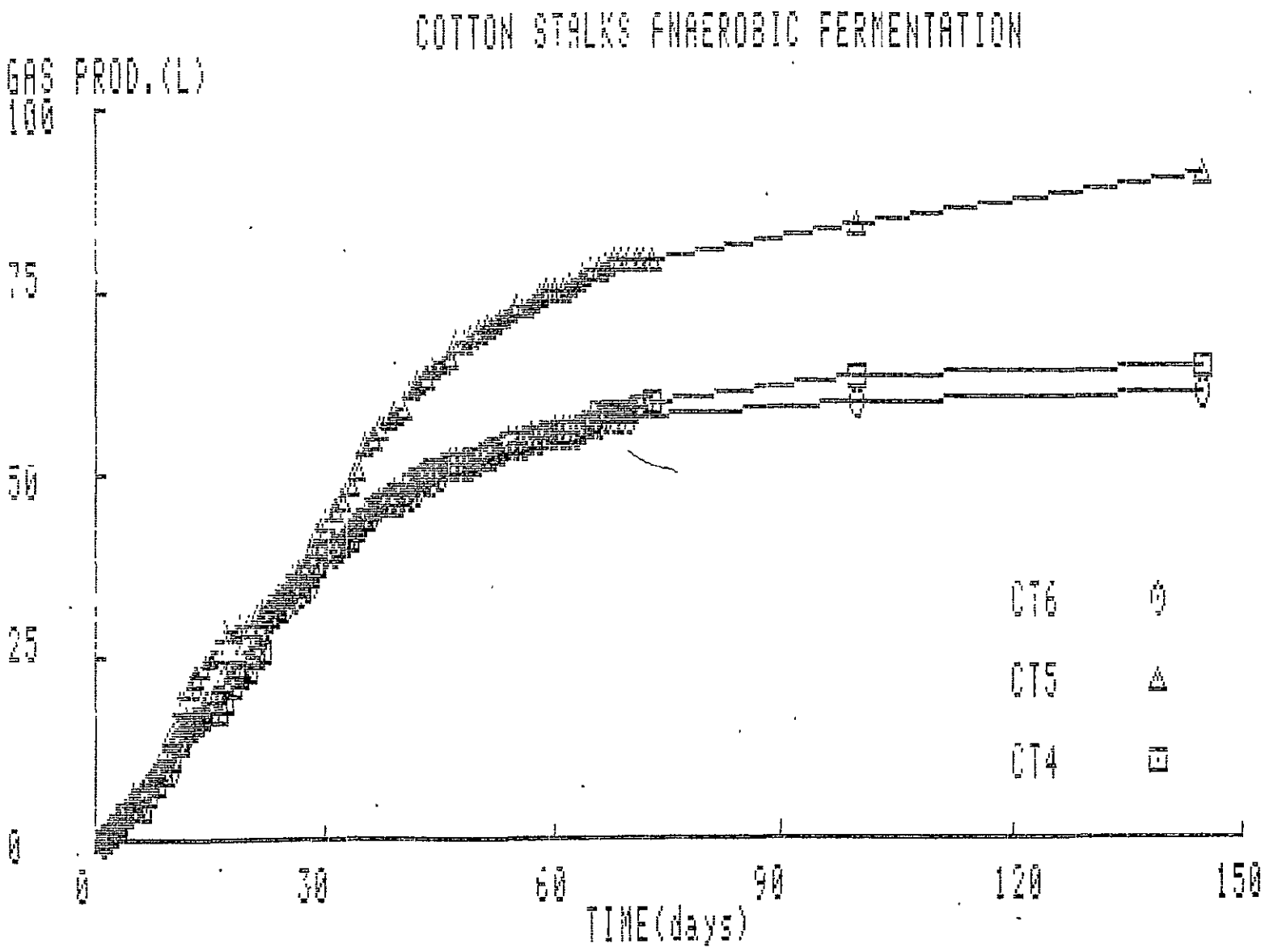
FIG. 3: Biogas production rate in thermophilic anaerobic digester (of 4 L working volume) of cotton stalls, with mechanical stirring. The digester was charged continuously with powdered cotton stalls immersed in water.

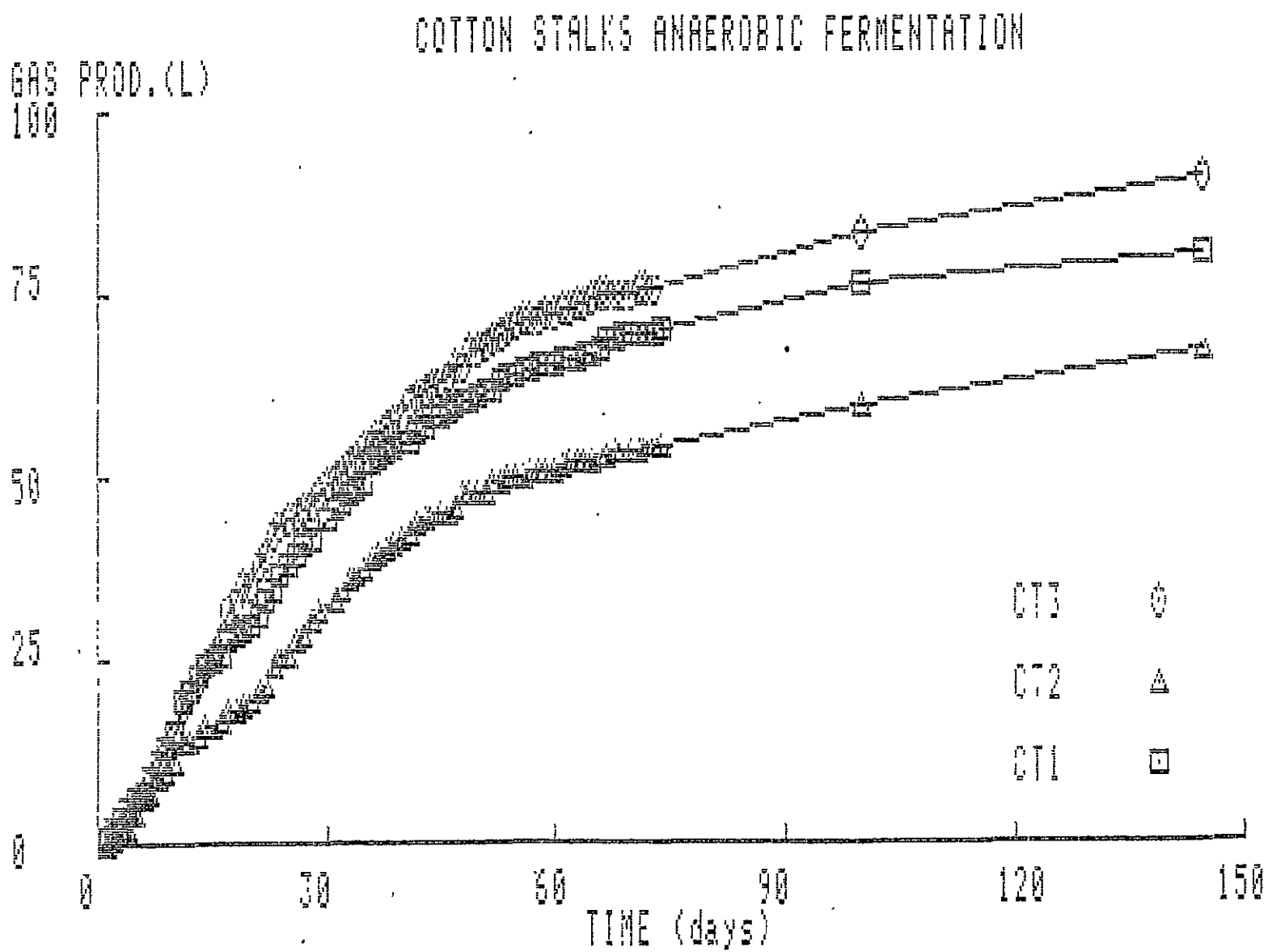


[illegible] in operation.



[illegible] 15 L [illegible] in which the liquids are [illegible] in operation.


COTTON STALKS ANAEROBIC FERMENTATION
GAS PROD.(L)
100
75
50
25
0
0
30
60
90
120
150
TIME(days)
CT6
CT5
CT4


COTTON STALKS ANAEROBIC FERMENTATION
GAS PROD.(L)
100
75
50
25
0
0
30
60
90
120
150
TIME (days)
CT3
CT2
CT1

LIST OF TABLES

Table 1: Over all quantities of agricultural wastes in Israel. (From 10)

Type of waste	Inclusive quantity of dry organic matter (tons)
Manures	745,000
Crop waste	870,000
Agro-Industrial waste	500,000

Table 2: Approximate composition of some cellulosic materials (%) (From 17).

Material	Cellulose	Hemicellulose (percent dry weight)	Lignin
Coniferous wood	40-50	20-30	25-35
Deciduous wood	40-50	30-40	15-20
Corn cobs	45	35	15
Corn stalks	35	23	35
Wheat straw	30	50	15

Table 3: Chemical composition of stored cotton stalks, harvested on September, dried in the field and kept in closed container..

DATE	SOLIDS (%)	ASH (%)	C.O.D. (g/Kg)	TOTAL NITROGEN (g/Kg)	AMMONIA (g/Kg)	pH	VOLATILE ACIDS (g/Kg)
March	87.4	8.0	166.95	2.4	0.1	7.0	9.696
March	90.6	6.0	307.77	2.0	0.1	7.0	7.488
April	88.7	-	505.92	1.7	0.1	7.0	-

Table 4: Chemical composition of different layers of thermophilic digested slurry at the end of experiment 2.

LAYER	SOLIDS (%)	ASH (% dry matter)	C.O.D. (g/Kg)	TOTAL NITROGEN (g/Kg)	AMMONIA (g/Kg)	PHOSPHATE (g/Kg)	PH
Upper	17.48	13.0	111.30	5.5	4.6	1.0	6.3
Middle	13.44	19.0	733.58	5.7	5.1	1.0	6.5
Lower	6.95	9.0	383.65	9.6	4.0	2.6	7.0

Table 5: Efficiency of anaerobic digestion of cotton stalks in mixture with cow manure in thermophilic digestion with retention time of 10 days and 12% solids in the digester (From 31)

TS cotton of mixture (%)	Gas production rate (L/L/Day)	Digestion efficiency in feed (L/grams solids)	
		Manure solids	Cotton solids
0	2.69	0.224	-
20	2.10	0.224	0
40	1.68	0.224	0.01
60	1.26	0.224	0.03

Table 6: Chemical composition of cotton stalks (raw material) and of the mixture at start up of the anaerobic digestion experiments.

	PH	TOTAL SOLIDS (%)	ASH (%)	VOLATILE SOLIDS (%)	TOTAL NITROGEN (g/L)	AMMONIA (g/L)	PHOSPHATE (g/L)	TOTAL VOLATILE ACIDS (g/L)
Cotton Stalks	-	80.35	3.32	76.03	-	-	-	-
Mixture 1 without Nitrogen	7.65	9.72	1.11	8.61	1.61	0.20	1.01	-
Mixture 2 without Nitrogen	7.50	9.76	0.87	8.89	1.88	0.25	1.13	1.27

Table 7: Chemical composition of digest slurry after 146 days of batch mesophilic anaerobic digestion with and without added nitrogen.

	PH	TOTAL SOLIDS (%)	ASH (%)	VOLATILE SOLIDS (%)	TOTAL NITROGEN (g/L)	AMMONIA (g/L)	PHOSPHATE (g/L)	TOTAL VOLATILE ACIDS (g/L)	CONDUCT-IVITY (MMOHOS)
Mixture 1 without Nitrogen	7.68	4.62	0.52	4.11	0.09	1.27	0.40	0.05	7.51
Mixture 2 with Nitrogen	7.69	4.05	0.56	3.51	0.18	1.20	0.46	0.11	8.85

(3 replicates for each treatment).

Table 8: Summary of the results of the batch mesophilic anaerobic digestion of cotton talks with and without added ammonium nitrate (after 150 days of digestion in 4 Liter working volume).

	without added nitrogen	with nitrogen
accumulated Gas Production (L)	72.25 +/- 16.55	79.67 +/- 11.66
% Efficiency = $V \times 1.2 \times 100/VS_o$	27.7	30.5
% Efficiency = Lgas/gr VS des.	0.43	0.42
CH_4/CO_2 in Biogas	1.64	1.79

REFERENCES

1. Dvoskin, D., Szeskin A., Gur S., and Fox S.. A survey of all energy use in Israel agriculture. Report for the Ministry of Energy and Infrastructure, Jerusalem (in Hebrew) pp. 217, 1981.

2. "NEFAH" project - Kibbutz Industries Association, Tel-Aviv, Israel.

3. Flesenstien, G.. Research and Development on energy and agriculture. International symposium on Energy and Agriculute, Qiryat-Anavim, Israel, March 1983, 26, 1983.

4. Flesenstien, G. Energetic aspects of growth under covers. Hassadeh, 64 (11), 2337 (In Hebrew), 1984.

5. Dvoskin, D., Link O., Zor G., and Gazit M. Survey of green-houses heating systems (A), Heshev, Tel-Aviv, Israel (In Hebrew), 1983.

6. Ben Gadalia and Miron

7. Keli, J. Personnal Communication, 1981.

8. Tagari, H. The nutritional value of digested and of fresh cattle manure. In "Utilization of agricultural wastes - NEFAH project". Research Progress Report No. 5, (in Hebrew), 1978.

9. Wise, D. L., Wentworth, R. L., and Ashare E. Methane production from biomass and agricultural residues. Ind. Eng. Prod. Res. Dev. 18, pp. 151-156, 1979.

10. Marchaim, U., and Criden, J. Research and Development in the utilization of agricultural wastes in Israel for energy, feedstock fodder, and industrial products. In. D. L. Wise (Ed), "Fuel Gas Production from Biomass", Vol. 1, CRC Press Inc. Boca Raton, Florida, pp. 95-120, 1981.

11. Rymon, D., and Wainshtein, M. A survey of organic waste from agricultural sources of potential value for recycling, in Israel. Special Publication No. 114, The Volcani Center, Bet-Dagan, Israel (in Hebrew), 1978.

12. Shafir, Z., Moaz, Y., Shaltiel, M. and Segal, I. A survey on the potential of plant wastes for energetic uses. Submitted to the Ministry of Energy and Infrastructure (in Hebrew), 1984.

13. Marchaim, U., Ilany, J., and Dozoretz, C. Preliminary study for the production of methionine-rich yeasts. Research No. 7381, Ministry of Industry and Commerce, Israel (in Hebrew), 1980.

14. Goldstein, I. S. Biomass availability and utility for chemicals. In "Organic Chemicals from Biomass", CRC Press Inc., Boca Raton, Florida, pp. 1-8 and 9-18, 1981.

15. Linden, J.C., Murphy, V.G., and Smith, D.H. Forage crops as chemical feedstocks. In. D.L. Wise (Ed.) "Bioconversion Systems", CRC Press Inc., Boca Raton, Florida, 71, 1984.

16. "CRC Series in Bioenergy Systems" (1-5). (Ed. D.L. Wise), Boca Raton, Florida, 1984.

17. Rugg, B., Amstrong, P., and Dreiblatt, A. Liquid fuel and chemicals from cellulosic residues by acid hydrolysis. In D.L. Wise (Ed.) "Liquid Fuel Developments", CRC Press Inc., Boca Raton, Florida, 139, 1984.

18. Salnikov, N. The production of edible yeast from agricultural waste as food supplement for humans and livestock. Research Program Report No. 1, Migal Laboratories (in Hebrew), 1984.

19. Marchaim, U., Perach, Z., and Kimchie, S. An integrated approach to the anaerobic digestion process. In. D.L. Wise (Ed.) "Fuel Gas Systems", CRC Press Inc., Boca Raton, Florida, 141, 1984.

20. Shefet, G., and Ben-Gedalia, D. Effect of Ozone and Sodium Hydroxide treatments on the digestability of cotton straw monosaccharides by rumen microorganisms. Eur. J. App. Microbiol. Biotechnol., 15, 47, 1982.

21. Ben-Gedalia, D. Shefet, G. and Miron, J. Effect of Ozone and Ammonium Hydroxide treatments on the composition and in vitro digestability of cotton straw. J. Sci. Fond. Agric., 31, p. 1337; J. Sci. Food Agric. (1982), 33, 1213, 1980.

22. Wentworth, R. L., Ashare E., and Wise, D.L. Fuel gas production from animal residue, part 1. Res. Rec. and Conservation, 3, 343, 1979.

23. Buswell, A.M. Illinois State Water Survey, Bull No., 1936.

24. Buswell, A.M. In: L.A. Underkofler and R.J. Hickey (Editors), Industrial Fermentations, Vol. w, Chemical Publishing Co., New York, 518, 1949.

25. McCarty, P.L. Public Works, 95: 12, 1964.

26. Hobson, P.N., Bousfield, S. and Summers, R. CRC Crit, Rev. Environ. Control, 4: 2, 1974.

27. Stewart, D.J. Methane from crop-growing biomass. In "Fuel Gas Systems" (Wise, D. L. ed.). CRC Press Inc., Boca Raton, Florida, 1983.

28. Marchaim, U. Anaerobic digestion of agricultural wastes. The economic lie in the effluent uses. Int. Symp. on Anaerobic Digestion 83. Boston Ma., 1983.

29. Levanon, D., C. Dosoretz, B., Motro, and I., Kahn. Recycling agricultural waste for mushroom casing. Mushroom J., 133, 13, 1984.

30. Klinger et. al. NEFAH annual reports (In Hebrew). Kibbutz Industries Association, 1982, 1983.

31. Kimchie, S. High-rate anaerobic digestion of agricultural wastes. Ph.D. Thesis, submitted to the Haifa Technion, Israel, 1984.

"BIOENERGY RECOVERY AND CONSERVATION IN THE PHILIPPINES"

Report Presented By:

Dr. William G. Padolina
Department of Chemistry
University of the Philippines at Los Banos
College, Laguna 3720,
PHILIPPINES

BIOENERGY RECOVERY AND CONSERVATION IN THE PHILIPPINES[1/]

William G. Padolina[2/], Elizabeth C. Bugante[3/] and Catalino Alfafara[3/]

ABSTRACT

Sources of biomass-based raw materials for energy conversion are presented. Experiments on the biomethanation of crop residues - rice straw, coconut coir dust and coconut water - are presented and their feasibility for biogas conversion is assessed.

In a span of 10 years, the Philippines has been able to reduce its dependence on imported oil by 30%. Its energy supplies have been diversified so as to take advantage of indigenous resources like oil, coal, hydroelectric, geothermal and biomass. Thus in 1983, this meant a savings of $1 B out of a total energy bill of $3 B. For the same year, nonconventional resources, mainly biomass-based, accounted for 14.6 million barrels of oil equivalent or about 15% of the total energy mix, valued at $400 M in foregone oil imports (Table 1). Studies have indicated that around 87 million barrels oil equivalent could be derived from agricultural wastes alone (Ministry of Energy, 1983).

[1/] Paper presented at the "Internatioanl Workshop on Bioenergy Recovery and Conservation" sponsored by USAID, 31 October to 2 November 1984, Boston, Massachusetts, USA.

[2/] Associate Professor of Chemistry and Executive Deputy Director, National Institutes of Biotechnology and Applied Microbiology (BIOTECH), University of the Philippines at Los Baños, College, Laguna, Philippines.

[3/] Science Research Specialists, BIOTECH, College, Laguna, Philippines.

Most of these agricultural wastes is burned as fuels. Of these bagasse is the largest resource, displacing an equivalent of 5.5 million barrels of oil in 1983 which amounts to a savings of $160 M. Woodwaste (excluding firewood in households) saved 4.43 million barrels of oil in 1983, worth $128 M; followed by coconut shell and husks which save 3.5 million barrels of oil 1983, worth $100 M (Ministry of Energy, 1983).

Biogas made an appreciable contribution to the energy supply in 1983, estimated at 20,000 barrels of oil equivalent. One of the biggest and most successful applications of biogas technology in the country may be found in Maya Farms, a food processing complex in Metro Manila. From about 70,000 tons daily of manure from 50,000 pigs and 20,000 ducks, Maya farms produces 5,600 m^3 of biogas per day. In fact it has become fully independent in electric power generation early in 1984 (Ministry of Energy, 1983). In the last few years, 700 domestic and industrial biogas digesters have been built, 500 of which are for domestic usage (Ministry of Energy, 1983a).

Around 80% of domestic cooking fuel needs in our country is derived from fuelwood (National Economic and Development Authority (NEDA), 1980). This accounts for 8-13.2 million barrels of oil equivalent in 1980. It has been observed that the volume of fuelwood used in 1980 was much greater than the peak volume of commercial logs harvested in 1969 (NEDA, 1980). This can put very heavy pressure on the wood supply from our forests so that even young trees may be cut for fuelwood and thus accelerate forest destruction.

It is thus imperative that efforts towards the development of alternative and indigenous sources of fuel, be intensified. Biogas production or biomethanation using a variety of substrates, apart from animal manure, appears to be a viable alternative, considering the volume of agricultural by-products that may be derived from the farm.

MAJOR PHILIPPINE CROPS AS RAW MATERIALS

Any scheme to harness bioenergy must be based on a careful assessment of raw material resources. In the Philippines, the major source of these raw materials are the crops, the forests and possibly, in the future, the sea.

In 1982, the total land area harvested was 12,204,800 hectares out of 15,000,000 hectares of arable land (NEDA, 1983). Rice, corn and coconut accounted for 9,955,500 hectares (Table 2) with each occupying roughly a third of the land area. The total quantity of crops produced in 1982 was 30,000,000 metric tons of which 22,000,000 mt was for food and 8,000,000 mt for commercial crops. In the case of the major food crops like rice, corn, banana and pineapple, a significant part of the plant biomass remains after they are harvested for food. The biomass residue may be solid or liquid and may also be saccharine, starchy or lignocellulosic (Table 3).

Data on the quantities of these biomass residues are not complete, but from what is available, a ton of rough rice would have residue of a ton of rice straw. Based on the rough rice yield

of 1982, around 8.0 M mt of rice straw would have been available. An estimate of rice hull produced in 1982 is 1.3 M metric tons (UNIDO, 1983). The composition of rice straw is given in Table 4.

Del Rosario (1982) notes that 80,000 tons of banana fruits are thrown away every year because they fail to meet the quality standards for exports. Banana fruits are approximately 75% carbohydrates and 5% protein on a dry basis (Pontiveros, et al., 1978).

For the major commercial crops, coconut and sugar cane, the biomass residues obtained after processing are of considerable amounts (Padolina, 1983a; 1983b).

One of the interesting processing wastes from coconut is coconut water. Each nut yields around 0.3 liter of coconut water and it is now estimated that the total nut production in 1981 would have yielded 4.3 B liters of coconut water (Padolina, 1983c). One third of the weight of the whole nut consists of the husk. This is mainly lignocellulosic material used in the manufacture of coir fiber wherein the processing residue is coir dust. The UNIDO (1983) estimate for 1982 was 3.19 M mt of coconut husk available. Other parts of the coconut tree like the leaf blades, petiole, the trunk and the shell may be considered for various applications. The composition of coconut coir dust and coconut water are in Tables 5 & 6 respectively.

In the case of sugar cane, the most valuable residues and by-products are molasses and bagasse. In 1982, around 885,000 tons of molasses was produced in the Philippines (Hoshiai, 1984)

and around 544,000 mt of bagasse was avilable as surplus from its use as fuel for sugar mills and refineries (UNIDO, 1983).

In addition to biomass from crop residues and processing wastes, around 3.1 M mt of wood wastes was estimated to have been available in 1982 (UNIDO, 1983).

STUDIES ON THE BIOMETHANATION OF CROP RESIDUES

Dry Anaerobic Fermentation of Rice Straw

Dry Anaerobic Fermentation of Rice Straw

Studies on dry anaerobic fermentation was started about 10 months ago to determine its applicability to locally available crop wastes. For a start, rice straw was used as substrate.

Experimental Set-up

The set-up used was a modification of that described by Maramba (1978). Each set-up was composed of three one-gallon bottles interconnected by an air tight network of rubber stoppers and glass and rubber tubings (Fig. 1). Bottle A served as the reactor bottle; bottle B, the gas collector and bottle C, the water overflow collector. At the start, bottle B is filled with water while C is empty.

The connection between the reactor and the gas collector was provided with a clamp which was opened or closed whenever pH measurement, gas sampling or gas volume measurement was done. Gas volume was measured by the water displacement method.

The starter used came from an actively fermenting slurry which have been kept for almost three years. The starter was rejuvenated about a week before the start of the experiment by adding fresh hog manure and liquid sludge from terminated experiments in the ratio of 1.4.

The fermentation mixture was composed of rice straw (chopped or ground), starter and distilled water. The ratio of each component depended on the level of starter used and the amount of total solids.

Results

Presoaked rice straw

Chopped rice straw was presoaked in water a day before inoculation. The moisture content of the soaked rice straw was determined to allow for proper total solids adjustment.

The presoaked rice straw was inoculated with 10 and 20% starter and total solids adjusted to 5, 10, 15, 20 and 25%.

The effect of increased starter level and total solids is presented in Figures 2 and 3. At both starter levels, there was a significant decrease in gas yields with increase in total solids. At 10 and 20% starter level, gas yields decreased from 5.55 to 1.02 and 5.77 to 1.06 m^3/kg dry matter (Tables 7 and 8) respectively. Although there was an increase in gas yield with increase in starter level, the increase was insignificant.

From the above results, it may be inferred that 10% starter is optimum to start a reactor. There is a need to study some form of pretreatment on rice straw to increase digestibility especially at very high total solids (15 - 20%) and thereby approximating the gas yields at low total solids (5%).

Table 9 summarizes the composition of gas obtained from the biomethanation of the presoaked rice straw. Except for one instance (First week, 10% starter and 20% total solids), methane gas composition ranged from 35 - 59% and carbon dioxide 65 to 41%.

It was observed that at the relatively dry compositions (15 - 25% total solids), growth of green and red molds were noticeable. As yet, no study has been conducted to identify the molds.

Unsoaked rice straw

Chopped, dried rice straw were inoculated with 5 to 20% starter and total solids adjusted to 20 and 30%.

The effect of starter level and increased total solids on gas yields is presented in Figures 4 and 5. From Table 10 it is observed that increasing the total solids loading from 20 - 30% caused the gas yields to decrease by approximately 40%. From an average of 1.03, gas yields decreased to about 0.6 m^3/kg dry matter. Also, there was a slight increase in the yields with increase in starter levels. At 20% total solids, gas yields increasedfrom 0.94 to 1.05 m^3/kg matter. Likewise, at 30% total solids, gas yields increased from 0.57 to 0.67 m^3/kg dry matter.

Flammability test conducted showed a blue flame starting at the 7th day of fermentation.

One problem which may have caused the low production of gas at 30% total solids was the slow wetting of the rice straw that resulted in the slow mobility of the microorganisms. A piston type

compactor is not possible in the present set-up so that mixing was done by tilting the bottle sideways to allow the liquid to get in contact with the straw which adhered on the side.

The gas yields obtained in this experiment was lower than that the obtained in presoaked rice straw. Taking for example the treatment at 20% starter level and 20% total solids, at 130 days retention time, the presoaked rice straw produced 1.23 m^3/kg (Table 8) while the unsoaked rice straw produced 1.05 m^3/kg dry matter (Table 10).

Ground rice straw

One possible solution to the wetability problem of rice straw is grinding.

Rice straw was ground to 60 mesh, inoculated with 10 and 20% starter and total solids adjusted to 20 and 30%.

The effect of the treatment is presented in Figures 6 and 7. It was observed that gas yields decreased when starter level increased from 10 - 20%. At 20% total solids, gas yields decreased from 1.14 to 0.97 while at 30% total solids gas yields decreased from 0.74 to 0.43 m^3/kg dry matter (Table 11). The same relationship was observed with increase in total solids. Increased solids loading from 20 - 30% decreased biogas yields by 1/2. At 10% starter level, gas yields was reduced from 1.14 to 0.74 m^3/kg dry matter and at 20% starter level, gas yield was reduced from 0.97 to 0.43. m^3/kg dry matter.

Grinding of rice straw slightly improved gas production as compared to chopped rice straw inoculated with the same level of

starter and amount of total solids. As compared to presoaked rice straw, grinding, is not much better than presoaking.

Biomethanation of coconut coir dust

Experimental Set-Up

Coconut coir dust was obtained from a local coconut coir factory. Portions of it was air dried and the rest washed under running water for about two weeks. After washing, the coir dust was air dried.

Details of the coir dust treatment were as follows:

Washed - 5 and 8% total solids (50 and 100 grams)

Unwashed - 5 and 8% total solids (50 and 100 grams)

The treated coir dust was charged into the digester together with 15 grams dried hog manure, 500 ml starter (10% solids) and 1.5 liters water.

Results

The cumulative gas production curve for coir dust is presented in Figure 8, based on Table 12. The fifty grams washed, coir dust produced the highest gas volume (0.129) while the 100 grams unwashed coir dust produced the least amount of gas (0.095 m^3/kg matter).

From the results obtained, it appears that the least amount of solids (50 grams) favor gas production. There was a marked improvement in gas yields from 0.095 to 0.125 m^3/kg dry matter when 100 grams of coir dust was prewashed. Only a slight increase was observed in the 50 grams washed coir dust.

Retention time for all treatments was 26 days. Active growth phase was from the first to the 10th day.

The gas chromatographic analysis of the biogas produced is presented in Table 13. The methane gas composition ranged from 59-73%. Although the volume of gas produced from coir dust is lower than that produced from rice straw, the quality of gas is comparable to rice straw.

Biomethanation of coconut water

Experimental Set-Up

Freshly extracted coconut water was obtained from a desicated coconut factory. The following treatments were done:
A) addition of 1 gram/liter sodium carbonate and B) no addition of sodium carbonate.

Two liters of coconut water was inoculated with 200 ml starter (10% solids) and 2 grams of sodium carbonate for the treated substrate. The treatments were replicated four times. The initial pH and COD value was determined.

The fermentation was allowed to proceed until gas production was practically stopped after which the final pH and COD value was determined.

Results

The gas production curves for the biomethanation of rice straw is presented in Figure 9, based on Table14. There was a significant increase in gas production with the addition of

sodium carbonate to the slurry. From a volume of 5.69 (untreated), gas production rose to 21.26 m^3/liter of coconut water (treated).

The gas chromatographic analysis of biogas from coconut water is shown in Table 15. The composition of methane gas during the first week of fermentation was low (23%) but it increased during the subsequent weeks (86-89%). In the treated coconut water methane gas composition ranged from 53.5-79%.

Table 16 summrizes the physical and chemical change which occurredin the biomethanation of coconut water. There was a slight increase in pH from 3.96 to 4.97 in the untreated coconut water. Although the pH of untreated coconut increased, it was still too low for methanogens to survive. This condition resulted in the low production of gas. The treated coconut water increased the pH to the level optimum for bacterial growth.

The efficiency of COD removal in the treated coconut water was twice that of the untreated coconut water (40%). In the untreated coconut water, COD value was reduced from 30,000 to 18,200 mg/1 while the treated coconut water reduced COD value to 5,000 mg/1. Thus, the volume of biogas/COD removed was 0.51 and 0.84 for untreated and treated coconut water respectively.

Conclusions

The feasibility of producing biogas from rice straw, coconut coir dust and coconut water has been shown. However, further studies are needed to optimize conditions and to conduct experiments on a larger scale based on dry anaerobic fermentation.

The use of the residue after biomethanation has to be further developed.

Acknowledgements

The authors wish to thank USAID, through DYNATECH, for including their laboratory in this network of biogas researchers. Also, the authors wish to acknowledge the National Institutes of Biotechnology and Applied Microbiology (BIOTECH), University of the Philippines at Los Baños and the Ferdinand E. Marcos Foundation for their financial support of this work.

References

DEL ROSARIO, E.J. and O.N. Gonzalez. 1982. Fermentation technology applied to the utilization of food waste materials in the Philippines. Country report presented at the First ASEAN Workshop on Fermentation Technology Applied to the Utilization of Food Waste Materials, Kuala Lumpur, Malaysia, 22-24 February 1982.

GONZALES, B.P. 1970. Analysis and pulping of coir dust. In Emata, R. (Ed) 1970. Coconut Research and Development, V. 3 UCAP: Manila.

HOSHIAI, K. 1984. Personal communication.

MARAMBA, F.D. 1978. Biogas and waste recycling: The Philippine experience. Maya Farms: Manila, Philippines.

Ministry of Energy (Philippines) 1983. Accomplishment report: Energy self-reliance 1973-1983.

Ministry of Energy (Philippines) 1983a. Report for 1983.

National Economic and Development Authority 1980. Philippine Statistical yearbook.

National Economic and Development Authority (NEDA) 1983. Philippine Statistical Yearbook.

PADOLINA, W.G. 1983a. Biotechnology and the coconut industry. Paper delivered at the Integrated Chemists of the Philippines Annual Convention, Bacolod City, Oct. 1983.

PADOLINA, W.G. 1983b. Biotechnology and the Sugar Industry. Paper delivered at the Integrated Chemists of the Philippines Annual Convention, Bacolod City, Oct. 1983.

PADOLINA, W.G. 1983c. Coconut water and coconut sap: suggestions research and development. Paper delivered during the "Miniworkshop on Coconut Water and Sap Utilization" sponsored by PCARRD and PCRDF, 20 Sept. 1983. Manila, Philippines.

PONTIVEROS, C.R., J.A. ALCANTARA and E.J. DEL ROSARIO. 1978. Acid saccharification and alcohol fermentation of unripe banana fruits (*Musa sapientum* L.) Phil. J. Crop Science 3: 153-158.

ROXAS, D.B., L.S. CASTILLO, A. OBSIOMA, R.M. LAPITAN, V.G. MOMONGAN and B.O. JULIANO. 1983. Chemical composition and in vitro digestibility of straw from different varieties of rice. Proceedings of the 3rd Annual Meeting, Australian-Asian Fibrous Agricultural Residues Research Network, Peradeniya, Sri Lanka (in press).

of

SISON, B.C. JR. 1976. Disposal/coconut processing wastes. Proceedings of the Seminar-Workshop on Coconut Industrial Research. Philippine Coconut Authority: Manila.

UNIDO. 1983. Techno-economic study of production of ethanol from cellulosic materials in the Philippines. Report of UNIDO Contract No. 82/47 MK.

Table 1. Nonconventional resources of energy in the Philippines for the year 1983.

SOURCES	THOUSAND BARRELS OF OIL EQUIVALENT	PERCENT OF TOTAL ENERGY SOURCES
Bagasse	5470	5.6
Woodwaste	4430	4.5
Cocoshell/husk	3500	3.6
Rice Husk	700	0.7
Black Liquor	420	0.4
Producer Gas	30	-
Biogas	20	-
Alcohol	20	-
Coco Oil/Solar/Windmill	-	-
TOTAL	14590	14.8

Source: Ministry of Energy, (1983)

Table 2. Quantity, hectarage and mean yield of some major crops in the Philippines in 1982.

CROP	QUANTITY (THOUSAND METRIC TONS)	AREA (THOUSAND HECTARES)	MEAN YIELD (TONS/ HECTARE)
Palay	8107.9	3432.8	2.36
Corn	3290.2	3360.7	0.98
Coconut	3785.5	3162.0	1.20
Sugarcane	3402.7	470.8	7.23
Banana	4076.8	331.4	12.30
Pineapple	1242.1	60.0	20.70
Root crops	3173.4	479.7	6.62

Source: NEDA, 1983

Table 3. Processing biomass residues of some major crops.

CROPS	SACCHARINE	STARCHY	LIGNOCELLULOSIC
Rice	-	bran broken grains	straw hull
Corn	-	broken grains	stalks cobs husk
Banana	ripe banana fruit rejects	banana fruit rejects	stalk leaves peelings
Pineapple	juice from processing wastes	-	processing wastes
Coconut	water	-	coir dust husk plant parts meat residue
Sugarcane	molasses	-	bagasse
Root crops	-	processing wastes	plant parts

Table 4. Range and mean composition and digestibilities of straw from 15 modern rice varieties, 1981-1982 dry season.

PROPERTY AT 14% MOISTURE	RANGE	MEAN
Gross energy (KJ/g)	11.05 - 12.57	11.72
Crude protein (%)	4.1 - 7.5	6.0
Crude fiber (%)	23.8 - 28.0	26.0
Crude ash (%)	18.3 - 24.7	21.8
Cellulose (%)	21.6 - 29.8	25.8
Hemicellulose (%)	0.6 - 16.2	5.2
Lignin (%)	4.4 - 10.3	6.6
Silica (%)	11.9 - 19.6	15.1
In vitro dry matter digestibility (%)	30.9 - 42.8	36.8
In vitro organic matter digestibility	30.0 - 45.8	37.6

Source: Roxas, et al. (1983).

Table 5. Composition of coir dust.

CONSTITUENT	PERCENT (DRY BASIS)
Moisture	15.38
Ash	6.19
Cellulose	24.15
Pentosan	27.31
Furfural	17.40
Lignin	54.78

Source: Gonzales, B.P. (1970).

Table 6. Composition of coconut water.

CONSTITUENT	PERCENT
Sugars	2.5
Chlorides	0.17
Protein	0.55
Oil	0.74
Total solids	4.71
Ash	0.46
Specific gravity	1.02
pH	5.6

Source: Sison, B.C. Jr. (1976).

Table 7. Mean cumulative gas volume from presoaked rice straw inoculated with 10% starter and adjusted to different total solids level (m^3/kg dry matter).

DAY	% TOTAL SOLIDS 5	10	15	20	25
10	1.07	0.60	0.38	0.09	0.18
20	2.33	1.09	0.67	0.24	0.32
31	3.04	1.45	0.93	0.28	0.44
40	3.51	1.67	1.09	0.50	0.52
49	3.80	1.82	1.19	0.57	0.59
60	4.07	1.96	1.25	0.63	0.66
70	4.29	2.08	1.29	0.67	0.72
80	4.47	2.17	1.33	0.71	0.77
91	4.67	2.28	1.37	0.75	0.82
101	4.82	2.37	1.40	0.77	0.85
112	4.94	2.44	1.41	0.79	0.87
123	5.05	2.50	1.43	0.81	0.89
130	5.14	2.54	1.44	0.82	0.91
140	5.23	2.59	1.47	0.83	0.93
151	5.30	2.62	1.48	0.84	0.94
161	5.35	2.65	1.48	0.85	0.96
175	5.40	2.67	1.49	0.86	0.97
189	5.47	2.71	1.49	0.88	0.99
200	5.51	2.74	1.49	0.90	1.00
214	5.55	2.76	1.50	0.92	1.02

Table 8. Mean cumulative gas volume from presoaked rice straw inoculated with 20% starter and adjusted to different total solids level (m^3/kg dry matter).

DAYS	% TOTAL SOLIDS 5	10	15	20	25
10	2.03	0.82	0.43	0.34	0.29
20	3.11	1.40	0.78	0.59	0.50
31	3.81	1.77	1.00	0.76	0.64
40	4.23	1.98	1.12	0.84	0.75
49	4.5	2.13	1.21	0.91	0.81
60	4.8	2.27	1.30	0.98	0.87
70	5.0	2.37	1.36	1.04	0.91
80	5.1	2.46	1.41	1.09	0.94
91	5.3	2.54	1.47	1.13	0.98
101	5.4	2.60	1.51	1.17	.099
112	5.5	2.64	1.54	1.19	1.00
123	5.5	2.68	1.56	1.22	1.01
130	5.6	2.71	1.58	1.23	1.02
140	5.61	2.75	1.59	1.25	1.03
151	5.66	2.77	1.61	1.27	1.03
161	5.67	2.79	1.62	1.27	1.04
175	5.70	2.82	1.62	1.28	1.04
189	5.73	2.84	1.64	1.29	1.05
200	5.75	2.86	1.65	1.29	1.05
214	5.77	2.88	1.66	1.30	1.06

Table 9 . Gas chromatogrphic analysis of biogas from presoaked rice straw.

TREATMENT		WEEK							
		FIRST		THIRD		FIFTH		SEVENTH	
% STARTER	% TOTAL SOLIDS	% CH_4	% CO_2	% CH_4	% CO_2	% CH_4	% CO_2	% CH_4	% CO_2
10	5	47	43	49	51	59	41	53	47
	10	42	58	48	52	55	45	51	49
	15	40	60	50	50	54	46	52	48
	20	16	84	54	46	53	47	50	50
	25	35	65	50	50	49	51	53	47
20	5	51	49	48	52	50	50	52	48
	10	50	50	47	53	52	48	52	48
	15	49	51	50	50	52	48	51	49
	20	43	57	48	52	53	47	51	49
	25	47	53	49	51	48	52	51	49

Table 10. Mean cumulative gas volume from unsoaked rice straw inoculated with different levels of starter and different total solid (TS) (m^3/kg dry matter).

DAY	5% STARTER		10% STARTER		15% STARTER		20% STARTER	
	20% TS	30% TS	20% TS	30% TS	20% TS	30% TS	20% TS	30% TS
10	0.20	0.11	0.30	0.17	0.32	0.17	0.35	0.19
20	0.38	0.21	0.50	0.27	0.53	0.28	0.55	0.32
30	0.48	0.27	0.60	0.34	0.66	0.36	0.67	0.39
40	0.57	0.32	0.69	0.39	0.75	0.42	0.77	0.45
50	0.63	0.36	0.75	0.43	0.82	0.49	0.83	0.50
60	0.68	0.40	0.81	0.47	0.87	0.52	0.88	0.53
70	0.73	0.43	0.86	0.50	0.92	0.56	0.89	0.56
81	0.77	0.46	0.90	0.53	0.96	0.58	0.93	0.58
91	0.81	0.49	0.93	0.56	0.99	0.61	0.95	0.60
100	0.84	0.51	0.96	0.58	1.02	0.62	0.97	0.62
112	0.88	0.53	0.98	0.62	1.05	0.65	1.00	0.64
199	0.91	0.55	1.00	0.62	1.07	0.66	1.02	0.65
130	0.94	0.57	1.03	0.64	1.10	0.68	1.05	0.67

Table 11. Mean cumulative gas volume for ground (60 mesh) rice straw inoculated with different levels of starter and different total solids (TS) (m^3/kg dry matter).

DAY	10% STARTER		20% STARTER	
	20% TS	30% TS	20% TS	30% TS
5	0.27	0.14	0.40	0.22
9	0.49	0.25	0.71	0.35
15	0.76	0.39	0.91	0.43
20	0.90	0.47	0.94	0.43
26	0.97	0.54	0.96	0.43
30	1.03	0.57	0.97	0.43
35	1.07	0.61	0.97	0.43
41	1.10	0.64	0.97	0.43
44	1.11	0.66	0.97	0.43
50	1.14	0.68	0.97	0.43
55	1.14	0.70	0.97	0.43
61	1.14	0.72	0.97	0.43
66	1.14	0.74	0.97	0.43

Table 12. Mean cumulative gas volume from the biomethanation of 5% and 8% Total Solids washed and unwashed coir dust (m^3/kg dry matter).

DAY	TREATMENTS			
	50 GRAMS		100 GRAMS	
	WASHED	UNWASHED	WASHED	UNWASHED
1	0.009	0.009	0.009	0.009
2	0.020	0.020	0.022	0.021
5	0.054	0.052	0.047	0.022
6	0.066	0.063	0.059	0.032
7	0.075	0.071	0.070	0.039
8	0.082	0.078	0.078	0.046
9	0.08	0.084	0.084	0.051
12	0.101	0.094	0.091	0.062
13	0.105	0.097	0.094	0.065
14	0.108	0.100	0.098	0.068
15	0.111	0.103	0.101	0.071
16	0.114	0.105	0.104	0.074
19	0.120	0.113	0.113	0.083
21	0.122	0.117	0.117	0.087
26	0.129	0.124	0.125	0.095

Table 13. Gas chromatographic analysis of biogas from coconut coir dust.

TREATMENT	DAYS 2		9	
	% CH_4	% CO_2	% CH_4	% CO_2
5% Total Solids (Washed)	68.75	29.31	67.89	32.11
(Unwashed)	70.9	25.6	73.0	27.0
8% Total Solids (Washed)	71.95	25.93	59.0	41.0
(Unwashed)	72.7	24.01	61.25	37.98

Table 14. Mean cumulative gas volume from the biomethanation of coconut water (m^3/liter coconut water).

DAY	TREATMENTS	
	CONTROL	SODIUM CARBONATE
6	4.78	5.77
10	5.32	8.35
15	5.32	11.78
20	5.41	15.43
24	5.45	18.64
30	5.50	19.69
35	5.56	20.38
41	5.62	20.98
45	5.69	21.26

Table 15. Gas chromatographic analysis of biogas from coconut water.

TREATMENT	DAYS 7		14		21	
	% CH_4	% CO_2	% CH_4	% CO_2	% CH_4	% CO_2
Control	23.0	77.0	86.0	14.0	89.5	10.5
Sodium carbonate	53.5	46.5	72.5	27.5	79.0	21.0

Table 16. Physical and chemical changes which occur in the biomethanation of coconut water.

	pH		COD (mg/1)		% COD	m^3 BIOGAS/
	INITIAL	FINAL	INITIAL	FINAL	REMOVAL	gm COD REMOVED
Control	3.96	4.97	30,400	18,200	40	0.51
Sodium carbonate	3.96	7.66	30,400	5,000	84	0.84

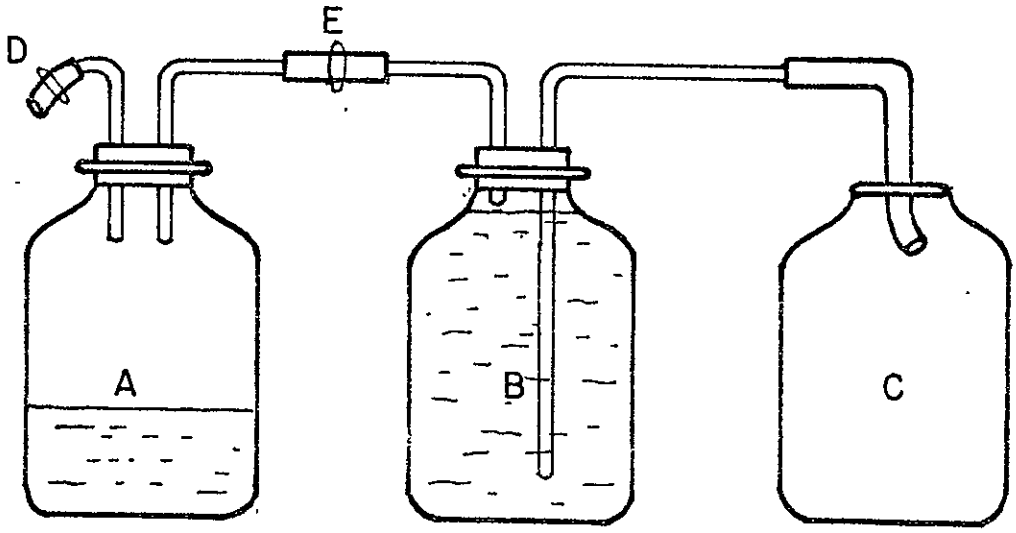


Fig. 1. Laboratory set-up for biogas production.

A - Digester bottle
B - Gas collector
C - Water collector
D and E - Gas outlets

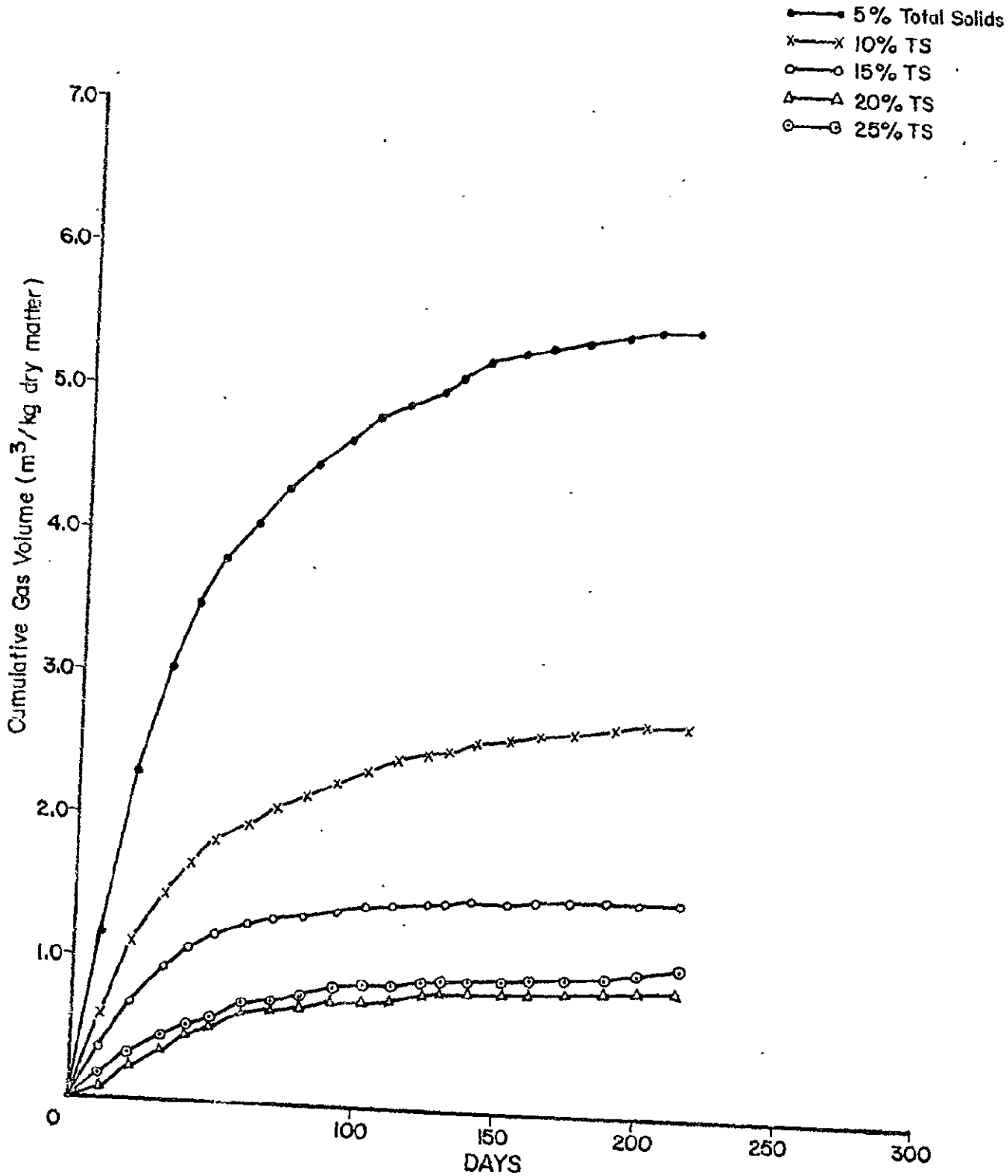


Fig. 2. Gas production curves for previously wet rice straw inoculated with 10% starter and varying total solids content.

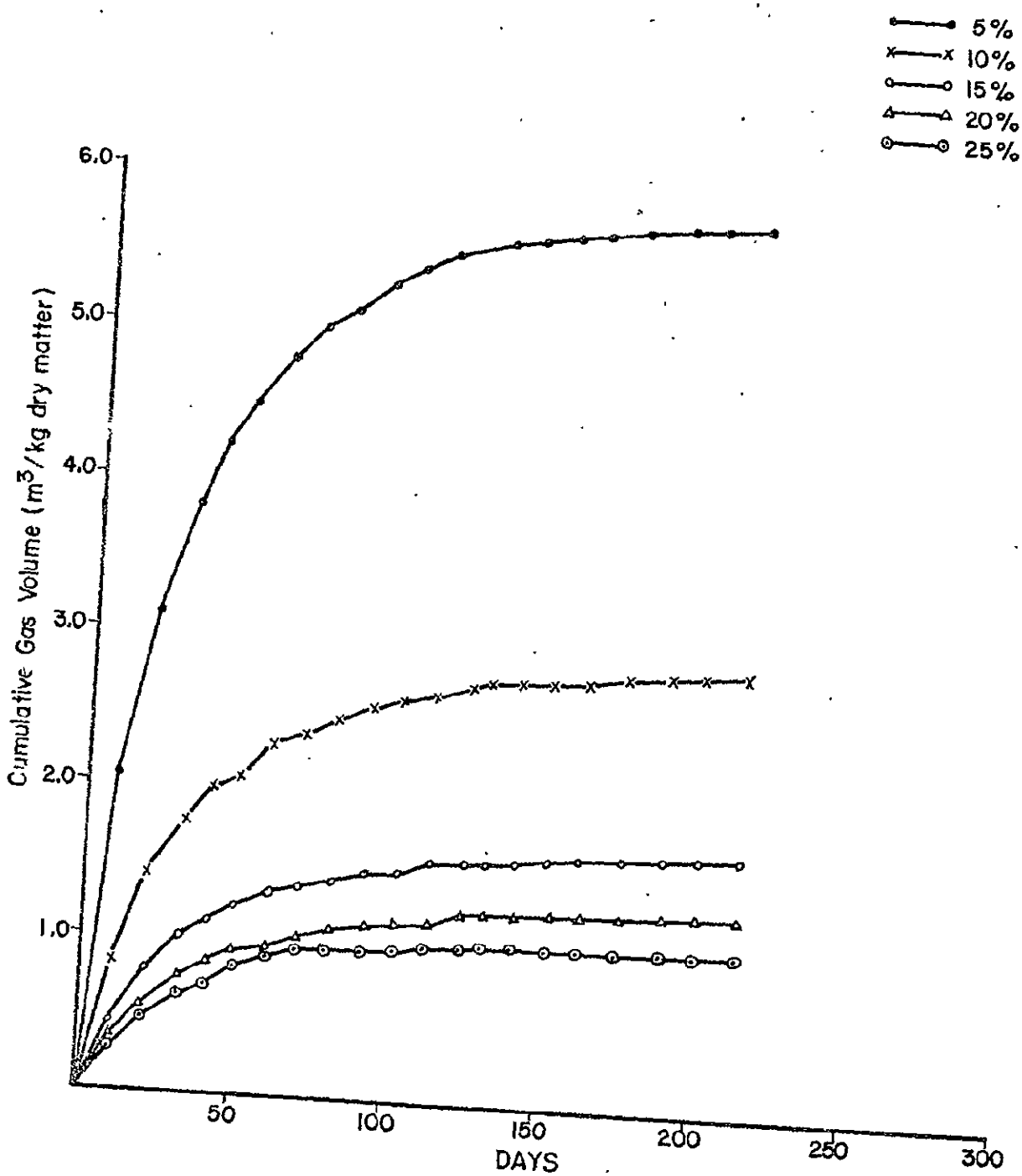


Fig. 3. Gas production curves for previously wet rice straw inoculated with 20% starter and varying total solids content.

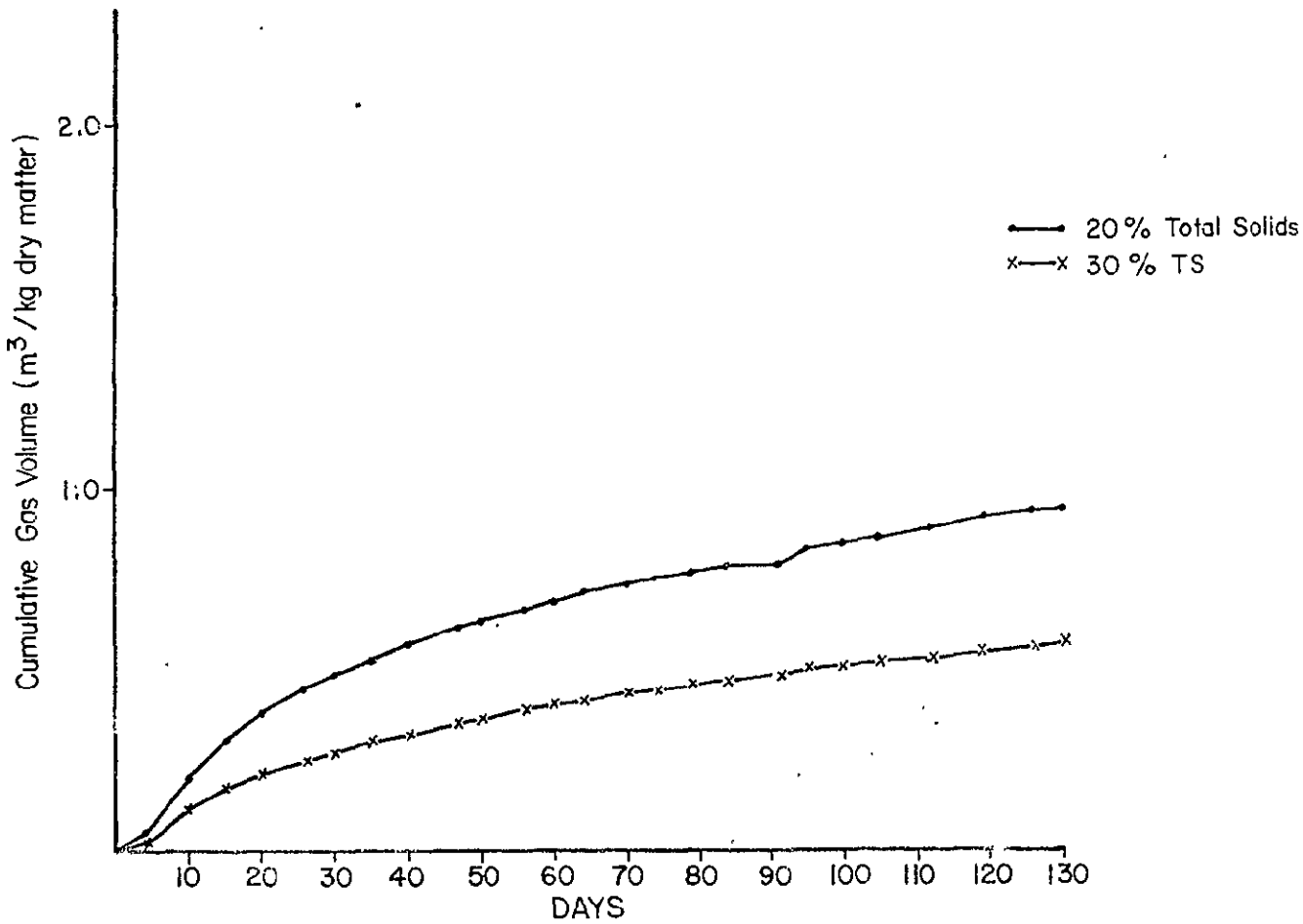


Fig. 4. Gas production curves for dry rice straw inoculated with 5% starter.

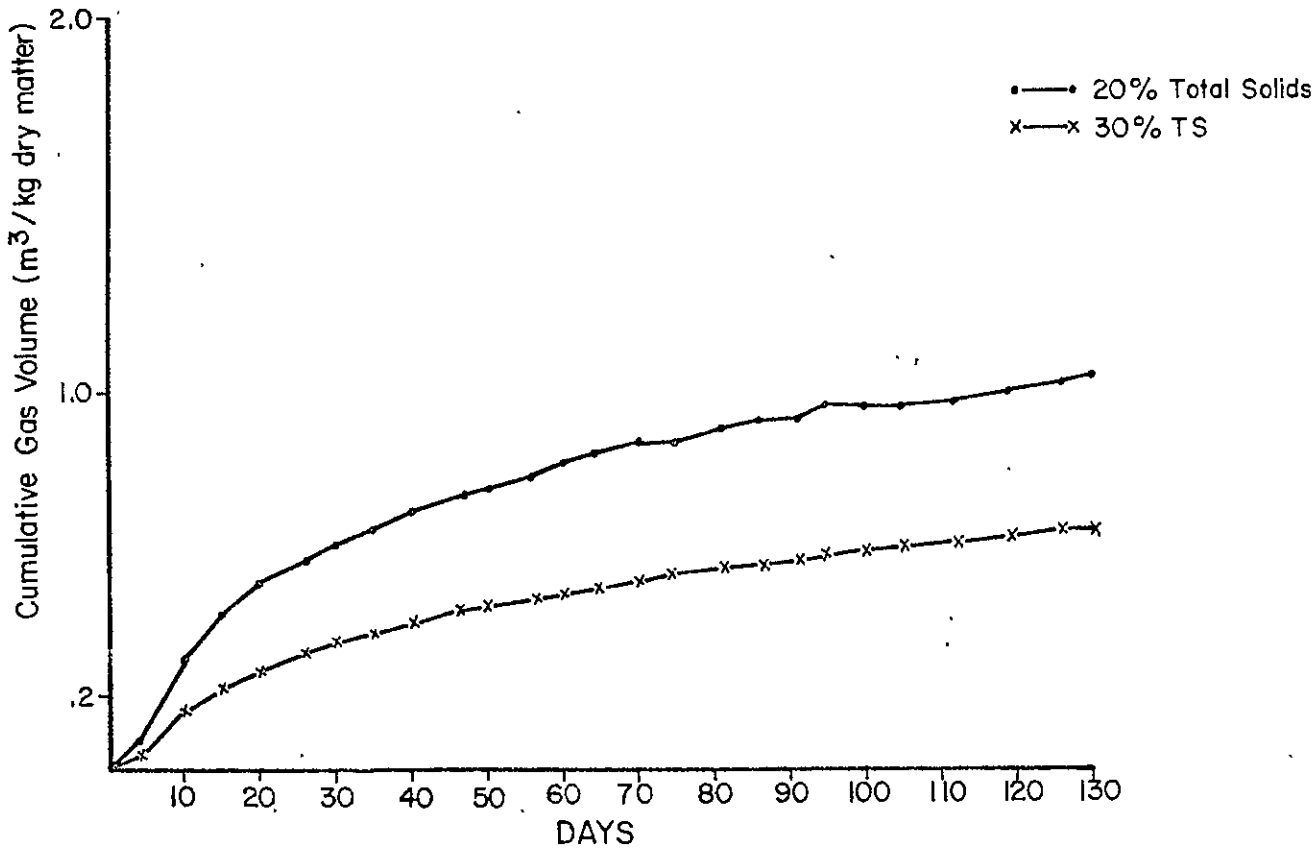


Fig. 5. Gas production curves for dry rice straw inoculated with 10% starter.

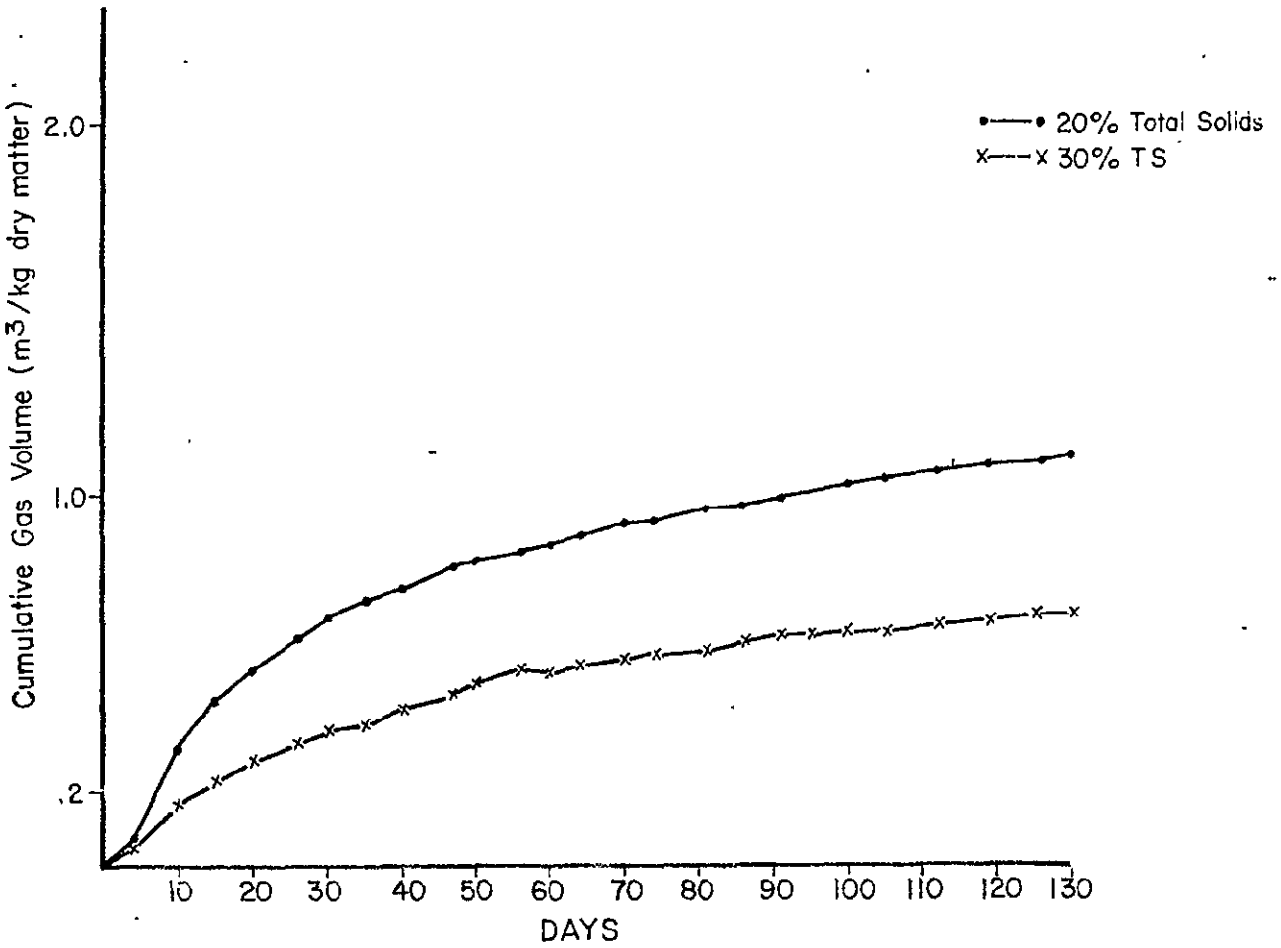


Fig. 6. Gas production curves for ground rice straw inoculated with 10% starter.

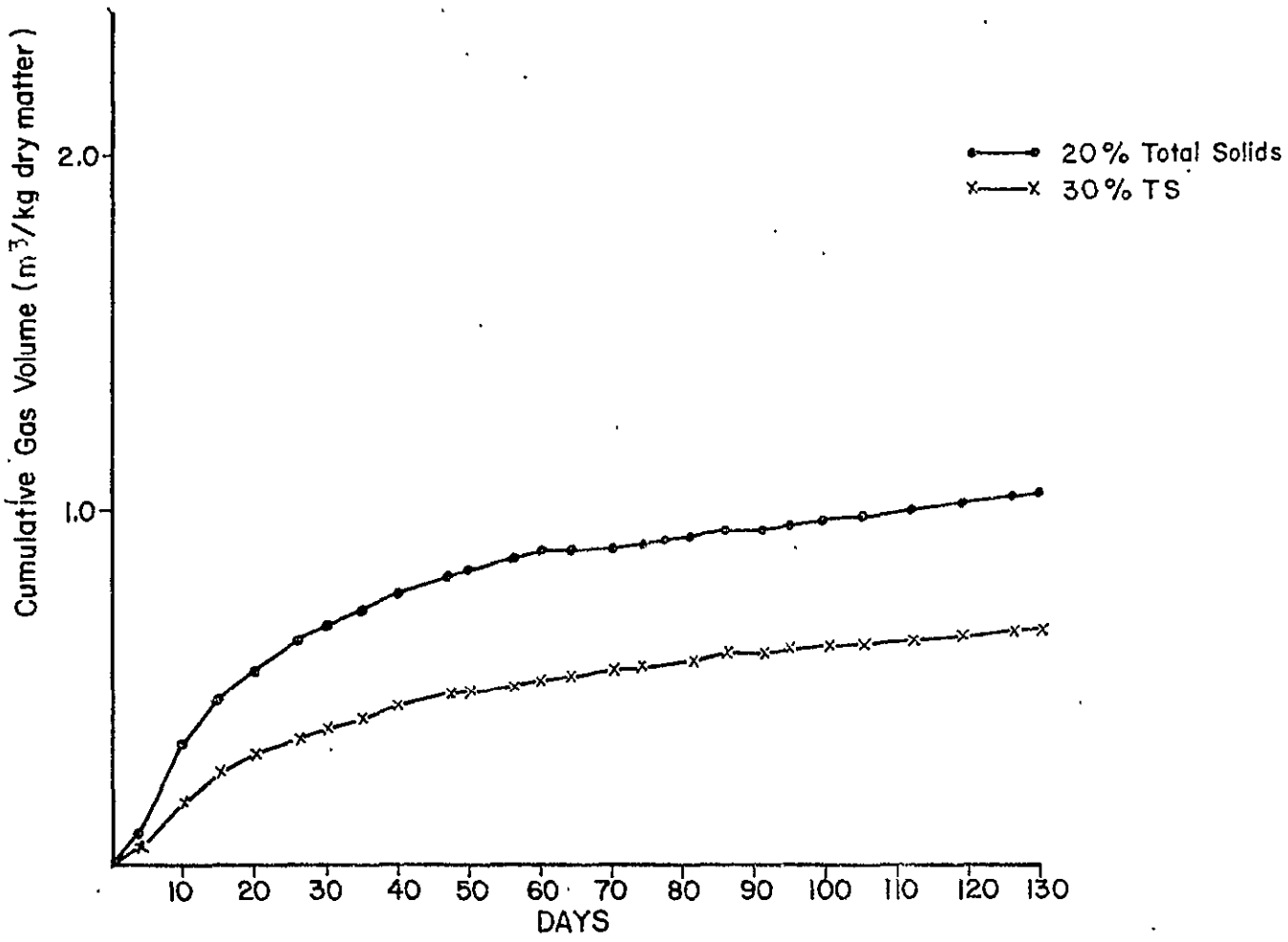


Fig. 7. Gas production curves for ground rice straw inoculated with 20% starter.

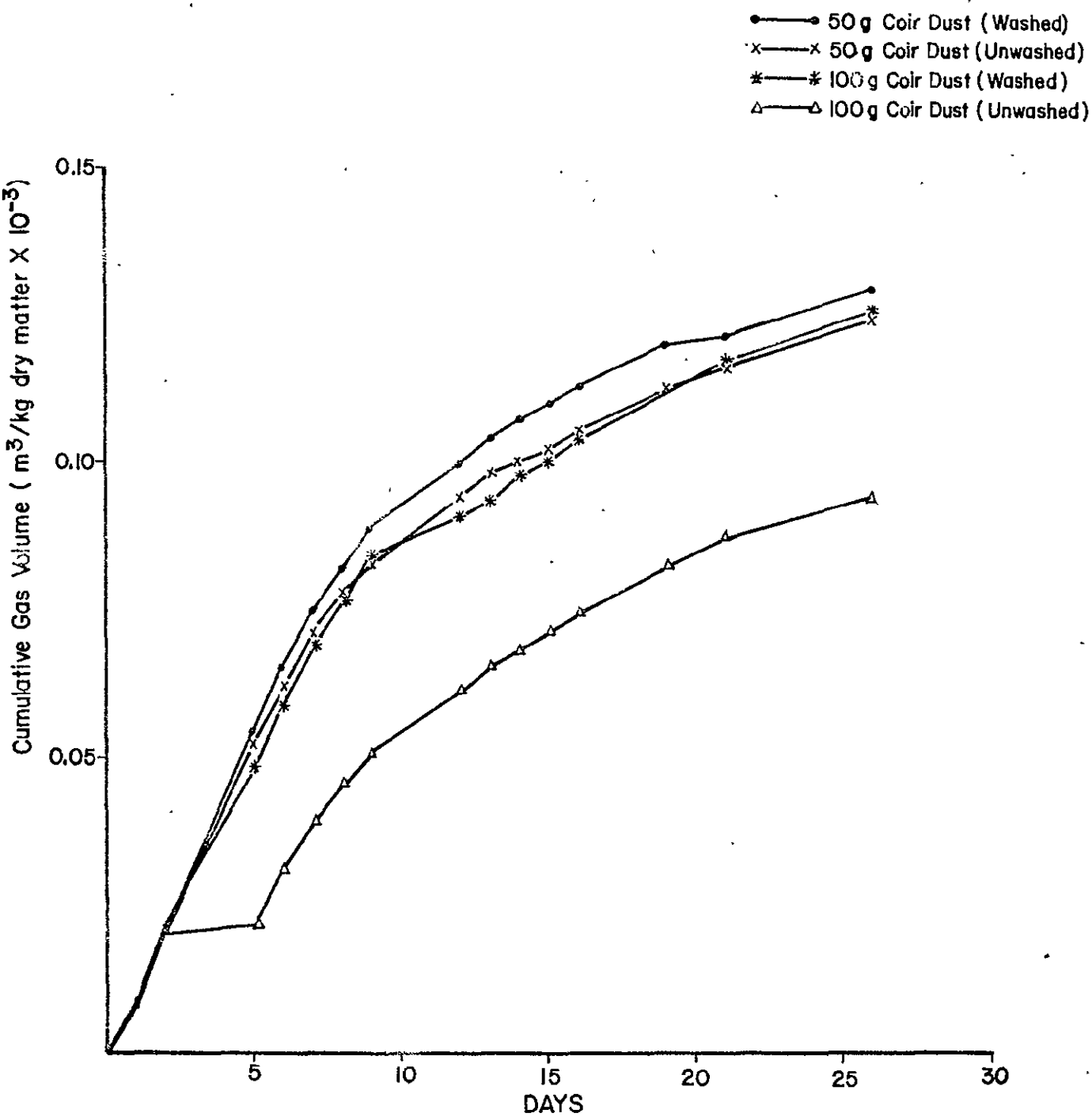


Fig. 8. Gas production curves from the biomethanation of coir dust.

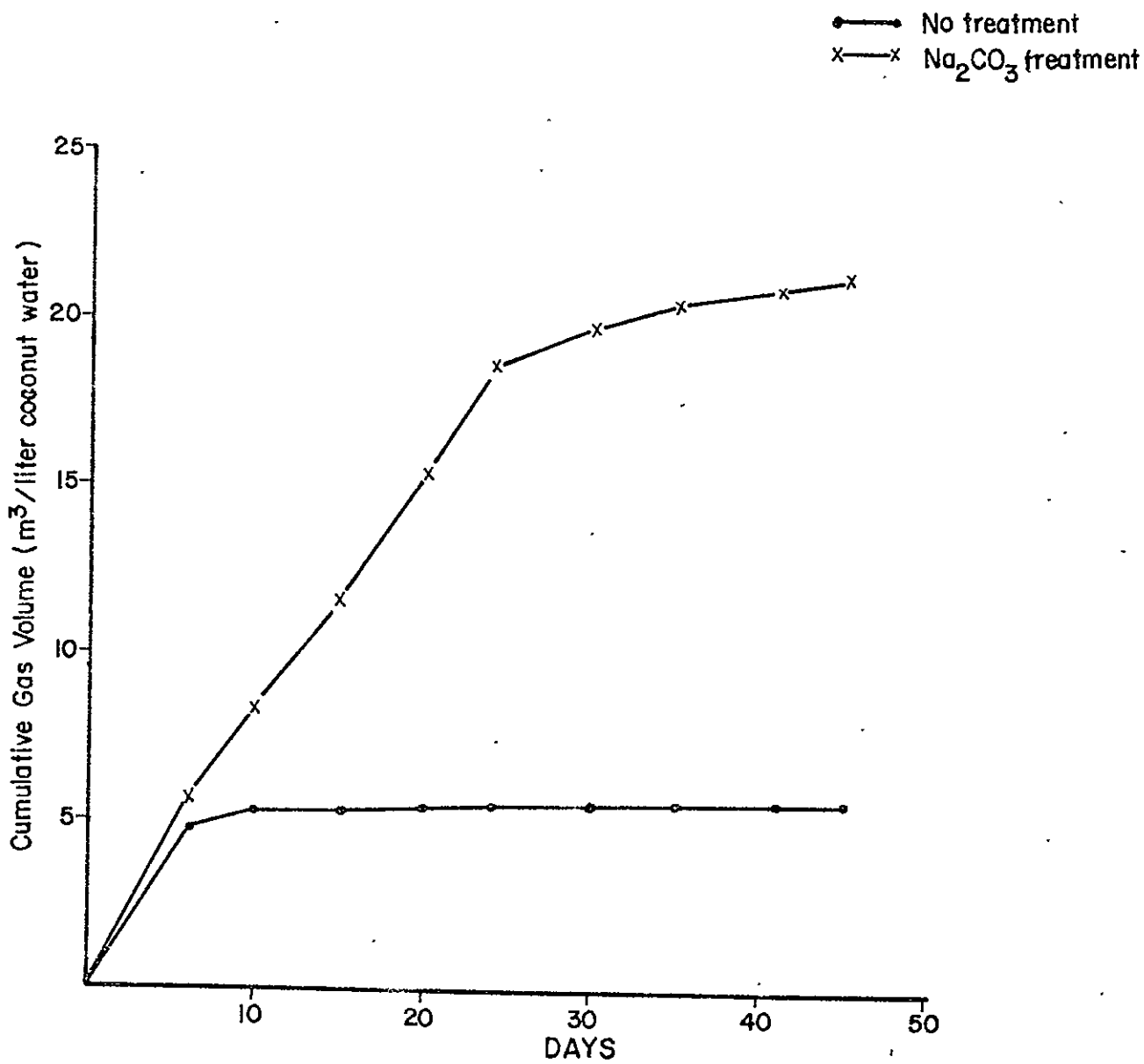


Fig. 9. Gas production curves from the biomethanation of coconut water.

"BIOENERGY RECOVERY AND CONSERVATION IN SINGAPORE"

Report Presented By:

Dr. Kee Kean Chin
Professor, Department of Civil Engineering
National University of Singapore
Faculty of Engineering
12 B Patterson Hill
Singapore 9,
SINGAPORE

Bioenergy Recovery and Conservation in Singapore

by

Chin, Kee Kean
National University of Singapore
Singapore

I. INTRODUCTION

Singapore is an island state of 2.5 million population. Population increase, rapid urbanization, industrialization, and the expansion of commercial activities and tourism have increased its demand for raw materials and energy and at the same time generate a substantial amount of wastes. Although a major oil refining centre, Singapore depends solely on import for its energy needs. Various energy conservation measures including legislation have been taken into effect to reduce energy usage. Due to the limitation of land, alternate sources of energy are confined to recovery of conversion products from wastes which could be used as fuel for the generation of electricity. Energy is at present recovered from sewage sludges and from solid wastes. This paper summarises work carried out to recover energy from wastes.

II. BIOENERGY RECOVERY FROM SINGAPORE SEWAGE SLUDGES

The water consumption rate in Singapore is around 650,000 m^3/d of which 53% are domestic. The city is nearly 90% sewered and industrial wastes after pretreatment to remove toxic matters and excessive organic substances are discharged into the sewer systems. These resulted in approximately 500,000 m^3/d of sewage flow. Typically the BOD and suspended solids concentrations of the raw sewage are 250 mg/l and 300 mg/l respectively. Sewage is treated to meet the 30/30 standards of BOD and suspended solids. There are six sewage treatment works in operation - namely the Ulu Pandan, Kim Chuan, Bedok, Kranji, Jurong, and Seletar

Sewage Treatment Works. All these works use the activated sludge systems for secondary treatment. Primary solids and excess secondary solids are thickened to around 3-5% solids and fed to the anaerobic digesters at the works. There are 10 digesters at Ulu Pandan, 12 at Kim Chuan, 4 at Kranji, 3 at Seletar, 4 at Bedok, and 6 at Jurong. These digesters are all operating at the mesophilic range of temperatures. Loading rate of the digesters is in the order of 1 to 5 kg vs/m^3/d and the hydraulic retention times range from 15 to 30 days. The main objective of the anaerobic treatment process is to degrade and stabilized primary and secondary solids which amount to 4000 tonnes wet sludge per day. Between 60 to 70% reduction in sludge volume is achieved through anaerobic digestion. All digesters are mixed by recirculation of the biogas produced through the anaerobic digesters. Gas generation rate is around 0.6 m^3/kg vs feed. The biogas produced contains at least 60% methane gas. This gas is used as fuel for the duel fuel engines to generate electricity. Electricity produced currently meets up to 40% of the plant electricity needs resulting in considerably saving in running costs of the treatment works.

III. ENERGY RECOVERY FROM REFUSE

The solid waste generation rate in Singapore has increased significantly from 0.57 kg/capita-day in 1969 to the present level of 1.14 kg/capita-day. A total of 2800 tonnes/day solid wastes were collected in 1983 of which 66% were domestic and trade refuse, 22% industrial wastes, and 12% institutional wastes. It is estimated that by 1990, 4200 tonnes/day of refuse will be produced. This increase is due not only to the increase in population but to an increasing affluence of the society. At present, about 68% of the refuse are disposed of by landfilling, 31% by incineration, and 1% by composting. Characteristics of the refuse collected from the Housing and Development Board (HDB)

estates, shopping centres, the wet markets, and institutional buildings are given in Table 1. The complex nature of these wastes creates disposal problems. The composting plant handles only a limited amount of wastes and the compost produced is used for turfing and tree planting by the Park and Recreation Department. Refuse disposal facilities are at present available at the Ulu Pandan Refuse Incineration Plant and the two dumping grounds at Lorong Halus and Lim Chu Kang (Figure 1). Refuse dumped at the landfill sites are levelled by bulldosers, compacted by machinery, and then covered with a layer of earth. There is no gas nor material recovery operation at the sites. The Ulu Pandan Refuse Incineration Plant is designed to handle only domestic refuse having a 45% moisture content and a net calorific value of 6000 kJ/kg-refuse. The Plant, with a capacity of 1200 tonnes of refuse per day was completed in December, 1978. Its capacity was increased to 1600 tonnes of refuse/day in October 1982. A schematic diagram of the incineration process is shown in Figure 2. Heat produced from the refuse incinerator operating at a normal temperature of 1000°C at the furnace is recovered through water tube boilers built integrally above the incinerator furnace. There are four boilers each with a nominal capacity of 25 tonnes/hour. The back-pressure turbine is capable of generating 16 MW of electricity from a steam flow rate of about 120 tonnes/hour. The generator voltage is 6.6 kV. The prime objective of the Plant is to provide an efficient means of refuse disposal although energy and scrap iron are recovered in the process. The total revenue collected for the year 1983 amounted to around S $6 million (US $1.0 = S$2.1) of which about 89% was from the sale of electricity. This revenue was just enough to cover the more than S $5 million operating expenditure of which 52% were labour costs. A second incineration plant is under construction at Tuas and there is plan to develop a new refuse dampsite in Ponggol. By 1990 more than 60% of the refuse will be disposed by

incineration. Controlled landfilling with biogas recovery is being evaluated for possible application at the proposed dumping ground at Ponggol in the near future.

IV. RESEARCH IN BIOENERGY RECOVERY

A number of projects was initiated at the National University of Singapore on biogas recovery from wastes.

A. Biogas recovery from palm oil mill effluent (POME)

Oil palm is an important cash crop in South East Asia. World production of palm oil currently stands at around 3.5 million tonnes of which Malaysia alone accounts for about 80%. Palm oil is extracted from the fresh fruit bunches (FFB) at the oil mill by a 5-stage procedure: steam sterilization, fruit bunch stripping, digestion, oil extraction from the mesocarp and clarification. The kernel is separated from the shell using the hydrocyclone separator. At each of these stages, some wastewater is produced (Figure 3). Current mill practice combines all process wastewaters with spillage, washwaters and steam condensate to give a thick, brownish effluent which amounts to 2-3 tonnes wastewaters per tonne of finished oil[1]. There are at present approximately 280 mills in Malaysia generating more than 130,000 tonnes BOD/annum. The quantity and quality of POME vary from mill to mill depending on the individual mill operating procedures. General characteristics of POME are given in Table 2.

Table 2 Characteristics of POME

Parameters	Concentrations
BOD_5, mg/l	28,200
COD, mg/l	67,400
Suspended solids, mg/l	31,800
Total solids, mg/l	54,000
TKN, mg/l	1,000
Total phosphorous, mg/l	120
Oil and Grease, mg/l	7,000
Volatile Acids, mg/l	1,200
pH	4.4
Temperature, ^{o}C	60
Potassium, mg/l	1,500
Calcium, mg/l	320
Magnesium	300
Iron	120

The BOD : N : P ratio shows that POME is amenable to the anaerobic fermentation process as cell synthesis in anaerobic process is only around one tenth to one third that in aerobic process[2]. Laboratory scale (2-16ℓ capacities), completely mixed, continuously flow units were set up for the anaerobic fermentation studies. Figures 4 to 6 show the comparative treatment performance of mesophilic, thermophilic, and two-phase digestion systems for POME. For the mesophilic single stage reactor system, inbalances occurred at 7-day solids retention time. However, at the thermophilic range stability was achieved even at 5-day detention time. It would be advantageous to carry out the anaerobic fermentation at 49°C to 57°C in the tropical environment as POME from the mills is normally around 60°C. The anaerobic fermentation system is essentially diphasic

with the acid forming micro-organisms achieving the initial acidification, and the methane forming species effecting the final conversion of the volatile acids to methane. These two groups of bacteria differ with respect to their physiology and nutritional requirements. Two-phase anaerobic fermentation system with separate units for the acidification phase and the methane fermentation phase by means of appropriate control of the loading rates of the reactors seemed to have improved the stability of the process and the overall BOD and COD removal efficiency of POME. Anaerobic fermentation systems in general show high BOD and COD removal efficiency. At 15-day overall detention time, more than 80% BOD and COD removal can be expected. Gas yield as high as 0.9 m^3/kg BOD removed had been recorded. CH_4 content was more than 60%. It is estimatd that for a 30 tonnes FFB/hr mill operating at 20 hours per day, the biogas produced will be able to run a 900 kw electricity generator for 24 hours a day at an efficiency of only 30%.

B. Biogas recovery by controlled landfilling of municipal refuse

Controlled landfilling is the managed, batch anaerobic digestion of high solids lignocellulosic substrates to enchance fuel gas production[3]. Simulated controlled landfilling studies are being carried out using 0.2 m^3 (44 gallons) oil drum filled with 100 kg of compacted domestic refuse. The density of the compacted refuse was around 350 to 500 kg wet weight per m^3. The refuse was covered with a 75 mm layer of clay simulating landfilling operation. Four experimental units were set-up between February and May, 1984, two without sludge seeding and one unit was seeded with 1% Ulu Pandan digested sewage sludge, and another seeded with 3% digested sludge. No buffer was added for pH correction. As moisture content of the refuse used was greater than 50%, water was not added during set up of the units. All study units were run and monitored

in an identical manner and a clay liner at mid-depth was placed to control the downward movement of liquids and gases. At the bottom of each drum, a graded gravel layer was placed as base for the compacted refuse and for leachate collection. The oil drum units were sealed and gas collection was carried out by pipes and tubings from the units to displace an acidified tap water saturated with table salt at the gas holders. Systems for gas and leachate collection and monitoring, temperature monitoring and rain water application were installed in all units. Whenever leachates were withdrawn for analysis an equivalent amount of rain water collected was added to replenish the moisture loss. For comparative study, volumes of rain water equivalent to approximately 10% of the rainfall were added to unit G3 at each rainfall occurrence (Fig. 9). Performance parameters monitored include volume and composition of the gas, temperature, and composition of leachate. Data on biogas production and composition would provide information to assess performance of the methane fermentation process. The composition of the leachate would provide needed information to assess the development of the aqueous phase which has direct influence on the process. Figures 7-10 show the performance data over a six-month periods.

Temperature remained relatively constant at 28-32°C throughout the studied period. The addition of rain water to G3 did not affect the performance of the unit when compared to G1 which has no water supplement. Gas production was recorded in all units almost immediately after the start-up. In the first two months, most of the gas produced was CO_2 indicating aerobic decomposition of the wastes. CH_4 content increased with time and after 6 months all units studied showed a CH_4 content of over 50%. Gas generation rate remained relatively constant at 0.001 to 0.0025 m^3/kg-dry vs/day. Seeding with sewage sludge did not show a significant improvement of performance over that of units without

seeding. Seeding, however, did indicate earlier start-up of the units studied. At steady state conditions, there was no significant difference in gas composition and gas production rate in all 4 units. Composition of leachate (Table 2) remained relatively uniform at the studied period. pH was in the range of 5.6 to 6 and alkalinity at a level ranging from 7600 to 16000 mg/l as $CaCO_3$. Acidic acid concentration levels were in general greater than 6000 mg/l. Concentration levels of other volatile acids were also high. Metals contents were relatively high compared to allowable discharge standards to the open drains in Singapore. However, they didn't seem to have adverse effect on the fermentation process. Preliminary results show good biogas recovery from the simulation studies. Long term evaluation of performance is necessary to obtain design data for actual field implementation.

C. Biogas recovery from piggery wastes and water hyacinth

Anaerobic fermentation studies using piggery wastes and water hyacinth as substrates were also carried out. In Singapore, small pig farms are being phased out and large commercial pig farms with more than 10,000 standing pig population were encouraged. Piggery wastes from these farms will have to be treated to less than 50 mg/l BOD_5 and 50 mg/l SS to meet effluent discharge standards. In the past, most pig farmers kept water hyacinth ponds for the dual purposes of fish cultivation and hyacinth production as feed meal. This practice had allowed the water hyacinth to get into water courses and reservoirs. Each year the Public Utilities Board spends more than half a million Singapore dollars for clearing the water hyacinth from its reservoirs. Piggery wastes and water hyacinth are two large sources of biomass in Singapore. Anaerobic fermentation units of 16-litre capacity were set up to study the fermentation process using piggery wastes and water hyacinth as substrates. The

characteristics of the piggery wastes and water hyacinth feeds are given in Table 3. Test runs were carried out over a year period. Anaerobic fermentation systems using these substrates showed process stability throughout the studied period. BOD and volatile solids reduction were high (Table 4). Methane yields were 0.293 m^3/kg-vs feed for piggery wastes and around 0.237 m^3/kg-vs feed at twenty-day solid retention times. Studies are still being carried out to evaluate the performance of thermophilic and the two-phase anaerobic fermentation systems for organic substrates degradation and biogas production at different organic loading rates and solids retention times. Anaerobic filters are also being tested for nitrogen removal and biogas recovery using piggery wastes as feed. Table 4 shows selected results of these studies.

TABLE 3 Characteristics of Piggery Wastes and Water Hyacinth

	Piggery wastes	Water hyacinth feed
Moisture Content, %	-	97 - 98
Total solids, %	-	2 - 3
Total volatile Solids, %	-	1.5 - 1.8
BOD_5, mg/l	11,000 - 15,000	-
COD, mg/l	28,000 - 45,000	-
TVSS, mg/l	18,000 - 48,000	-
Total Nitrogen, mg/l	680 - 1,450	125 - 280
Total Phosphorous, mg/l	150 - 450	250 - 400
Chloride, mg/l	80 - 480	15 - 85
Ca^{2+}, mg/l	60 - 220	12 - 80
Cu^{2+}, mg/l	0 - 28	-
Fe^{2+}, mg/l	6 - 80	5 - 48
pH	6.8 - 7.7	5.6 - 7.6

TABLE 4 Steady state performance of piggery wastes and water hyacinth feed digesters

	Piggery Wastes	Water Hyacinth	
Temp., ^{o}C	30	30	30
θ_c, days	20	10	20
BOD_5, mg/l	4200	–	–
Volatile Acids, mg HAc/l	620	440	320
Alkalinity, mg $CaCo_3$/l	2700	1200	1500
Volatile Solids reduction, %	55.8	56	66
pH	7.1	6.6	6.9
Gas Production, ℓ/g-vs degraded	0.89	0.67	0.64
CH_4, %	59	56	56
CH_4 yields, l/g-vs feed	0.293	0.210	0.237

V CONCLUSION

The wastes generation rate in Singapore is increasing rapidly. As wastes treatment and disposal costs are high, measures are taken to conserve resources and recovery of useful materials and conversion products from wastes. Biogas recovery from anaerobic fermentation of high strength organic wastes is being carried out or under evaluation. Since 1959, biogas has been recovered from sewage sludge using the mesophilic anaerobic digestion systems. There are six sewage treatment plants in Singapore processing around 500,000 m^3/day sewage. The biogas recovered from approximately 4000 tonnes of sewage sludge fermented each day is able to meet up to 40% of the electricity requirement of the treatment plants. Controlled landfilling studies using municipal refuse showed that methane rich biogas could be recovered at a rate of 0.001 to 0.0025 m^3/kg-refuse/day after more than 160 day operation. Anaerobic fermentation

studies also showed promise of bioenergy recovery using piggery wastes and water hyacinth as substrates. Methane yields were around 0.293 m^3/kg-vs feed for piggery wastes and 0.237 m^3/kg-vs feed for water hyacinth. Long term studies are needed to obtain design data for field application.

VI ACKNOWLEDGE

The author appreciates the cooperation of staff members at the Ministry of the Environment. He appreciates greatly the assistance and discussion provided by his collegues Mr K.K. Wong of the Environmental Science Department, Universiti Pertanian, Malaysia and Dr W J Ng of the Civil Engineering Department, National University of Singapore.

VII REFERENCES

1. **TJENG T.D. and OLIE J.J.**, Why solvent extraction of palm oil is not to be recommended. Oleagineax, 30, p 523-528, 1975.
2. **McCARTHY, P.L.**, Anaerobic waste treatment fundamentals : I chemistry and microbiology. Public Works, Sept., pp. 107-112, 1964.
3. **ANGENSTEIN, D.C., WISE, D.L., WENTWORTH, R.L., and COONEY, C.L.**, Fuel gas recovery from controlled landfilling of municipal wastes. Resource Recovery and Conservation, 2 : pp. 103-117, 1976.

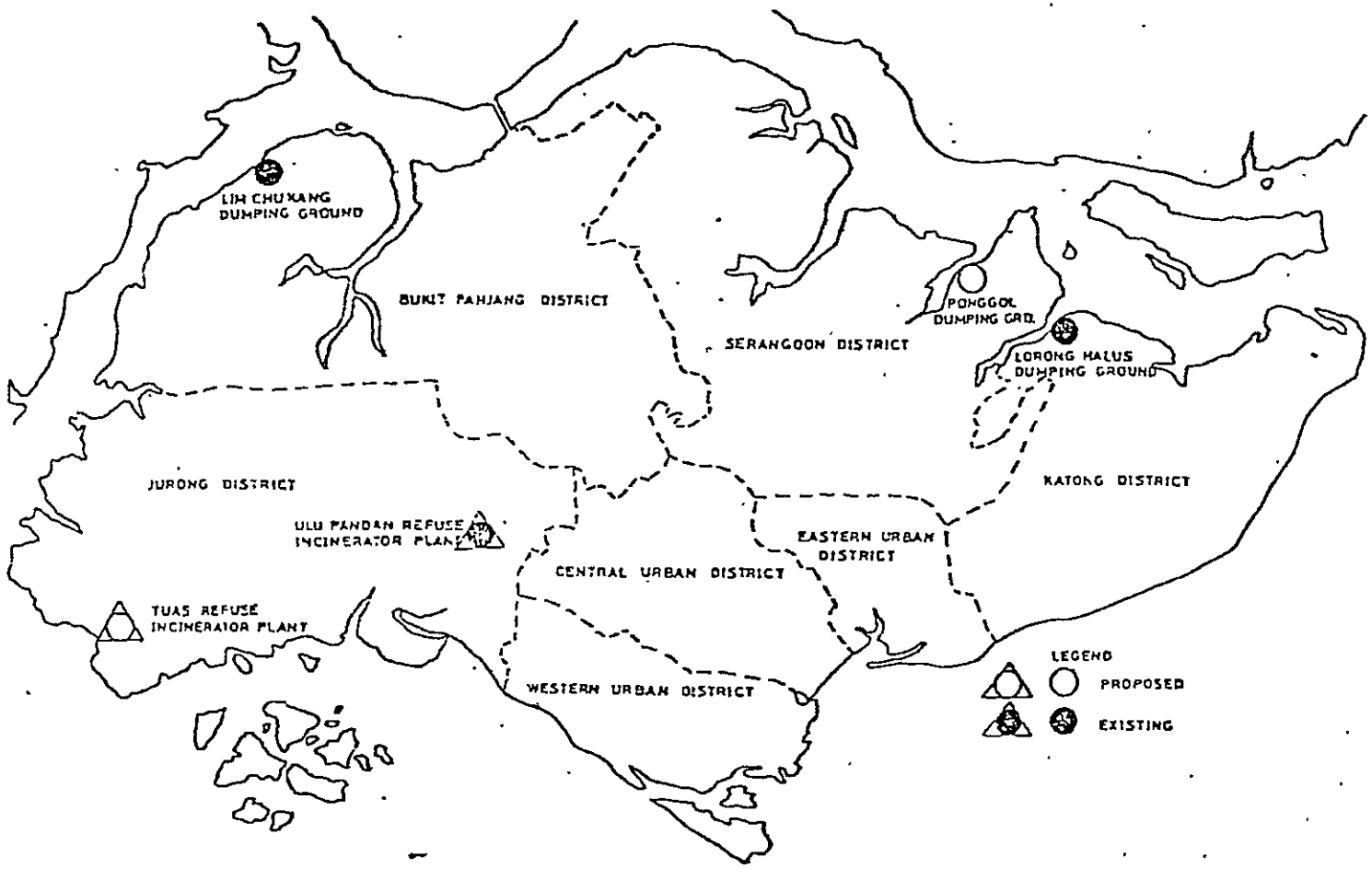


Fig. 1 Location of Health Districts and Disposal Facilities

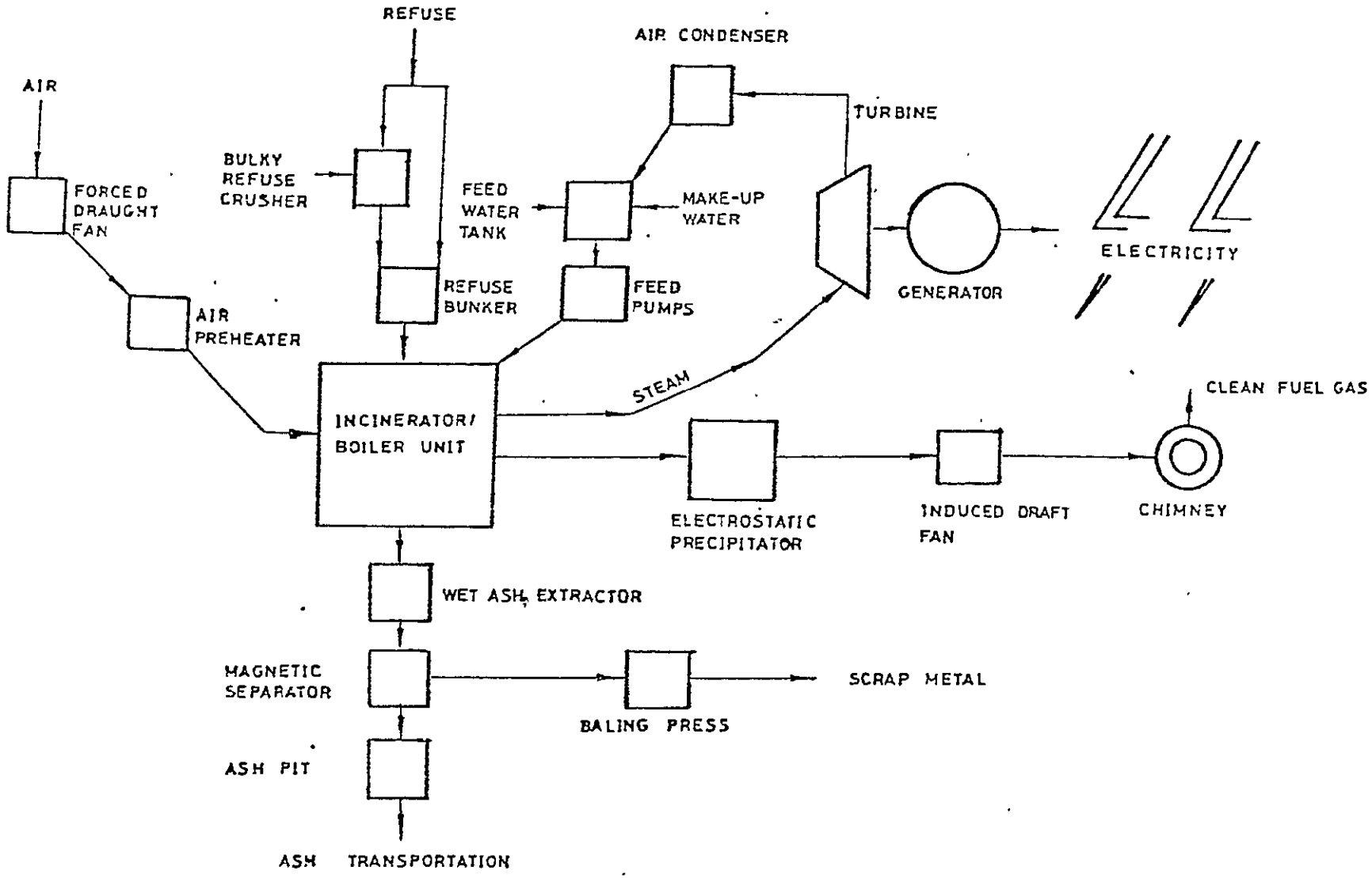


Fig. 2. Process Chart of Refuse Incineration Plant

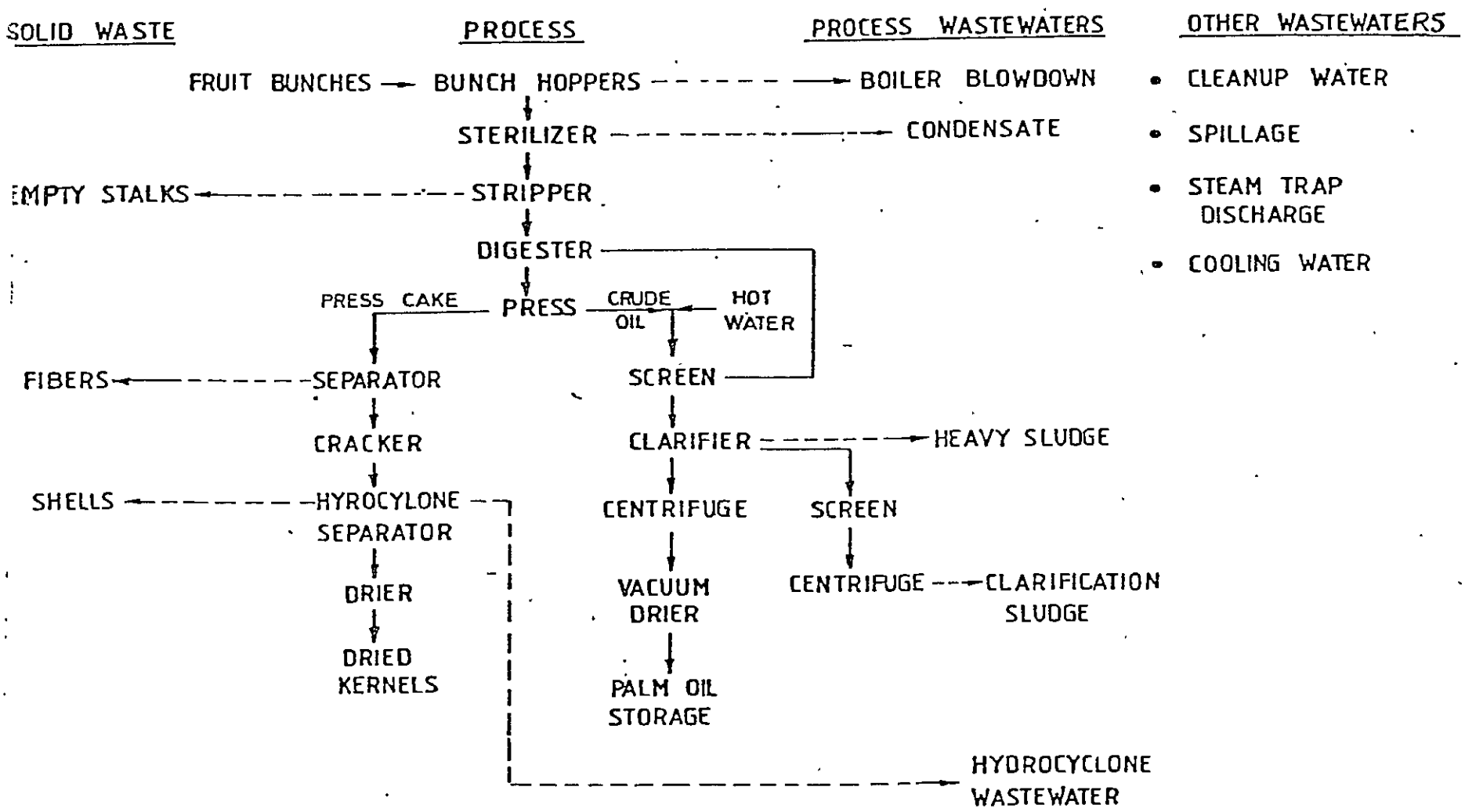


FIG. 3 PALM OIL MILLING PROCESS

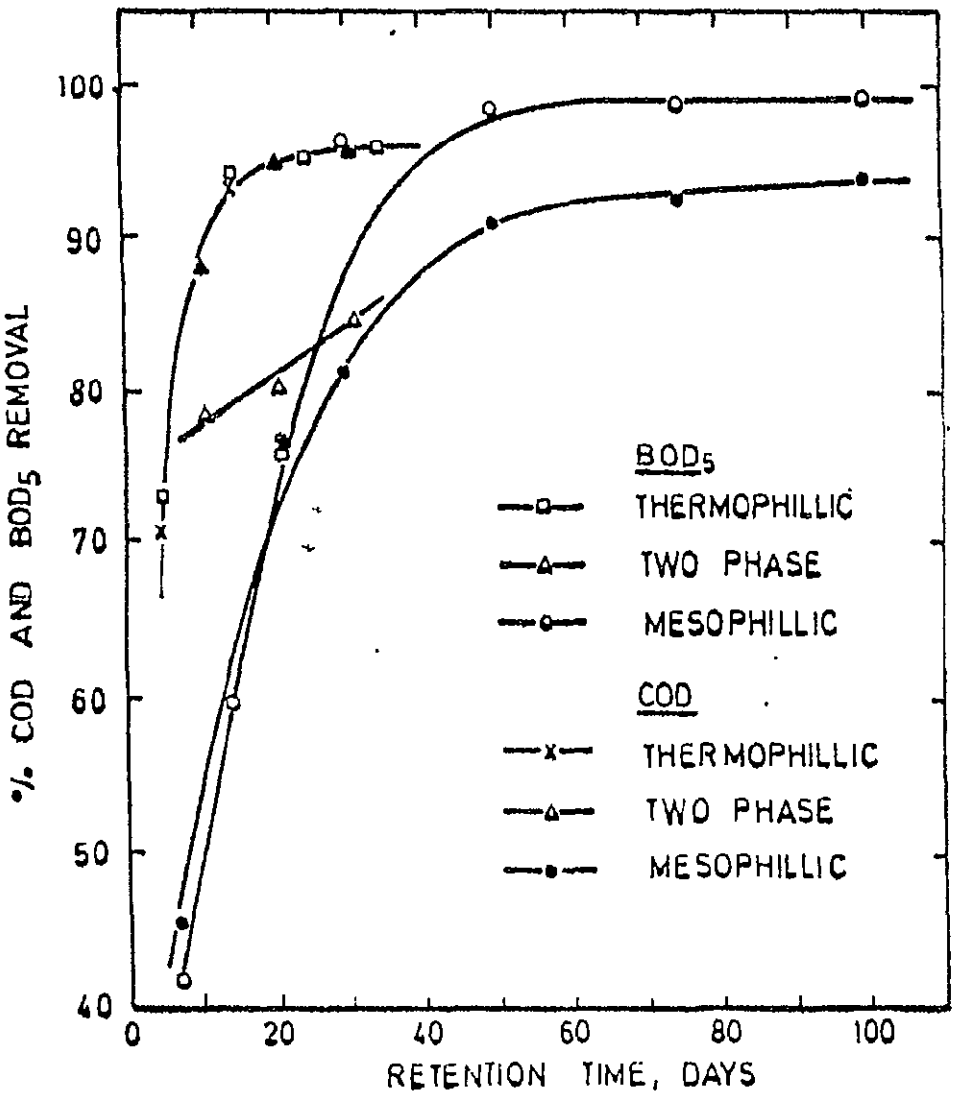


FIG. 4. TREATMENT EFFICIENCIES IN RELATION TO RETENTION TIME.

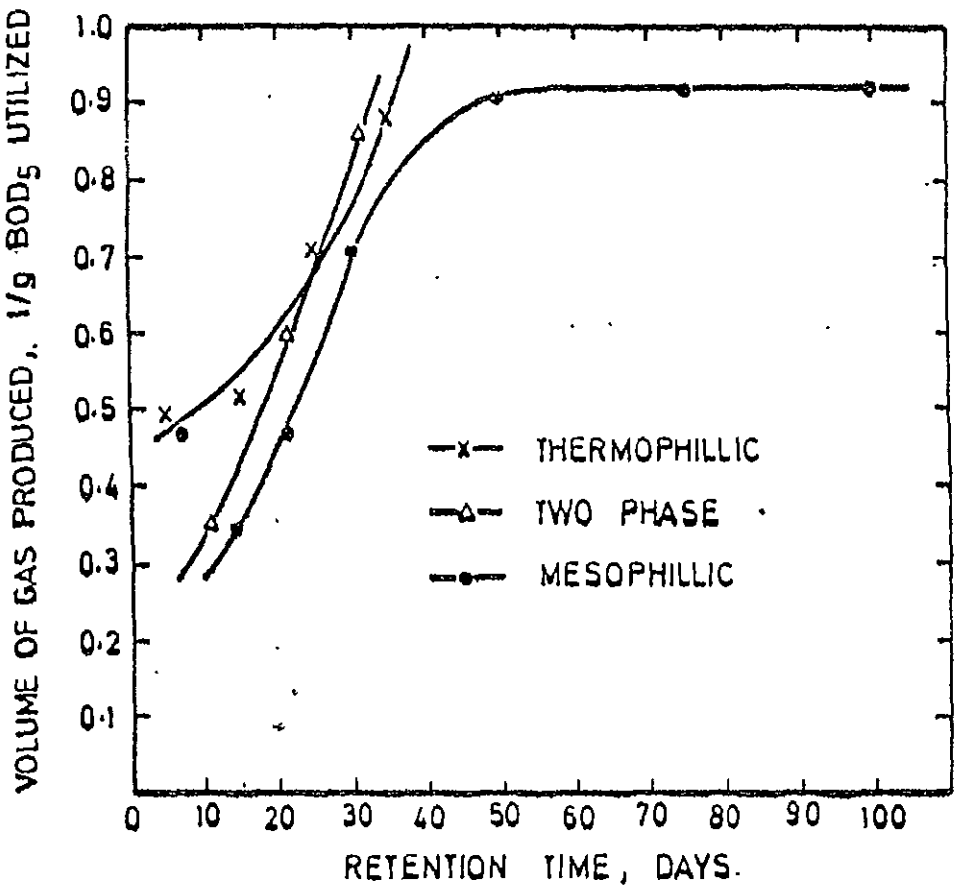


FIG. 5 VOLUME OF GAS PRODUCED IN RELATION TO RETENTION TIME.

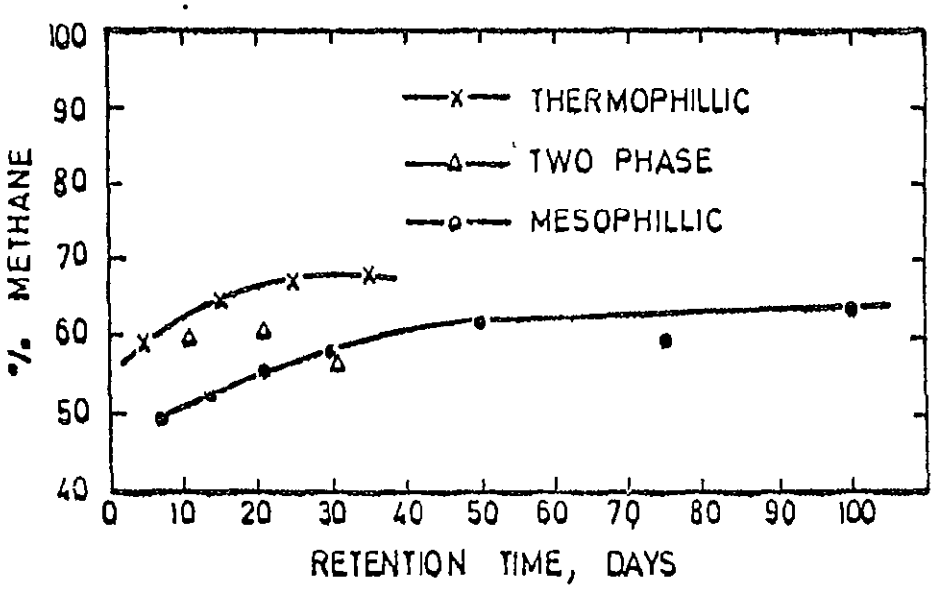


FIG. 6 METHANE CONTENT IN RELATION TO RETENTION TIME.

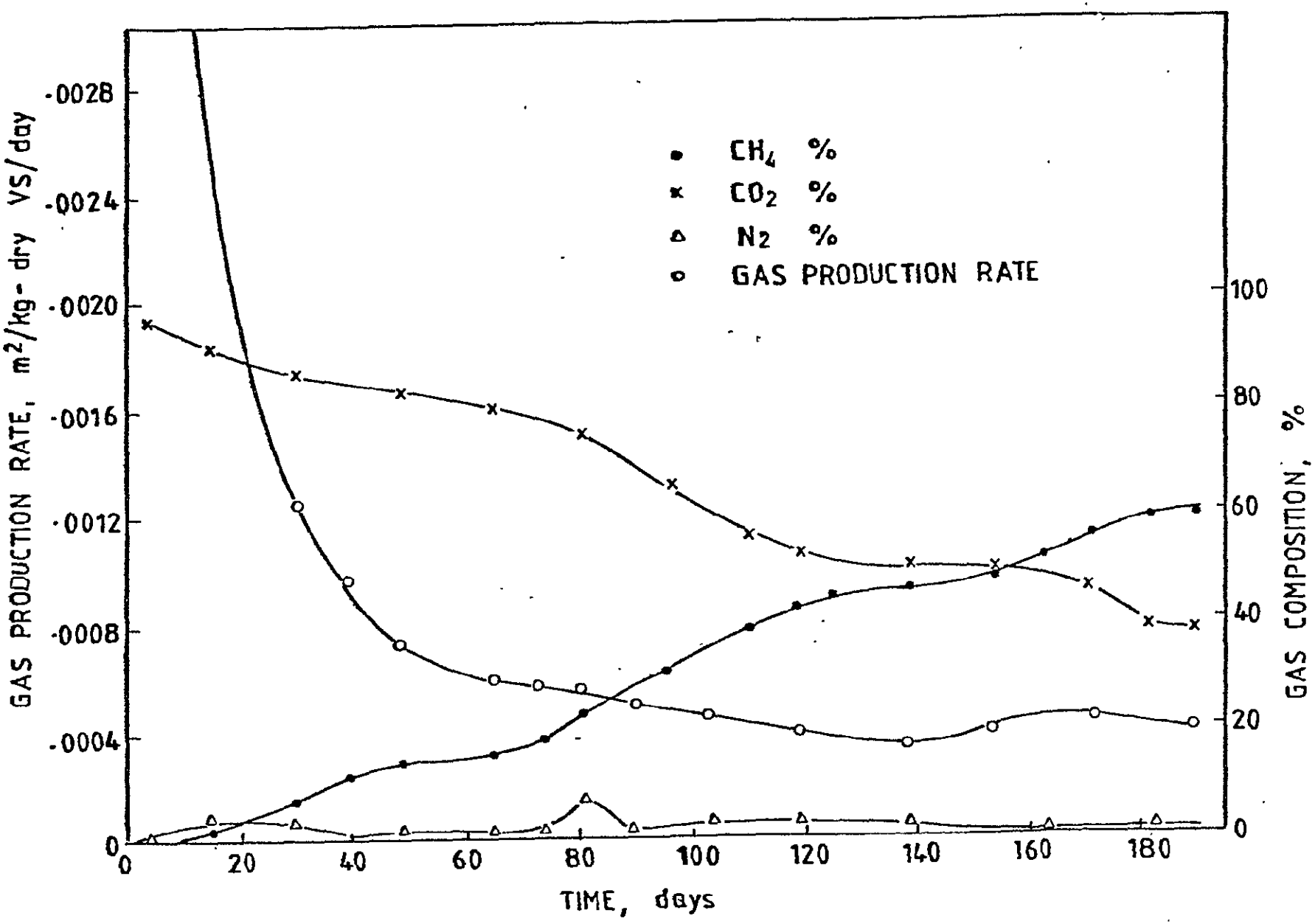


FIG. 7. GAS PRODUCTION RATE AND COMPOSITION (G1) NO SLUDGE SEED

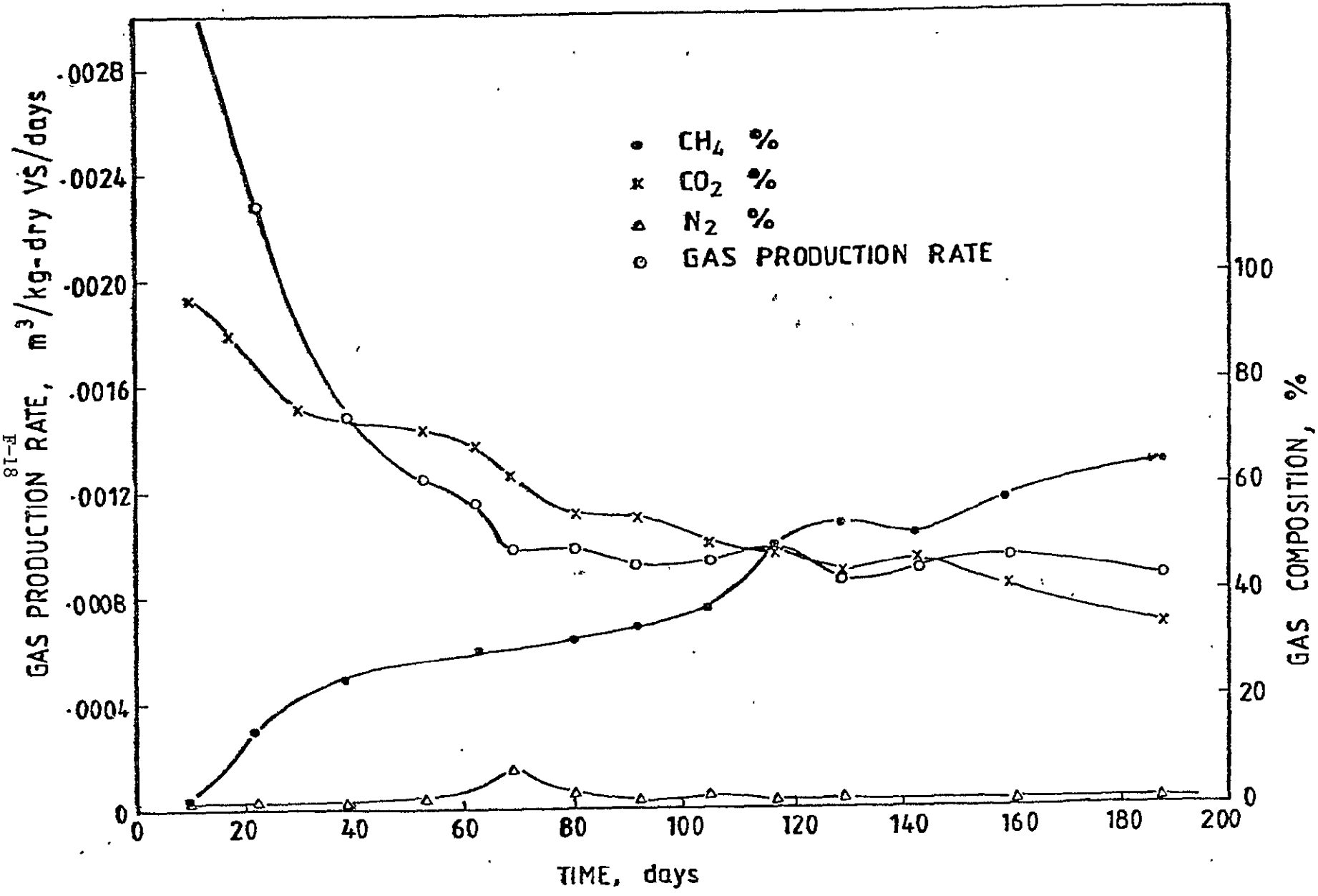


FIG. 8. GAS PRODUCTION RATE AND COMPOSITION (G2) 1% SLUDGE SEED

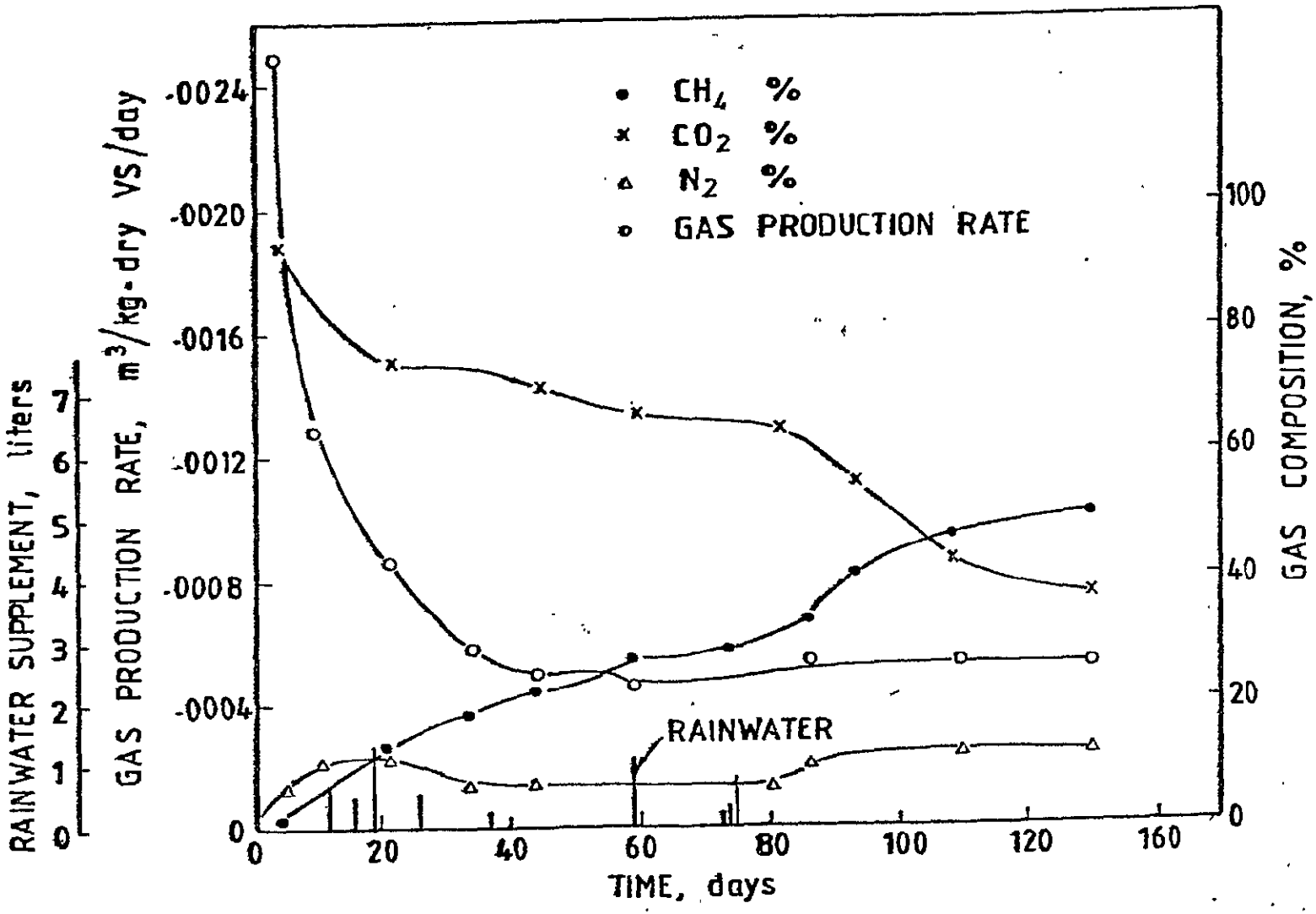


FIG. 9 GAS PRODUCTION RATE AND COMPOSITION (G3) NO SLUDGE SEED

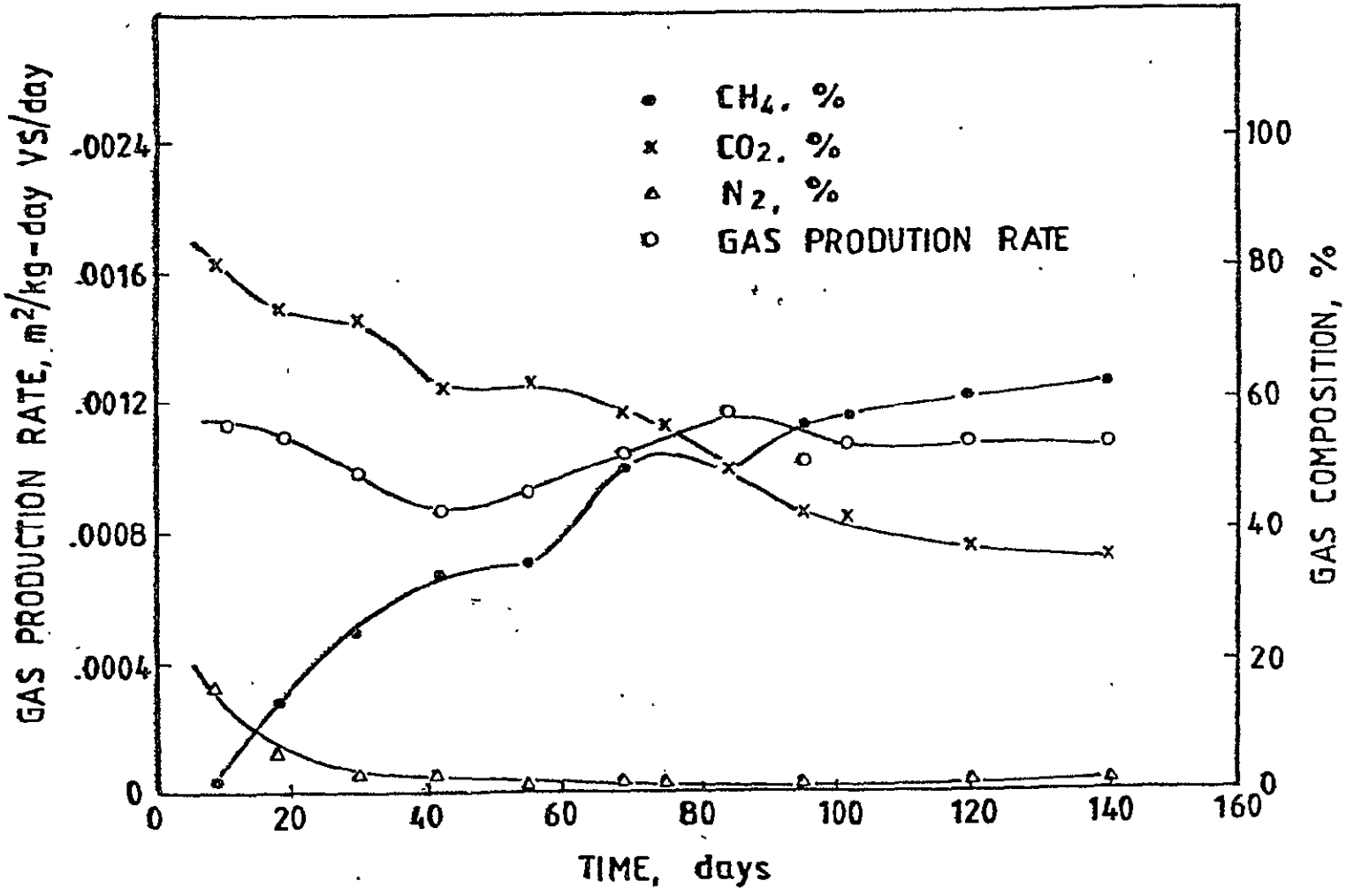


FIG. 10. GAS PRODUCTION RATE AND COMPOSITION (G4), 3% SLUDGE SEED

TABLE I

CHARACTERISTICS OF SOLID WASTES

Item	HDB Estates %		Shopping Centre %		Wet Market %		Institutional Building %	
	by Weight	Moisture	by Wt	Moist	by Wt	Moist	by Wt	Moist
Fruit, vegetable, food wastes	28.1	20.5	33.5	25.6	28.7	22.6	34.5	29.2
Textiles, leather, rubber	4.2	2.6	3.1	1.3	–	–	0.2	0.1
Paper	21.6	14.3	13.0	6.3	14.8	10.8	25.7	10.8
Cardboard, wood, straw, mats	11.1	4.9	25.3	9.1	40.2	22.2	17.3	4.2
Plastic material	15.8	6.6	13.4	1.6	5.3	2.7	11.9	4.2
Ferrous metals	7.0	–	3.1	–	7.2	–	3.4	–
Non-ferrous metals	0.1	–	0.2	–	–	–	–	–
Glass ware	4.8	–	1.9	–	–	–	3.6	–
Ceramic ware, stones, shells	1.2	–	–	–	–	–	–	–
Residues	6.1	3.9	6.5	4.6	3.6	2.4	3.4	2.4
Total	100	52.6	100	48.3	100	60.3	100	50.5

Table 2 Leachate from Simulation Studies (mg/ ℓ except pH unit)

	no sludge seed G1		1% dry sludge seed G2		no sludge seed G3		3% sludge seed G4	
Acetic Acid	8700	- 11100	5950	- 7665	7380	- 11010	3070	- 9485
Propionic Acid	4010	4505	2650	2940	2970	3750	1575	3565
Butyric Acid	7960	8680	5950	6175	7335	8315	3865	7110
n-valeric Acid	2890	3750	2400	2520	3140	4055	2070	3640
pH	5.7	6.0	5.82	5.95	5.75	5.96	5.6	5.9
Alkalinity	13724	16264	10534	13488	13552	16472	7640	12960
COD	74624	116604	52237	77736	59699	100952	34109	80859
BOD	37574	53775	25863	37069	28376	47435	13691	36113
Otho-Phosphates	2.5	42	2	5	4.8	7.7	10.5	53
TSS	166	477	125	310	363	663	150	1520
TVS	125	310	232	412	320	427	130	990
Total Kjeldahl-N	3531	5129	2099	3360	2959	4794	1523	3046
Total Ammonia-N	3150	3250	1800	2200	2550	2800	582	1180
Iron	137	352	176	660	244	406	180	200
Cobalt	0.025	0.51	0.170	0.580	0.040	0.270	0.250	0.420
Lead	0.510	1.100	0.333	0.850	0.445	1.510	0.390	0.770
Copper	0.268	1.050	0.055	0.162	0	0.320	0.780	1.850
Cadmium	0.054	0.064	0.051	0.092	0.033	0.060	0.043	0.068
Nickel	1.590	3.500	0.776	1.496	0.836	1.610	1.430	1.000
Chromium	0.170	0.360	1.200	1.340	0.295	0.590	0.160	0.490
Calcium	225	1555	275	3035	283	1825	202	1852
Magnesium	22	286	169	302	60	418	50	294

"BIOGAS FROM SANITARY LANDFILL TECHNIQUE IN EGYPT"

Report Presented By:

Dr. M. Nabil Alaa El-Din
Head of Research, Microbiology
National Director, Biogas Project
Agricultural Research Center
Giza,
EGYPT

BIOGAS FROM SANITARY LANDFILL TECHNIQUE IN EGYPT

BY

M.N. Alaa El-Din [x] ; E.A. Saleh [xx] ; Y.Z. Ishac [xxx] ;
S.A. El-Shimi [x] and M. El-Housseini [x] .

ABSTRACT

Cairo is a 8 million inhabitants big city and generates about 4300 tons of garbage/ day. Dumping and burning of garbage cause threatened air pollution and the losses of badly needed organic manure. Sewage sludge accumulating from treatment plants is dried using ineffcient and hazardous methods to organic manure.

The present study aimed at evaluating the sanitary landfill concept as a source for biogas and compost and as a tool for improving health and environment.

Different laboratory experiments were conducted to ferment city garbage in combination with water or with sewage sludge at different levels (10,25 and 35% total solids). Fermentation took place in 1.25 and 3.5 L. Fermenters. Some of fermenters were kept at ambient temperature , while others were incubated at 35 and 55 °C. The experiments lasted for 4 - 6 months. Gas volume, methane content, pH , soluble-N. and contents of total and volatile solids were estimated regularly. Counts of anaerobic acid formers and cellulose decomposers as well as the survival of coliform and salmonella groups of pathogenic bacteria were also estimated. The data were discussed in view of possible solutions for garbage and sewage problems of large cities in Egypt.

G-1

INTRODUCTION

The cairo area generates about 4300 Ton/day (tpd) municipal solid waste (MSW), about 1500 tpd are collected and recycled by private garbage collectors for feeding pigs and preparing organic manure at very severe conditions. The remainig 2800 tpd are collected by governmental system to be burned in several dumping places

---

x Head of Research and Researchers , soils and Water Res. Institute Agricultural Research Center. Giza, Egypt.

xx Assoc. Professor and Professor of Agric. Microb., Fac. Agric. Ain Shams University. Cairo, Egypt.

1) Paper presented at "International Workshop on Bioenergy Recovery and Conservation," held on October 31-Nov. 2, 1984 at Boston, Massachusetts, USA.

and thus losing energy, fertilizers and soil conditioners as well. Air pollution is also one of the threates. Alaa El-Din et al . (1980) estimated that sanitary landfills combined with production of high Btu gas and Soil conditioners could be a good solution for the increasing MSW accumulated in Cairo and other cities of Egypt.

Their figures were, however, of theoretical nature. Biogas and soil conditioner from sanitary landfill of MSW were found to be the cheapest option as compared with composting and burning of it.

At present it is estimated that 80% of the urban Cairo is sewered, 65% of the population is connected. There is no sufficient capacity to handle the waste water now collected. It is also assumed that 472 ton of volatile solids/day could be made available for energy production through anaerobic digestion. Expected energy produced was calculated by Alaa El-Din et al. (1980) to be about 1.4×10^{12} jules/day. The cost of plants is however high.

The combined fermentation of MSW and sewage sludge for production of biogas and soil conditioners became an attractive option as Alaa El-Din et al. (1982) found improved biogas production from mixtures of garbage and sewage sludge in different Chinese and Indian biogas digesters.

The present study aimed at evaluating the biogas productivity, the production of soil conditioners, the

behaviour of different types of bacteria with special reference to pathogenic ones and the changes occurring during the fermentation of MSW in sanitary landfill system.

MATERIALS

A) Garbage : Municipal solid waste was collected from three big vegetable markets of Cairo, dried and ground. The chemical composition of the ground garbage was as follows: Moisture content, 10.020% ; Volatile solids, 78.270% ; Organic carbon , 45.397%; Total nitrogen content, 0.945% and C/N ratio, 49.61.

B) Sewage sludge: Sewage sludge was collected from the bigest sewage treatment plant of great Cairo at zenin (Giza Governorate). Its chemical analysis was as follows: Total solids, 2.269%; volatile solids, 68.089%; Organic carbon, 39.492% ; Total nitrogen, 1.981% and C/N ratio , 19.935.

EXPERIMENTAL PROCEDURE:

Three sets of experiments were prepared to evaluate the behaviour of different concentration of garbage , sewage sludge and water when fermented at room temperature (10 - 30 °C) , at 35°C (mesophilic) and at 55°C (thermophilic). Garbage was mixed with either water or sewage sludge to satisfy 3 concentrations of total solids, namely, 10, 25 and 35%. Fine pulverized $CaCO_3$ was mixed thoroughly with the garbage to satisfy 10% of the total solids

in each fermenter. The mixtures fermented at room temperature were poured in 1.25 liter capacity fermenters, while those incubated at 35°C were put in 3.5 liter fermenters and kept in a walk—in incubator (10 m^3 Capacity) and the thermophilic incubated fermenters were kept in 3 similar incubators adjusted at 55 °C. The amount of the fermenting material differed according to fermenter size, giving the same size proportion of fermenting material to fermenter. Six replicalte fermenters were prepared for each treatment, totaling 108 fermenters running at the same time.

After 0, 1, 2, 4, 14 weeks of incubation, the content of one of the fermenters was thoroughly mixed and representative samples were analyzed for the follwing:

a) pH, in 1 : 2 water extract using glass electrode pH-meter.

b) Ammoniacal - N , in the extract made by 1 normal solution of KCL by distillation with MgO according to Piper (1950).

c) Contents of total and volatile solids according to the standard methods (American Puplic Health Association, 1976).

d) Counts and Survival of the following groups of microorganisms in the fermenting material.

   1) MPN of acid formers on nutrient broth enriched with 5g glucose/ litre and bromothymol blue solution as indicator and Durhams tubes, Cunningham (1954).

2) MPN of cellulose decomposers on Omeliansky's medium (1902) , Allen (1959).

3) Counts of E-coli by plate counting on MacConkey's medium (Difco manual, 1977).

4) Counts of Salmonella and Shigella by plate counting on SS. agar medium (Difco manual, 1977).

Gas yield was measured every day up to 23 weeks of fermentation. Gas Samples were analyzed for their methane and carbon dioxide contents every week using the following methods:

1) Methane content: Methane content was estimated weekly using the following technique as described by Walter and Williams (1980). Gas samples were withdrawn into a 50 ml syring and 0.5 ml gas samples were injected into GOW MAC gas chromatogragh model 750P , fitted with a 120 cm long and 0.2 cm diameter stainless steel coulmn filled with 5% OV -101 on CHROM-PAW 80 - 100 mesh and with dual flame ionization detector. Carrier gas was nitrogen at a flow rate of 28 ml/min. Hydrogen was generated by attached hydrogen generator and provided at the rate of 30 ml/min. Air at the rate of 300 ml/min was applied for the flame. The operation temperatures were 75°C for column oven, 100°C for injection port and 150°C for detector. Standard curves were prepared using pure methane gas (Messer Griessheim GMBH, Frankfurt, FAG)

and were used as a reference for calculating methane concentration in the biogas produced.

2) <u>Carbon dioxide:</u> Co_2 Content was measured weekly by Orsat's apparatus using caustic potash solutein for CO_2 absorption (American Puplic Health Association, 1976).

The data are presented in 10 figures and 2 tables,

RESULTS AND DISCUSSION

The average daily production of biogas from garbage presented as m^3 biogas / ton total solids / day (m^3/ ton / day) and the average daily yield of methane (m^3/ton/day) are illustrated in fig. (1). The data showed that at room temperature no considerable gas production was recorded for any of the garbage concentrations but for 10% garbage combined with sewage sludge, The production started after 14 weeks of incubation and reached its maximum after 21 weeks, being about $6m^3$/ton/day. The maximum methane production rate was also reached after the same period of incubation being about $3m^3$/ton/day. The gas generation and the yield of methane as well decreased there after rapidly. The incubation of garbage mixtures at 35 ^{o}C led to early production of biogas and methane, except in the case of high concentration of garbage miostened with sewage studge. Garbage at 35 % TS. moistened with water showed delayed gas production as it started its activity after 23 weeks of incubation. The gas produced during the first two weeks was very poor in methane conent. Starting from the 5 th week , however, the methane yield increased as a result of increasing both gas yield and methane content. The generation of biogas decreased by all treatments after reaching the values rapidly . The thermophilic biogas generation seemed to favour the low concentration of garbage (10 % TS.) receiving sewage sludge for moistening. The highest values for biogas produced (about 23 m^3 / ton/ day) and for methane generated (about 15 m^3 / ton / day)

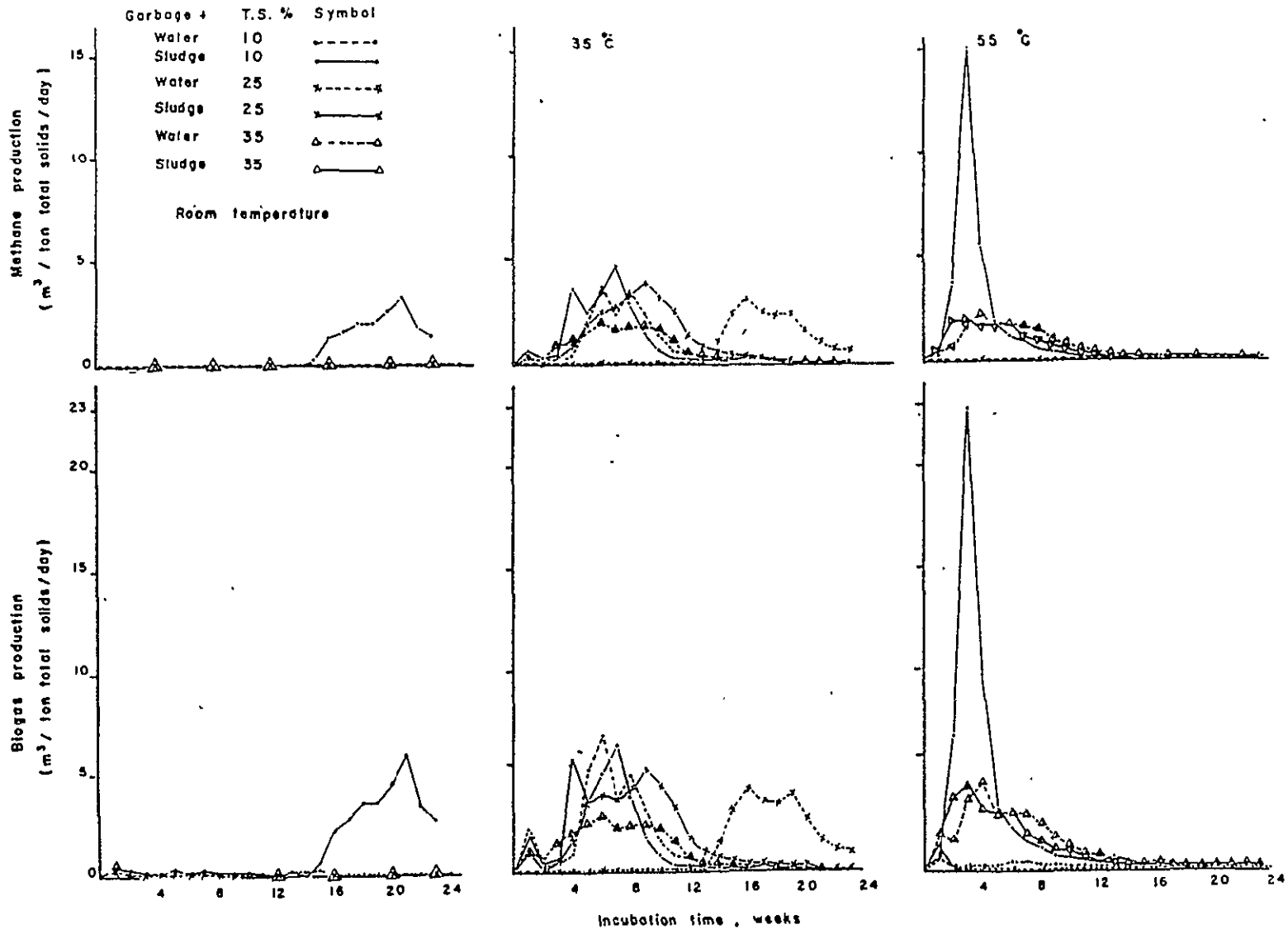


Fig (1) Daily production rate of bio-gas and methane (m^3 / ton total solids) from sanitary landfill system containing different amounts of garbage fermented in combination with water or sewage sludge at different temperatures .

were recorded after 3 weeks of incubation. The gas and methane production, however, decreased very rapidly there after. Higher concenteration of garbage either did not show any biogas generation (25 % TS.) or produced much less biogas and methane. The peak of production, however, was recorded during the same period of fermentation as for the lower concenteration.

The accumulated gas production of fermented garbage showed more clear and differentiated figures (Fig 2). The total biogas production was after 23 weeks almost the same for garbage mixed with sewage sludge (10 % T S.) when incubated at room temperature or at 35 C^{o}, being 220 m^3/ton solids / 23 weeks. The difference was, however, in the time needed to start active biogas generation. This was about 3 weeks and 15 weeks when incubating at 35 C^{o} and room temperature respectively. The total methane yield was, however, higher for the same garbage concentration when fermented at 35 C^{o} (about 150 m^3/ton/23 weeks) than incubating at room temperature (110 m^3/ton/23 weeks). Similar findings were reached by Naser (1980) using cow dung . She stated that the temperature affected the biogas production and the detention time but not the final volume of biogas produced or the amounts of volatile solids destroyed. Under thermophilic condition (55 C^{o}) Velsen et al.(1979 a) found that methane production decreased by about 25% as compared to the mesophilic digestion when using big manure . In the present study the opposite was recorded for the low concentration of garbage (10 % TS.). The difference could

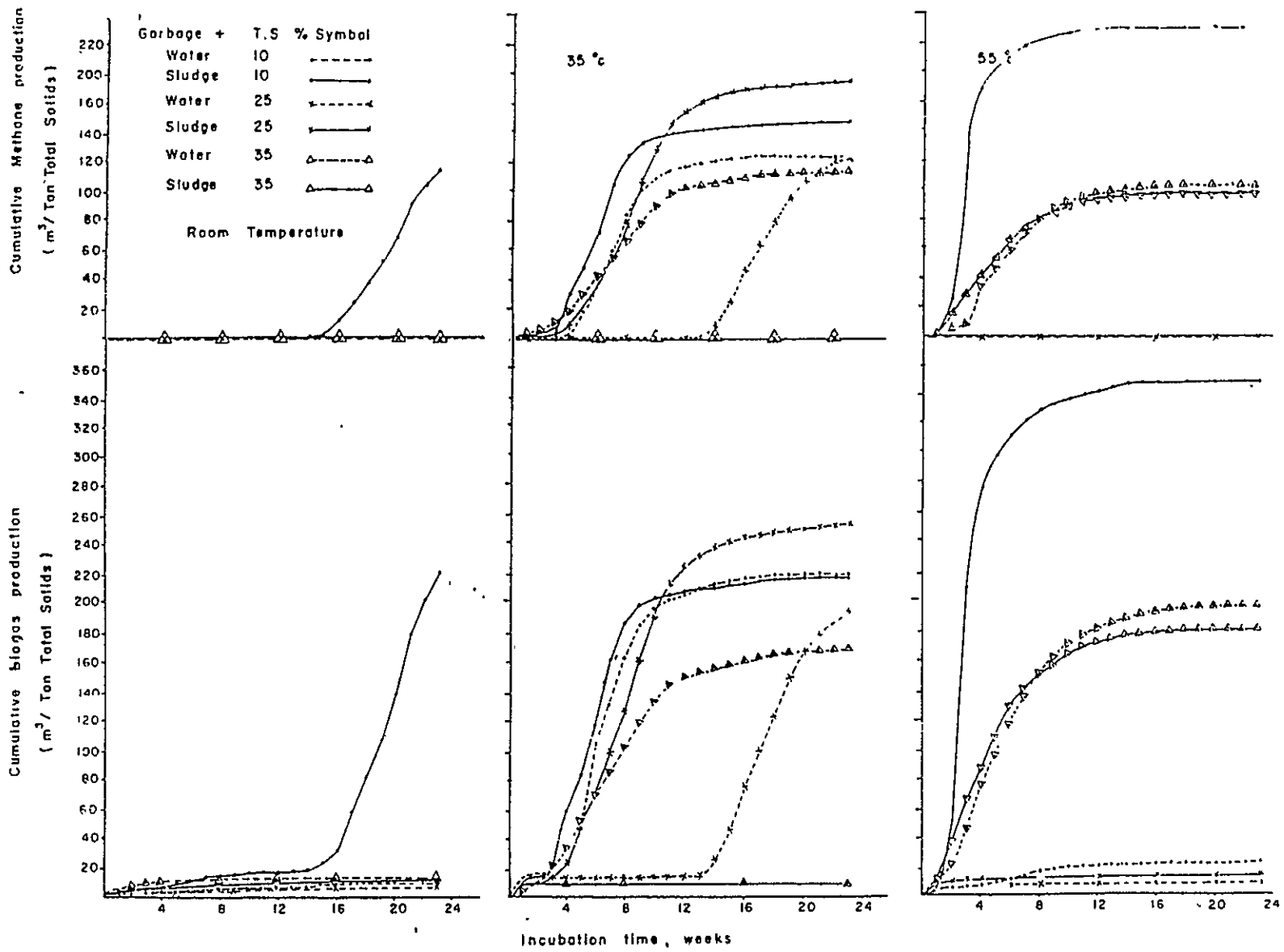


Fig (2) Cumulative biogas and methane production (m^3 / ton total Solids) from fermentation of different loading Rates of garbage combined with water or sewage sludge in sanitary landfill system at different temperatures

be attributed to the substrate used in those experiments. Wise et al.(1981)reported that an increase of biogas production by 10 % from the sanitary landfill when the temperature increased from mesophilic to reach thermophilic temperature (60 °C) .

Application of sewage sludge to garbage gave higher yields of biogas. The differences were much bigger when considering the methane concentration. This was true for all temperatures and specially for low solid concentrations. High garbge concentration (35 %) did not show this difference when incubated at 35°C .

The changes in methane contents in biogas produced during the fermentation of garbage mixed with water or sewage sludge and incubated at different temperatures are illustrated in fig. (3). The data showed in general that fermentation of garbage at room temperature generated low concentration of methane in the biogas. The lowest values were recorded for garbage moistened with water. This indicates the stimulation effect of sewage sludge which acted as good starter for methane fermentation . The best starter effect of sewage sludge on methane concentration was recorded for the lowest loads of solids (10 %) and about 61 % methane was estimated after 16 weeks, while the higher loads of solids gave only 28 and 20 % methane for the concentration 25 and 35 % respectively. Hobson and Show (1973), Welsen (1979 a), Wise et al. (1981) and Alaa El-Din (1982) reported also of the stimulative effect of digested sludge as a good starter and Wise attributed this to its

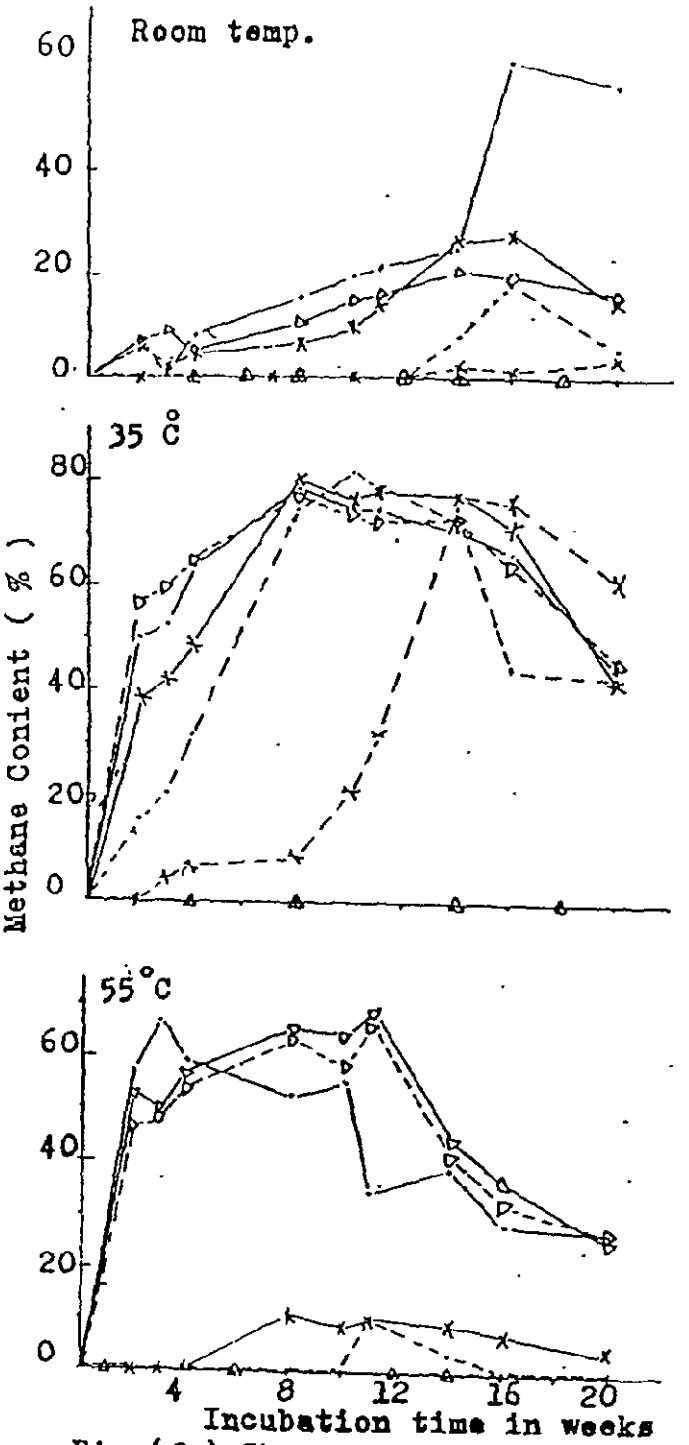


Fig (3) Changes in methane content of biogas produced from garbage in combination with water or sewage sludge incubated at different temperatures in sanitary landfill system.

GARBAGE +	Total solids%	
Water	10	•- - - - - •.
Sewage sludge	10	•———•.
Water	25	x- - - - -x
Sewage sludge	25	x———x
Water	35	Δ- - - - -Δ
Sewage sludge	35	Δ———Δ

role in supplying the system with high numbers of acid formers and methanogenic bacteria, nitrogen, phosphours and buffering agents.

Increasing the incubation temperature to reach the mesophilic optimal range (35 °C) did help to increase the methane concentration in the biogas produced. This was also reached after shorter periods. Sewage sludge proved also to increase the methane concentration at faster rates.

The thermophilic methane formation was very low in water treated garbage at low or medium loading rates (10,25 and 35% T.S.). Sewage sludge application improved the situation specially at low and high concentrations of garbage (10 and 35 %). Water treated garbage showed surprisingly high methane content in the biogas produced as compared with other water treatments.

The pH values presented in table (1) showed in general a sharp increase in the hydrogen ion concentration during the first week of incubation specially in the fermenters treated with water while those receiving sewage sludge showed modrate increase in hydrogen ion concentration or modrate decrease in pH values. This occured although $CaCo_3$ was added at the rate of 10% of the total solids. There was, however, no clear relation between pH values and either the biogas generation rate or the concentration of methane. Many of the fermenters showed a pH range favourable to biogas generation and methane formation although no or little biogas production could be recorded.

Table (1) Changes in pH during the fermentation of different loading rates of garbage combined with water or with sewage sludge in a sanitary landfill system incubated at different temperatures.

Sampling time, Weeks	Total solids %					
	10		25		35	
	Source of moisture					
	Water	Sludge	Water	Sludge	Water	Sludge
Initial,	7.15-7.30	6.4-6.45	8.0-8.35	7.3-7.95	8.25-8.8	7.1-7.6
	A) Incubation at room temperature					
1	6.10	6.00	6.45	6.10	6.85	6.95
2	5.80	5.50	6.20	5.90	6.20	6.80
4	5.90	5.70	6.20	6.30	6.90	6.90
14	5.20	5.10	5.60	5.70	6.00	6.10
	B) Incubation at 35 C° (mesophilic)					
1	5.80	5.60	7.30	6.85	7.10	7.10
2	5.40	5.40	6.80	6.90	6.90	7.30
4	5.40	5.40	7.00	6.90	8.70	6.50
14	7.90	8.15	6.45	7.75	8.55	6.70
	C) Incubation at 55 C° (thermophilic)					
1	6.20	6.40	6.30	7.10	7.30	7.35
2	7.2	8.20	7.70	7.00	7.50	7.20
4	6.1	8.80	7.00	6.90	8.00	8.20
14	5.8	8.45	6.3o	6.30	8.20	8.40

The analysis of fatty acids carried out so far (unpublished data) showed accumulation of high concentrations of propionic and butyric acids in those fermenters.

Propionic acid as the principal component of the volatile fatty acids (VFA) was made by Hobson et al (1974) resposnsible for the failure of production or for low productivity of biogas. Accumulation of propionic acid and the increase in VFA concentration was found by velsen (1977) to be as a result of increasing the load of volatile solids. Accumalation of ammonia in the digesting material beyond the concentration of 1500 ppm.was found by Fisher et al. (1977) and lapp et al. (1975) to be responsible for increased accumulation of fatty acids.

In the present experiments the concentrations of ammonia fig (4) were in some casses much higher than 1500 ppm . Application of sewage sludge to the garbage increased the ammonia concentration in the fermenting material. In general ammania concentration increased by increasing the fermentation time to reach a maximal value after 14 weeks of incubation at room temperature, while this value was reached after 4 weeks when incubating at 35 ^{o}C and 55 ^{o}C . The concentration of ammonia decreased there after . The concentration of ammonia was after 14 weeks of incubation still higher than the initial one.

Ammonia concentrations higher than 3000 ppm. were reported to be inhibitory to generation of biogas without affecting the production of VFA (Melbinger and Donnellan, 1971). The digesting material was, however , diluted pig manure.

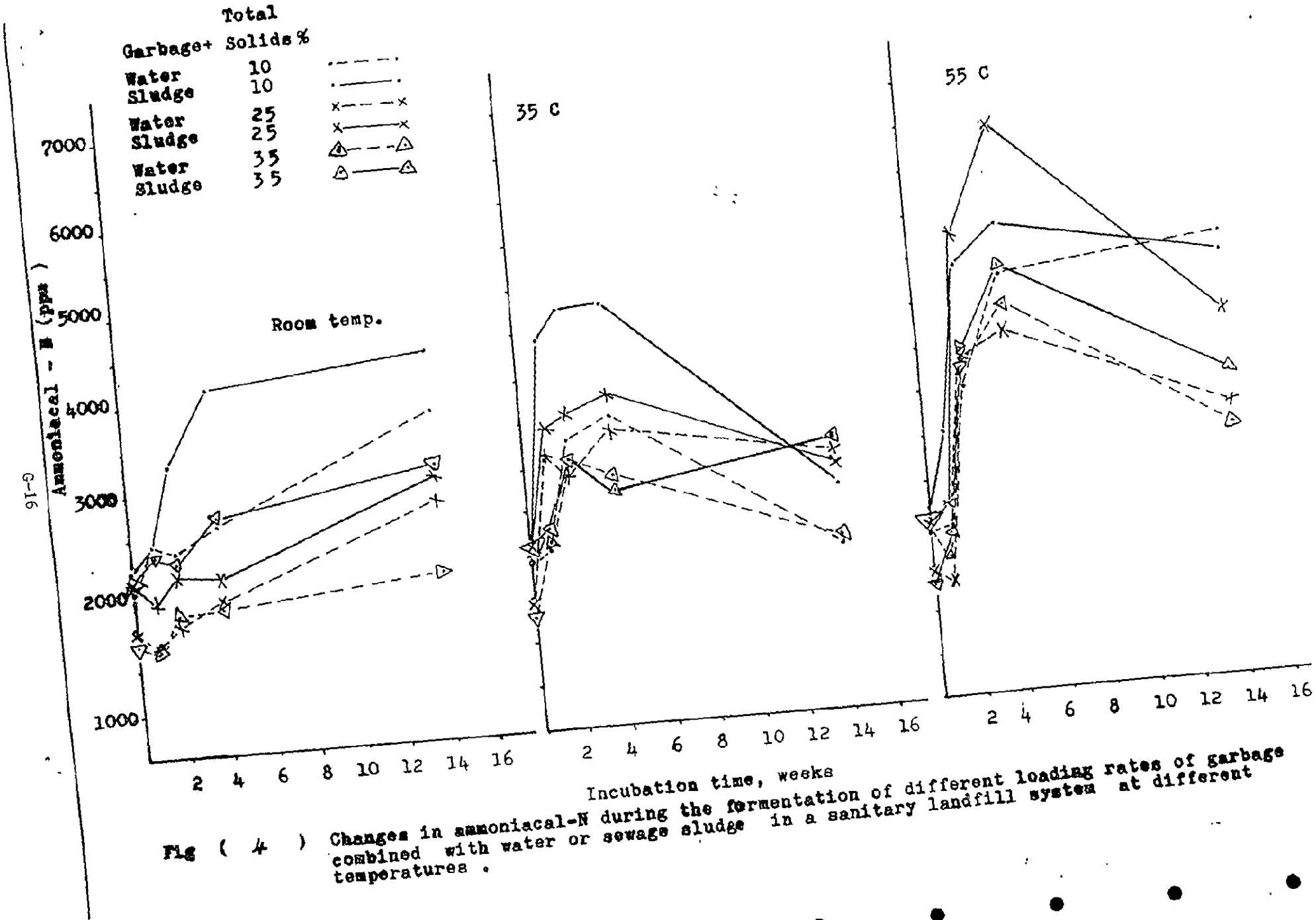


Fig (4) Changes in ammoniacal-N during the fermentation of different loading rates of garbage combined with water or sewage sludge in a sanitary landfill system at different temperatures .

In the present study higher solids concentrationsof garbage were fermented and no clear relation was found between increasing ammonia concentration to reach more than 6000 ppm. and the biogas generation. The fact that presence of suffciently high pH (above 7.5) the equilibrium between ammonia form (NH_3) and ammonium ion (NH_4^+) is shifted to side of ammonia predominance, which in turn is less inhibitory to biogas generation than ammonium ion (Wujcik and Jewell 1980), this fact could not help explaning the differences in gas production in the present study bosed ammonia - ammonium balanse

The relation between biogas generation and the disappearance of volatile solids is givien in table (2). The percent of volatile solids (VS.) destroyed showed clearly the optimal effect of the mesophilic temperature range for incubation on both gas and methane generation. The stimulative effect of sewage sludge on gas yield of fermenting garbage was also proved. the data showed also that the rate of biogas production from volatile solids added was in the sanitary landfill system close to those recorded for typical biogas digesters. The rates recorded in the present study ranged between 217 and 377 L biogas /Kg VS. added. Naser (1980) recorded a sharp decline from 349 - 102 L biogas/Kg VS. when the total solids cntent was increased from 8.2% to 18.3% and incubted at 37 °C in regular fermenters. In the present study 25% and 35% solids gave 225 - 312 L biogas /Kg VS. The duration, however, was much longer in the latter to match the sanitary

Table (2) Biogas and methane production in relation to the concentration of solids during fermentation of garbage in sanitary landfill system for 23 weeks at 3 different temperatures.

Treatments		Volatile Solids			Biogas produced	Methane produced	Biogas	Methane
% of Solids as garbage	Source of moisture	Initial	Final	% V.S. destroyed	L/fermenter	L/fermenter	L/Kg V.S. added	L/Kg V.S. added
			A) Incubation at room temperature					
10	water	38.744	38.380	0.940	0.439	0.020	11.331	0.516
10	sludge	46.310	37.169	19.739	11.045	5.805	238.501	125.351
25	water	105.664	105.000	0.628	0.803	0.001	7.600	0.012
25	sludge	110.521	109.333	1.075	1.435	0.146	12.984	1.321
35	water	144.408	142.439	1.363	2.379	0	16.474	0
35	sludge	147.333	145.662	1.134	2.018	0.174	13.697	1.181
			B) Incubation at 35 °C (mesophilic)					
10	water	154.975	118.723	23.392	43.804	25.094	282.652	161.923
10	sludge	181.784	145.605	19.902	43.716	29.622	240.483	162.95
25	water	464.924	369.902	20.427	114.759	74.023	246.834	159.215
25	sludge	482.978	358.285	25.818	150.670	103.939	311.960	215.704
35	water	563.544	462.516	17.927	122.075	82.509	216.620	146.411
35	sludge	575.631	569.988	0.980	6.819	0	11.846	0
			C) Incubation at 55 °C (thermophilic)					
10	water	38.744	37.891	2.203	1.032	0.009	26.636	0.232
10	sludge	46.310	31.865	31.192	17.454	10.613	376.895	229.173
25	water	105.664	104.812	0.807	1.031	0.019	9.959	0.180
25	sludge	110.521	109.138	1.251	1.671	0.013	15.121	0.118
35	water	144.408	114.444	20.750	36.200	19.329	250.679	133.650
35	sludge	147.333	111.931	18.599	33.111	18.196	224.736	123.503

landfill. Similar digestion rates were reported by Wise et al (1981) using sherded MSW and sewage sludge indicating 0.1 - 30% destroyment of volatile solids under different incubation conditions(37 - 60 °C). In some fermenters , however, up to 72.1% of VS. were converted to biogas.

The average daily production rates of biogas and methane refered to the volume of the digesting material were also calculated to provide some comparison with digesting systems used for biogas generation. The data are presented in fig(5) and fig(6). The data showed similar trend to the production rates based on the total solids added. The productivity of unit digesting volume of the landfill increased by time reaching their maximium after 21 weeks of incubation at room temperature (0.55 volume/ volume / day - V/V/day- for biogas and 0.3 V/V/day for methane) , or after 6 - 16 weeks of incubation at 35 °C (0.55 - 1.8 V/V/day for biogas, 0.53 - 0.85 V/V/day for methane) while thermophilic incubation gave early high rates (4 weeks incubation) ranging between 0.75 to 2.1 V/V/day for biogas and from 0.35 to 1.4 V/V/day for methane.

The cumulative figures were caculculated to provide clear idea about the rate of production / unit volum of the landfill throughout 23 weeks period of incubaction (fig 6). This type of calculation can help in calculating the expected gas yield from a known volume of sanitary landfill in a certian peroid of time.

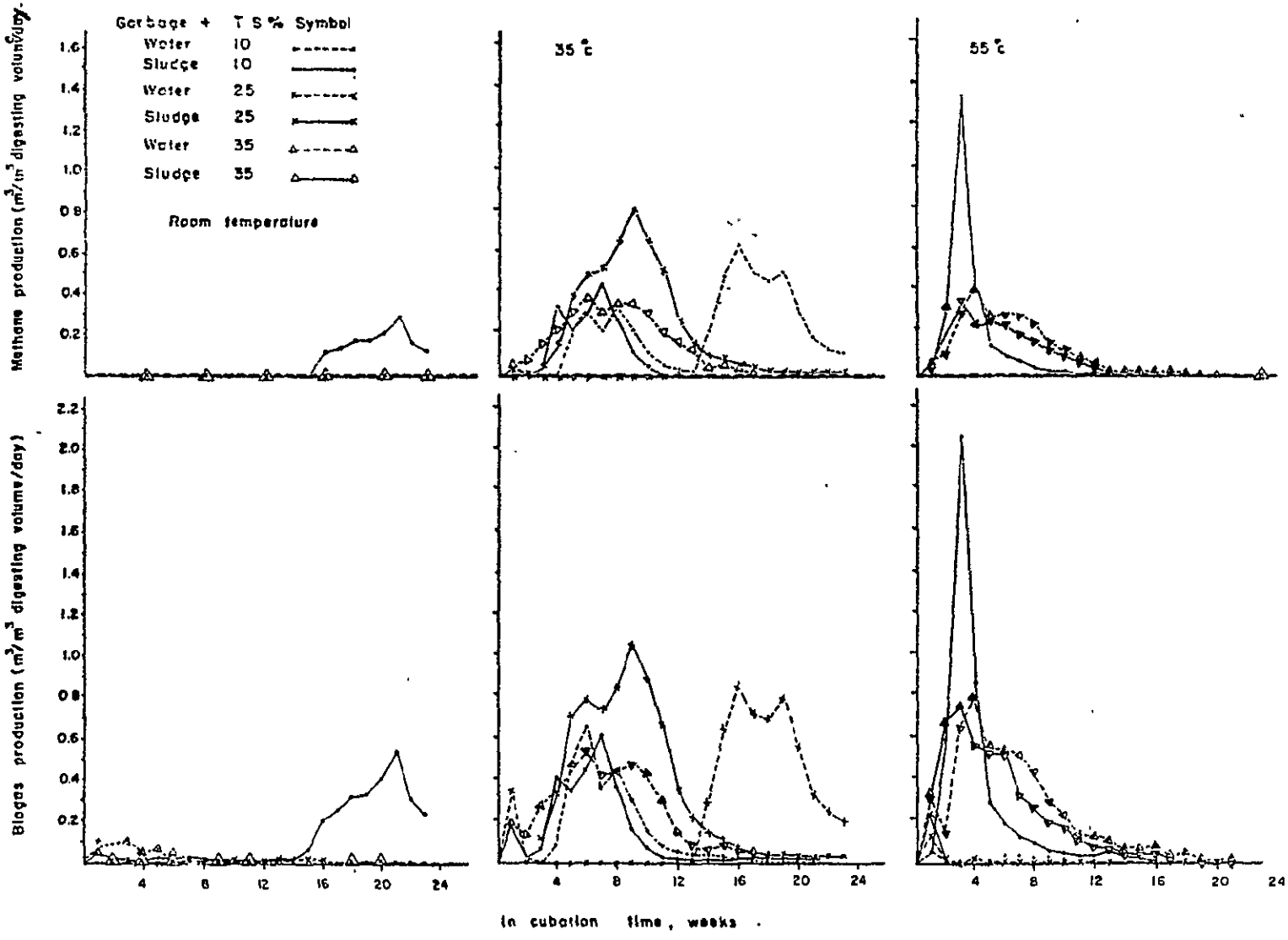
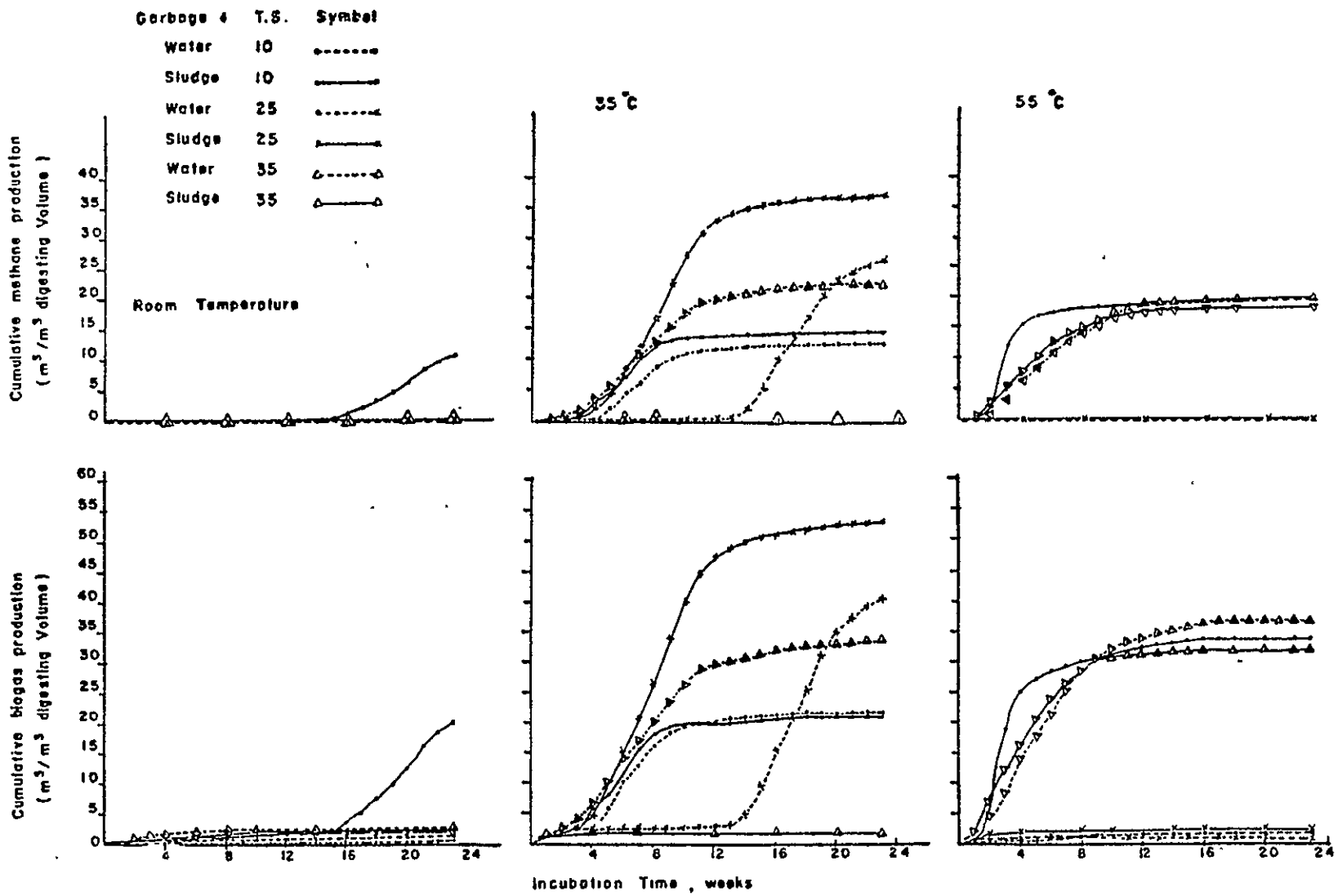


Fig (5) Daily production rate of biogas and methane (m^3/m^3 digesting volume / day) from sanitary landfill System containing different amounts of garbage fermented in combination with water or sewage sludge at different temperatures .



Fig(6) Biogas and methane production (m³ / m³ digesting Volume) from the fermentation of different loading rates of garbage combined with water or sewage sludge in sanitary landfill system at different temperatures, cumulative curves.

Wise et al , recorded also the highest gas production rate (about 0.82 V/V/day methane after 30 days of incubation at 37 °C and 25% solids). There after the production decreased sharply to reach about 0.2 V/V/day after 90 days of incubation. This was still higher than mathane production rates recorded for optimal operation of indian type biogas digesters and more than double the rates recorded for chinese type digesters (Alaa El-Din et al. 1982).

The acid producing bacteria (fig.7) increased in numbers to reach their maximum after 1 , 2 , or 4 weeks of incubation at room temperature . the numbers decrease there after rapidly to reach numbers which were still higher than at the start. Incubation at higher termperatures (35 and 55 °C) increased the numbers slightly. In general the application of sewage sludge favoured the growth of acid formers bacteria, as the sludge provided the system with both inoculum and nutrients needed. Increasing the load of solids was also accompanied with higher numbers of acid formers. In the thermophilic range high concentration of garbage showed lower numbers of acid formers, at the early stages of growth. There was, hewever, no clear relation between the numbers of acid forming bacteria and the activity for biogas generation.

The anaerobic cellulose decomposers (fig 8) showed almost the same trend as the acid formers. Their numbers , however , were much lower than the acid formers, but

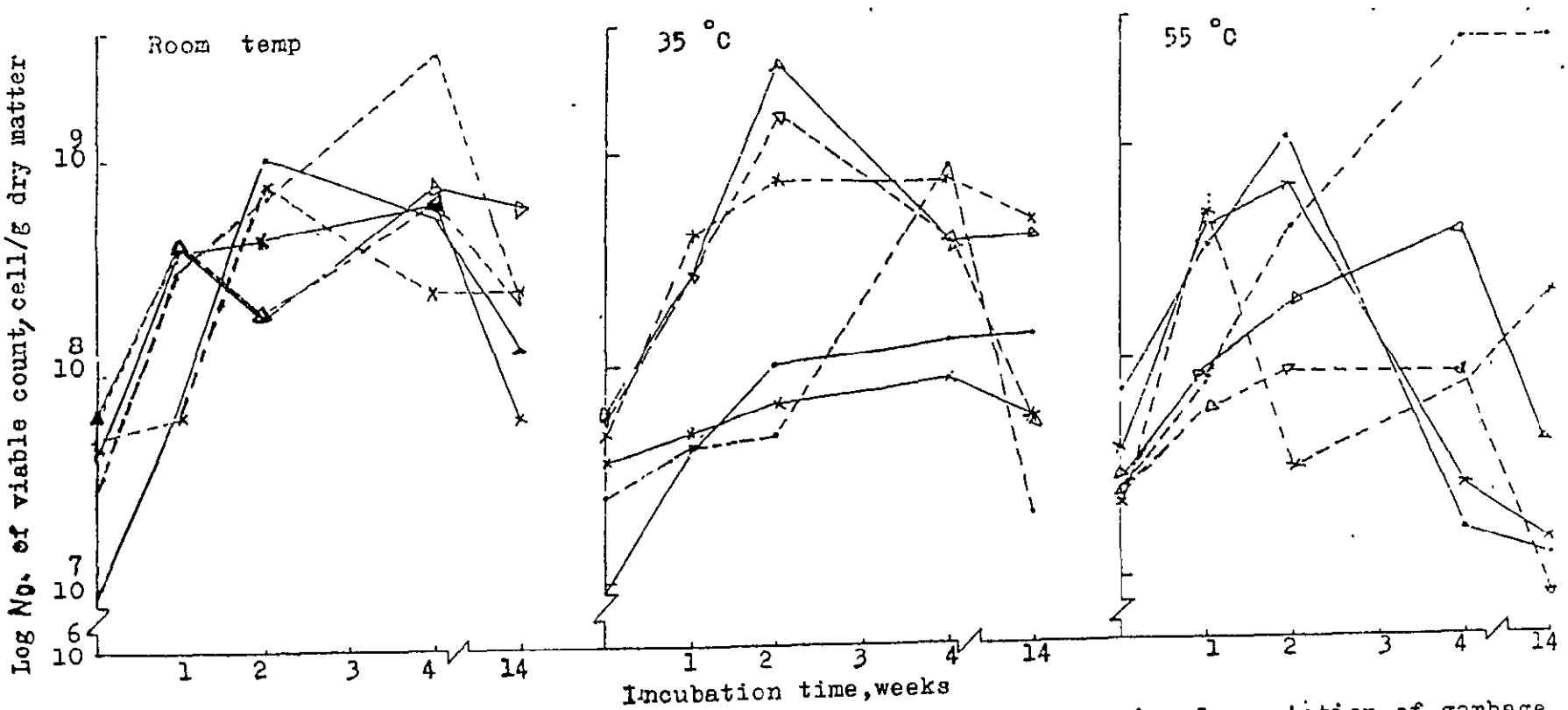


Fig (7) Changes in populations of acid producing bacteria during fermentation of garbage moistened with water or sewage sludge at different temperatures.

Garbage +	Total solids%	
Water	10	•----•
Sewage sludge	10	•——•
Water	25	x---x
Sewage sludge	25	x——x
Water	35	△---△
Sewage sludge	35	△——△

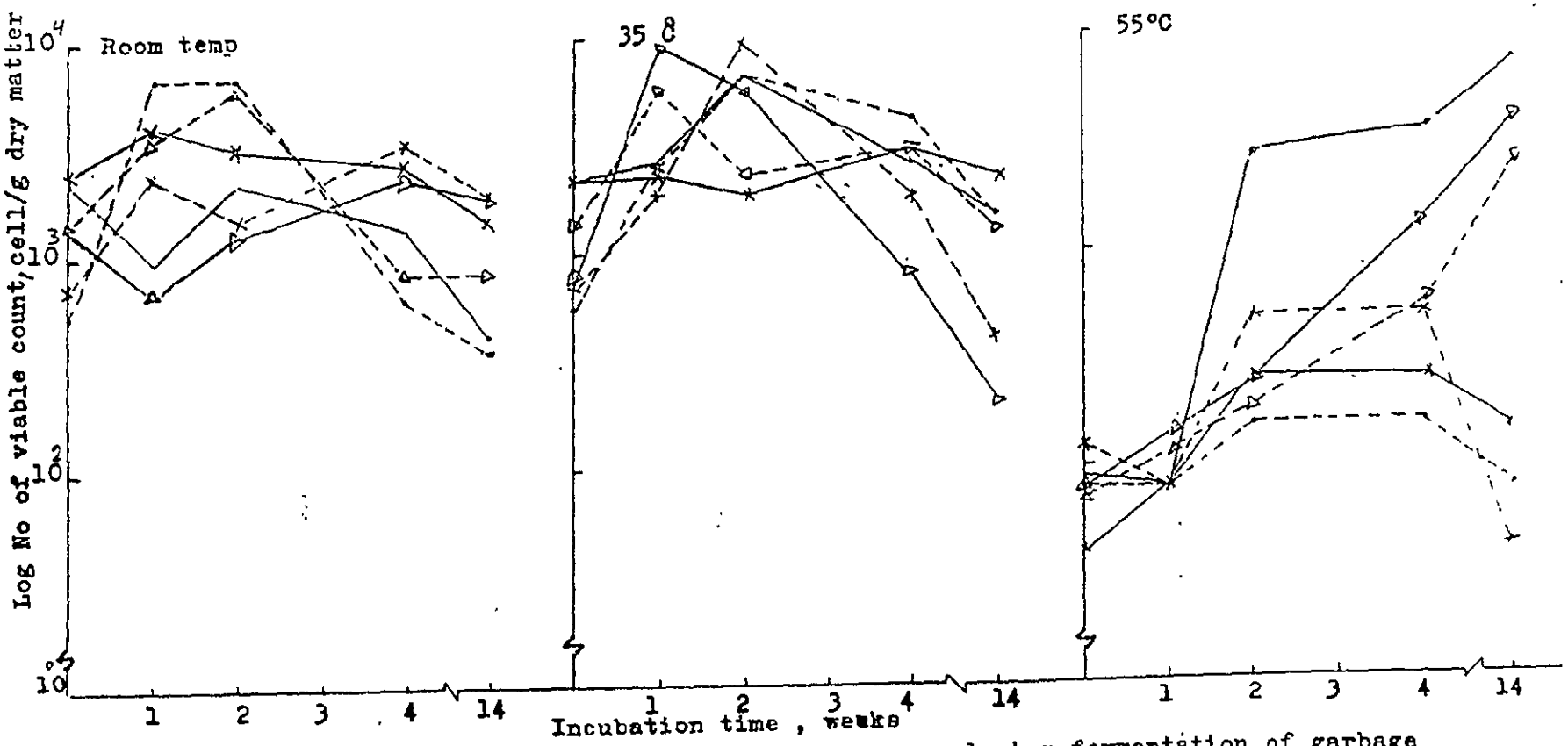


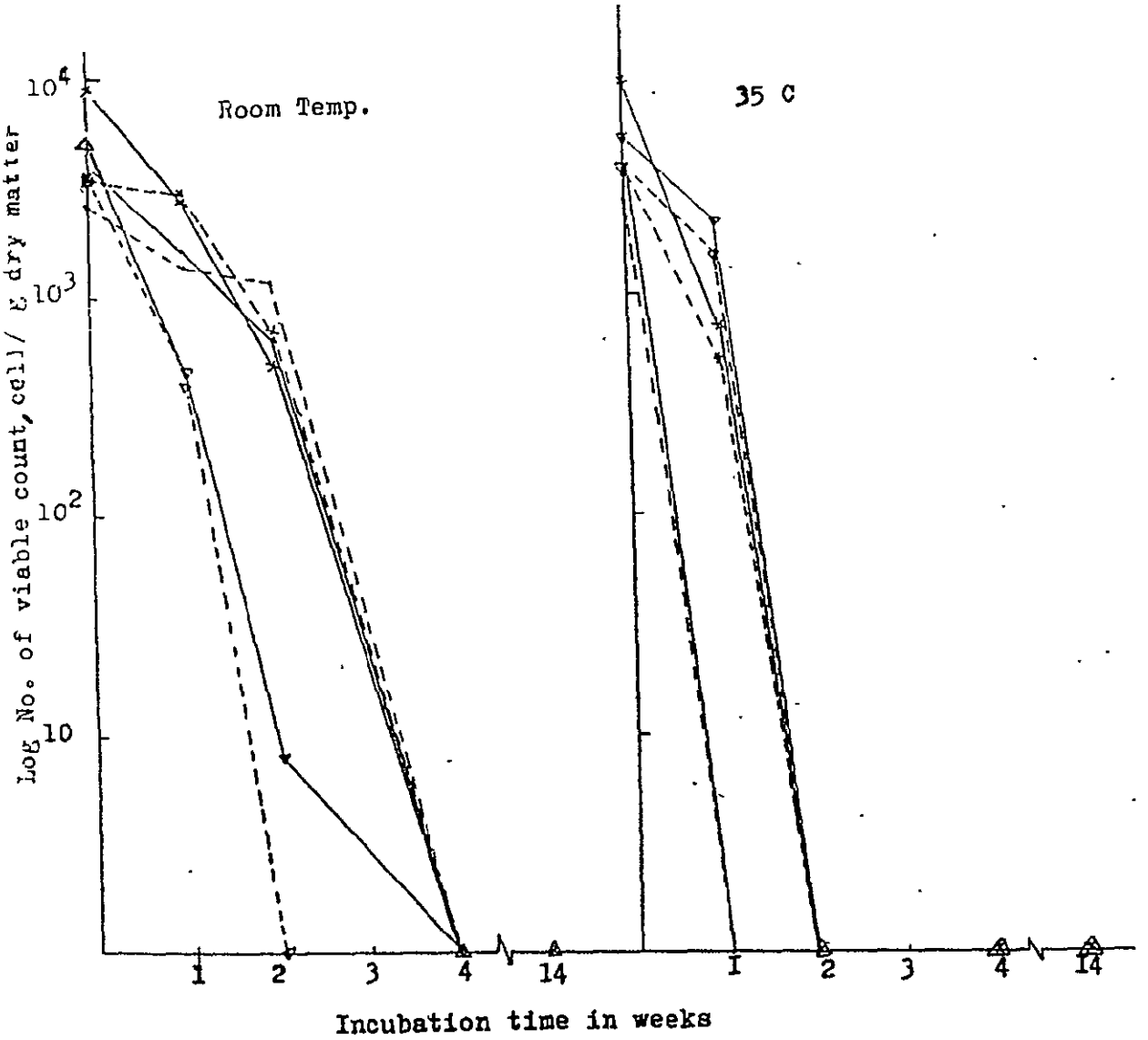
Fig (8) Changes in populations of cellulose decomposers during fermentation of garbage moistened with water or sewage sludge at different temperatures.

Garbage +	Totalsoilds %	
Water	10	•------•
Sewage sludge	10	•———•
Water	25	×- - -×
Sewage sludge	25	×———×
Water	35	△- - -△
Sewage sludge	35	△———△

they also did not show clear relation to biogas production.

The survival of phathogenic bacteria Salmonella and Shigella (fig 9) showed a rapid reduction in their numbers indicating complete disappearance within four weeks of incubation at room temperature (10 - 21 °C). This was achieve at earlier time (2 weeks) when incubated at 35 °C . The thermophilic incubated fermenters did not show any of the Salmonella or Shigella from the very begining. Garbage moistened with sewage sludge showed higher loads of Salmonella and Shigella. Increasing the solids concentration provided same protection for Salmonella and Shigella when incubated at 35 °C. They disappeared from the low solid loaded fermenter (10%) during the first week of incubation. Their numbers were higher in the heavly loaded fermenters (35 % TS.) than in those loaded with 25% TS. Similar protective effect of high solids was recorded to pathogenic bacteria by naser (1980). She reported that longer time was needed for destroying of pathogenic bacteria when the concentration of solids in the digesting mixtures were increased . Similar reslts were obtained by El-Housseini (Unpublished data) for sewage sludge.

The counts of E. Coli (fig 10) decreased rapidly by increasing the time of incubation. Their numbers were,



(Fig (9) Survival of pathogenic bacteria (Salmonella and Shigella) in garbage fermented in combination with water or sewage sludge in sanitary landfill system at differet temperatures .

Garbage +	Total solids%	
Water	10	•- - - - •
Sewage sludge	10	•———•
Water	25	x- - - - x
Sewage sludge	25	x——— x
Water	35	△- - - - △
Sewage sludge	35	△——— △

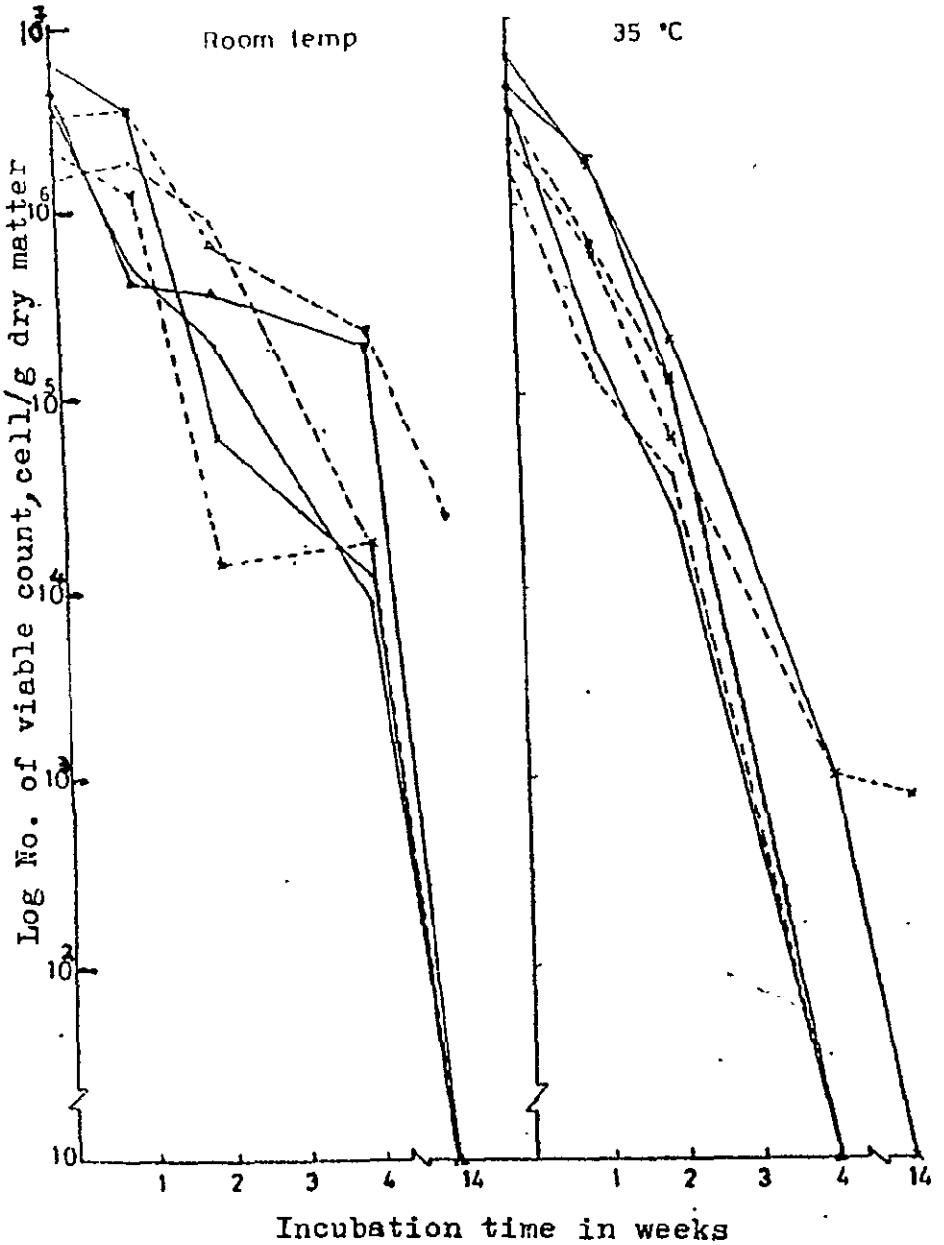


Fig (10) Survival of pathogenic bacteria (Coliform group) in garbage fermented in combination with water or sewage sludge in sanitary landfill system at different temperatures.

Garbage +	Total solids%	
Water	10	•- - - - - •
Sewage sludge	10	•———•
Water	25	x- - - - x
Sewage sludge	25	x———x
Water	35	△- - - - △
Sewage sludge	35	△———△

however , much higher than Salmonella and Shigella . Its rate of disappearance was lower than the other group , but it was higher when incubating at 35 °C than at room temperature.

REFERENCES

Alaa El-Din, M.N.; Abu-Talib and Fritz, J. (1980)
Biomass energy potential in Egypt. A realistic Appraisal. Bioenergy, 80, World Congress, Atlanta Georgia, USA , April, 21 - 24.

Alaa El-Din, M.N.; Ishac, Y.Z.; Saleh, S.A; El-Shimi, S.A. and El-Houssini, M. (1980)
Biogas from City refuses in Egypt., The first OAU / STRC Inter - African Conference on Bio-fertilizers Cairo (Egypt) 22 - 26 March, 1982 (1982)

American Public Health Association, 14 th ed., Washington, D.C. (1976). Standard methods for the examination of water and waste - water.

Allen , O.N (1959)
Experiments in soil microbiology. Burgess Publishing Co.

Cunningham A. (1954)
Practical Bacteriology, 2 nd ed.
Oliver and Boyd. Edinburgy and London.

Difco manual and Dehydrated culture media and reagents. 8 ed (1977)
Difco laboratories, Detroit. Michigan.

Fisher, J.R; Lanotti, E.L.; Proter, J.H. and Garcia, A. (1977)
Producing methane gas from swine manure in a pilot- Size digester. ASAE Paper No. MC 77 - 604 (March)

Hobson, P.N. and Show, B.G. 1973
The anaerobic digestion of waste from an intensive pig unit. Water Res. 7:437 - 449.

Hobson, P.N., Bousfield, S. and Summers, R. (1974)
Anaerobic digestion of organic matter. CRC. Crit. Rev. environm. Control (june - 131 - 191.

Lapp, H.M.; Sparling, A.B.; Schult, D.D. and Buchaman, L.C. (1975)
Methane Production from animal wastes. 1. Fundamental Considerations. Can - agric. Engng 1.7 : 97 - 101.

Melbinger, N.R. and Donnellon. J. (1971)
Toxic effects of ammonia nitrogen in high-rate digestion. J. Water Poll. Control Fedn. 43 (8) 1658 - 1668.

Naser, A. Fayza (1980)
Production of methane from Biomas pH.P theses. Fac. of engeneering Cairo university.

Omeliansky, W.L. (1902)
Zentrbl. Bakt. Parasitenk., Abt. 118 : 224 from Allen, O.M. (1953).

Piper, C.S. (1950) . (1950)
Soil and plant analysis. Inter-science puplishers. Inc. N.Y.

Velsen, A.F.M - van (1977)
Anaerobic digestion of piggery wast. 1 - The influence of detention time and monure Concentration Neth. J. orgic. Sci. 25 (1977) 151 - 165

Velsen, A. F.M. Van (1979a)
Anaerobic digestion of piggary waste. 2, start up procedure Neth - J. Agric. Sci 27 : 142 - 150

Velsen, A.F.M. Van Lettinga, G and Ottelander D. den (1979b)
Anaerobic digestion of piggery waste. 3-Influence of temmperature. Noth - J - agric. Sci 27 : 255 - 267.

Walter, J.W. and Williams, J.J. (1980)
Dry anaerobic fermentation. Biotechnology and Bioengineeringb Symp. No 10, 34 - 65. John Wiley & Sons, Inc. N.Y.

Wise, D.L.; Blamchet, M.J.; Boyd, W.F. and Pacey J.G. (1981)
Fuel gas enhancement by controllrd of municipal solid waste. Resoures and Conservation, 6 (1981) 3 - 20

Wujcik, W.J. and Jewell, W.J (1980)
Dry anaerobic fermentation., Bioc chemical and Biotchnology Symp. No. 10, 43 - 65. Tohn wiley & sons , Inc. N.Y.

"BIOGAS PRODUCTION FROM RICE STRAW AND *CLITORIA TERNATEA*"

Report Presented By:

Dr. Suhirman
Head, Microbiology Laboratory
Kantor/Office
Lembaga Biologi Nasional
J.L. IR.H. Juanda 18, Bogor
INDONESIA

BIOGAS PRODUCTION FROM RICE STRAW AND *Clitoria ternatea*.

by

Suhirman and Ruth Melliawaty*

Introduction

There is approximately 67 million tons of agricultural residues (from rice, maize, soyabeans, cassava, sweet potato, peanut and sugarcane) every year in Indonesia, which is a potential resources of energy (appendix 1). But the use of agricultural residues in Indonesia is still very limited. The majority of the residues are burnt. In Nusa Tenggara Timur for example, where cattle is the main product, maize and rice straw is left in the field to be eaten by cattle. The rest is burnt. In Karawang (West Jawa), some of rice straw has been used as a substrate for mushroom production. Husk has also been used as a kind of charcoal for mushroom production. The majority of the straw, however, is left in the paddy field and burnt.

If one kilogram of residues can produce 13 cubic feet of methane (Leuschner and Wise, 1983), 67 million tons of agricultural residues may produce 871 million cubic feet of methane.

The government of Indonesia has been considering biogas as an important source of energy. Some trials have been established in several villages, using manure as material, and oil drum as digester (Harahap *et al*, 1978). Eceng gondok (*Eichhornia crassipes*) has also been tried to be used as a substrate for biogas production (Soerjani, 1979). But there has not been any report concerning the use of agricultural wastes for that purpose in Indonesia.

The efficiency of a digester system is influenced by several factors, i.e. the moisture content of subatrate, pH, temperature, and CN ratio. The moisture content of agricultural residue, e.g. rice straw is usually low and not sufficient for anaerobic microorganisms to survive and degrade the residue. Leuschner and Wise (1983) suggested that the percent moisture in the digester be at least 50 percent.

Because the bacteria which carry out the biodegradation process grow best within a narrow pH range, the pH within the digester should be controlled. Augenstein et. al. (1976) showed that the optimal range of 6.25 to 7.50 had been controlled by the addition of calcium carbonate, in simulated landfill cell.

To bring the substrate to be digested into intimate contact with the various populations of microorganisms involved in digestion, stirring or shaking can be provided. Stirring or shaking also prevent

*National Biological Institute, The Indonesian Institute of Sciences (LIPI), Bogor, Indonesia.

souring.

Leuschner and Wise (1983) suggested that mesophilic temperature be the most appropriate temperature for biogas production, and the CN ratio be 20. Since the CN ratio of rice straw is too high, it need an addition of materials rich in nitrogen. The purpose of this experiment is to investigate the effect of combining rice straw with leguminous leaves in an anaerobic digestion system on the biogas production. It is hoped that the results can be used to help farmers on how to combine rice straw with leguminous leaves during the operation of biogas production.

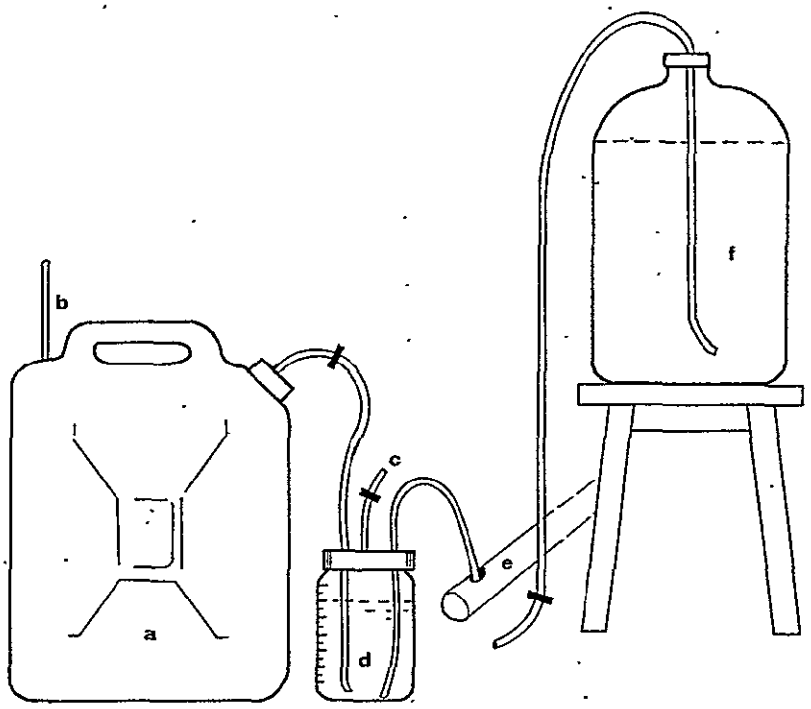
Materials and methods

The experiment was conducted using batch fermentation process. The mixture of rice straw, Clitoria ternatea leaves, inoculum, calcium carbonate and water was put into digesters. The digesters were then sealed. And the quantity of gas, pH, and temperature were monitored.

One of the experimental apparatus is illustrated in figure 1. The digester was a 21-liter palstic container. The measurement of gas production was by water displacement method, using a callibrated one-liter flask containing 900 ml NaCl saturated water (d). Gas generated in the digester was accumulated in the flask until the quantity was recorded. Then the water was rezeroed by releasing the gas through a controled ruber tube (c), and adding some water from a 20-ml glass container into the flask.

The amounts of residues, inoculum, buffer and water are presented in table 1. There were three digesters for each treatment. Dry rice straw collected from a paddy field in Dermaga, Bogor, West Jawa was used. To lower the CN ratio of the residue, leaves of Clitoria ternatea were added into the digester. Prior to digestion, the rice straw was chopped to the length of between one and three cm. Fresh cow manure collected from a stable in Bogor botanical garden was used as inoculum. The amount of inoculum was 10 percents of total solid loaded. Calcium carbonate powder which could pass 1 mm^2 sieve was used to keep the fermentation system at pH high enough (above 6) for optimum methane production. Five percents of total solid loaded of calcium carbonate was used. The water, which has pH of 6.75, was collected from a well inside the Bogor botanical garden. Fifteen liters of water was put into each digester. The digesters were shaked throughly by hand. Shaking was done every weekday, to avoid souring.

The rice straw contained 44% of C and 0.74% of N, so that its CN ratio was 64. Whilst Clitoria ternatea contained 50% of C and 4.1% of N, so that its CN ratio was 12. The CN ratioes of residues for five treatments were 12, 20, 30, 40 and 64.



a - 21-liter digester
b - thermometer
c - ruber tube to release gas
d - callibrated one-liter flask with NaCl-saturated water
e - pralon pipe to drain the displaced water
f - NaCl-saturated water to fill the flask

Figure 1. Diagrammatic representation of apparatus used for biogas experiments

Table 1. The amount of residues, inoculum, buffer and water for five treatments and the CN ratioes of residues.

Treatments	Residues			Inoculum (grams)	$CaCo_3$ (grams)	Water (liters)
	Straw (grams)	C. ternatea (grams)	C/N			
I	0	283	12	31.4	15.7	15
II	144	139	20	31.4	15.7	15
III	216	67	30	31.4	15.7	15
IV	250	33	40	31.4	15.7	15
V	283	0	64	31.4	15.7	15

Results and discussion

Results of this experiment are presented in figure 2, and table 2, and the daily gas production is presented in appendix 2.

The results show that the addition of leguminous leaves into rice straw residue could increase the total gas production. The proportion of leaves and rice straw in a digester has to be considered in order to obtain a maximum gas production. The addition of leguminous leaves which resulted in CN ratio of residues between 20 and 30 (table 1) produced more total biogas than the other treatments.

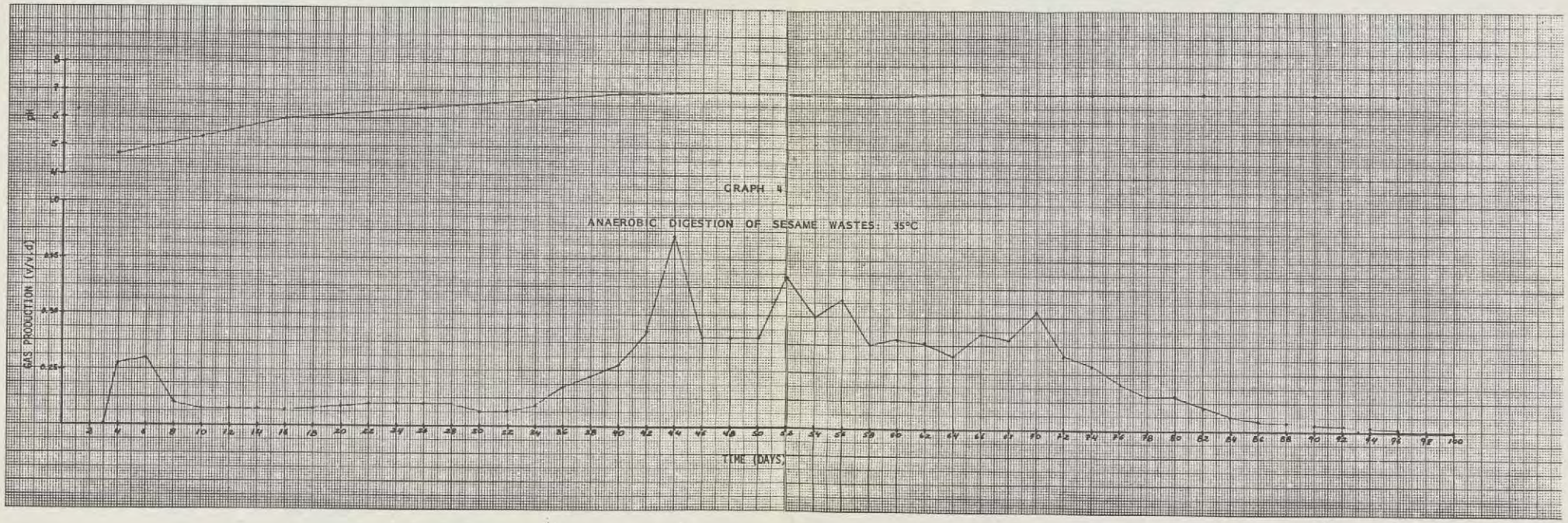
Table 2 shows that the initial pH of five treatments were between 6.10 and 7.63, of which the pH of treatment I being the lowest. Stafford et. al. (1978) listed the optimum pH for some methane bacteria. For example Methanobacterium formicium needs optimum pH of 7.5 to 8.0, M. ruminantium needs pH between 6.0 and 8.0, whilst Methanococcus vanniellii requires pH 7.4 to 9.2. The lowest gas production of treatment I might have also been substantiated by its pH condition, which dropped below 6 for six weeks. During the final week .. the pH went up to between 6.23 and 6.75, when the gas production was the highest for this treatment.

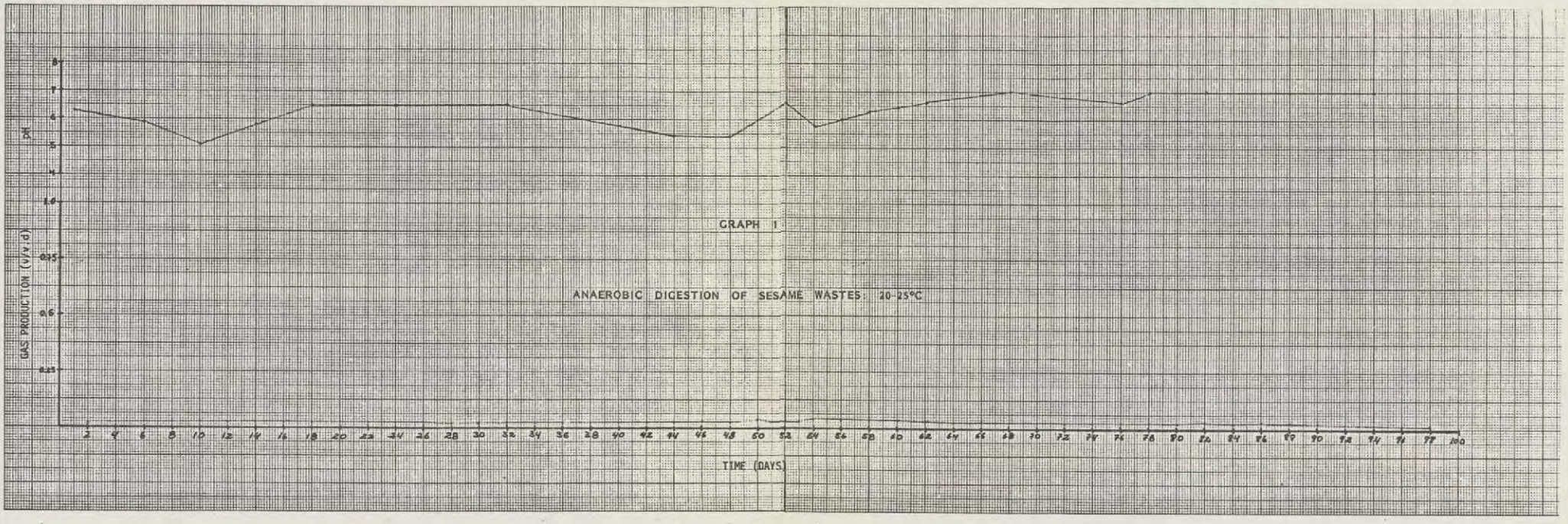
The temperature of the digesters was between 24 and 30, which was too low for an optimum biogas production. This might have been due to the dimension of the digester, which could be too small to increase the temperature or to retain the heat. In fact the temperatures were very similar to the embient temperature where the digesters took place.

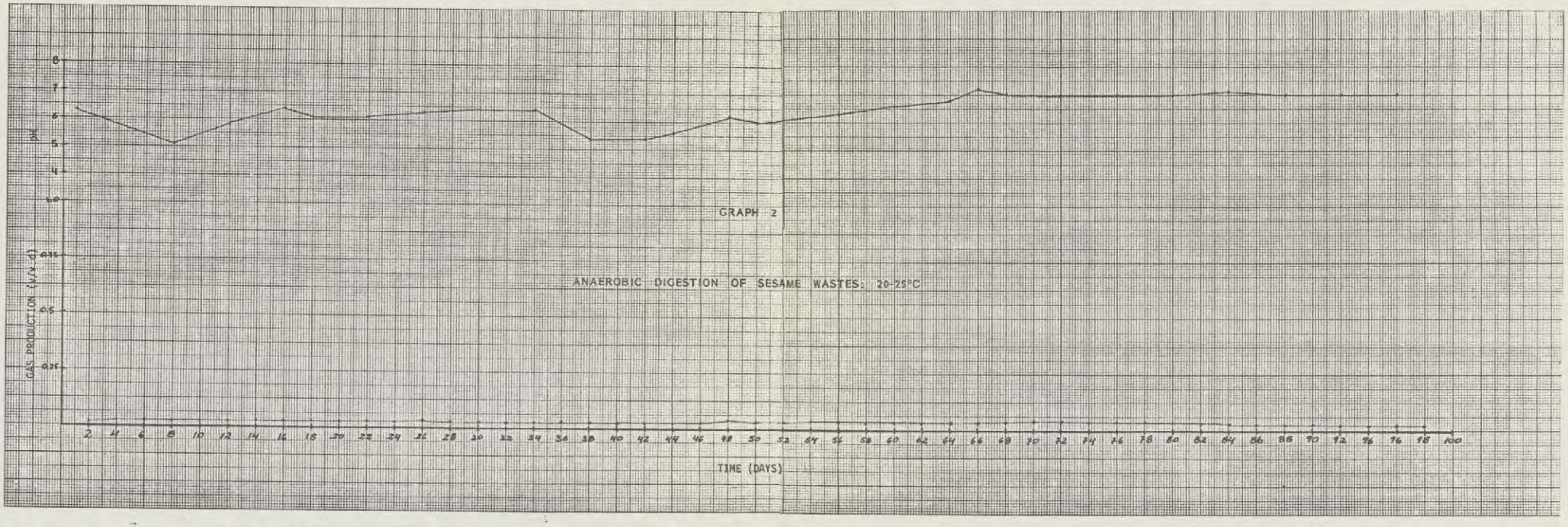
Due to inavailability of a suitable equipment to detect the amount of methane correctly, the data presented here are of total gas production. Theoretically, however, it can be estimated that the amount of methane increases with the increase of the duration of fermentation, and the total volume of methane is between 50 and 60 for such residues (Wise, 1982).

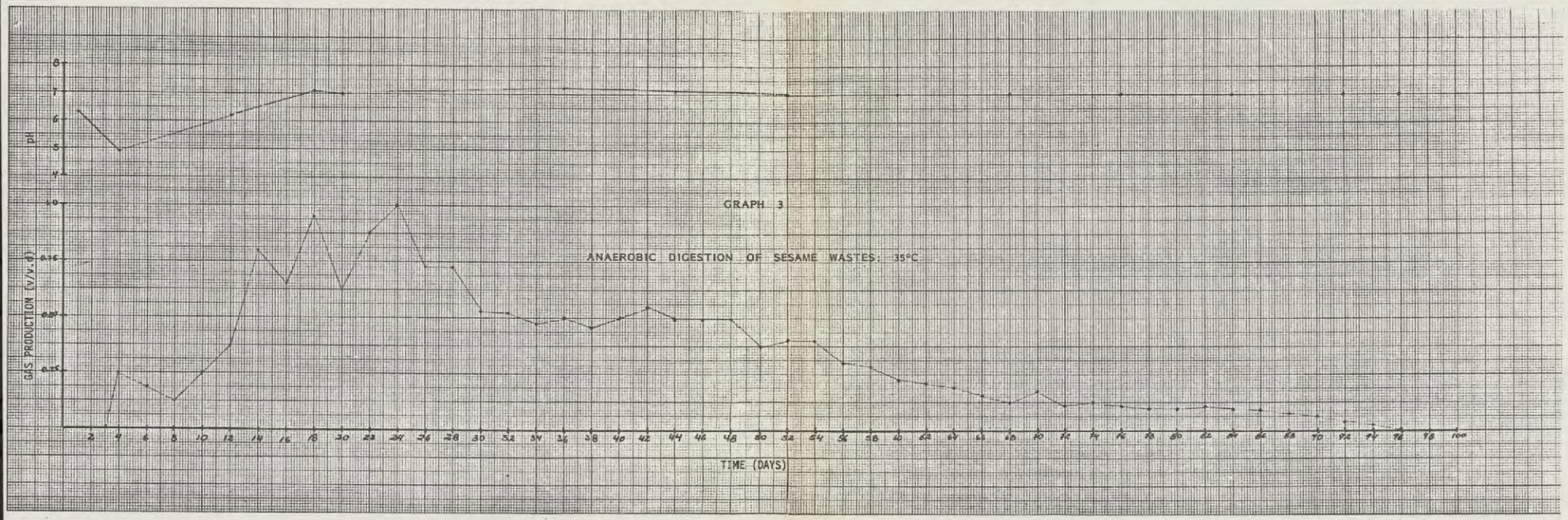
The implementation of the results of this experiment in the rural areas in Indonesia may have a good support from the government, because one of the government's policies is to encourage the exploitation of our renewable energy resources, while using our oil more efficiently. The problem is how to invent a type of digester which is cheap and easy to handle. A 'HIG' (hole in ground) system (Leuschner et. al., 1984) can be tried to solve the problem.

Some other renewable resources in Indonesia are firewood, charcoal and peat. It has been estimated that firewood and charcoal fulfill 50 percent of energy requirement in Indonesia. Majority of the people live in desa or villages, where they use firewood for cooking. It is easily available and cheaper than kerosene. Small industries such as brick, ce-


GRAPH 4
ANAEROBIC DIGESTION OF SESAME WASTES: 35°C
pH
GAS PRODUCTION (V/V.d)
TIME (DAYS)


GRAPH 1
ANAEROBIC DIGESTION OF SESAME WASTES. 20-25°C
GAS PRODUCTION (l/v/d)
TIME (DAYS)


GRAPH 2
ANAEROBIC DIGESTION OF SESAME WASTES: 20-25°C
pH
GAS PRODUCTION (L/L-d)
TIME (DAYS)


GRAPH 3
ANAEROBIC DIGESTION OF SESAME WASTES. 35°C
pH
GAS PRODUCTION (v/v.d)
TIME (DAYS)

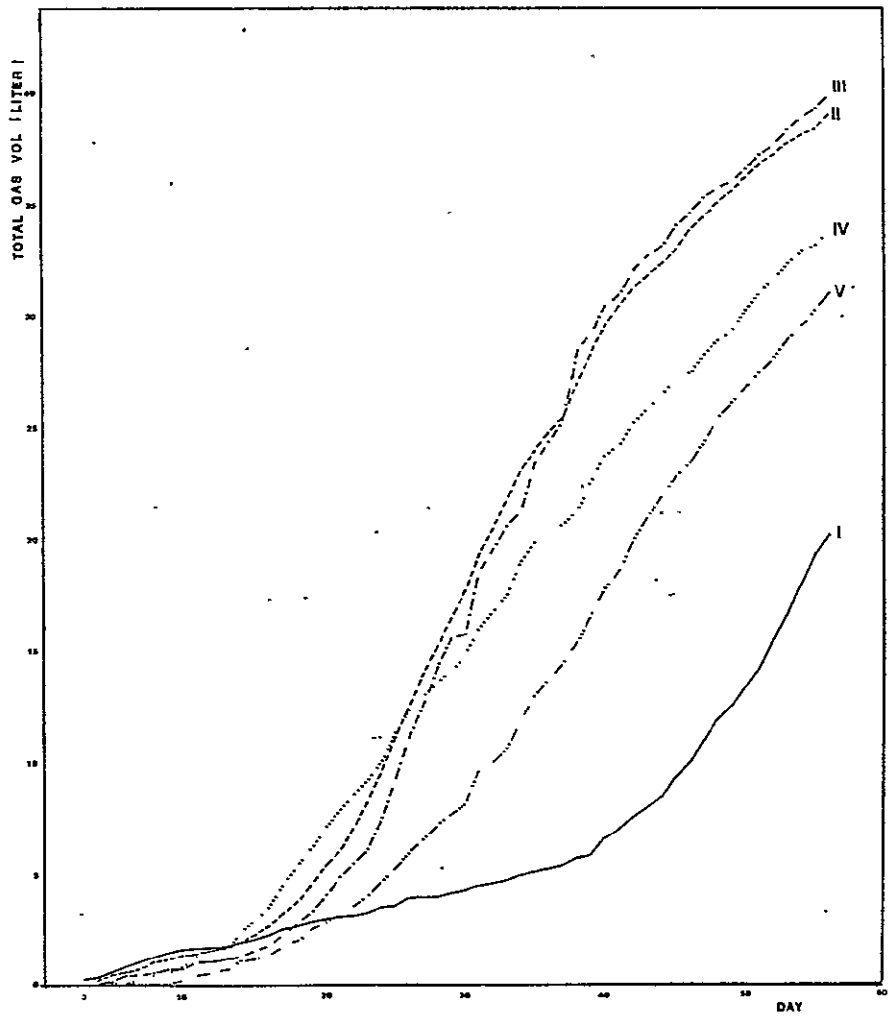


Figure 2. Results of gas production vs. time

Table 2. Total gas production, pH and temperatures

Day	Total gas production (liters)					pH					Temperature									
											I		II		III		IV		V	
	I	II	III	IV	V	I	II	III	IV	V	m	n	m	n	m	n	m	n	m	n
1	0.0	0.0	0.0	0.0	0.0	6.10	6.95	7.18	7.63	7.57	24.50	28.00	24.83	28.83	24.83	28.50	24.33	28.17	24.17	28.50
7	1.1	0.7	0.5	0.2	0.1	5.70	6.22	6.32	6.62	6.28	23.83	26.50	23.93	26.83	24.10	27.00	23.83	26.00	23.83	26.50
14	1.9	2.0	1.3	2.4	1.0	5.57	5.85	5.15	6.12	5.53	23.83	24.83	24.17	25.33	23.67	25.00	23.00	24.67	23.33	24.33
21	3.0	5.9	4.8	7.9	3.1	5.47	5.92	6.22	6.08	5.28	23.67	25.17	24.67	26.50	24.83	27.00	24.17	26.33	24.17	26.17
28	4.1	15.2	15.5	4.6	7.2	5.45	6.40	6.62	5.92	5.78	24.17	27.67	24.17	27.50	23.83	27.00	24.33	27.83	23.67	27.33
35	5.1	24.1	23.4	19.8	12.9	5.43	6.72	6.63	6.53	5.73	24.50	26.67	25.17	27.17	24.83	27.33	24.33	27.17	24.50	27.17
42	7.5	31.3	32.1	25.2	19.9	5.62	7.07	7.47	7.40	6.83	25.33	29.17	25.33	30.00	25.67	29.67	24.83	29.67	24.83	29.67
49	12.5	36.6	36.0	29.3	26.1	6.23	7.57	7.13	7.12	6.55	24.17	27.00	24.83	27.83	24.67	28.17	24.00	28.50	24.67	28.33
56	28.2	39.9	40.9	33.7	30.9	6.75	7.45	7.53	7.17	7.33	24.67	28.67	26.17	29.00	25.67	29.33	24.67	29.00	25.17	29.33

m - morning

n - noon

ramics, lime, sugar and food industries use firewood. In 1980, the domestic consumption of firewood in Indonesia was about 43.9 million tons, or 83.4 million cubic meters (Anonymous, 1984). Uncontrolled use of firewood can be a serious threat for our forest especially in Jawa (Harahap et. al., 1978), so that alternative energy such as biogas need to be considered seriously.

Indonesia has about 20 x 10^9 m^3 of peat in Sumatera and Kalimantan, which can be used as a material for biogas.

The principle of producing biogas presented in this paper can also be used for recovering methane gas from municipal landfill. In Jakarta, 17 thousand m^3 of garbage is produced every day, which means about 6 million m^3 every year. And in Bogor, much smaller city, 300 thousand m^3 of garbage is produced annually. There has not been any report concerning the amount of municipal garbage in Indonesia, althought it is obviously a potential source of energy. The principle of recovering methane gas from municipal landfill has been discussed by Leuschner (1983).

In conclusion, to produce optimum biogas from agricultural residues which have too high CN ratio, such as rice straw, one can mix the residue with the leaves of leguminous plants, e.g. Clitoria ternatea. The mixture has to have a CN ratio between 20 and 30 for a maximum gas production. Further investigation is needed to determine the carbon and nitrogen contents of many other leguminous leaves, especially the species which are easily available, so that recommendation on how to make up the composition of rice straw and leaves of leguminous plants can be given whenever required. Results of this experiment might be applied to support biogas production in rural areas and from municipal landfill. In order to be accepted by people living in rural areas, the field method of gas production has to be cheaper and more practical than the use of firewood.

Acknowledgement

We would like to acknowledge Mr. Muljadi for his technical assistance.

Refferences

Anonymous. 1983. Statistical Yearbook of Indonesia. Biro Pusat Statistik. Jakarta.

Anonymous. 1984. The Fourth Five-year Planning 1984/1985 - 1988/1989.

Augenstein, D.C., Wise, D.L., Wentworth, R.L. and Cooney, C.L. 1976. Fuel Gas Recovery from Controlled Landfill of Municipal Wastes. Resources Recovery and Conservation. 2(1976): 103-117.

Harahap, Apandi, M., Ginting, S. 1978. Teknologi Gas Bio. Pusat Teknologi Pembangunan. Institut Teknologi Bandung.

Leuschner, A.P. 1983. Feasibility Study for Recovering Methane Gas from The Greenwood Street Sanitary Landfill, Worcester, Massachusetts. Dynatech Report No. 2265.

Leuschner,A.P., Levy, P.F. and Wise, D.L. 1984. Low Capital Cost Fuel Gas Production from Combined Organic Residues. Dynatech Report No. 2291.

Leuschner, A.P. and Wise, D.L. 1983. Low Capital Cost Fuel Gas Production from Combined Organic Residues. Dynatech R/D Company.

Soerjani, M. 1980. Gulma Air dalam Pengembangan Wilayah Sungai Kali Brantas. Departemen Pekerjaan Umum. Direktorat Jendral Pengairan. Jakarta.

Statford, D.A., Hawkes, D.L. and Horton, R. 1978. Methane Production from Waste Organic Matter. CRC Press, Inc. Boca Raton, Florida.

Wise, D.L. 1982. Low Capital Cost Fuel Gas Production from Combined Organic Residues. Dynatech Technical Proposal PBD-161.

Appendix 1. Some agricultural production in 26 provinces of Indonesia (1982)*

Province	Production (M ton)					
	Paddy	Cassava	Maize	Sweet potato	Soyabeans	Peanuts
1. Daerah Istimewa Aceh	867 466	43 772	4 767	14 139	20 311	7 806
2. Sumatera Utara	1 834 709	250 441	65 854	140 409	2 505	13 327
3. Sumatera Barat	1 131 448	59 360	9 681	16 826	942	6 384
4. R i a u	297 469	60 614	15 699	11 334	966	2 097
5. J a m b i	426 687	28 695	1 917	7 501	1 599	942
6. Sumatera Selatan	968 296	169 072	8 245	29 422	2 472	5 916
7. Bengkulu	214 519	29 592	4 958	17 759	1 936	3 500
8. L a m p u n g	875 055	882 904	74 787	14 432	17 828	6 601
S U M A T E R A	6 615 649	1 522 450	185 908	251 822	48 559	46 573
9. D.K.I. Jakarta	49 235	4 471	207	1 395	–	252
10. Jawa Barat	7 431 497	1 963 335	81 801	305 011	16 268	57 503
11. Jawa Tengah	5 774 064	2 828 596	554 018	176 091	65 140	93 297
12. D.I. Yogyakarta	548 984	555 407	35 069	15 592	28 044	32 395
13. Jawa Timur	7 051 258	3 758 113	1 482 122	231 545	293 477	126 547
JAWA & MADURA	20 855 038	9 109 922	2 153 217	729 634	402 929	309 994
14. B a l i	734 755	284 599	71 575	111 399	7 159	10 880
15. Nusa Tenggara Barat	884 273	105 066	24 817	47 268	41 406	7 591
16. Nusa Tenggara Timur	275 775	683 621	268 322	104 177	294	10 218
BALI & NUSA TENGGARA	1 894 803	1 073 286	364 714	262 844	48 859	28 689
17. Kalimantan Barat	632 818	116 550	5 499	14 023	358	354
18. Kalimantan Tengah	222 523	70 426	4 114	9 632	128	203
19. Kalimantan Selatan	738 973	46 441	2 858	10 752	597	6 253
20. Kalimantan Timur	185 005	53 586	3 735	13 129	826	1 019
K a l i m a n t a n	1 779 319	287 003	16 206	47 536	1 909	7 829
21. Sulawesi Utara	257 258	97 613	78 429	46 527	7 274	4 732
22. Sulawesi Tengah	237 592	51 777	39 257	27 600	1 366	3 405
23. Sulawesi Selatan	1 854 466	300 530	307 027	69 426	7 883	31 518
24. Sulawesi Tenggara	71 437	383 612	66 055	22 926	1 959	2 121
S U L A W E S I	2 420 753	833 532	490 768	166 479	18 482	41 776
25. M a l u k u	13 881	134 841	20 839	50 345	83	1 085
26. Irian Jaya	4 234	26 857	3 173	166 997	573	876
MALUKU & IRIAN JAYA	18 115	161 698	24 012	217 342	656	1 961
I N D O N E S I A	33 583 677	12 987 891	3 234 825	1 675 657	521 394	436 822

* Statistical Yearbook of Indonesia. 1983
Biro Pusat Statistik. Jakarta

Production : residue = 1 : 1. (approximately)

Appendix 2. Daily gas production

Day	Gas production/day (liters)					Day	Gas production/day (liters)				
	I	II	III	IV	V		I	II	III	IV	V
1	0.0	0.0	0.0	0.0	0.0	31	0.2	1.6	1.8	1.4	1.2
2	0.0	0.0	0.0	0.0	0.0	32	0.1	1.2	1.0	0.7	0.7
3	0.3	0.0	0.0	0.0	0.0	33	0.1	1.2	1.0	0.7	0.7
4	0.1	0.2	0.1	0.0	0.0	34	0.3	1.3	1.6	1.5	1.2
5	0.3	0.2	0.1	0.1	0.1	35	0.1	1.1	1.2	0.9	1.2
6	0.3	0.1	0.2	0.1	0.0	36	0.1	0.7	1.0	0.4	0.7
7	0.2	0.1	0.1	0.1	0.0	37	0.1	0.7	1.0	0.4	0.7
8	0.2	0.3	0.1	0.2	0.0	38	0.3	1.5	3.2	0.6	0.9
9	0.2	0.3	0.1	0.2	0.0	39	0.3	1.3	0.7	1.3	1.2
10	0.2	0.1	0.1	0.2	0.1	40	0.6	1.3	1.3	1.2	1.2
11	0.1	0.1	0.2	0.5	0.3	41	0.4	0.9	0.5	0.5	0.9
12	0.1	0.2	0.1	0.2	0.1	42	0.6	0.9	1.1	1.0	1.3
13	0.1	0.2	0.1	0.2	0.1	43	0.4	0.5	0.7	0.6	1.0
14	0.1	0.3	0.3	0.8	0.3	44	0.4	0.5	0.7	0.6	1.0
15	0.2	0.3	0.3	0.6	0.2	45	1.0	0.9	0.7	0.7	1.0
16	0.2	0.3	0.3	0.6	0.2	46	0.6	0.6	0.6	0.3	0.6
17	0.3	0.5	0.5	1.1	0.4	47	1.6	0.6	0.7	0.7	1.0
18	0.1	0.4	0.5	0.8	0.2	48	1.0	0.6	0.4	0.6	1.0
19	0.2	0.8	0.5	0.8	0.5	49	0.6	0.5	0.3	0.5	0.7
20	0.7	0.8	0.7	1.0	0.3	50	0.9	0.6	0.6	0.9	0.7
21	0.1	0.6	0.8	0.7	0.3	51	0.9	0.6	0.6	0.9	0.7
22	0.9	1.1	0.6	0.7	0.4	52	1.3	0.4	0.5	0.6	0.7
23	0.9	1.1	0.6	0.7	0.4	53	1.2	0.5	0.6	0.7	0.9
24	0.2	1.2	1.4	0.8	0.7	54	1.3	0.4	0.6	0.5	0.6
25	0.1	1.7	1.8	1.3	0.7	55	1.3	0.3	0.4	0.3	0.7
26	0.4	1.3	1.9	1.1	0.8	56	0.9	0.6	0.7	0.7	0.7
27	0.1	1.5	1.5	0.5	0.6						
28	0.1	1.2	1.9	0.7	0.7						
29	0.1	1.3	1.1	0.5	0.4						
30	0.1	1.3	1.1	0.5	0.4						

"LOW CAPITAL COST FUEL GAS PRODUCTION FROM COMBINED ORGANIC RESIDUES"

Report Presented By:

Mr. Jose Francisco Calzada
Central American Research Institute for Industry
Avenida La Reforma 4-47
Zona 10,
GUATEMALA

INSTITUTO CENTROAMERICANO DE INVESTIGACION Y TECNOLOGIA INDUSTRIAL
(ICAITI)

APARTADO POSTAL 1552
Cables: ICAITI
Telex: 5312-ICAITI-GU

Avenida La Reforma 4-47, Zona 10
Guatemala, C. A.

TELEFONOS. 310631 y 317466

SECOND PARTIAL REPORT

LOW CAPITAL COST FUEL GAS PRODUCTION FROM COMBINED ORGANIC RESIDUES

Presentado por el ICAITI a

DYNATECH R/D COMPANY

Guatemala, October, 1984

1. REACTORS

Four anaerobic digestors were used. Two were kept at controlled 35°C and the other two were maintained at ambient temperature (20-25°C). As indicated in the previous report, cylindrical metal containers were used (25 cm diameter and 33.5 cm height). Slanted floor and recirculation were provided. Temperature control at 35°C was obtained using an environmental chamber (Biotronette Mark III, Lab-Line).

2. RAW MATERIALS

As in the previous studies, solid wastes derived from the alcaline dehulling of sesame seed were considered the most important substrate. Sugar cane bagasse was added to increase the porosity of the mixture. Inoculum was provided through the use of cow manure.

2.1 Initial load:

SUBSTRATE	PARTS BY WEIGHT
Sesame wastes	7.0
Bagasse	0.3
Manure	0.7
Water	2.0

2.2 Composition of raw materials:

MATERIALS	SESAME WASTE	CANE BAGASSE	COW MANURE
Total solids, %	9.75	94.47	19.67

MATERIAL	SESAME WASTE	CANE BAGASSE	COW MANURE
Volatile solids, %	5.00	83.70	16.37
Nitrogen, (% dry weight)	0.45	0.25	1.09
Phosphorous (% dry weight)	0.17	0.04	0.03

3. GAS PRODUCTION

Graphs 1 and 2 show the values of pH and gas productivity for digestors operated at ambient temperature (20-25°C average 22.8°C) during a 100 days-period.

Graphs 3 and 4 show the same values for the digestor operated at 35°C.

4. CONVERSIONS AND GAS COMPOSITION

Tables 1 and 2 show the changes in volatile solids, total solids, nitrogen and phosphorus, during the digestion period. Gas analysis have been included. Tables 3 and 4 correspond to similar values for a digestor operated at 35°C.

5. RESIDUAL MATERIAL

At the end of the experiment, the reactors were discharged.

Samples of liquid and drained fractions were taken. Table 5 shows the results of the analysis. It must be indicated that the digestors operating a 35°C yield a final product that showed much better estabilization. Even the bagasse was partially attached. Color differences in both effluents was also observed.

6. POTENTIAL APLICATION

The production of sesame seed in Central America (1981) was 17 387 metric tons. Only part of this amount is currently decorticated through the use of alcaline solutions. In this later case, it has been estimated that 10 metric tons of effluent are discharged for each ton of seed processed.

Two dehulling plants were visited during the 1984 crop season. The first one discharges 4 360 metric tons of liquid effluent per year, with 15% drained solids. This drained solids (wet material, with water content close to 90%) was the raw material for the tests described in this work, and represent approximately 650 metric tons/year. The second processing plant discharges 8 000 metric tons of liquid effluent, with similar characteristics.

TABLE 1

ANAEROBIC DIGESTION OF SESAME WASTES: 20-25°C

DAY	Alcalinity (g/l $CaCO_3$)	Total Vol. Acid (%)	Total Solids (%)	Volatile Solids (%)	N (%)	CH_4 (%)
1*	-	-	11.01	7.16	0.41	-
8	7.80	0.16	-	-	-	-
15	-	0.21	-	-	-	-
22	2.25	0.25	4.78	2.17	-	39
29	7.34	0.34	-	-	-	-
36	10.30	0.10	-	-	-	27
43	6.12	0.64	-	-	-	-
50	11.10	-	3.08	1.49	0.02	49
57	10.14	0.60	-	-	-	-
64	11.72	0.78	-	-	-	75
78	11.04	0.77	-	-	-	-
85	12.24	0.71	3.16	1.28	0.03	84
92	16.16	0.64	-	-	-	-
99	-	0.42	2.60	1.15	0.03	-

* Sample of liquid and solids

TABLE 2

ANAEROBIC DIGESTION OF SESAME WASTES: 20-25°C

DAY	Alcalinity (g/l $CaCO_3$)	Total Vol. Acid (%)	Total Solids (%)	Volatile Solids (%)	N (%)	CH_4 (%)
1*	-	-	11.04	7.16	0.41	-
8	-	0.19	-	-	-	-
15	-	0.20	-	-	-	-
22	1.44	0.24	6.24	3.54	-	34
29	3.34	0.29	-	-	-	-
36	6.18	0.77	-	-	-	39
43	9.88	0.67	-	-	-	-
50	10.04	-	4.49	2.25	0.03	47
57	10.08	0.70	-	-	-	-
64	10.72	0.70	-	-	-	59
78	11.32	0.67	-	-	-	-
85	11.52	0.65	2.83	1.06	0.03	76
92	11.68	0.59	-	-	-	-
99	19.96	0.21	2.47	1.01	0.03	-

* Sample of liquid and solids

TABLE 3

ANAEROBIC DIGESTION OF SESAME WASTES: 35°C

DAY	Alcalinity (g/l $CaCO_3$)	Total Vol. Acid (%)	Total Solids (%)	Volatile Solids (%)	N (%)	CH_4 (%)
1*	-	-	11.04	7.16	0.41	-
8	5.40	0.21	-	-	-	-
15	-	0.03	-	-	-	35
22	10.90	0.03	-	-	-	51
29	5.48	0.04	1.12	0.70	-	43
36	6.86	0.09	-	-	-	46
43	7.60	0.06	-	-	-	52
50	5.72	-	0.99	0.29	0.01	-
57	7.80	0.03	-	-	-	58
64	7.76	0.02	-	-	-	-
78	8.00	0.02	-	-	-	57
85	8.00	0.01	0.99	0.30	0.01	-
92	7.46	0.01	-	-	-	60
99	8.52	0.01	1.15	0.43	0.02	-

* Sample of liquid and solids

TABLE 4

ANAEROBIC DIGESTION OF SESAME WASTES: 35°C

DAY	Alcalinity (g/l $CaCO_3$)	Total Vol. Acid (%)	Total Solids (%)	Volatile Solids (%)	N (%)	CH_4 (%)
1*	-	-	11.07	7.16	0.41	-
8	3.52	0.25	-	-	-	-
15	0.57	0.34	-	-	-	30
22	7.1	0.07	2.35	1.15	-	38
29	4.32	0.06	-	-	-	44
36	5.46	-	-	-	-	43
43	8.05	0.14	-	-	-	40
50	6.88	-	1.20	0.45	0.01	-
57	7.24	0.12	-	-	-	42
64	6.60	0.04	-	-	-	-
78	17.30	0.04	-	-	-	48
85	8.36	0.01	1.04	0.32	0.02	-
92	7.48	0.01	-	-	-	54
99	8.60	0.01	1.33	0.36	0.02	-

* Sample of liquid and solids

TABLE 5

SOLID (DRAINED) DISCHARGES OF
ANAEROBIC DIGESTORS USING SESAME WASTES

PARAMETER	DIG. 1	DIG. 2	DIG. 3	DIG. 4
Total solids, %	19.38	20.24	16.44	15.73
Volatile solids, %	14.00	12.52	9.17	8.89
Nitrogen, %	0.38	0.42	0.59	0.71
Phosphorous	0.02	0.05	0.01	0.01

"LOW CAPITAL COST FUEL GAS PRODUCTION FROM COMBINED ORGANIC RESIDUES"

Report Presented By:

Dr. Javier Verastegui
Jr. Morelli 2da. cda.-esquina av. de las Artes
(altura cuadra 21 av. Javier Prade Este)
San Borja - Surquillo, Lima 34
apartado 145, Lima,
PERU

INSTITUTO DE INVESTIGACION TECNOLOGICA INDUSTRIAL Y DE

NORMAS TECNICAS (**ITINTEC**)

"Low Capital Cost Fuel G.s Production from Combined Organic Residues"

Final Report of 1st. Stage
Research Proyect proposed
by Dynatech R/D Company
Executed by ITINTEC

Prepared by :

Chem. Magda Mateo B.
Eng. Mercedes Carrasco U.
Eng. Johnny Ascue C.

BIOGAS RESEARCH PROGRAM
DIVISION OF FOOD AGRO-INDUSTRIES
DIRECTION OF TECHNOLOGY -ITINTEC

L I M A - P E R U

OCTOBER 1984

INDEX

1. INTRODUCTION

2. BIOGAS PRODUCTION IN DIGESTERS OF 200 LITERS

2.1 Process Duration and Position

2.2 Investigation Methodology

3. EXPERIMENTED PROCEDURE

3.1 Equipment Description

3.2 Analytic Process

3.2.1 Physico-Chemical Parameters

3.2.2 Analytic Methods

3.3 Operative Process

3.3.1 Pre-fermentation of raw materials

3.3.2 Preparation of the load

3.3.3 Digesters operation and digestion control

4. RESULTS

4.1 Biodigesters Evaluation Results

4.2 Discussing the Results

4.2.1 Biogas Production

4.2.2 Biogás Composition

4.2.3 Volatils Acids

4.2.4 Alkalinity

4.2.5 pH

4.2.6 Oxygen Chemical Demand

4.2.7 Anmoniacal Nytrogen and total

5. CONCLUSIONS AND RECOMENDATIONS

Annex N° 1 Table and Graphic

Annex N° 2 Calculation for the Charging of 220L-Digesters.

Abbreviations

- Cm^3/cm^3 dig : Cubic centimeter of biogas per centimeter cubic of digester.
- Cm^3/cm^3 mass : Cubic centimeter of biogas per cubic centimeter of mass.
- Cm^3/gr s.v destroyed/day : Cubic centimeter of biogas per gram Total Volatile Solids destroyed per day.
- Cm^3/day : Cubic centimeter per day.
- C/N : Relation carbon/nitrogen.
- % T.S. : Percent total solids.
- Mg/l : Milligram per liter
- Gr. : Gramme
- Kg. : Kilogramme.
- % : Percent
- COD : Chemical Oxygen Demand
- L : Liter
- ° C : Centigrade
- E : Manure
- C_t : Total carbon
- N_t : Total Nitrogen
- Ch : Stubble corn

LOW CAPITAL COST FUEL GAS PRODUCTION FROM COMBNED ORGANIC RESIDUES

I. INTRODUCTION

Peru is a country partially dedicated to Agriculture. The fifty percent (50%) of its population is located in rural zonas, where problems sucha as energy and nourishing agravate the already proverty situation between farmers. As a result, their development chances are reduced to a minimum.

To overcome this situation, the work has been oriented to obtain a new type of rural development based on the rational and integral use of local natural resources and in the residues overlook, with energetic objectives and food production through the use of appropriate technologies for each ecologic system.

The biogas digesters become useful as a new type in rural development. It makes possible to overlook the residues in order to produce energy and fertilizers to supply the farmer's necessities.

Since 1976, ITINTEC has been developing a biogas research program, which is based on non-conventional energetic resources.

In 1979, ITINTEC enunciated its own biogas production program, taking as a first point the organic residues, which has been performed in three phases: familiar rural digesters, agroindustrial comunal digesters and industrial digesters.

These investigations are being made using our own resources and through agreements suscribed between ITINTEC and others institutions, which presented satisfactory reports of the work advanced.

The present study took as principal the methodology work given by DYNATECH R/D Co. from USA in its document "Low Capital Cost Fuel Gas Production from Combined Organic Residues" under the AID sponsorship, which is orientes to a standard evaluation of an anaerobic fermentation from different substracts. For that objective, some international institutes had been participating.

II. BIOGAS PRODUCTION IN DIGESTERS OF 200 LTS.

2.1 Process duration and position

This study took place in our biogas pilot plant in the district of Villa El Salvador, which is located about 25Km. to the south of Lima, with a media height of 100 m.o.s.l. and 18°C temperature.

The experimental evaluation phase had 90 days of duration as indicated in the established activities program.

2.2 Investigation methodology

This biogas investigation, at laboratory level, was performed with the use of 4 digesters that have 200 lts. capacity in their respective gasometers as indicated in the draft given by A.P. Leuschmer of DYNATECH R/D Company, only with some changes.

The procedure becoming consisted on the evaluation of different fickles which take part in anaerobic digestion in determined conditions. The summary of these conditions is explained in the Figure N° 1.

The anaerobic digestion process is evaluated by measuring the biogas diary production. The control of this is being made by an analytical and technical way. Afterward, we present the description of the following physics-chemical parameters, pH, total solids, volatile solids, alkalinity, volatile acids, Kjeldahl nitrogen, total organic carbon, chemical demand of oxigen and total phosphorus.

III. EXPERIMENTAL PROCEDURE

3.1 Equipment description

For this work, there built 4 brass digesters of 55 glns. capacity with a cilindric form and in with upper flanges at the top of the cilindric, there are two equidistant gate valves, in one of them it was placed a screen tube in order to let the dispersion of the liquid effluent; the another one, an outlet gas tube in "L" form. For the middle part a gate valve with longer diameter is located to extract the sample and to take the internal temperature.

At the bottom of the cylinder, a cement layer was casted with a light slope. Over it was placed crushed stone; then near the cylindric base, a gate valve was inserted to withdraw the liquid effluent.

A re-circulation system for the liquid effluent was conditioned with an inferior outlet and a superior injection. As a result of this, it is possible to obtain an agitated movement in the system, which is operated by a 1.5 HP pump. The system period duration was about 1 to 1.5 minutes once a day.

TABLE N° 1

EVALUATION PARAMETERS FOR BIOGAS PRODUCTION FROM FARMING AND CATTLE WASTES

Variables \ Number of digesters	1	2	3	4
Raw material	Corn husk + Manure of cattle			
Formulation of materials Relation in dry weight	7.7:1	7:1	7:1	7.3:0.5
Relation C/N/P	100/5.1/1	100/5/1	100/5/1	100/5/1
Dilution (% S t)	12.82	24	24	24
Buffer (% CaO)	1	1	5	5
Temperature (°C)	32	32	32	32
Shaking	Recycling of liquid effluent			
System	Batch			
Time of evaluation	91			

The gas resulted is stored in the gasometers, which consisted on 2 sheet brass cylinders of different diameter, the shortest is inverted nad introduced in the another one with a central guide acting as a floating bell, where the gas is accumulated; as a displacement liquid we used water.

The daily gas volume is measured by liquid displacement and the pressure is indicated by the difference in heights in a manometer.

Up to this point we, calculated the cm^3 of biogas to normal conditions as the relations showed in the Figure N° 2.

In order to work with a constant temperature, we used an insulator cabin (before used as a freezing cabin), where the four digesters were located.

The source of heat was conformed by 4 electric bulbs of 100 W, which start on is regulated by a previous calibrated thermostat.

By controlling the turning on-off period, it was possible to get the desired temperature. The digesters arrangements and details are showed in the figures N°s. 1 and 2.

TABLE 2

BIOGAS VOLUMEN ESTIMATION

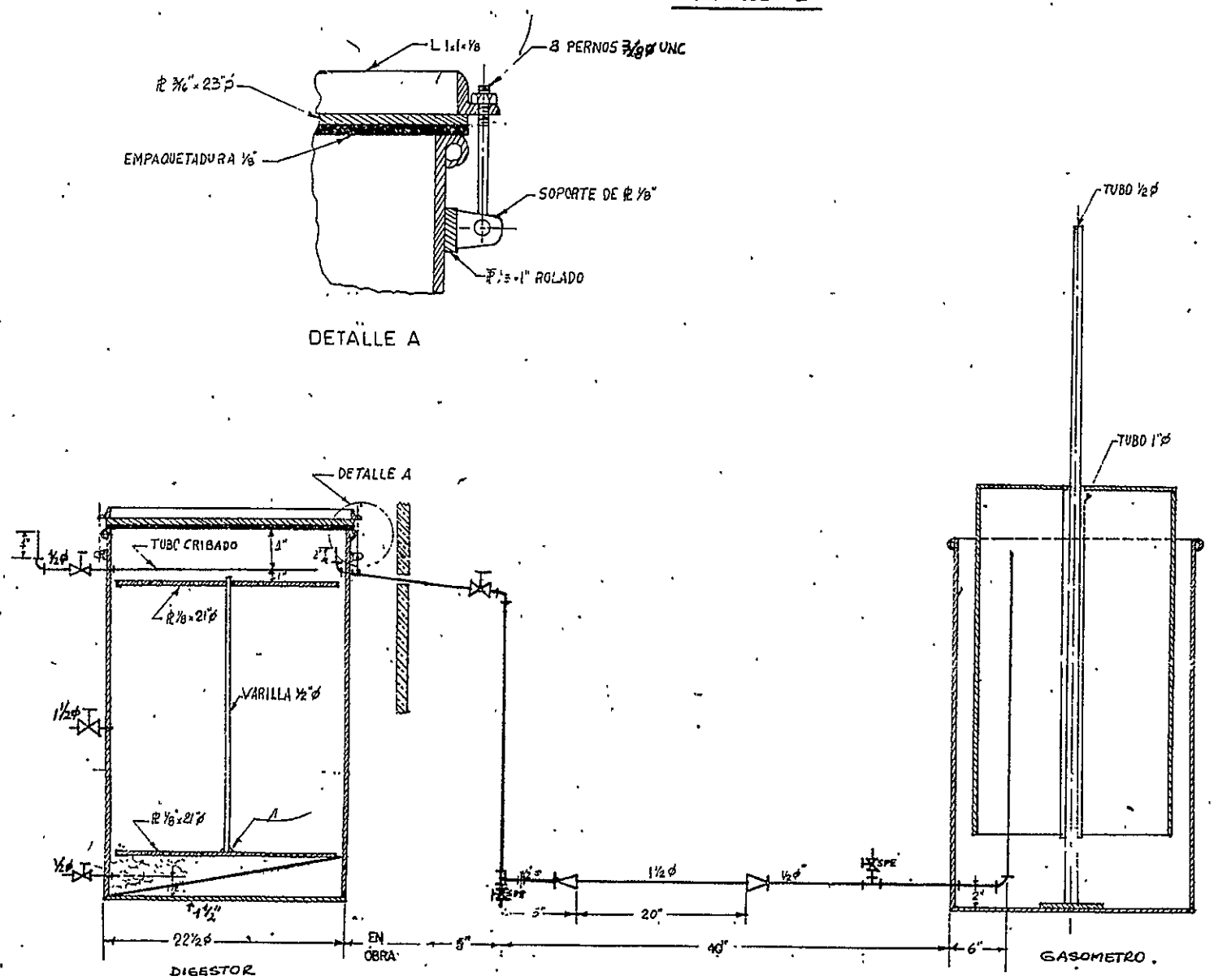
Digester	Gas Pressure (P) (mm. H_g)	Biogas Volume (V) cm^3/day	Biogas Volume (C.N) cm^3/day
1	$P_g = 760 + 0.7356(h_m)$	$V_i = A\ h_{g0}$	
		$V_f = A(h_g + h_m)$	$0.3592\ \frac{P_g\ \Delta V}{T}$
		$\Delta V = V_f - V_i$	

3.2 Analytical Process

3.2.1 Physico-chemical parameters

By evaluating the physico-chemical parameters, the digestion process was evaluated following the procedure indicated in Figure N° 3 and the weekly work chronogram showed in Table 3 .

FIGURE 1



SIMBOLOS

- UNION SIMPLE
- UNION UNIVERSAL
- VALVULA DE COMPUERTA
- VALVULA DE GLOBO
- VALVULA DE PURGA (SPELL)
- CODO 90°
- TEE
- REDUCCIÓN CAMPANA

Nº	DESIGNACION	Cant.	Material
29	Tubo 1/2" x 65" LONG.	1	Fe-Ga
28	Tubo. 1"ø x 33" LONG.	1	Fe-Ga
27	Válvula de Purga	2	Bronce
26	Válvula de globo 1/2"ø	1	Bronce
25	Válvula de compuerta 1/2"ø	2	Bronce
24	Valvula de compuerta 1 1/2"ø	1	Bronce
23	Unión simple 1/2" ø	3	Fe-Ga
22	Unión universal 1/2" ø	1	Fe-Ga.
21	Tee 1/2" ø	2	Fe-Ga
20	Codo 90° 1/2"ø	4	Fe-Ga
19	Reducción 1 1/2"-1/2" ø	2	Fe-Ga
18	Niple 1 1/2" x 2" LONG.	1	Fe-Ga
17	Tubo 1 1/2"ø x 20" LONG.	1	Fe-Ga
16	Niple 1/2"ø x 1"	4	Fe-Ga
15	Niple 1/2"ø x 2" LONG.	2	Fe-Ga
14	Niple 1/2"ø x 2 1/2" LONG	4	Fe-Ga
13	Niple 1/2" ø x 4" LONG.	2	Fe-Ga
12	Tubo 1/2" ø x 18" LONG.	1	Fe-Ga
11	Tubo 1/2" ø x 20" LONG.	1	Fe-Ga
10	Tubo 1/2" ø x 28" LONG.	1	Fe-Ga
9	Tubo 1/2"ø x 37" LONG.	1	Fe-Ga
8	Disco PL 1/16" x 21" LONG	2	Fe
7	PL 1/8" x 1" x 73" LONG	1	Fe
6	Pernos 7/16 ø UNC x 3" LONG	8	Fe
5	Empaquetadura 1/8" x 20 ø$_i$ x 24 ø$_e$	1	Jebe
4	L 1 x 1 x 1/8 x 77 LONG.	1	Fe
3	Disco PL 3/16" x 23"ø	1	Fe
2	Cilindro 30 GL.	1	Fe-Ne
1	Cilindro 55 GL	2	Fe-Ne

SERVICIOS GENERALES DE INGENIERIA EIRL.

ITINTEC - DIPA

Designación: BIODIGESTOR-200 Litros.

B. Serpa V.

Escala: S/E.

O.T. 3435

Fecha 09-02-88

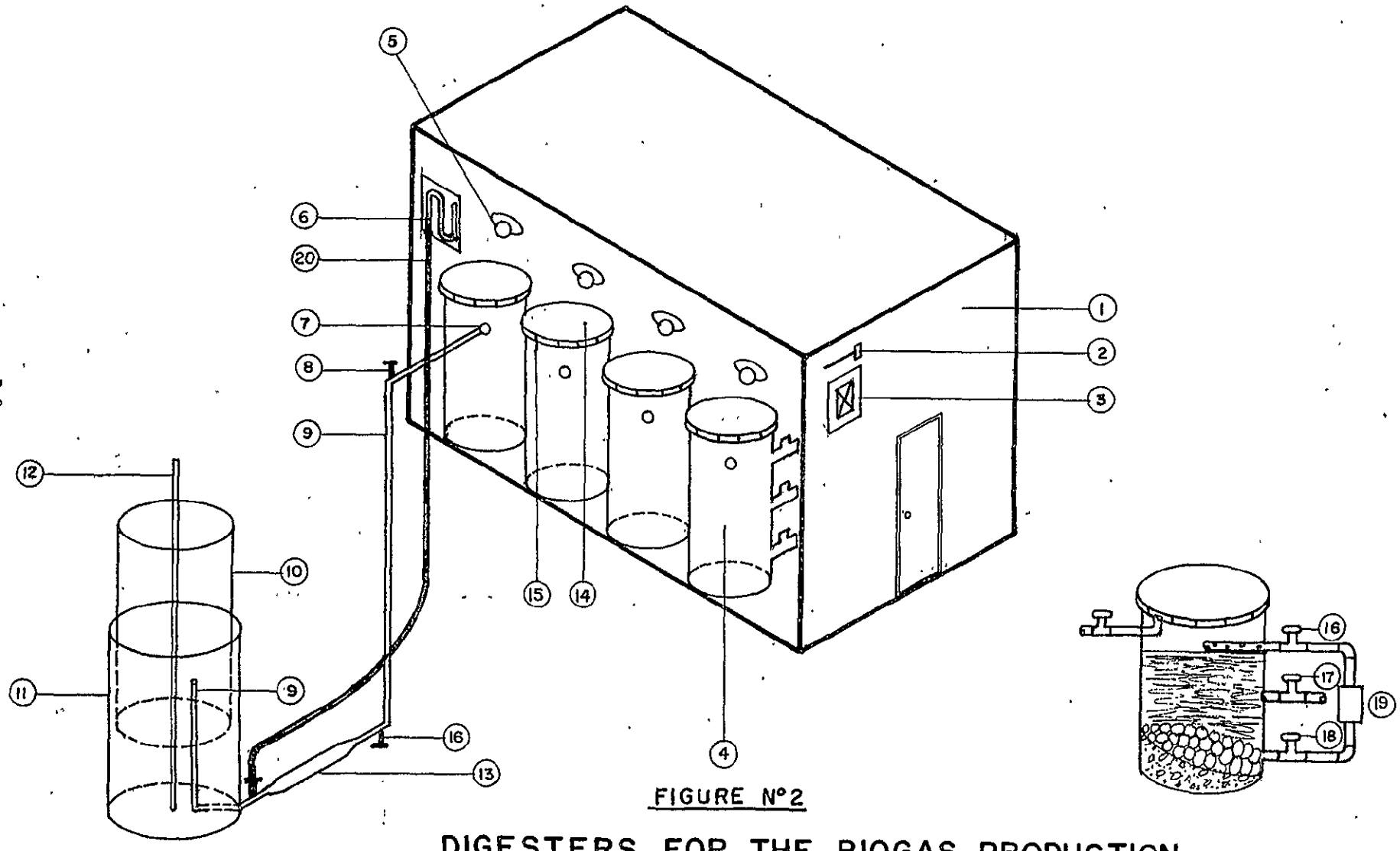


FIGURE Nº2

DIGESTERS FOR THE BIOGAS PRODUCTION
TYPE BATCH

REFERENCES

1. Thermal case
2. Thermostat
3. Switch
4. Digester
5. 100 watt bulb
6. Manometer (Water Column) 6-7.5
7. Outlet of Biogas
8. Biogás outlet key
9. Biogas pipe
10. Gasometer
11. Gasometer holder drum
12. Central guide
13. Filter pipe for SH_2
14. Digester cap
15. Metallic belt
16. Key with disperser pipe of liquid
17. Lock gate for sample taking
18. Lock gate for recycling of liquid effluent

FIGURE N° 3 PHASES IN THE SAMPLE TREATMENT

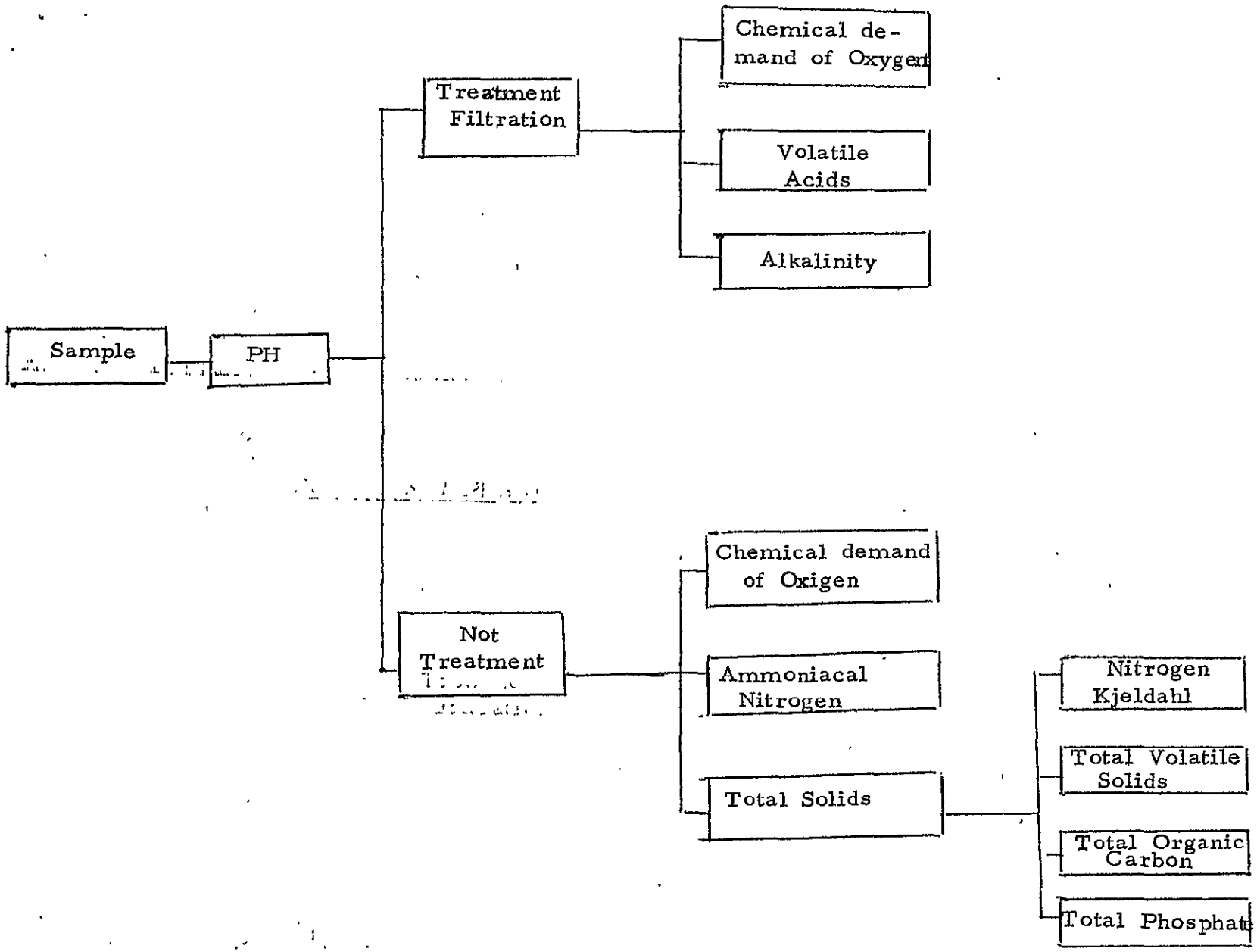


TABLE N° 3

WEEKLY WORK PLAN

Hour \ Day	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
	Pilot Plant	Pilot Plant	Pilot Plant	Pilot Plant	Pilot Plant	Pilot Plant	Pilot Plant
09.00	-Measure of gas ometer and manometer height -Outer temperature 36°C -Internal temperature 32°C	Idem.	Idem.	Idem.	Idem.	Idem.	Idem.
09.30	-Gas composition analysis (in plant)	-To take out or burn the gas	-Re-circulation of liquid effluent or emanant	-To take out or burn the gas	Re-circulation of liquid effluent or emanant	-To take out or burn the gas	-To take out or burn the gas
10.30	-Re-circulation of liquid effluent or emanant -pH in situ -Burn or take out the gas		-pH in situ -Burn or take out the gas.				
	In the laboratory	In the laboratory	In the laboratory	In the laboratory	In the laboratory		
	Checking of reactives for analysis	Preparation of reactives for analysis standarization	pH analysis Alkalinity Volatile acids Ammonia nitrogen and so on.	Continue with the analysis	Continue with the analysis		

¡GUARDI As maximum time for closing the digester valve: 2 hours.

3.2.2 Analytical methods

The major part of the analytical methods were taken from "The Standard Methods for the examination of Water and Wastewater" 15th. ed.

Because the nature of the samples (solid and semi-solid residues with a great organic contecnt), the procedure of analysis was adapted and pre-treatment of samples was realized.

- Volatiles acids.-

  The three indicated standard methods were tested, choosing especifically the steam distilation method with a previous sample pre-treatment, because doing that, we could obtain recovery percent ages of about 98%. This analysis was made in a micro-Kjeldhal unit, because its versatility and great distilation efficient.

- Alkalinity.-

  The sample natural coloration did not allow us the use of the indicator recommended by standard methods. 5 ml. of filtrated sample was tittled potenciometrically with 0.02 N sulphuric acid up to 4.5 pH.

- Oxygen chemical demand.-

  The digestion methods with concentrated sulfuric acid was used for two hours with 0.25 N potassium bichromate, tittling the excess of K_2, Cr_2, O_7 with Mohr salt using ferroingas indicator.

- Total phosphorus.-

  The ascorbic acid method was used. It consist on the digestion of the sample with HNO_3 - H_2SO_4 (Proportion 5/1). The product of the digestion is diluted and neutralized. Then, 8 ml. of a mixture of ascorbic acid, H_2SO_4, ammoniun molybdate, and tortrate of sodium and potasium was added, obtaining a blue colour that is measured in the espectrofotometer at 880 mμ

- Nitrogen.-

  Using 5 ml. of original sample and according to the Kjeldhal method, organic and amoniacal nitro gen was analized.

- Total organic carbon.-

  Because the lack of the appropriate instruments, COT was determined using the "Walkley-Black" method.

  The principe of the method is the same as the DQO determination: oxidation in an acid medium by the action of potassium bichromate. The digestion is realized in cold, for 30 minutes and then it is titled with amoniacal ferrous sulphate to know the quantity of remanent bichromate and determine the organic carbon making the use of the chemical equivalents.

- pH Measuring.-

  The sample colour do no allow us to obtain exact readings with pH indicator paper. Then the pH potentiometric measuring was used.

- Total solids.-

  It was determined by the gravimetric method drying the sample between 103°C - 105°C.

- Volatile solids.-

  They are fuel solids up to 550 $\pm$ 50°. It was determined gravimetrically after burning of the sample at that temperature.

  Respecto to the analysis of gases, it was made through an empiric method, measuring the solubility of CO_2 in a solution of sodium hydroxide with the formation of sodium bicarbonate; in this method we assumed that biogas is compounded only by methane and CO_2

  Recently, we bought an ORSAT-gas analyzer, model FISHER which allowed us to obtain a better efficiency in gas analysis.

The present work reports the results of the analytic evaluations according to our limitations in materials and equipment, trying to follow as much as possible the methodology given by DYNATECH R/D Company.

3.3 Operative process

According to the methodology of investigation, the work program consisted on the evaluation of different variables, that have some influency in the anaerobic digestion process under determined conditions.

In this part, the digestion of a mixture of corn husk and cattle manure as inoculum was evaluated.

3.3.1 Pre-fermentaion of raw-materials.-

The farm residues were taken from the Universidad Nacional Agraria (La Molina). They were submitted to an aerobic pre-fermentation in order to take out the waxy hardwood of cellulosic materials and help the anaerobic digestion.

The corn husk was chopped in small pieces of 3 to 4 cm. and were piled by layers adding only water.

This pre-fermentation had a duration of 2 weeks, at the end of these 2 weeks, the digesters loading was carried out obtaining temperatures as high as 80°C.

3.3.2 Preparation of the load.-

To load the digester with the selected materials, in determined substrate quantity with a C/N/P relation of 100/5/1 was needed.

The quantities were determined from the chemical composition of raw material (See Table N° 4).

To establish that balance, it was requiered the addition of chemical ferlizer as urea and diammoniacal phosphate which composition was reporting in Table N° 5.

According to the research methodology (Table N°1), The calculation for determining the load weight (based on total solids concentration in the mixture) was made.

A summary of this calculation is presented in Table N° 6. In the Eclosure N° 1 there is an example of teoric calcules for the digester N° 1

TABLE N° 4

CHEMICAL ANALYSIS OF FARM AND CATTLE WASTES

Raw Material	% S.T.	% C	% N	% P	% P_2O_5
Manure of Cattle	25.73	42.879	3.416	0.97	2.23
Corn Husk	87.22	52.29	0.9235	0.087	0.20

TABLE N° 5

CHEMICAL COMPOSITION OF THE EMPLOYED FERTILIZERS

Fertilizer	PM	% C	% N	% N-NH_4	% P	% P_2O_5
Urea $(NH_2)_2$ CO	60	20	46.6	46	-	-
Phosphate diammonic $PO_4H(NH_4)_2$	132	-	21.21	21	23.48	53.8

TABLE N° 6

SUMMARY OF THE CALCULATIONS TO CHARGE A DIGESTER OF 200 LITERS

Digesters / Type of materials	Calculations			
	1	2	3	4
Corn Husk (Kg.)	22	33.99	33.02	35.15
Manure	9.72	16.32	16.32	8.18
Urea (Kg.)	0.596	0.986	0.986	1.079
Phosphate Biammonic (Kg.)	0.366	0.606	0.606	0.694
Calcium oxide (Kg.)	0.254	0.421	2.011	2.011
Water (liters)	103.5	75	75	75

3.3.3 Digesters operation and digestion control.-

The selected process of anaerobic digestion was batch loading, evaluated in a period of 90 days.

Daily, the biogas production was determined measuring the volume, pressure and temperature of gas produced and accumulated in the gasometers.

Biogas samples were taken and analized (methane); the excess of biogas was used in combustion tests. The determination of pH, alkalinity and volatiles acids were realized weekly; and the rest of the analysis were made monthly as indicated in the analytic work chronogram. (See Table N° 7).

TABLE N° 7

CHRONOGRAM OF ACTIVITIES

Activities / Months	June				July				August				September				October			
Weeks	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
- Conditioning of Digesters	X	X																		
- Elaboration of Farming and Cattle Wastes			X																	
- Digesters Charging				X																
- Taking of Solid,(initial and final) samples				X												X				
- Taking of Liquid Effluent Sample.																				
100 ml					X	X	X		X	X	X		X	X	X					
200 ml				X				X				X				X				
- Effluent Chemical Analysis																				
. Total Solids				X				X				X				X				
. Volatile Solids				X				X				X				X				
. Chemical Oxygen Demand				X																
. Nitrogen Kjeldahlt				X																
. Total Phosphate				X																
. PH				X	X	X	X	X	X	X	X	X	X	X	X	X				
. Alkalinity				X	X	X	X	X	X	X	X	X	X	X	X	X				
. Volatile Acids				X	X	X	X	X	X	X	X	X	X	X	X	X				
- Analysis of Gases				X	X	X	X	X	X	X	X	X	X	X	X	X				
- Discharge of Digesters																X				
- Elaboration of the Final Report																	X	X	X	

4- RESULTS

4.1 Biodigesters Evaluation Results

In the enclosure N° 1, the data tabulation is presented - as the drafts obtained during the evaluation of each digester: Biogas production per day, weekly production average, pH control, alkalinity, total volatile acids (TVA), COD - and so on.

Because ther were problems in the implementation of some - initial analysis, these reports partially (TKN, COD) and - in other cases, didn't reach as total phosphore.

4.2 Biogas Production

In tables N° 1, 2 (enclosure 1) are reported data of diary, weekly control and weekly average production per solid/gr,- destroyed volatils, the same that are diagrammed in funtion of the evaluation time. Graphic N° 1, 2.

In these charts you can observe that the biogas quantity - produced, is more in the Digester N° 1 which is operated to 15% t.s. load with a relation in dry weight of organic residues (9: 1°), getting the major Biogas production between the fourth and seventh evaluation week. In reference to the digesters N° 2 and 3 with the 30% s.t., these obtain its major production between the eighth and eleventh week to the same - relation in dry weight as described before.

In the seme way, you can observe that the Digester N° 4, the biogas production is less, in relation with the others digesters. Is in this way that, you can obtain its major production between the tenth and thirteenth evaluation week, maintaining the same total solid concentration, making a variation in the dry weight proportion of the organic residues in 9.5: - 0.5.

Its important to indicate the formation of laitances that were formed in the digesters (this was observed while the unload - was made), being the variables between them, the laitances' - heights.

In the Digester N° 4 the laitance's height had 18 cm. average and the others had 12 cms. because of the fibrous material no-digestionable, this meant that in the Digester N° 4 the biogas production was affected, as it was the total digestion of the organic material.

TABLE Nº 8

EVALUATION SUMMARY OF 200L - DIGESTERS

DIGESTERS		1	2	3	4
MAXIMUM PRODUCTION cm3/day		138,609.78	110,440.49	105,392.83	106,684.07
MAXIMUM EFFICIENCY	cm3/cm3 dig	0.693	0.552	0.527	0.5334
	cm3/cm3 mass	0.840	0.669	0.6387	0.6466
WEEKLY AVERAGE MAXIMUM PRODUCTION. cm3/day		117,684.52	80,028.63	80,672.29	76,199.51
AVERAGE EFFICIENCY	cm3/cm3 dig	0.5884	0.4001	0.4034	0.381
	cm3/cm3 mass	0.7132	0.485	0.489	0.462
ACCUMULATED VOLUME	cm3	4'805,099.4	4'156,459.31	4'061,433.50	3'035,933
	liters	4,805	4,156	4,061	3,036
EVALUATION TIME (days)		91	91	91	91

The Biogas production accumulated for an evaluation period of 91 days (see chart N°8*) is more in the Digester N° 1 to 15% s.t., which is followed by the Digesters 2 and 3 with - the 30% s.t. (thirty percent); being the middle and maximum efficient the best.

In the enclosure N° 1, table N° 3 show the cm3 biogas pro - duced per grame of distroyed volatile solid; the major biogas production per grame of distroyed volatile solids have direct relation with weekly average Gas Production Table N° 2.

Making a comparison between the obtained results, with data- showed in the table N° 10 (which were operated in evaluation conditions that are showed in chart N° 9), it was determined that, in the evaluated digesters to high control temperatu- res (32° C), in the digestion mass the efficient increases- in the Biogas production, being longer in the Digester N° 1. We sometimes had problems during the evaluation process by - electric fluid cut. This made that the biogas production - were less than before, getting to temperatures of 22 to 24°C in the digestion mass, but when the temperature increased - the bacterial digestion activity, was reactived.

This heating system is suggested in winter time but it is - not convenient in summer time. Because of this, we had plan ned the following evaluation conditions in the second phase: (see Table N° 11).

4.2.2 Biogas Composition

In table N° 5 (enclosure 1) is shown the gases analysis by the empiric method and Orzat Analyzer, existing a big dif- ference between both systems used.

The Metano gas concentration is major in the Digester N° 4, followed by the Digesters N° 2 and 3, and in a shorter per- centage, the Digester N° 1.

This, make us think that a more adding of dragged corn; the more biogas efficient is produced.

4.2.3 Volatils Acids

In table N° 7 and draft N° 4 you can observe in the Digester N° 1 that the volatile acids concentration is in the permis- sible ranges for the biogas production. In respect with the others digesters, the total solid concentration is major. - Consequently, the organic matter quantity is bigger and also it is suceptible of being solubilized and transformed to - acids, raising in this way, the volatile acids concentration.

TABLE Nº 9

EVALUATION CONDITIONS IN DIGESTERS OF 200L CAPACITY

DIGESTERS / VARIABLES	O_1	O_2
RAW MATERIAL	Cor husk : cattle manure	
RATIO IN DRY WEIGHT	6 : 1	1 : 3
RATIO C/N	13	25
DILUTION (% ST)	26	30
BUFFER % Ca CO_2	2%	
TEMPERATURE °C	Environment	
SHAKING	None	
SYSTEM	Batch	

1982

TABLE Nº 10

EVALUATION SUMMARY OF 200L - DIGESTERS

DIGESTER		O_1	O_2
MAXIMUM PRODUCTION (cm3/day)		96,580	107,236.3
MAXIMUM EFFICIENCY	cm3/cm3 dig	0.48	0.536
	cm3/cm3 mass	0.57	0.631
WEEKLY AVERAGE MAXIMUM PRODUCTION (cm3/day)		67,716	88,102.61
AVERAGE EFFICIENCY	cm3/cm3 dig	0.33	0.441
	cm3/cm3 mass	0.39	0.518
ACCUMULATED VOLUME	cm3	3'816,219	4'549,059.03
	liters	3,816	4,549
EVALUATION TIME (days)		91	91

1982

TABLE N° 11

EVALUATION CONDITIONS IN 200 L - DIGESTER PHASE II

DIGESTERS / VARIABLES	1	2	3	4
Raw Material	Corn husk + cattle manure			
Ratio in dry Weight	9 : 1			
Ratio C/N/P	100 : 5 : 1			
Dilution % ST	15 ó 20			
Buffer % Ca CO_2	0	2	4	6
Temperature	30 - 32°C			
Shaking	Recycling of liquid effluent			
System	Batch			

In the same manner, you can observe that as the evaluation days passed, the volatile acids has been raising, maintaining themselves for a period in order to decrease and in some cases, to make better the biogas production.

Due to this, we could say that it is maintaining in a dynamic balance that is established between the activity of acidogenic bacteriums and methanogenic bacteriums.

The elevated values that are presented, are surprising, because of this, we assume, that there were chemical fertilizers influence, used for establish the relation C/N/P.

The Biogas production, in these cases, were low.

4.2.4 Alkalinity

Is a process of anaerobic digestion is being made, a natural alkalinity production is presented.
This tends to raise as the retention time process is raising also. But in the Graphic N° 5 and table N° 8; you could appreciate manifestly, the concentration buffer influence aggregated to the digesters 3, 4, 5 and 6.

They have a similar tendency in its conduct, registering higher values in which the biogas production is low; as the evaluation days passed, these values tend to fall, raising in this way, the Biogas production, where a balance in the process is determined.

4.2.5 pH

The pH depends on the relation between the volatils acids and the alkalinity, indicating the digester cushion capacity. In Graphic N° 3 and table N° 6 the pH conduct is showed. Initially it is high, then is established between 7 to 8, where the Biogas production is maintained during the evaluation process, being ones more efficient than others.

4.2.6 Owygen Chemical Demand

In table N° 9, you can appreciate the obtained values for each control period, where we can consider that in the D_3 exists an estabilization of the organic material, getting efficient in the degradation and major biogas production.

The high values are considered less efficient in the degradation of the organic material as in the biogas production also.

4.2.7 Ammoniacal Nytrogen and Total

If we considered that the principal form of alkalinity are the bicarbonates which result from the ammoniac formation- CO_2, H_2O to produce ammoniac bicarbonate, and that this increase when the retention time raises; we could then, infer that a major ammoniac bicarbonate formation and the retention time, will be major the ammoniacal nytrogen accumulated and the organic nytrogen descomposition.

Consequently, to major time, we could obtain acids of major fertilizer content. See table N° 10 and 11.

5. CONCLUSIONS AND RECOMENDATION

1) Dilution degree of organic matter to be used is so important because it has a great influence in biogas production showed a better biogas production at 15% of total solids with a week average of 117,684.52 cm^2 per day and an efficiency of 0.7132 cm^3 biogas/cm^3 of mass.

2) Week average maximum production is given with digestor N° 1 between the 4th. and 7th. week, from digestor N° 2 and 3; at 8th. and 11th. week; and from digestor 4 at 10 th. and 13th. week.

3) This time sequency in high degradation of digested organic matter is related with stirring of the mixture which is an important factor in biogas production from plant residues by forming scum layer.

4) Evaluation of fuel gas production is at 7 day when digestors are operated at 15% of total solids.

5) Week average maximum biogas production is obtained from digestor N° 1 with 49.68 cm^3 of Biogas/g. of destroyed volatile solids per day during 91 days at 32 ° C of temperature.

6) Higher concentrations of methane are obtained at higher amounts of maize stubble and manure.

7) There is an inverse relation among volatil acids production and alkalinity during the evaluation process.

8) There is no great difference in biogas production when digestors are operated at high and low buffer concentrations.

9) Fertilizer power and stabilization degree of digested muds increased their quality with time.

10) In winter time is convenient to use heater system for mesophylic conditions.

11) Higher gas production were obtained using heater system in winter time than utilizing digestors at room temperature in summer.

12) Operation temperature must be between 30 to 35° C to obtain better efficiency whether gas production increases nearly optimum temperature, moreover biogas production speed also increases.

13) Better contact among bacteria and organic matter is obtained stirring the mixture, moreover an uniform internal temperature results. Consequently at high total solids concentrations, a

mechanic system must be install so that the scum layer could be break and gas evolve.

14) Is possible to use simple procedures and digestors for ana - erobic digestion of farming residues without adding fertilizers.

15) It's advisable to continue with the second part of the project so that technologycal design of anaerobic treatment of farming residues could be conclude.

ANNEX N° 1

TABLE N° 1

GAS PRODUCTION(cm^3/day)

Days \ Digesters	1	2	3	4
6	--	24,178.30	--	--
7	14,233.49	21,516.48	--	--
8	26,574.69	32,666.09	16,073.28	--
9	46,614.42	59,933.83	21,103.31	--
10	74,475.06	50,170.45	22,261.30	--
11	85,058.34	51,428.32	31,715.38	--
12	74,437.58	61,302.06	37,147.27	17,301.91
13	88,256.19	69,076.21	59,442.28	24,784.47
14	74,909.42	94,691.93	56,299.83	15,012.27
15	85,413.77	73,041.52	89,742.36	38,356.62
16	94,822.33	82,094.20	74,410.78	35,731.90
17	79,678.34	83,400.57	92,785.25	41,807.07
18	90,403.15	69,926.26	66,550.35	33,402.17
19	108,916.82	83,323.11	70,911.87	36,550.91
20	101,673.30	--	59,285.85	32,347.16
21	102,899.35	--	60,457.66	40,173.96
22	--	60,228.44	--	--
23	--	60,228.44	--	--
24	89,984.44	--	--	--
25	100,710.77	63,434.94	59,728.71	38,203.51
26	125,519.90	52,300.01	54,140.27	43,861.12
27	121,314.32	79,812.10	71,103.46	50,988.93
28	125,557.88	54,825.35	58,676.28	--
29	83,903.63	80,073.86	46,047.61	35,613.43
30	137,089.83	70,089.83	78,498.50	42,381.86
31	134,090.15	65,622.01	86,278.73	--
32	125,007.94	--	--	--
33	--	64,548.93	78,254.52	32,686.85
34	--	--	--	--
35	--	--	--	--
36	--	--	--	--
37	--	--	--	--
38	131,518.06	62,415.31	70,653.18	27,573.19
39	136,869.56	79,469.97	80,797.48	29,911.59
40	138,609.78	75,549.03	86,872.84	23,801.74
41	--	--	--	--
42	133,606.90	--	--	--
43	133,606.91	66,560.02	73,963.31	32,316.28

Days \ Digesters	1	2	3	4
44	97,306.59	53,963.65	62,077.86	-
45	100,059.75	60,602.85	71,552.34	29,599.02
46	102,799.09	65,551.13	73,173.60	35,065.60
47	--	--	--	25,740.26
48	79,832.52	72,153.58	73,451.12	25,740.26
49	--	--	--	25,740.26
50	74,580.70	65,432.03	68,695.16	36,731.31
51	56,851.67	--	59,274.19	30,247.00
52	65,497.31	68,668.62	72,994.96	29,636.78
53	66,906.61	75,931.81	79,994.47	50,599.28
54	--	--	--	--
55	64,950.38	65,795.64	67,492.73	66,720.75
56	--	--	--	--
57	80,517.33	110,440.49	103,203.93	73,974.25
58	67,458.65	97,117.31	96,265.98	68,896.68
59	48,870.82	86,091.69	89,700.70	61,487.57
60	50,402.76	86,489.76	87,109.03	66,581.63
61	--	--	-- --	--
62	63,908.32	67,950.83	67,831.23	67,707.11
63	--	--	--	--
64	50,207.44	83,551.03	82,548.09	81,890.95
65	52,472.27	88,649.46	88,212.80	88,556.32
66	36,842.87	71,363.86	74,225.65	73,914.10
67	36,842.87	71,363.86	74,225.65	73,914.10
68	--	--	--	--
69	35,507.77	69,155.62	69,489.93	68,712.12
70	--	--	--	--
71	57,245.86	93,299.00	91,639.26	98,535.44
72	33,271.33	78,655.00	79,495.72	78,946.49
73	37,235.85	81,232.60	85,029.67	80,550.96
74	35,598.61	100,868.49	105,392.83	106,684.07
75	33,246.14	--	--	--
76	33,246.14	69,559.44	70,623.29	63,537.78
77	33,246.14	--	--	--
78	31,988.73	61,994.06	63,227.89	62,372.28
79	45,493.47	73,792.19	66,329.35	79,233.02
80	32,479.92	57,366.35	56,453.76	70,780.73
81	36,405.68	67,017.46	56,735.52	66,136.00
82	31,774.03	--	--	--
83	31,774.03	69,281.39	45,004.17	69,497.70
84	31,774.03	--	45,004.17	--
85	33,164.92	52,889.45	39,329.39	75,321.88

Days \ Digesters	1	2	3	4
86	28,357.01	46,303.52	34,498.26	63,666.59
87	32,102.79	49,359.85	29,023.82	74,836.17
88	31,938.73	47,800.79	27,237.74	78,410.43
89	29,282.05	41,691.44	24,686.45	74,532.87
90	29,449.35	41,779.17	13,058.76	77,104.55
91	17,596.32	30,616.76	18,937.55	61,524.08

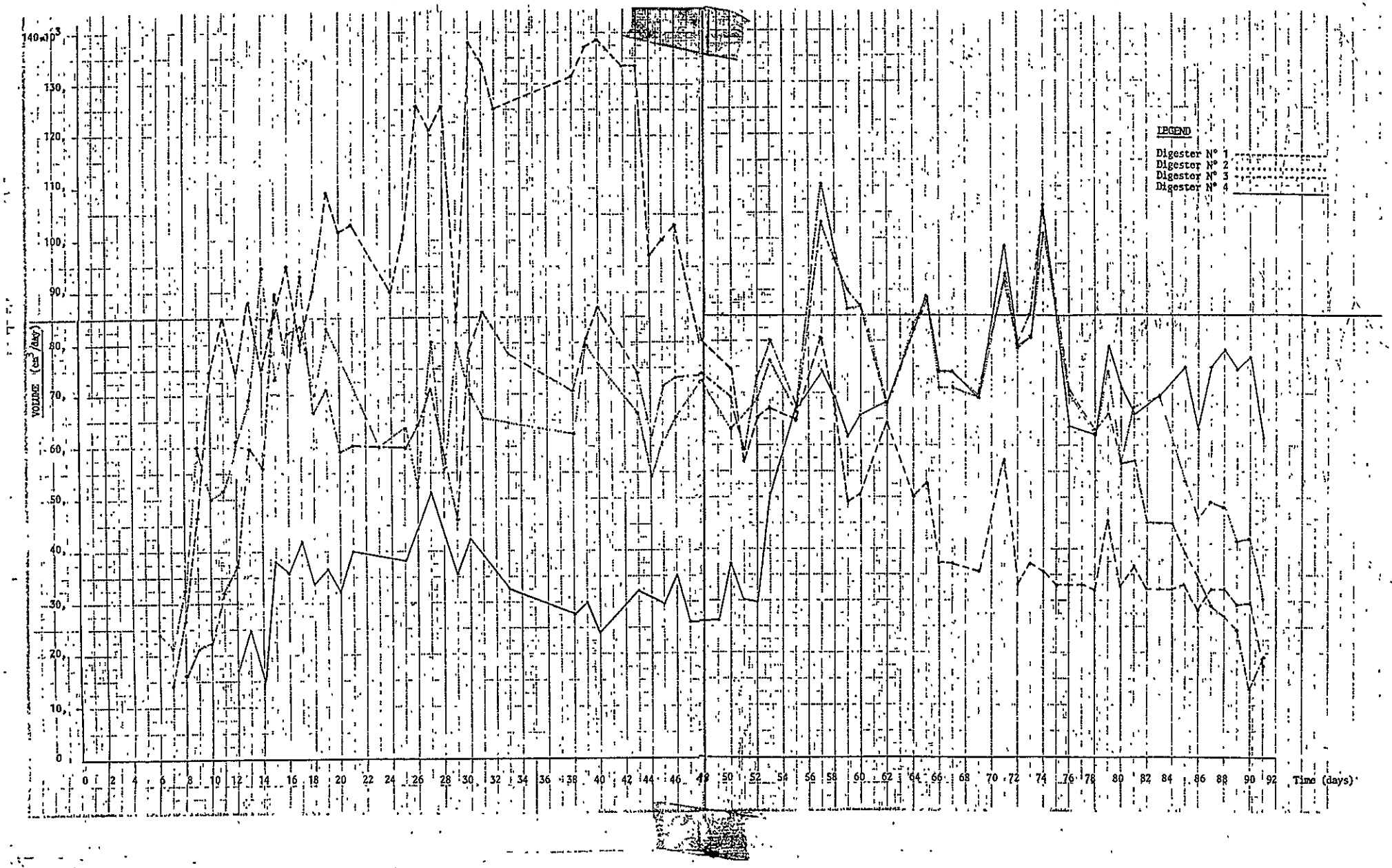

LEGEND
Digester N° 1
Digester N° 2
Digester N° 3
Digester N° 4
VOLUME (m³/day)
140x10³
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92
Time (days)

TABLE N° 2

WEEKLY AVARAGE GAS PRODUCTION (cm/day)

Digester / Week	1	2	3	4
1	---	---	---	---
2	67,189.39	59,895.56	34,863.24	8,156.95
3	94,829.58	78,357.13	73,449.16	36,909.97
4	112,617.47	62,120.17	60,912.18	44,351.19
5	120,249.45	70,083.66	72,269.84	36,894.05
6	135,151.08	72,478.10	79,441.17	27,095.51
7	102,720.09	63,766.27	70,841.65	29,033.61
8	65,757.33	68,957.03	69,690.30	42,787.02
9	62,231.58	89,617.82	88,822.29	67,729.45
10	42,374.64	16,816.77	77,740.42	77,397.52
11	38,013.44	84,722.91	86,436.15	85,650.95
12	34,519.98	65,890.29	53,965.58	69,603.95
13	28,841.60	44,348.71	26,681.71	72,199.51

GRAPHIC N° 2

WEEKTY AUARAGE GAS PRODUCTION VS

EVALUATION TIME

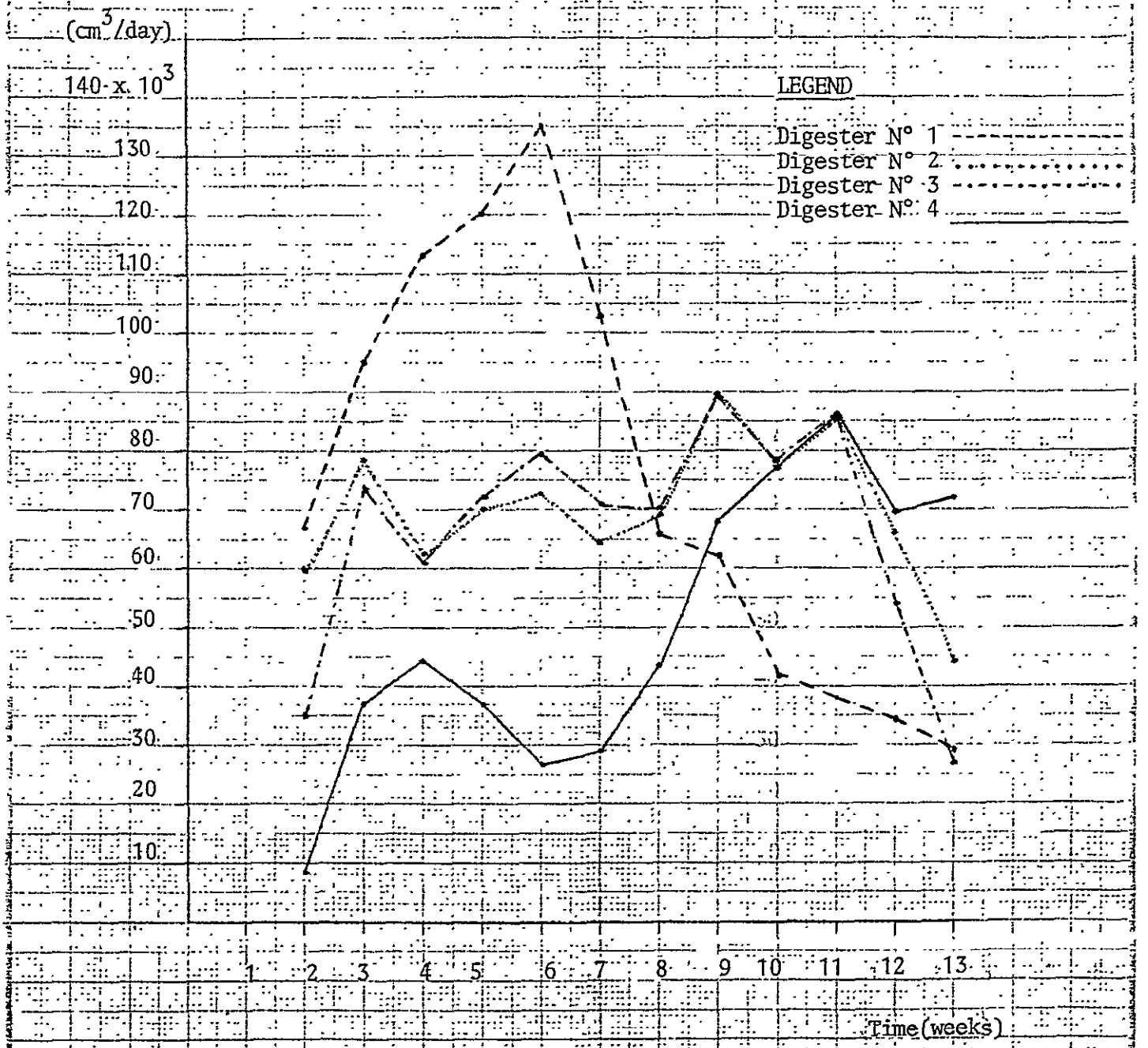


TABLE N° 3

WEEKLY AVARAGE GAS PRODUCTION

(cm^3/gr s.v. destroyed/day)

Digester / Week	1	2	3	4
1	-	-	-	-
2	29.75	19.59	8.97	2.38
3	39.41	25.63	18.90	10.77
4	49.87	20.32	15.67	12.94
5	49.98	18.36	20.05	10.02
6	56.17	18.99	22.05	7.36
7	42.69	16.71	19.66	7.88
8	27.33	18.07	19.34	11.62
9	25.86	23.48	24.65	18.39
10	23.65	30.45	32.62	26.71
11	21.21	33.58	36.26	29.56
12	19.26	26.12	22.64	24.02
13	16.09	17.58	11.19	24.92

TABLE N° 4

WEEKLY DEGRADED VOLATILE SOLIDS

(gr.)

Time (week) since to \ Digester	1	2	3	4
1 - 4	2,258.19	3,057.3	3,887.18	2,427.85
5 - 9	2,406.06	3,816.35	3,603.59	2,682.20
10 - 13	1,792.08	2,523.07	2,383.49	2,897.41

TABLE N° 5

DIGESTERS GASES ANALYSIS

Digesters / Weeks	1			2			3			4		
	% O_2	% CO_2	% CH_4	% O_2	% CO_2	% CH_4	% O_2	% CO_2	% CH_4	% O_2	% CO_2	% CH_4
1	-	-	-	-	-	-	-	-	-	-	-	-
2	-	29	71	-	27.4	72.6	-	18.2	81.8	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-
4	-	30	70	-	27.8	72.2	-	25.8	74.2	-	29.4	70.6
5	-	-	-	-	-	-	-	-	-	-	-	-
6	-	15.6	84.4	-	11.2	88.8	-	8.8	91.2	-	-	-
7	-	10.1	89.9	-	12.4	87.6	-	12.3	87.7	-	11.6	88.4
8	-	-	-	-	-	-	-	-	-	-	-	-
9	0.6	42.6	56.8	0.2	36.6	63.2	0.2	36.4	63.4	2.2	36.4	61.4
10	-	-	-	-	-	-	-	-	-	-	-	-
11	0.2	41.6	58.2	0.4	30.8	68.8	0.2	33.1	66.7	0.1	29.7	70.2
12	0.2	40.4	59.4	0.5	30.4	69.1	0.2	32.1	67.7	0.2	29.8	70.0
13	0.4	40.6	59.0	0.4	31.8	67.8	0.4	31.2	68.4	0.2	32.6	67.2
14	0.2	36.6	63.2	0.4	28.6	71.0	-	-	-	0.4	32.8	66.8
15	-	-	-	0.4	28.0	71.6	-	-	-	0.2	33.0	66.8

Note: The first seven weeks was carried out the analysis using the empiric method. In the following weeks the orsat gases analyser was used.

TABLE N° 6

pH

Weeks \ Digesters	1	2	3	4
1	9.18	9.17	12.38	9.09
2	8.25	8.45	8.85	8.85
3	6.75	7.21	7.16	7.27
4	7.83	7.89	7.70	7.59
5	7.70	7.68	7.98	7.45
6	8.15	8.01	7.60	8.02
7	7.66	7.59	7.58	7.04
8	7.70	7.50	7.82	7.18
9	7.78	7.67	7.85	7.45
10	7.73	7.55	7.45	6.79
11	7.57	7.65	7.61	7.63
12	7.34	7.50	7.57	7.44
13	7.51	7.91	7.85	7.72

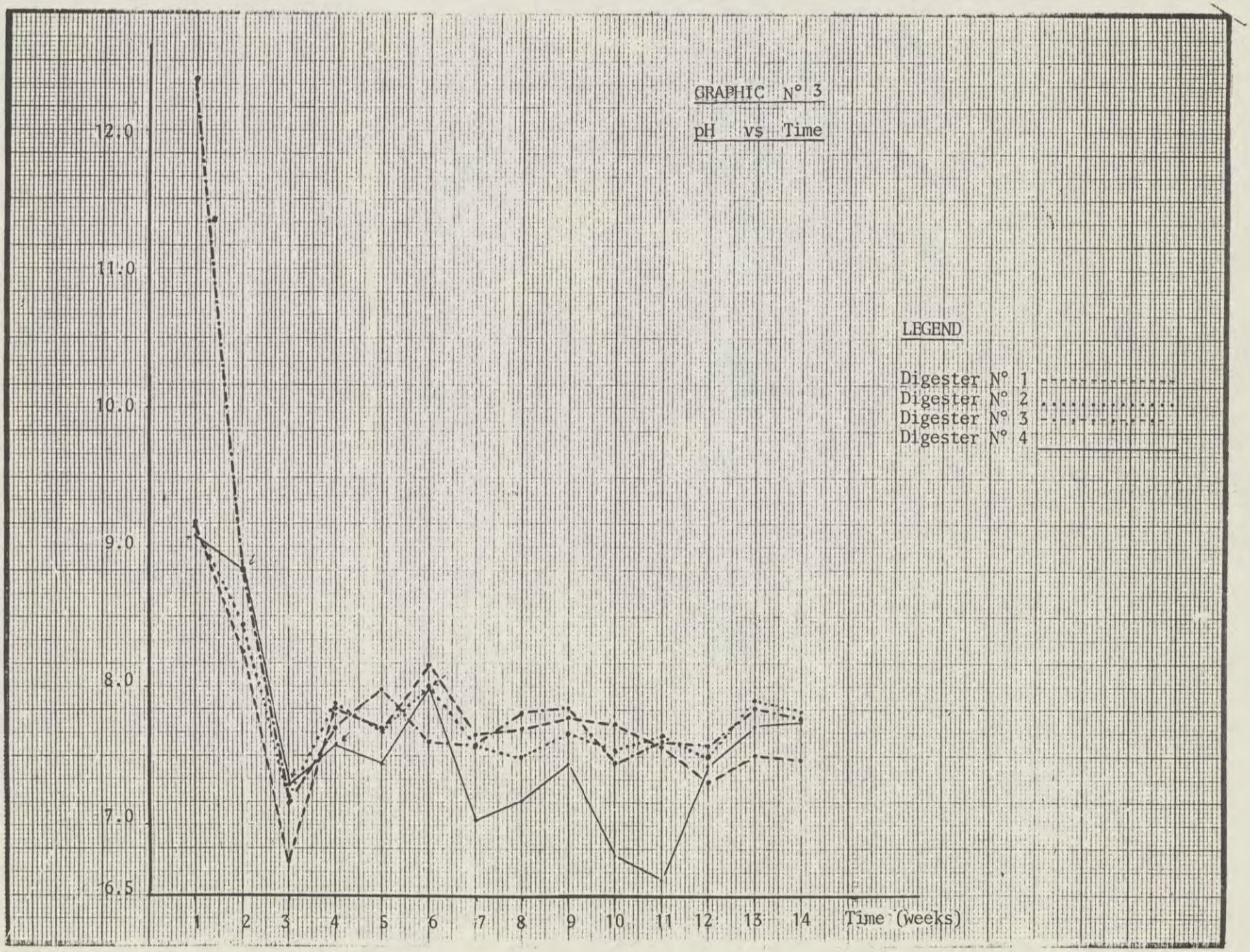

GRAPHIC N° 3
pH vs Time
12.0
11.0
10.0
9.0
8.0
7.0
6.5
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Time (weeks)
LEGEND
Digester N° 1
Digester N° 2
Digester N° 3
Digester N° 4

TABLE N° 7

VOLATILES ACIDS

(mg/l.)

Weeks \ Digesters	1	2	3	4
1	-	-	-	-
2	880.94	3,804.45	2,843.17	2,671.56
3	3,988.45	7,341.18	9,250.25	8,914.29
4	3,936.65	9,956.95	9,684.57	14,901.56
5	3,570.02	9,224.88	9,511.12	13,260.00
6	1,584.00	10,195.90	14,747.67	15,536.64
7	1,244.00	9,771.00	11,895.00	14,565.60
8	546.21	7,646.94	15,293.88	14,322.84
9	182.00	8,137.80	6,296.40	12,533.40
10	118.80	4,989.60	4,811.40	10,276.20
11	59.40	1,722.60	1,544.40	5,880.60
12	178.00	1,900.80	1,306.80	4,573.80
13	118.80	712.80	831.60	4,811.40
14	59.4	356.40	356.40	4,098.6

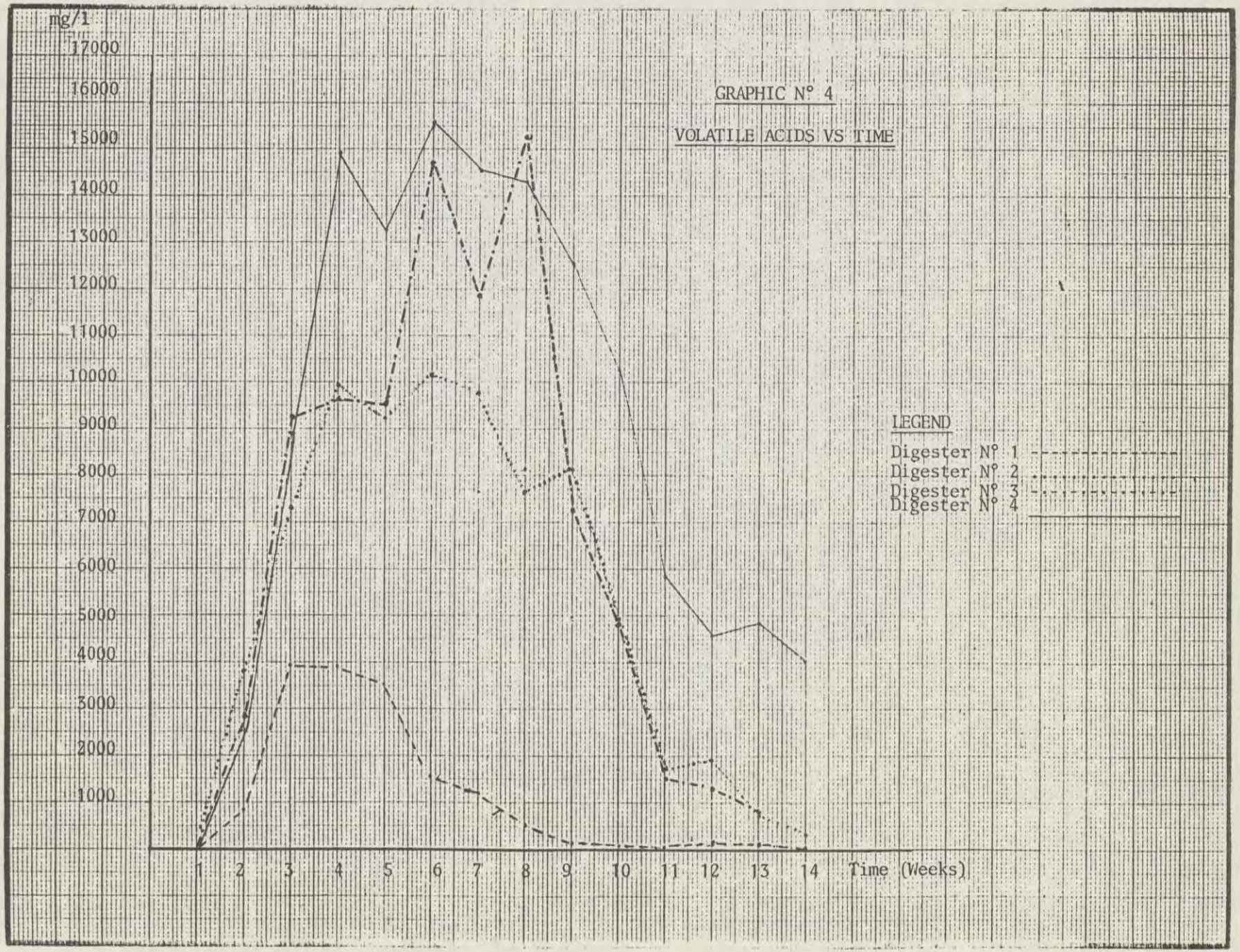

mg/l
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Time (Weeks)
GRAPHIC N° 4
VOLATILE ACIDS VS TIME
LEGEND
Digester N° 1
Digester N° 2
Digester N° 3
Digester N° 4

TABLE N° 8

ALKALINITY

(mg/l)

Weeks \ Digesters	1	2	3	4
1	9,665.76	17,286.84	6,505.80	6,505.80
2	6,459.33	10,641.63	8,968.71	11,385.15
3	8,829.30	15,288.63	16,171.56	15,753.33
4	11,245.74	17,426.25	10,000.34	17,008.02
5	10,865.12	17,294.48	12,032.48	17,244.60
6	7,276.50	12,111.12	11,088.00	11,484.00
7	8,068.50	8,068.50	11,533.50	11,484.00
8	8,860.50	13,315.50	14,008.50	14,008.50
9	8,736.00	13,488.00	10,656.00	12,912.00
10	8,160.00	13,488.00	13,008.00	9,312.00
11	8,613.00	14,404.50	14,800.50	14,652.00
12	8,811.00	15,345.00	14,899.00	14,850.00
13	9,486.00	16,473.00	13,107.00	13,158.00
14	10,812.00	19,635.00	19,227.00	19,125.00

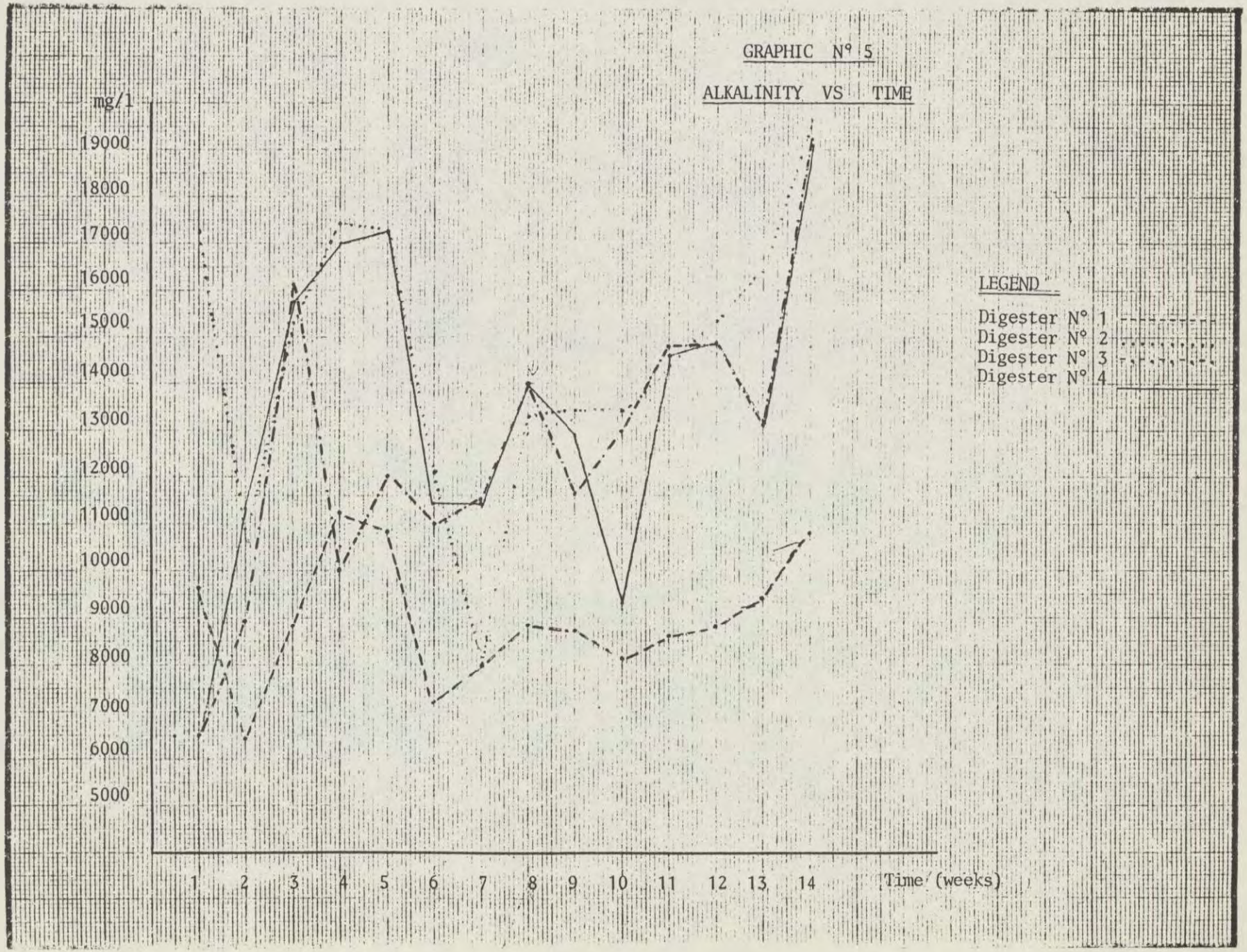

GRAPHIC N° 5
ALKALINITY VS TIME
mg/1
19000
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Time (weeks)
LEGEND
Digester N° 1
Digester N° 2
Digester N° 3
Digester N° 4

TABLE N° 9

CHEMICAL OXYGEN DEMAND

(mg/l)

Weeks \ Digesters	1	2	3	4
5	5,360	5,200	6,480	6,200
10	4,560	5,120	5,080	6,040
13	3,620	4,308	3,683	3,838

TABLE N° 10

* TOTAL NITROGEN

(%)

Weeks \ Digesters	1	2	3	4
1	1.871	0.6132	1.885	1.897
5	1.892	1.9	1.611	1.920
10	1.829	1.764	1.866	1.695
13	2.939	3.460	3.583	3.605

* dry sample

TABLE N° 11

AMMONIACAL NITROGEN

(mg/l)

Weeks \ Digesters	1	2	3	4
1	2702	5488	3500.00	1680
5	1929.31	3858.62	3071.38	3564.79
10	1720.32	3628.8	2688.00	3290.11
13	1806.11	3542.36	3315.102	6548.71

ANNEX N° 2

TABLE N° 1

CALCULATION FOR THE CHARGING OF 220 L - DIGESTERS

Raw Material	% C	% N	% P	% P_2O_5	% ST	C/N
Cattle Manure	42.879	3.416	0.97	2.23	25.73	12.55
Corn husk	52.29	0.9235	0.087	0.20	87.22	56.62

DIGESTER N° 1

1. Charge Volume : 165 liters
   Density : 1.025 Kg/liter
   Charge weight : $W = \rho \times V$

$$\boxed{W = 169.13 \text{ Kg.}}$$

- S.T. Concentration in the mixture to 15%
  $S_{tm} = 169.13 \times 0.15 = 25.37$ Kg.
- Knowing that
  $W_{ch} + W_{\varepsilon} = 25.37$ Kg. (1)

$$\frac{W_{ch}}{W_{\varepsilon}} = \frac{9}{1}$$

$$W_{ch} = 9\, W_{\varepsilon} \qquad (2)$$

- Replacing (2) in (1)

$$10\, W_{\varepsilon} = 25.37 \text{ Kg.}$$

$$\boxed{W_{\varepsilon} = 2.5 \text{ Kg.}}$$

$$W_{ch} = 25.37 - 2.5$$

$$\boxed{W_{ch} = 22.87}$$

- in most weight:

$$W_{\varepsilon} = \frac{2.5 \text{ Kg.}}{0.2573} = 9.72 \text{ Kg.}$$

$$W_{ch} = \frac{22.87}{0.872} = 26.23 \text{ Kg.}$$

TABLE N° 2

COMPOSITION OF THE EMPLOYED FERTILIZERS

FERTILIZER	PM	% C	%N	N-NH_4%	%P	% P_2O_5
Urea: $(NH_2)_2$ CO	60	20	46.6	46	--	--
Biammonic phosphate $(NH_4)_2$ H PO_4	132	--	21.21	21	23.48	53.8

Biammonic phosphate 1 Kg. ⟶ 0.235 Kg.

X ⟶ 0.086 Kg.

$\boxed{X = 0.366 \text{ Kg.}}$

Phosphate 1 Kg ⟶ 0.21 N

0.366 Kg. ⟶ x

X = 0.077 Kg. N

Biammonic phosphate = 366 gr.

Absent N = 0.355 - 0.077 = 0.278 N

Urea 1 Kg ⟶ 0.466 N

X 0.278 N

$\boxed{X = 0.596 \text{ Kg of Urea}}$

$\boxed{\text{Urea} = .596 \text{ gr.}}$

- Aggregate Buffer Quatity to 1%

25.37 ⟶ 100%

X 1%

$\boxed{X = 0.254 \text{ Kg.}}$

****

- Balance of Carbon :

$0.42879 \times \mathcal{E} + 0.5229 \times ch = C_t$

$0.42879 \times 2.5 + 0.5229 \times 22.87 = C_t$

$1.072 + 11.96$

$\boxed{13.031 = C_t}$

- Balance of Nitrogen :

$0.03416 \times \mathcal{E} + 0.009235 \times ch = N_t$

$0.03416 \times 2.5 + 0.009235 \times 22.87 = N_t$

$0.0854 + 2.112$

$\boxed{0.2966 = N_t}$

- Balance of phosphate

$0.0097 \times \mathcal{E} + 0.00087 \times ch = P_t$

$0.0097 \times 2.5 + 0.00087 \times 22.87 = P_t$

$0.02425 + 0.0198 = P_t$

$\boxed{0.044 = P_t}$

- Ratio C/N/P $\longrightarrow$ 100 : 5 : 1 Ratio : $\frac{C}{N} = 20$

Actual Analysis : 13.031/0.2966/0.044

We look expected : 13.031/0.652/ 0.1303 $N = \frac{13.031}{20} = 0.652$

Absent Nutrients Quantity

+ N = 0.355

+ P = 0.086

TABLE N° 1

EVALUATION PARAMETERS FOR BIOGAS PRODUCTION FROM FARMING AND CATTLE WASTES

Variables / Number of Digesters	1	2	3	4
- Raw Material	Corn husk + Manure of cattle			
- Formulation of Materiales (Retation in dry Weight)	9:1	9: 1	9: 1	0.5 : 0.5
- Ratio C/N	20	20	20	20
- Dilution (% TS)	15	30	30	30
- Bufler (% Ca0)	1	1	5	5
- Temperature (°C)	32	32	32	32
- Shaking	Recyeling of liquid effluent			
- System	Batch			
- Time of Evaluation (days)		90		

TABLE N° 6

SUMMARY OF THE CALCULATIONS GIVEN TO CHARGE DIGESTER OF 220 LITERS

Type of Materials \ Digesters	Theoretical Calculation				Real Charging			
	1	2	3	4	1	2	3	4
Corn Husk (Kg.)	26.23	43.46	43.46	45.85	22	33.99	33.02	35.15
Manure (Kg.)	9.72	16.32	16.32	8.18	9.72	16.32	16.32	8.18
Urea (gr.)	596	986	986	1,079	596	986	986	1,079
Phosphate Biammonic (gr)	366	606	606	694	366	606	606	694
Calcium oxide (gr)	254	421	2,011	2,011	254	421	2,011	2,011
Water (liters)	-	-	-	-	103.5	75	75	75

DYNATECH R/D COMPANY
A Division of Dynatech Corporation
99 Erie Street, Cambridge, MA 02139
TEL: 617-868-8050