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DYNATECH R/D COMPANY

LOW CAPITAL COST FUEL GAS PRODUCTION FROM COMBINED ORGANIC RESIDUES

Progress Report

Dynatech Project No. AID-1
Dynatech Report No. 2291

Submitted to:

Office of the Science Advisor
Agency for International Development
U.S. Department of State
Washington, D.C. 20523

Prepared by:

A.P. Leuschner
P.F. Levy
D.L. Wise

March 27, 1984

a division of DYNATECH CORPORATION

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Section 1

INTRODUCTION

1.1 Overview

This program, "Low Capital Cost Fuel Gas Production From Combined Organic Residues," was initiated in August, 1983, at Dynatech R/D Company. This report serves as the first formal progress report for this 18 month program, although two other reports have been sent to participants. The objective of this project is to investigate the applicability of a low cost, batch "controlled landfill" anaerobic digestion system for producing methane gas from agricultural residues in developing countries. The framework under which this study is being performed is a three phased approach. The first phase primarily involves experimental digestion work in ten developing countries; a list of the ten Co-Principal Investigators is presented in Table 1.1. In each of these countries batch digestion experiments are being performed on indigenous residues. Data from these experiments and other information will be used in the second phase of this program by Dynatech R/D Company to develop an engineering model, including technical design and economic analyses, for utilization of this technology. The third and final phase of this program is to hold a Workshop for all the participants in this study to review progress on this anaerobic digestion system and make recommendations.

1.2 Task Review

Presented in Figure 1.1 is the project completion schedule bar chart presented originally in Dynatech's proposal to A.I.D. Indicated in this chart is the work completed as of January 1, 1984, for each task and subtask associated with this program. In the following sections a complete description of the work accomplished by subtask is presented.

Table 1.1

LIST OF CO-PRINCIPAL INVESTIGATORS
(Listed in Alphabetical order)

CO-PRINCIPAL INVESTIGATOR	LOCATION
Dr. J.F. Calzada Head, Applied Research Division Investigacion y Tecnologia Industrial Central American Research Institute for Industry Avenida La Reforma 4-47 Zona 10 Guatemala	Instituto Centroamericano de Investigacion y Tecnologia Industrial Guatemala
Dr. Kee Kean Chin National University of Singapore Faculty of Engineering 12 B Patterson Hill Singapore 9	National University of Singapore Faculty of Engineering Singapore
Dr. M. Nabil Alaa El-Din Senior Researcher of Soil Microbiology Director, Biogas Project Agricultural Research Center Giza, Egypt	Agricultural Research Center Egypt
Dr. William G. Padolina Department of Chemistry University of the Philippines at Los Banos College, Laguna 3720 Philippines	University of the Philippines at Los Banos Philippines
Dr. Uri Marchaim Kibbutz Industries R & D Institute Kibbutz Kfar-Giladi Israel 12-210	Kubbutz Industries Association Israel
Dr. Joan Mata Universidad de Barcelona Facultad de Quimica Diagonal 647 Barcelona 28 Spain	Universidad de Barcelona Spain

Table 1.1 (Continued)

LIST OF CO-PRINCIPAL INVESTIGATORS

CO-PRINCIPAL INVESTIGATOR	LOCATION
Dr. V.V. Modi Professor and Head Dept. of Microbiology The Maharaja Sayajirao University of Baroda Baroda - 390 002 India	Maharaja Sayajirao University of Baroda India
Dr. Didin S. Sastrapadja Deputy Chairman for Natural Sciences Kantor/Office Lembaga Ilmu Pengetahuan Jln, Teuku Cik Ditiro 43 Jakarta Indonesia	Deputy Chairman for Natural Sciences Indonesia
Dr. Javier Verastegui Jr. Morelli 2da. cda esquina av. de las Artes (alt. cda. 21 av. Javier Prado-este) San Forja - Surquillo Lima, 34 apartado 145 Lima, Peru	Lima, Peru
Dr. M. H. Wong Senior Lecturer Department of Biology University Science Center The Chinese University of Hong Kong Shatin. NT Hong Kong (with the assistance of:) Mr. Chen Ru-Chen Hoi Peng Garment Factory 17 Rua De Manuel De Arriaga Maucau via Hong Kong	University Science Center Hong Kong

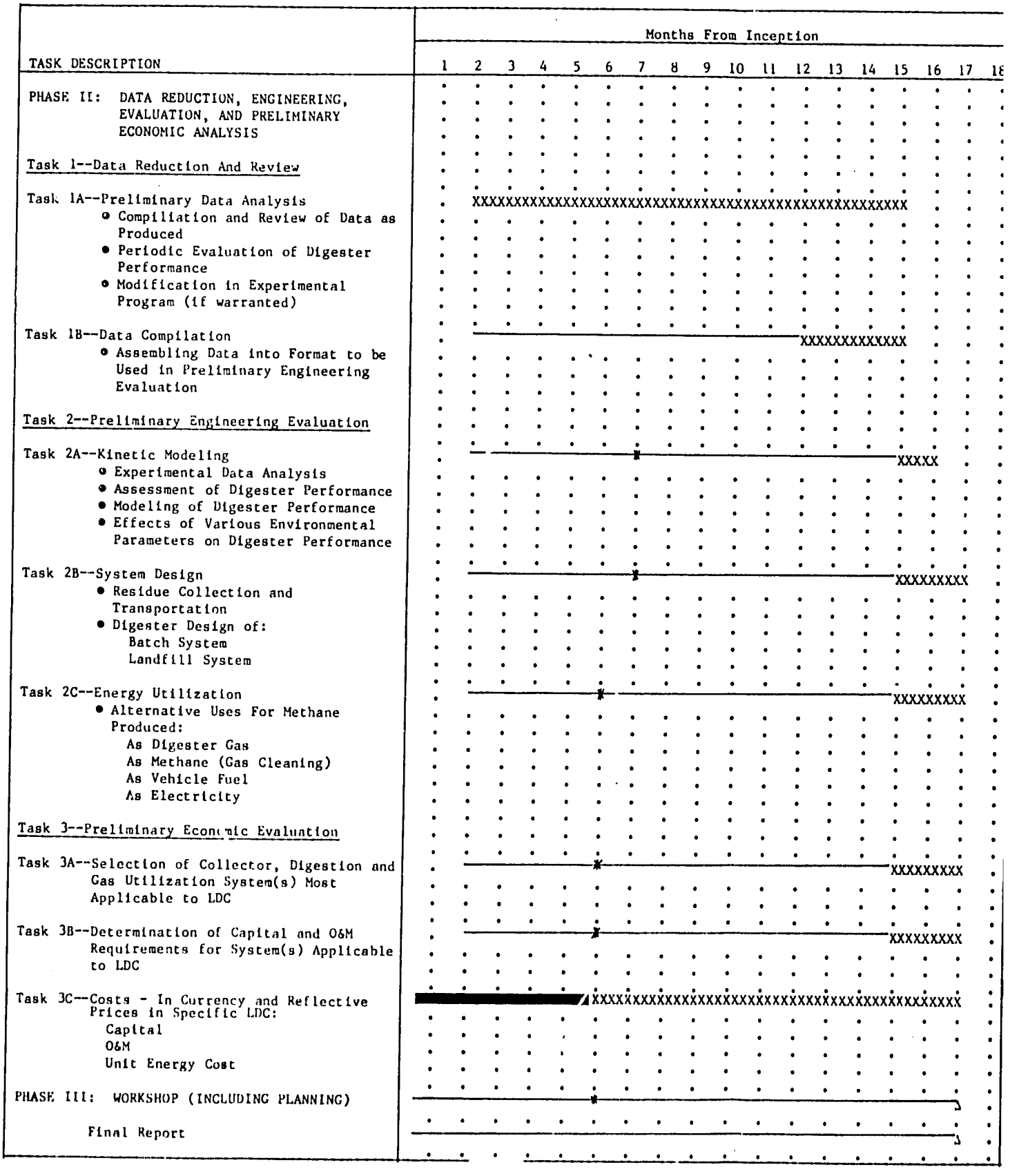
Figure 1.1

LOW CAPITAL COST FUEL GAS PRODUCTION FROM COMBINED ORGANIC RESIDUES

Bar Chart Showing Project Completion Times and Project Milestones

TASK DESCRIPTION	Months From Inception																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
PHASE I: BATCH ANAEROBIC DIGESTION STUDIES																		
Task 1--Data Collection - Specific to LDC																		
Task 1A--Residue Generation Data	X																	
• Types of Residues: Agricultural, Municipal																		
• Residue Quantities																		
• Geographic Distribution and Residue Densities																		
Task 1B--Present Residue Disposal/Utilization Data	X																	
Task 2--Experimental Program																		
Task 2A--Formulation of Digestion Parameters																		
• Residue Characterization																		
• Residue Proportions																		
• Environmental Variables - Specific to LDC: Temperature, Moisture, Nutrient and Buffer Additions																		
Task 2B--Experimental Criteria																		
• Number of Digesters to Set Up in each LDC Based Upon: Residue Proportions, Digestion Regimes																		
• Analysis Schedule: Selection of Analysis Parameters, Frequency of Analysis																		
Task 2C--Digestion Program		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
• Operation, Testing and Data Collection (in LDC)																		

Figure 1.1 (Continued)



Section 2

PHASE I: BATCH ANAEROBIC DIGESTION STUDIES

2.1 Task 1 - Data Collection

In order to fully assess the potential impact of anaerobic digestion of crop residues in developing countries, data on quantities and availability of residues is required. Of prime importance is a knowledge of the total quantity of residue produced by a specific country. This information can then be translated into a given quantity of energy which could be produced if all of the residue were used for this purpose. This establishes an upper limit on energy generation. Many factors can then impact on what percentage of this maximum potential is feasible.

The geographical distribution of the residues is an important factor in determining utilization potential. For example, it may be questioned if the residues are concentrated in relatively small geographic areas, or are they scattered throughout the entire country? If they are concentrated in a small area, what are the energy needs of that particular locality? How can biogas be most effectively utilized? If the residues are scattered, is collection and transportation to a centralized location warranted? What effect does this have on the economics of energy generation and the overall energy balance for the process?

The seasonality of residue production will also have an impact on biogas production. Specifically, seasonality of residue production is seen in terms of the reactor design and thus the efficiency of residue conversion to biogas. If residues are produced on an annual or semiannual basis, batch anaerobic digester designs are most appropriate. However, if residue production is on a continuous basis - such as from a food or beverage processing facility - alternative designs may be more advantageous.

Lastly, the present residue utilization or disposal practices will impact significantly on the feasibility of utilizing these residues for

energy production. If residues are extensively utilized for fertilizer, animal feed, or other energy production activities, biogas production from these residues will only be practical if substitutes can be found; and if redirecting these residues to biogas production will not be prohibitive economically. If the residues are disposed, then utilizing them for energy production will be significantly more economical and desirable.

Finding accurate information on types, quantities and utilization practices of agricultural residues for the countries participating in this program has proved to be a difficult task. The Food and Agriculture Organization (FAO) of the United Nations (1979) performed a survey of 128 countries to assess the potential of agricultural residue utilization. The purpose of this study was to establish quantities of agricultural residues, and the availability of these residues for utilization. Also outlined in this survey were utilization options for agricultural residues. Methane production was considered one of the three most acceptable and desired utilization options - the other two being animal feed and fertilizer production. Table 2.1 summarizes the results of the FAO study for those countries associated with this program. (It should be noted that India, the Peoples Republic of China and Israel were not included in the FAO survey.) It is important to note that significant quantities of agricultural residues are produced; however, much of these residues are presently utilized in some fashion.

The FAO study acknowledged the difficulty in obtaining accurate data on agricultural residue production. The important conclusions from this report can be summarized as follows (FAO, 1979):

- The characteristics, the volume and the extent of the availability of residues in time and space are seldom known even with a reasonable approximation.

- The aims of utilization are generic and the end-products are not in all cases specified.

Table 2.1

RESIDUE GENERATION BY COUNTRY

Type of Residues	Quantities M.T.	Actual Utilization	Disposal	Proposed Utilization
EGYPT				
Sugars:				
Cane - Bagasse	Dry: 860,000	65,000 M.T. - particle board and pulp Rest fuel in sugar mills	-	Newsprint, writing/printing paper paper bags for cement; tissue paper
Various:				
Organic wastes in rural areas - Human, animal, agricultural	-	Fertilizer	Sewage	Fertilizer, energy
GUATEMALA				
Animal By-products:				
Poultry - Manure	1,400	Fertilizer	-	-
Beverage Industry:				
Coffee - Pulp	1,800	Fertilizer	-	-
Oilseeds and Nuts:				
Cottonseed - Husks	600	Cattle	-	-
Sugars:				
Cane - Molasses	6,000	Alcohol, feed	-	Improved utilization
- Bagasse	-	Fuel	-	-

Table 2.1 (Continued)

Type of Residues	Quantities M.T.	Actual Utilization	Disposal	Proposed Utilization
INDONESIA				
Cereals:				
Rice - Straw	Large quantity	Cattle feed, paper, particle board	Burned	Paper Board
Husks	" "	Fuel	-	Building and packing materials
Maize- Stalks, husks, cobs	" "	Cattle feed, soil conditioner, fuel	Burning	-
Forestry:				
Logging residues	10,0[illegible],000 m^3	Small quantity as construction material; teak as fuel	Left in the forest; teak burned in the forest	Pulp and paper; particle board; charcoal
Sawmill and plywood industry	3,000,000 m^3	Fuel: in boilers, in villages	Burned	Pulp and paper; particle board
Marine Products:				
Fish Processing - Residues	Large quantity	Fish cake, poultry feed	-	Fish meal
Oilseeds and Nuts:				
Coconut - All residues	" "	Fuel, charcoal, building material	Burning	Charcoal; building material, SCP
Oil Palm - All residues	" "	Fuel (solids); feed (cake)	Burning	Cattle and poultry feed
Sugars:				
Cane - Bagasse	" "	Fuel, building material, paper pulp	-	Paper, board
- Molasses	" "	Alcohol	-	Alcohol, SCP (yeasts)
MALAYSIA				
Beverage Industry:				
Cocoa - Pod husks	270,000	Some use as mulch	-	Pectin, cattle feed
Cereals:				
Rice - Husks	300,000	Partly as feed ingredient	Landfills	Feed; building material
- Straw	1,620,000	Partly feed ingredient; fiberboard	Burned in the field	" " "
Fruits and Vegetables:				
Pineapple - Canning	210,000	None	Disposed into river	Feed, alcohol
Oilseeds and Nuts:				
Oil Palm - Press fiber	9,840,000	Some use in boilers; feed	-	Feed; methane
- Oil sludge	270,000	None	Disposed into river	Feedstock for protein; biomass production

Table 2.1 (Continued)

Type of Residues	Quantities M.T.	Actual Utilization	Disposal	Proposed Utilization
PERU				
Fruit and Vegetables:				
Canning	1,600	-	Discarded	Alcohol, feeds
Citrus - Lemon peel oil extraction	1,200	Pig feeding	-	Pectin, feed, biomass production
Forestry:				
Sawmill - Residues	60,000 m^3	Partly as fuel	Disposed or burned	Boxes, pulp, pressed boards
Plywood industry - Residues	30,000 m^3	Pressed boards; packing boxes; pulp	Rest disposed or buried	Particle boards, pulp
Marine Products:				
Fish canning - Residues	-	None	Discarded in waters	Hydrolysates for feed and food
Frozen Crawfish - Heads	-	None	Heads thrown into the sea	Edible flour for fish soups
Fish filleting - Skins	-	Fish meal	Thrown away	Leather handicraft
Fish filleting	-	None	Mostly thrown into the Sea	Glue and gelatin
PHILIPPINES				
Animal By-products:				
Manure	12,700,000	Fertilizer	Disposal in rivers and lagoons	Biogas production
Cereals:				
Rice - Straw	12,000,000	Feed, mulch, fuel in pottery, edible mushroom production	Burning; ploughing under	Growing medium of mushrooms; fiber; particle board
- Husks	1,000,000	Feed	Burning; landfill	Animal feeds
Corn - Stubbles	200,000,000	Feed for work animals	Burning; ploughing under	Animal feeds
Forest:				
Sawmilling - Sawdust	10,000,000 m^3	Fuel, soil conditioner	-	Briquetted fuel
- Slabs, trims	14,000,000 m^3	Fuel, boxes, shipboards, toys	-	Chips for fiber and particle board
Veneer and plywood	56,000,000 m^3	Fuel, core veneer, crating	-	Fiber and particle board
Oilseeds and Nuts:				
Coconut - Water	2,200,000	Home vinegar and nata production	Disposed in rivers & creeks	Feed yeast, vinegar, fuel
- Coir dust	2,100,000	-	Natural decomposition	-
Various:				
Tobacco - Stalks, midribs	30,000	-	Ploughed under	Midribs: mushroom spawn production
- Dust	-	-	-	Stalks: composting Dust: insecticide formulation

Table 2.1 (Continued)

SPAIN

Fruit and Vegetables:				
Olive Milling - Effluents	1,500,000 m^3	None	Disposed of in drains	Feed yeast, methane production
Various:				
Cheese Industry - Whey	10,000,000	Some used in pig feeding	Most disposed of in drains	Food and feed

- In most of the developing countries agricultural residues are widely spread through the national territories creating problems of collection and transport.

- While available technologies might have feasible application under given circumstances, the economic feasibility might be missing.

- In most cases the constraints centered on lack of: qualified human resources, financial means, planning, research and development, technical and economic evaluation; and implementation of programs and projects at the national level.

- Whereas, there is an increasing public awareness of the economic, social and environmental importance of residues, such awareness is only slowly attracting the attention of national decision-makers and legislators responsible to cope with the inherent multiple problems.

In order to improve the data base on agricultural residue production, we have requested assistance from the Co-Principal Investigators in each country to provide us with information on agricultural residue quantities and availability. At this writing we have not yet received complete information on this subject. As a result, Figure 1.1 indicates that Tasks 1A and 1B have not been concluded at this time.

2.2 Task 2 - Experimental Program

Task 2A, Formulation of Digestion Parameters, and Task 2B, Experimental Criteria, have been completed. Dynatech has prepared a report and distributed it to each participant in this program to accomplish this task.

Task 2C is the experimental program which is to be conducted in each of the participating countries in this program. Meetings and visits have taken place in order to transfer technology from Dynatech to the participating countries. Dynatech has also requested that each Co-Principal Investigator review with Dynatech the progress of their experimental programs and data generated.

References to Section 2

Food and Agriculture Organization, 1979. "Agricultural Residues: Quantitative Survey Analysis of an FAO Identification Survey of the Utilization of Residues of Agriculture, Forestry, Fisheries and Related Industries." Rome, Italy.

Section 3

PHASE II : DATA REDUCTION, ENGINEERING EVALUATION, AND PRELIMINARY ECONOMIC ANALYSIS

3.1 Task 1 - Data Reduction and Review

Task 1 of Phase II of this study is comprised of two subtasks. Task 1A, Preliminary Data Analysis, includes compiling the data, making preliminary assessments of the performance of the digesters; and modifying the experimental program, if required. Task 1B, Data Compilation, consists of assembling the data collected into a useable engineering format. Dynatech has requested that each of the Co-Principal Investigators associated with this program review with Dynatech the data collected.

3.2 Task 2 - Preliminary Engineering Evaluation

Task 2 consists of three subtasks: Kinetic Modeling (2A), System Design (2B), and Energy Utilization (2c). A kinetic model describing a batch anaerobic digestion system is used to establish digester performance, predict methane production and to assess the effect of environmental conditions on performance. System kinetic modeling can also be used to predict internal heating occuring in a digester (since the anaerobic process is exothermic),and allows for a system design where no external heat is required to maintain digester temperature (35°). System design of this nature is crucial for digestion in developing since it eliminates the need to divert a portion of the biogas produced to keep the digester at operating temperatures and also eliminate capital expenditures for hot water heaters or boilers and associated piping for an external digester heating system. The majority of effort in Task 2 (2A and 2B) has been placed in developing this model. The utilization of the biogas (Task 2C) has been examined in less detail to date, and the work accomplished in this task has essentially been limited to obtaining background information.

The implementation of anaerobic digestion of agricultural residues to produce fuel gas has been suggested using a low cost digestion system. The system proposed in this program has been called a "hole-in-the-ground" or "HIG" digester, essentially a small "controlled landfill" batch digester. It is envisioned that these batch digesters will be constructed by excavating an appropriate area and forming a hole with steeply sloping sides and slightly sloped bottom to provide for collection and recirculation of water. The hole will be lined with water impermeable material (clay or plastic liner) and, after filling with the collected residue, the top closed with an airtight plastic liner which is vented for gas collection. This top liner may then be covered with clay. Figure 3.1 depicts such a digestion system.

These digesters are to be operated in a batch mode. The hole is filled with residue, buffer, nutrients, and inoculum. It is then sealed and the digestion process allowed to proceed. As the microbial reactions progress, methane and carbon dioxide gases are generated which may be collected for use. Heat is also evolved from these exothermic reactions. Some of this heat escapes from the digester through its walls or with the product gases. The remainder of the heat raises the temperature of the digester.

The rate of decomposition of organic residues and production of fuel gas is dependent on the digester temperature. The temperature of the digester with time is dependent on the rate of the anaerobic digestion reactions and the heat loss from the digester. The rate of heat loss from the digester is a function of digester design and construction and digester temperature. A model has been devised to describe the temperature history of a digester, given its volume to surface area ratio (V/SA).

There are two approaches for modelling the kinetics of anaerobic digestion. One approach, the Monod model (Monod 1949), develops the kinetics by consideration of the growth and removal of microorganisms. A second approach is to consider the microorganisms as "catalysts" and develop and over-all mass transfer kinetic model for a "catalyzed" reaction. This second approach is used in this model.

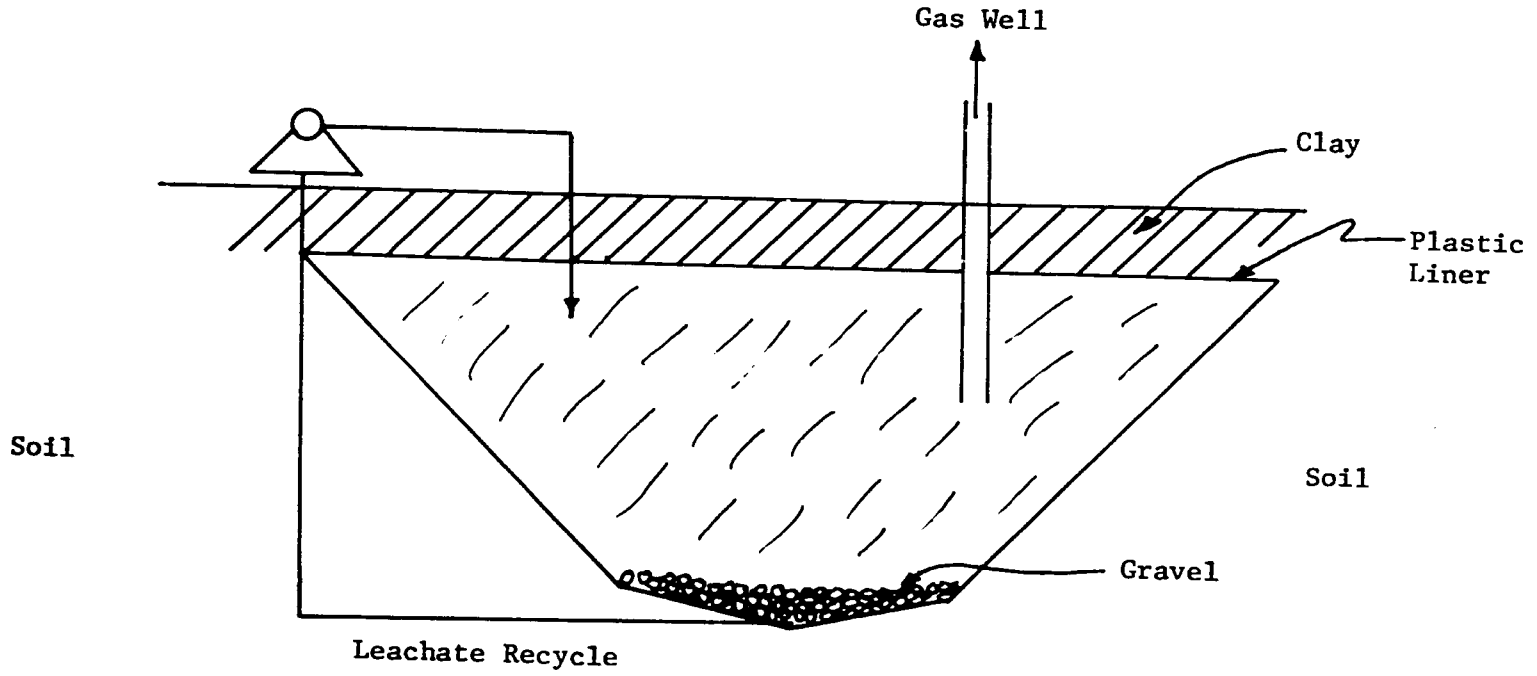


Figure 3.1: Hole In Ground Anaerobic Digester (Cross Section)

The anaerobic digestion process is also assumed to follow first order kinetics, in which the rate of substrate degradation is linearly proportional to substrate concentration (CB):

$$\frac{d(CB)}{dt} = -(RK)(CB)$$

where RK is the rate constant and CB is the concentration of biodegradable material. The concentration of biodegradable material at any time can be calculated by integrating the above expression between starting time, t = o, and any time later (t):

$$(CB)_t = (CB)_o \exp[-(RK)(t)]$$

where $(CB)_t$ is substrate concentration at time (t) and $(CB)_o$ is initial substrate concentration at time t = o. Similarly, the amount of gas produced can be represented:

$$G = A (CB)_o [1 - \exp[-(RK)(t)]]$$

where G is total gas production and A is the volume of gas produced per mass converted. An analogous expression for heat released by the exothermic reaction over time can be written:

$$DT = (DH) (CB)_o [1 - \exp[-(RK)(t)]]$$

where DT is the total heat released and DH represents the heat released by conversion of a unit mass of substrate.

The biodegradable substrate in conversion of agricultural residues is assumed to be a hexose polymer (i.e. starch or cellulose). Conversion of this material to methane and carbon dioxide can be described:

$$(C_6H_{10}O_5)_x + H_2O \rightarrow 3 \times CH_4 + 3 \times CO_2$$

This is an exothermic reaction in which approximately 500 Btu/lb carbohydrate converted are released. (The energy contained in the methane product will be 6074 Btu/lb of carbohydrate converted.) It is the heat released by this exothermic reaction which will provide the energy for reactor heating.

The rate of substrate conversion is dependent on the rate constant (RK). Previous work has been done to calculate the activation energy and pre-exponential factor by compilation of rate constants reported for digestion of agricultural residues at various temperatures (Ashare et al. 1977). An Arrhenius plot (1/T vs rate constant) is shown in Figure 3.2 and provides a reasonable correlation of the data. The rate constant (RK) is estimated as a function of temperature according to the Arrhenius equation:

$$RK = (RK)_o \exp[-Ea/RT]$$

where $(RK)_o$ is the pre-exponential factor, Ea is the activation energy, R is the gas constant, and T is the absolute temperature. From the plot, Figure 3.2, the activation energy is found to be 15,175 cal/mode (27,315 Btu/lb mole). The constant $(RK)_o$ may be adjust to give the desired rate constant at mesophilic temperature.

Heat loss from the digester occurs from the sides, top, and bottom of the digester. Heat loss from the digester walls is a function of digester temperature, surface area of the digester walls, and heat transfer properties of the walls and the material surrounding the digester. The heat resistance of the plastic liner inside the digester is negligible; the heat transfer co-efficient of the soil (k) surrounding the digester is taken to be 1.0 Btu/hr•ft•°F, the heat capacity of the soil (C_s) 0.25 Btu/lb°F, and the density of the soil (ρ_s) 120 lb/ft^3. The temperature gradient of the soil surrounding the digester wall one hour after a step change in digester temperature is shown by the series of curves in Figure 3.3. The temperature history of the soil surrounding the digester after a step increase in digester temperature can be determined as in Figure 3.4. Similar plots were

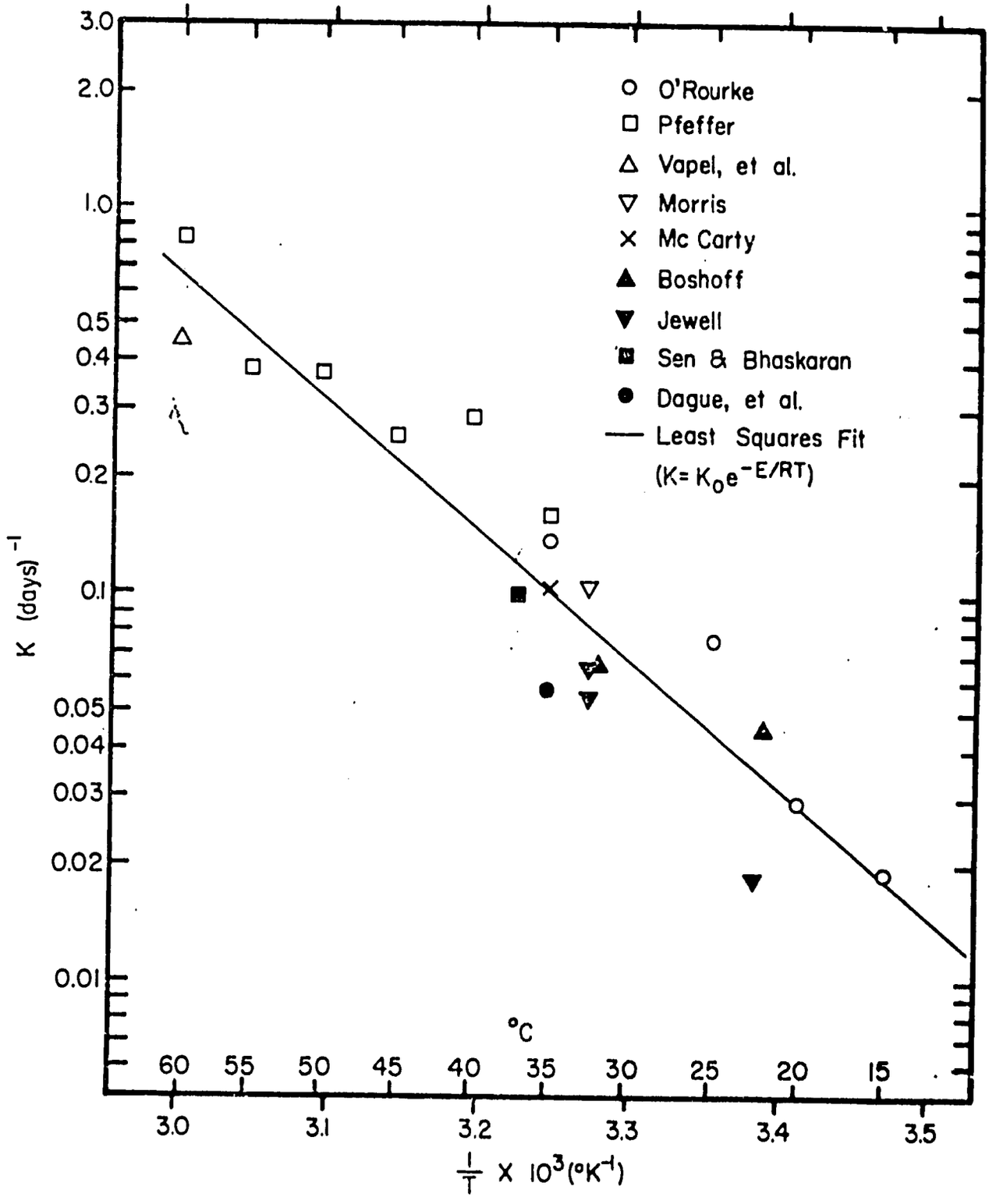


Figure 3.2 - Rate Constant as a Function of Temperature

Figure 3.3: Temperature Gradient In Soil After Step Change In Digester Temperature

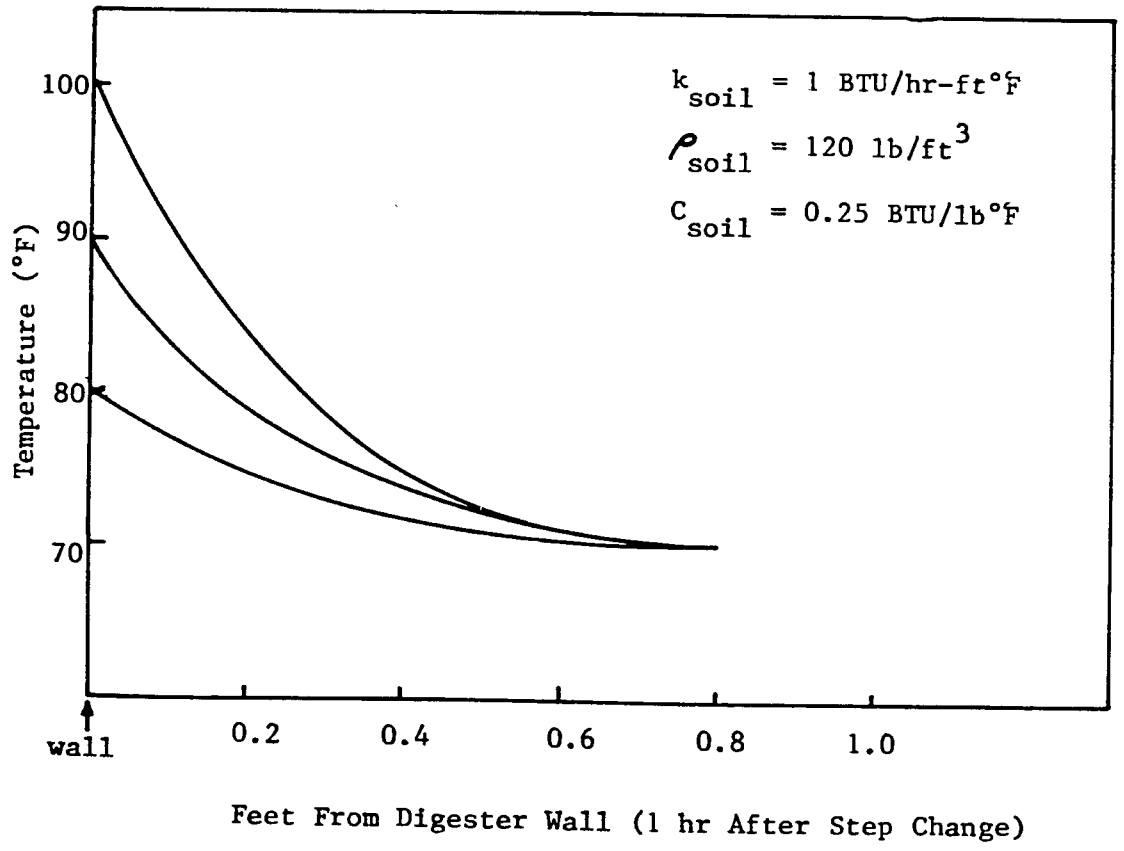
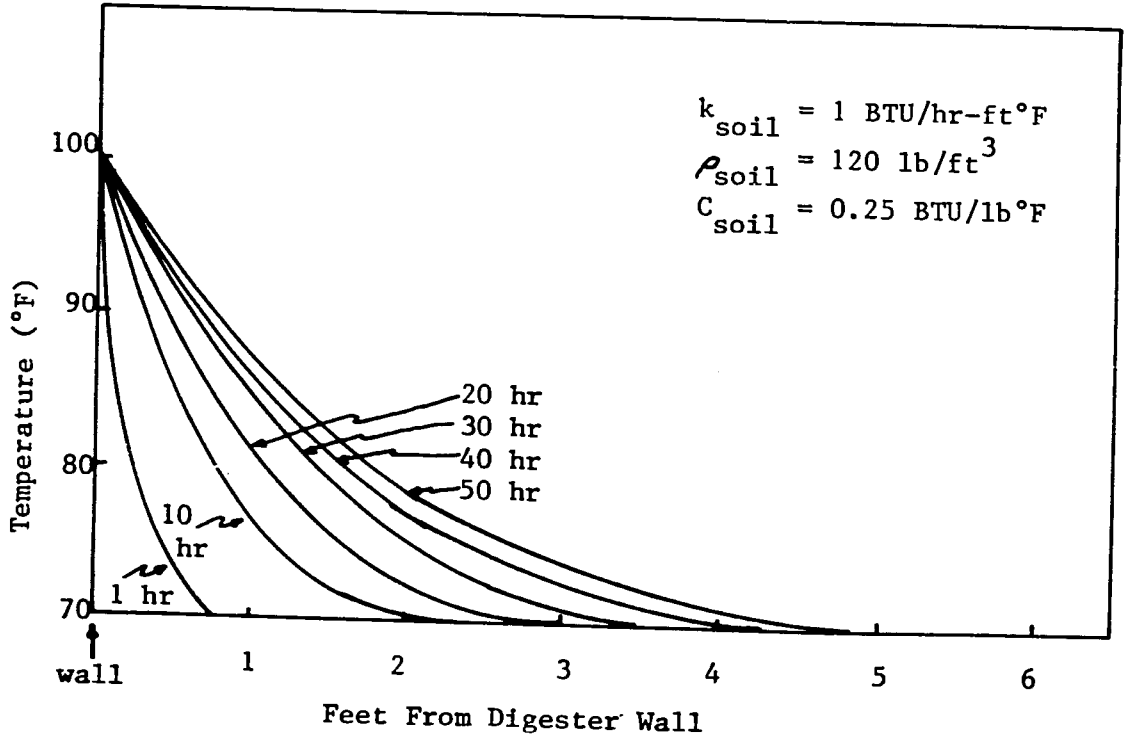


Figure 3.4: Temperature Profile of Soil Surrounding Digester After Step Increase In Digester Temperature



drawn for digester temperature increases from 70°F (assumed to be the average ground temperature) to 100°F (mesophilic digestion temperature) from temperature response charts (Schneider 1963). By integrating the area under each successive curve and using the assumed density and heat capacity for the soil, the rate of heat loss can be determined for each time interval. Examination of these graphs shows that the rate of heat loss for each step change approaches a constant value which, for all cases, can be approximated as 0.5 Btu/hr•°F•ft^2 wall area. This value, when multiplied by the temperature driving force (digester temperature minus ground temperature) gives the approximate rate of heat loss for 1 ft^2 of wall area.

It is clear that the actual heat loss rate will vary considerably depending on the nature of the soil used in constructing the digester, particularly its water content. In some instances, insulating materials may be desirable to use in constructing the digester.

The digester is assumed to be formed with trapezoil sides and square top and bottom. The sides are built at a 45° angle to the horizontal and the height (depth) of the digester does not exceed 10 feet. The volume can be calculated from the following formula:

$$\text{Digester Volume} = 1/3\ h\ [b^2 + 4bh + 4h^2 + b^2 + (b^4 + 4b^2h + 4b^2h^2)^{1/2}]$$

where h is the height (or depth) of the digester and b is the length of one side of the base (bottom). The surface area, including top and bottom is:

$$\text{Surface area} = 2b^2 + 8bh + 8h^2$$

The rate of heat loss per ft^2 of surface area is assumed to be the same for the sides, top, and bottom of the digester. The estimated rate of heat loss when the digester is at mesophilic temperature is in good agreement with previous by calculated values for the assumed temperature driving force (Jewell 1976).

All materials added to the digester (assumed to be primarily agricultural residues such as straws, manure, and water) are added at

ambient temperature (assumed to be 70°F) and must be heated to digester temperature. In our model, we assume the digester is filled with 20 lb solids/ft^3 and an equal weight of water (20 lb/ft^3). The solids are 75% volatile and 25% ash. The ultimate conversion of the volatile solids is 50%, making the initial loading of biodegradable solids 7.5 lb/ft^3. Raising the digester temperature by 1°F (assuming heat capacities of 0.4 Btu/lb°F for the solids and 1 for water) initially requires 28 Btu/ft^3 of material. Thus, raising the digester to mesophilic temperature from 70°F requires approximately 800 Btu/ft^3 under adiabatic conditions. This represents the heat evolved by conversion of 1.6 lb of organic material to biogas.

A computer program which calculates the digester temperature at indicated time increments was written following the logic in Table 3.1. The assumptions made for these calculations are indicated in Table 3.2.

It is clear that for a given conversion rate constant, the heat loss rate at which the digester is able to maintain its temperature can be calculated. Figure 3.5 is a plot of mesophilic rate constant vs the quotient of heat loss rate and volume to surface area ratio of the digester. This plot can be used to determine digester size once the conversion rate constant of the substrate is known. For instance, if the mesophilic rate constant has been measured as 0.01 $days^{-1}$, the maximum heat loss quotient is 0.0125. If the digester is constructed with a volume to surface area ratio of 4.0, the heat loss rate must not exceed 0.05 Btu/hr•°F•ft^2 surface area.

The volume to surface area ratios for the digester, if designed with trapezoidal sides and a 45° slope, can be calculated from the formulas presented earlier. If this is the design employed, with a maximum allowable depth of 10 feet, then to achieve a volume to surface area ratio of 4, a digester with a base (bottom) 100 feet long and depth of 10 feet must be constructed. This will have volume of 115,400 cubic feet. Some representative volumes and volume to surface area ratios are indicated in Table 3.3. Thus, by examining the digester dimensions, insulating properties of the materials of construction, and loading and conversion rate of the substrate the temperature history of the digester can be predicted.

Table 3.1

LOGIC FOR PROGRAM CALCULATIONS DIGESTER TEMPERATURE HISTORY

1. Input Initial Values:

   - Ambient temperature,
   - Digester initial temperature,
   - Digester solids loading,
   - Fraction solids which are biodegradable,
   - Digester water content,
   - Reaction activation energy,
   - Pre-exponential constant,
   - Heat loss rate as function of temperature driving force, and
   - Volume to surface area ratio of digester;

2. Calculate arrhenius rate constant;
3. Calculate heat released in time increment;
4. Calculate heat loss in time increment;
5. Calculate specific heat of digester contents;
6. Calculate new digester temperature;
7. Calculate new substrate concentration in digester;
8. Print valves calculated for time increment; and
9. Return to step 2 or stop.

Table 3.2

ASSUMPTIONS FOR CALCULATING DIGESTER TEMPERATURE HISTORY

1. Ambient and ground temperature is 70°F.
2. Digester is at uniform temperature at all times.
3. Heat loss rate can be calculated as a function of digester temperature, ground temperature, and volume/surface area ratio of digester.
4. Anaerobic digestion reaction rate can be described by an Arrhenius rate expression.
5. Total solids loading in the digester is 20 lb/ft^3.
6. Total solids of 37.5% are biodegradable.
7. Heat capacity of solids is 0.4 Btu/lb•°F.
8. Water content of digester is 20 lb/ft^3.
9. Activation energy is 15,175 cal/gmole.
10. Pre-exponential constant is adjusted to give desired rate constant at mesophilic temperature.
11. Heat loss occurs at the same rate for all digester surfaces (top, bottom and sides).
12. Once the digester reaches mesophilic temperature, heat is removed from the recirculating leachate to prevent further temperature increase.

Figure 3.5: Calculation Of Maximum Heat Loss Rate For A Digester Maintaining Mesophilic Temperature As A Function Of Digestion Rate Constant

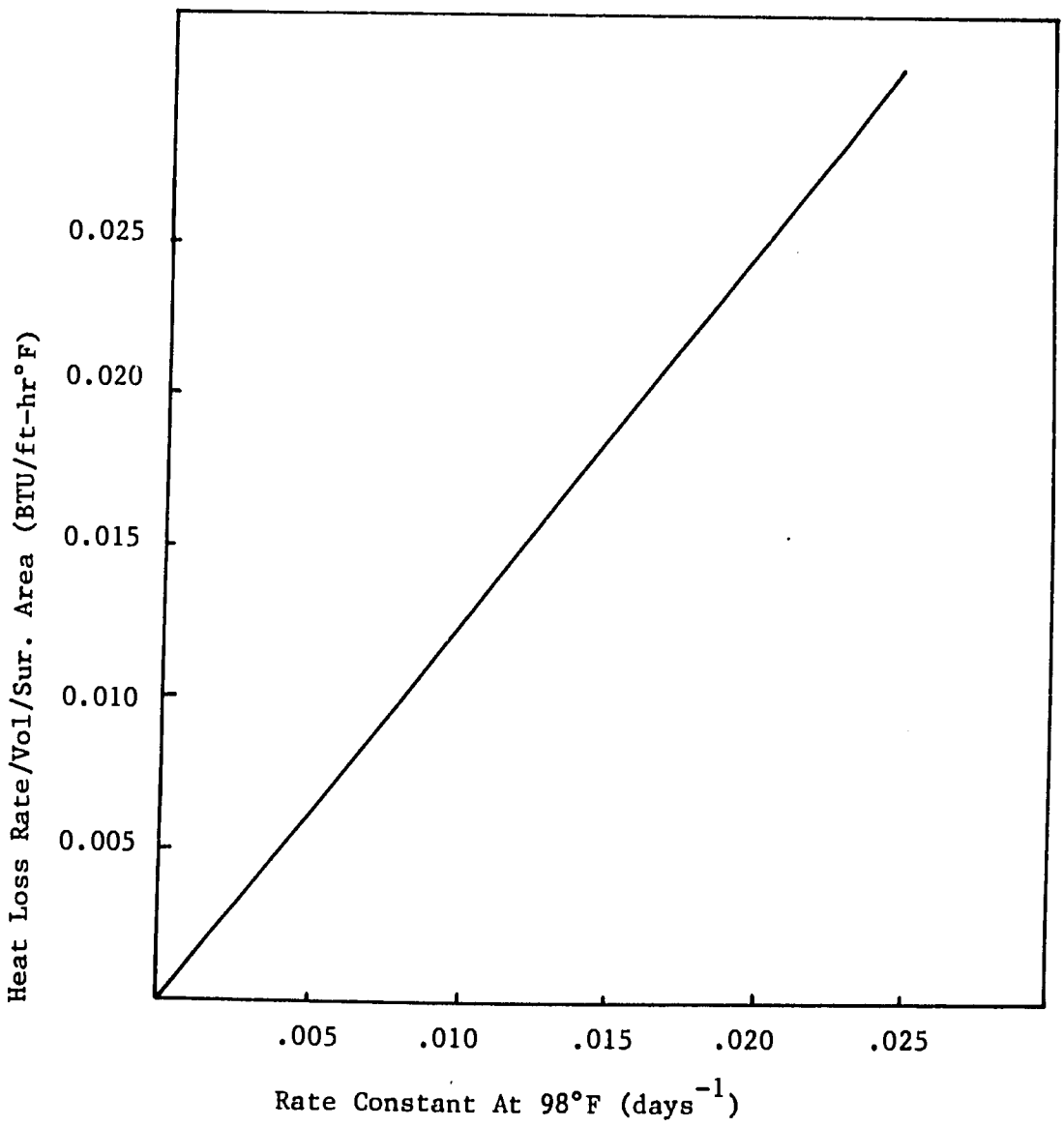


Table 3.3

VOLUME TO SURFACE AREA RATIOS OF DIGESTERS BUILT WITH 45° SLOPING TRAPEZOIDAL SIDES

HEIGHT	LENGTH OF VOLUME	VOLUME	VOLUME/SURFACE AREA
10 ft.	10 ft.	4,110 ft^3	2.28
10 ft.	20 ft.	8,600 ft^3	2.69
10 ft.	5 ft.	2,525 ft^3	2.02
10 ft.	100 ft.	115,400 ft^3	4.01
10 ft.	200 ft.	429,000 ft^3	4.43
5 ft.	5 ft.	517 ft^3	1.15

The information can also be used to determine the relative merit of preheating the digester (for example, by heating the leachate being recirculated) to mesophilic temperatures. For a digester with a volume to surface area ratio of 4.0, heat loss rate of 0.05 Btu/hr•°F•ft^2 surface area, and substrate conversion rate constant of 0.01 days^{-1} at 98°F the percent conversion to biogas vs time is plotted in Figure 3.6. The difference in conversion with and without digesters heat-up can be clearly seen from this plot.

Prior to construction and operation of this "controlled landfill" batch type digester, its performance may be predicted based on the following information:

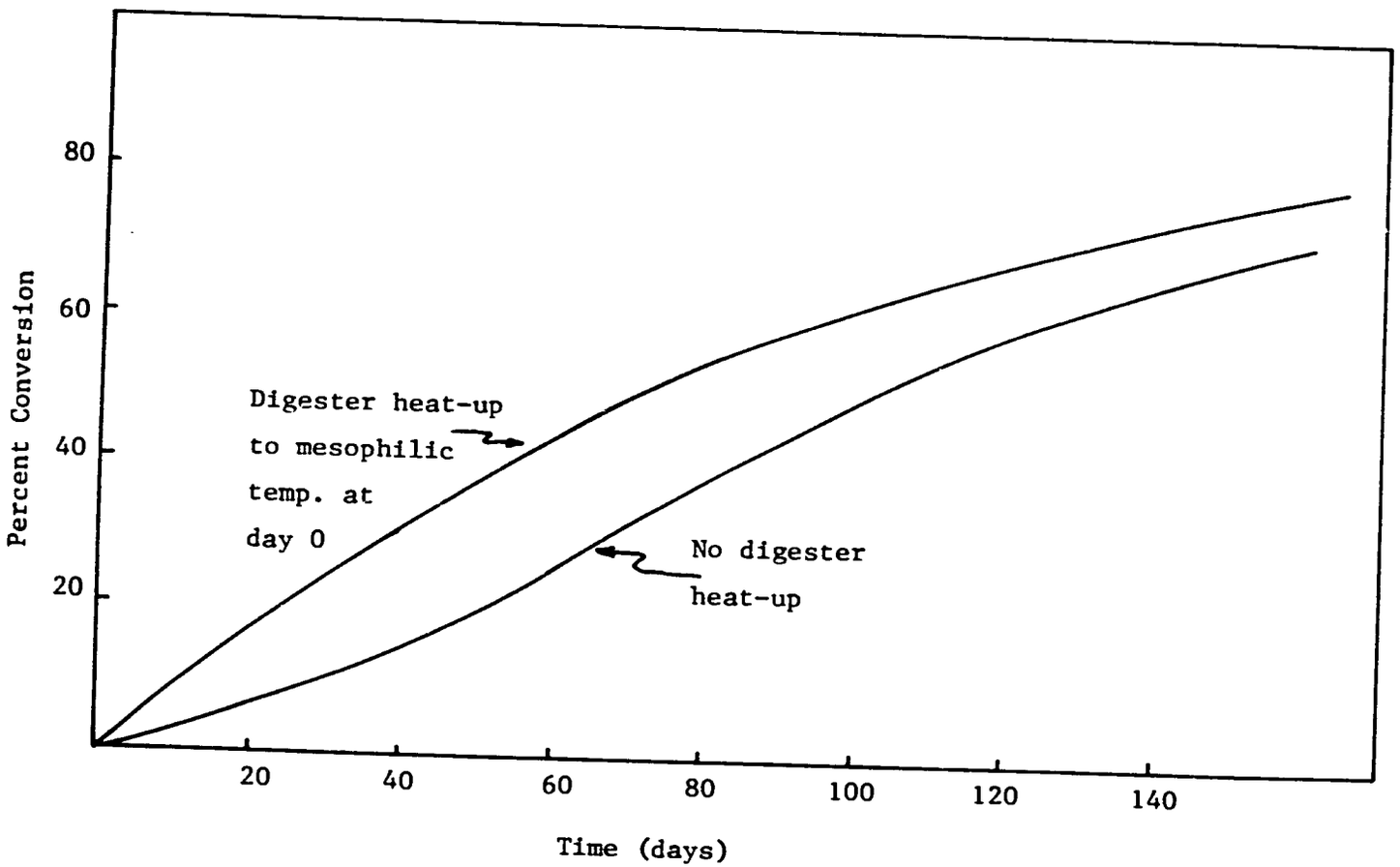
1) Rate and conversion data of the substrate;
2) Density of solids in the digester;
3) Water content of the digester;
4) Digester dimensions;
5) Insulating properties of materials of construction of digester; and
6) Ground temperature.

Since this information will vary depending on the residue chosen as substrate and the location of the digester, specific information for each site must be known prior to designing an efficient digester.

3.3 Task 3 - Preliminary Economic Evaluation

The final task in Phase II of this AID sponsored project is to utilize the information developed in this project for development of an economic model for these digestion systems. This economic model will be developed from the experimental portion and the preliminary engineering portion of the program; thus, this will be the last technical task to be performed. As shown in Figure 1.1, the work to be accomplished in this task will primarily occur at the end of this project. To date, work in this area has concentrated on gathering pertinent economic information and examining a variety of economic models directly applicable to biomass energy projects in developing countries. Reports gathered to date, to be used in developing an economic model include Ramuglia (1983), Gunnerson and Jones (1983), Foley

Figure 3.6: Comparison Of Conversion History Of Digesters With And Without Preheating To Mesophilic Temperatures*



*Rate constant at 98°F is 0.01 days^{-1}. Heat loss rate is 0.05 BTU/hrft°F. Volume to surface area ratio is 4.0.

and Barnard (1983), National Academy of Sciences (1977) and Makhijani and Poole (1975).

Work on development of an economic model for use in evaluating anaerobic digestion projects in developing countries is scheduled to be a meaningful area of development over the final months of this program.

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Section 4

COMMUNICATIONS WITH INTERNATIONAL CO-PRINCIPAL INVESTIGATORS

A very useful and keen dialogue has been progressively established with the participating Co-Principal Investigators. A summary of the major highlights to date of the technology transfer program which is so integral to this over-all project is as follows:

- Foremost, it is to be noted that D.L. Wise, Principal Investigator, was able to assemble a group of our international participants on this project for an initial meeting. This joint meeting of participants was held during the time of the Third International Symposium on Anaerobic Digestion (termed AD' 83), which was held in Boston, Massachusetts, during August, 1983. Those participants in our initial meeting included:

Name	Country
Dr. J.F. Calzada (representing Dr. Carlos Rolz)	Guatemala
Dr. Uri Marchaim	Israel
Mr. Chen Ru-Chen (participating with Dr. Wong)	Maucau
Ms. M. Mateo (representing Dr. Javier Verastegui)	Peru
Dr. Joan Mata	Spain

- A "hands-on" oriented "users manual" for the anaerobic digestion experiments on this project was prepared and distributed to all international Co-Principal Investigators early in the program. (Note: Earlier each Co-Principal Investigator received a complete copy of the technical proposal originally submitted to A.I.D. which contained reprints of three major Dynatech publications on "controlled landfilling.")

- A major two volume technical report on "batch" type anaerobic digestion was distributed to all international Co-Principal Investigators. This particular report was based on experimental work, coupled with an engineering evaluation, carried out by Dynatech for a major industrial firm. This firm, Commonwealth Gas Company, gave Dynatech permission to release this report for the use of the international Co-Principal Investigators.

Engineers and scientists at Dynatech believe this major two volume report to be the most complete experimental and engineering evaluation of closely related laboratory based batch digestion to be available. It is anticipated that this report will be a very practical guide to the international Co-Principal Investigators in carrying out their own laboratory based program.

- A mathematical model and supportive engineering calculations have been carried out on the preliminary design for a village/community sized batch type anaerobic digester for agricultural/municipal "solids" residues. This mathematical model has been shown to be operational on a standard "personal" type "home" computer. Over-all, one of the main objectives in preparing preliminary engineering process model for a village/community sized batch digester was to ascertain the minimum sized "pit" for a self-sustained reaction to take place. An over-view of the process model and engineering calculations is contained in this report which will be submitted to all international Co-Principal Investigators.

Note: We believe it would be very meaningful for officials of A.I.D. to consider extension of this on-going project in order to incorporate the technology transfer of process modeling, including the placement of a modern personnel computer for direct use of each of the international Co-Principal Investigators.

- Development is now in process for a more refined mathematical model and economic analysis for the village/community biogas system under investigation. This process model will require a main frame computer for operation and will be of further utility in the over-all concept of technology transfer which is so integral to this project. The full utility of this more refined model may not be possible on this present program; however, this activity will be of use in illustrating modern computational tools for system evaluation. The results on those more complete engineering evaluations will be available at the time of our Workshop.

Agricultural Research Center
Giza, Egypt

Israel — D.L. Wise met with our Co-Prinicipal Investigator, Dr. Uri Marchaim and reviewed with him his plans for long term batch digestion of cotton stocks. Dr. Marchaim plans to be able to carry out a field evaluation of the batch digestion of cotton stocks. Dr. Marchaim's full address is:

Dr. Uri Marchaim
Kibbutz Industries
R & D Institute
Kibbutz Kfar-Giladi
Israel 12-210

Hong Kong — D.L. Wise met with our Co-Principal Investigator Dr. M.H. Wong of the Chinese University of Hong Kong. Dr. Wong and Dr. Wise then visited and reviewed plans with Mr. Chen Ru Chen in Macau.

In general, the plan will be for Dr. Wong, with the assistance of Mr. Chen Ru Chen, to investigate long term batch digestion of wheat straw. Municipal solid waste, a serious problem in Hong Kong and a research interest of Dr. Wong, will also be investigated. It is to be noted that Dr. Wu Wen of the Peoples Republic of China, member of the Chinese Academy of Sciences, and Director of the Guangzhou Biomass Institute has invited Dr. Wong to visit his laboratories and discuss this project. Dr. Wong's complete address is:

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

Philippines -- D.L. Wise met with our Co-Principal Investigator Dr. William Padolina at the University of the Philippines, Los Banos. Dr. Padolina has initiated work on the bioconversion of rice straw to fuel gas following the procedures outlined in this project. In general, swine manure is being used as both the inoculum and source of nutrients. Several graduate students of Dr. Padolina's are involved in this work. Dr. Padolina's full address is:

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

Indonesia — D.L. Wise met with several of the people involved in energy recovery from biomass and residues in Indonesia. Specifically, the work is being coordinated under the direction of Dr. Didin S. Sastrapadja. More direct supervision of the work is under Dr. S. Saono.

In addition to reviewing the over-all plans for this project with Dr. Saono, Dr. Wise discussed detailed plans with Dr. Triadi Basuki. Basically, rice straw will be used as the primary agricultural residues for biogas production with water buffalo manure as the inoculum and nutrient sources. Dr. Basuki and Dr. Wise also visited several municipal solid waste dump sites in the greater Jakarta area with the objective of ascertaining the potential for methane recovery. Dr. Saono recently informed us that Dr. Suhirman is responsible for the work on this project, that work is progressing well, and the results will be presented at our November 1-2, 1984 Workshop. The address of Dr. Sastrapadja is:

Dr. Didin S. Sastrapadja
Deputy Chairman for Natural Sciences
Kantor/Office
Lembaga Ilmu Pengetahuan
Jln, Teuku Cik Ditiro 43 Jakarta
Indonesia

Singapore — D.L. Wise met with Dr. Kee Kean Chin of the University of Singapore and his assistant, Dr. NG Wun Jern. As a Professor of Civil Engineering, with a specialty in Sanitary Engineering, Dr. Chin is uniquely well qualified to participate in this project. Due to the very high population density in Singapore, Dr. Chin is primarily interested in the potential for methane recovery from municipal solid waste. Dr. Chin invited Dr. Wise to visit with him the very modern solid waste incinerator in Singapore. We also discussed with Prof. Chin's and Prof. NG's students, some experimental work on solid waste digestion and plans for evaluating the objectives of this project, namely, controlled landfilling. Dr. Chin may also be able to initiate experiments in Malasia with agricultural residues. The full address of Dr. Chin and his assistant, Dr. NG Wun Jern, are:

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

and

Dr. NG Wun Jern
Department of Civil Engineering
National University of Singapore
Kentridge Campus
Singapore 0511

Africa — D.L. Wise, while on an independently sponsored project by the United Nations, was able to attend a conference in Dakar, Senegal. Dr. Wise reviewed this A.I.D. project with a number of attendees at the conference with the objective of extending this project. Some of the persons interested in possible participation are as follows:

LIST OF INTERESTED PARTICIPANTS FROM AFRICA

Professor Kosonike Koso-Thomas
Department of Civil Engineering
Fourah Bay College
Freetown
Sierra Leone

Akuete T. Eklu-Natey
Director General
Societe Togolaise D'etudes
De Development
Lome, Togo

Professor Olumuyiwa Awe
Department of Physics
University of Ibadan
Ibadan, Nigeria

Professor Rene' Rabezandrina
Department of Agriculture
University of Madagascar
Antannarivo, Madagascar

Ms. Mile El Movatassime
Centre National de Coordination
de la Rechereche Scientifique
et Technologique
Agdal Rabat
Maroc (Morocco)

Dr. Paul Vitta
Director, Training Division
African Regional Centre for
Technology
Dakar, Senegal

In summary, it is seen that some personal contract has been made by Dr. Wise with all international participants or their direct representatives (with the exception of Prof. V.V. Modi in Baroda, India; travel plans have not yet enable this meeting to take place). These meetings range from participating in our initial group meeting in August 1983 through to having individual meetings in the laboratories of our Co-Principal Investigators. A summary table of meetings with our ten Co-Principal Investigators or their technical representatives is given in Table 4.1 along with other international workers who have indicated a keen interest in this program.

Table 4.1

SUMMARY OF COMMUNICATIONS WITH CO-PRINCIPAL INVESTIGATORS (OF THEIR TECHNICAL REPRESENTATIVES AND OTHER INTERNATIONAL WORKERS)

CO-PRINCIPAL INVESTIGATOR	BODY OF TECHNICAL PROPOSAL AND ALL PERTINENT REFERENCES	INITIAL MEETING AUGUST, 1983	VISITS TO LABORATORY	DESIGN MANUAL NOVEMBER 1983	TWO VOLUME DYNATECH REPORT	PRELIMINARY ENGINEERING EVALUATION (THIS REPORT)
Dr. J.F. Calzada Head, Applied Research Division Investigacion y Tecnologia Industrial Central American Research Institute for Industry Avenida La Reforma 4-47 Zona 10 Guatemala	✓	✓		✓	✓	✓
Dr. Kee Kean Chin National University of Singapore Faculty of Engineering 12 B Patterson Hill Singapore 9	✓		✓	✓	✓	✓
Dr. M. Nabil Alaa El-Din Senior Researcher of Soil Microbiology Director, Biogas Project Agricultural Research Center Giza, Egypt	✓		✓	✓	✓	✓
Dr. William G. Padolina Department of Chemistry University of the Philippines at Los Banos College, Laguan 3720	✓		✓	✓	✓	✓
Dr. Uri Marchaim Kibbutz Industries R & D Institute Kibbutz Kfar-Giladi Israel 12-210	✓	✓	✓	✓	✓	✓
Dr. Joan Mata Universidad de Barcelona Facultad de Quimica Diagonal 647 Barcelona 28 Spain	✓	✓		✓	✓	✓
Dr. V.V. Modi Professor and Head Dept. of Microbiology The Maharaja Sayajirao University of Baroda Baroda - 390 002 India	✓			✓	✓	✓
Dr. Didin S. Sastrapadja Deputy Chairman for Natural Sciences Kantor/Office Lembaga Ilmu Pengetahuan Jln. Teuku Cik Ditiro 43 Jakarta Indonesia	✓		✓	✓	✓	✓
Dr. Javier Verastegui Jr. Morelli 2da. cda esquina av. de las Artes (alt. cda. 21 av. Javier Prado-este) San Forja - 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 (with the assistance of:) Mr. Chen Ru-Chen Hoi Peng Garment Factory 17 Rua De Manuel De Arriaga Maucau via Hong Kong	✓	✓	✓	✓	✓	✓