SCALE EFFECT OF MODELLING ON BIOGAS GENERATION

by

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B.S. in C.E., Yıldız University, 1980

Submitted to the Institute for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Master of Science
in
Environmental Engineering

Boğaziçi University

1984

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DATE OF APPROVAL June 18, 1984

This study is dedicated

to my mother

FATMA

who passed away six days

before my thesis defense

examination

ACKNOWLEDGEMENT

I would like to express my sincere thanks to my thesis supervisor , Doç.Dr. Kriton Curi who guided this research and made the thesis possible. His foresight, invaluable guidance and suggestions are deeply appreciated and his understanding and patience will be long remembered.

I feel grateful to Miss Günay Kocasoy and to Miss Ayşegül Baysal for helping me throughout my laboratory experiments and for their assistance.

I also thank Mrs.Şemsa Uygun and Miss Fulya Ertek for their patience and skill in typing this thesis. Their comments about the organization of the thesis were of vital importance.

Special thanks are extended to "YTONG" factory for providing the YTONG used in the present study free of any charge.

Without the help of encouragement, patience and great moral support of my mother, FATMA , it would have been extremely hard for me to complete this study.

Recep Çukurova

SCALE EFFECT OF MODELLING ON BIOGAS GENERATION

Anaerobic decomposition of manure is an outstanding alternative energy source, appropriate for most developing countries.

Several studies related to this subject were conducted so far, however, the effect of the size of the model on the efficiency obtained was not investigated. The main purpose of the present study was to investigate, the scale effect on the performance of an anaerobic digestion. To achieve this three digesters, each of different size and volume, were installed and operated under ambient conditions.

The results obtained have shown that:

1. The size of the model has a slight effect on the efficiency of anaerobic digestion, better performance being obtained in larger model.
2. Any digester can be operated under ambient conditions if proper insulating precautions are taken.
3. Mixing has a positive effect on biogas generation.
4. The positive effect of yeast on anaerobic decomposition is verified.

BİOGAZ ÜRETİMİ İLE İLGİLİ ARAŞTIRMALARDA MODEL ÖLÇEĞİNİN ETKİSİ

Hayvan dışkılarının anaerobik şartlar altında parçalanması neticesinde meydana gelen gazlar gelişmekte olan ülkeler için çok önemli bir enerji kaynağı sayılabilir.

Anaerobik parçalanma neticesinde meydana gelen enerji ile ilgili bugüne kadar birçok araştırma yapılmış olmasına rağmen, model ebadının verim üzerindeki etkisi şimdiye kadar incelenmemiştir. Bu tezin amacı model ebadı tesirini incelemektir. Bu amaca erişebilmek için hacimleri farklı olan üç değişik anaerobik reaktör yapıldı ve tabii hava koşulları altında işletildi.

Elde edilen sonuçlar şunlardır:

1. Model hacminin verime az bir etkisi görülmüştür. Hacimin artması ile verim yükselmektedir.
2. Uygun tecrit önlemleri alındığı takdirde reaktörler tabî hava koşulları altında çalıştırılabilir.
3. Anaerobik şartlar altında parçalanan atıkların karıştırılması biogaz üretimini olumlu etkiler.
4. Reaktöre, belli bir miktarda maya eklenmesi, çürümeyi dolayisıyle biogaz üretimini olumlu etkiler.

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LIST OF SYMBOLS

A	Frequency factor
B	Biodegradable fraction
BVS	Biodegradable total volatile solids concentration
COD	Chemical oxygen demand
C	Constant
CSTR	Completely mixed-fed reactor
C_u	Concentration of unknown gas
C_s	Concentration of standard gas
E	Activated energy (H/2303, R^o)
E_b	The efficiency of biodegradable volatile solids removal
E_T	The efficiency of biodegradable total volatile solids removal
Eq	Equation
F	Volatile solids loading rate
G_t	Methane production (volume gas/ L slurry-day)
HRT	Hydraulic retention time
H_u	Peak height of unknown gas
H_s	Peak height of standard gas
K	Substrate utilization coefficient (Removal)
K_1	Substrate utilization coefficient at T_1^oC
K_2	Substrate utilization coefficient at T_2^oC
K_s	Half velocity constant
K_d	Endogenous decay coefficient
m	Proportionality constant
Q	Flow rate
Q_{10}	Temperature coefficient
R	Refractory fraction
R^o	Gas constant
r	Rate of the reaction
RVS	Refractory volatile solids concentration
S_1	Effluent total volatile solids concentration
S_o	Influent total volatile solids concentration
S_{bo}	Influent biodegradable volatile solids concentration
S_{b1}	Effluent biodegradable volatile solids concentration

$S_r = S_{ro} = S_{r1}$	Refractory solids concentrations
Semi-CSTR	Semi-continously-mixed-fer reactor
t	Incremental time period
T	Temperature
TS	Total solids concentration
TVS	Total volatile solids concentration
V	Reactor volume
v	Feeding and withdrawal volume
VA	Volatile acids
$V\frac{dS_b}{dt}$	Change in biodegradable volatile solids with time
ΔH	Activation energy
θ	Hydraulic retention time (HRT)
θ_c	Solid retention time (SRT)
θ_1	Temperature activity coefficient
θ_{10}	Temperature coefficient
μ_m	Maximum specific growth rate

CHAPTER I

INTRODUCTION

The energy crisis of 1970's proved the need for alternative energy sources to replace the conventional ones, like petroleum etc, which have started to become scarce.Research for the development of renewable energy sources gained importance.National as well as international organizations started to support activities aiming the development of these sources.The conference on New and Renewable Energy Resources which has been organized in Nairobi,Kenya by the United Nations in August,1981 was one of the most outstanding activities in this field.

The need for energy is more important in developing countries,which strive to rise their standards of life, It is well-known that development involves greater use of energy and " without access to increasing amount of energy,there can be no development " (Jackson,1981). Shortage or/and high price of the conventional energy sources of global importance such as oil,gas,coal and nuclear energy, forced developing countries to find and improve new and renewable sources with the understanding that this will not be the solution but a contribution to the energy problem.

The United Nations Conference, mentioned above, considered the following sources of energy as"new and renewable" ones :

Geothermal Energy
Wind-power Energy
Tidal-power Energy
Wave-power Energy
Thermal Gradient of the Sea
Biomass Conversion
Fuel-Wood
Charcoal
Peat and Energy from Draft Animals,Oil Shale,and
Hydropower (Jackson,1981)

Among these,the biomass conversion is of particular importance for Turkey.

The use of gases produced by anaerobic decomposition have been in use since the beginning of 20th century,however after the energy crisis of 1970's its use of biogas started to spread rapidly. At the end of 1978 in China, 7.15 millions biogas plants served to about 5.26% of the rural population (850 millions). In India, 70 000 plants were installed between 1962 and 1968 (Thery,1981) and in Korea, 24 000 plants were installed between 1969 and 1973 (NAS,1977)

Unfortunatelly,few studies on biogas generation have been conducted in Turkey till now.The number of biogas generation reactors was only at the range of 20-25 at the end of 1980 (Kırımhan,1981).Few organisations such as "Toprak Su Araştırma Enstitüsü", "TÜBİTAK", and recently "MTAE" contributed to the development of the currently available designs of biogas plants. Also "Toprak Su Araştırma Enstitüsü" recently started to provide credits for the installation of biogas reactors.The most important activity however was the project supported by UNICEF by 123 500 $ between 1980 and 1981. Details about which are given in the Official Gazette (Resmi Gazete) of 1980.

The reasons why biogas gained importance in recent years are the following :

a) It does not depend on imported goods and consequently on foreign currency ,

b) The end products of this process are methane which can be used as an energy source and the solid residuals which are good quality fertilizers ,

c) It is a safe and no energy consuming waste disposal method (Barnet et.al.,1978).

The Environmental Engineering Programme which is developed within the Civil Engineering Department of Boğaziçi University being aware of the significance of this process, supported several studies related to this subject among which the studies of Alpaslan (1979), Baban(1981) and Kocasoy (1982) should be mentioned.

The present study is an extension and verification of the previously conducted studies emphasizing more on the following objectives :

a) Determination of the size effect on the efficiency of a biogas reactor ,
b) Determination of the efficiency of a biogas reactor subjected to ambient conditions,
c) Verification of the results of the previously obtained studies.

After the first chapter, which is a general introduction to the subject, the literature review follows in the second chapter. In chapter three, the experimental set-up is explained in detail.This chapter is followed by chapter four where the experimental procedure is presented. The results obtained obtained and discussions are given in chapter five. The study ends with a conclusion chapter.

CHAPTER II

LITERATURE REVIEW

2.1 General Information on Biogas

Pure methane is a colourless and odourless gas, lighter than air, combustible and explosive when mixed with air in proportions ranging from 5% to 15%. It burns with a blue flame and has a calorific value of 37 KJ per liter.Methane can not be liquified under pressure at ordinary temperatures.The critical pressure of methane is 466.29 meters water column at -82.3°C.

Biogas mainly contains 60% to 70% methane, 30% to 40% carbon dioxide and small amounts of hydrogen sulphur,hydrogen,ammonia and oxides of nitrogen. It has a calorific value ranging from 22 to 26 KJ per liter depending upon the quantitiy of methane present. It can be directly used for cooking, lighting,heating purposes as well as a source of energy for combustion engines (WRN,1981). Some biogas consumption rates are given in Table 2.1 (Barnett,A.,et.al.,1978)

TABLE 2.1 BIOGAS CONSUMPTION RATES (BARNETT,A.,et.al.,1978)

Use	Specification	Consumption m^3/hr
Cooking	5.1 cm burner	0.33
Gas lighting	Per montel	0.07
Refrigerator	Per m^3 capacity	1.00
Incubator	Per m^3 capacity	0.5-0.7

2.2 Theory of Biogas Generation

Animal manure mixed with water and kept under anaerobic conditions decomposes to the end products,mainly carbon dioxide and methane.The anaerobic

digestion process can be divided into three different stages.The sequence of the phases of the process is shown in Figure 2.1. According to the Kasper and Wuhrman (1978), in the first stage predominantly insoluble complex organic components such as lipids,carbohydrates (general formula,CH_2O- e.g. cellulose, hemicellulose,pectin, starch) and nitrogen containing compounds (e.g. protein,nucleic acids) are first hydrolized into smaller soluble compounds and then broken down further to produce mostly short chain fatty acids. Protein and carbohydrates are broken down into their component amino acids.The first stage or hydrolysis is carried out by the extra cellular enzymes (Downing and Kell,1976). In the second stage which is known as acidification phase, the acids (e.g. acetic acids,propionic acids and lactic acids) are produced from the end products of bacterial metabolism of carbohydrates and proteins.During this phase, both carbon dioxide and hydrogen gases are formed by the H_2 producing acetogenic bacteria, or S organisms(Bryan
et.al., 1967) and sufficient energy is released for cell growth. A small proportion of the organic waste is converted to cell material.In addition a portion of the organic sulphur appears as sulphide.pH may decrease during the second stage.This phase is carried out by acid-forming bacteria. The third stage is the formation of methane and carbon dioxide. It is during this stage, that stabilisation of the waste occurs.This stage is carried out by two different groups of organisms which are MOH organisms (H_2- utilizing methanogenic bacteria, Bryant,M.P.et.al.,1967) and acetate organisms(Gujer and Zender,1982). Acetate organism forms methane and bicarbonate from acetic acid according to the following reaction,

$$CH_3COO^- + H_2O \longrightarrow CH_4 + HCO_3$$

Mc Carty(1964) has estimated that about 70 percent of the methane is produced from acetic acid. These bacteria carry out the major portion of waste stabilization. Their slow growth and their rate of acid utilization normally represent the limiting step around which the anaerobic process must be designed.MOH organism utilizes molecular hydrogen to form methane. Studies indicate that approximately 30 percent of methane production is from hydrogen according to the following reaction :

$$CO_2 + 4H_2 \longrightarrow CH_4 + H_2O$$

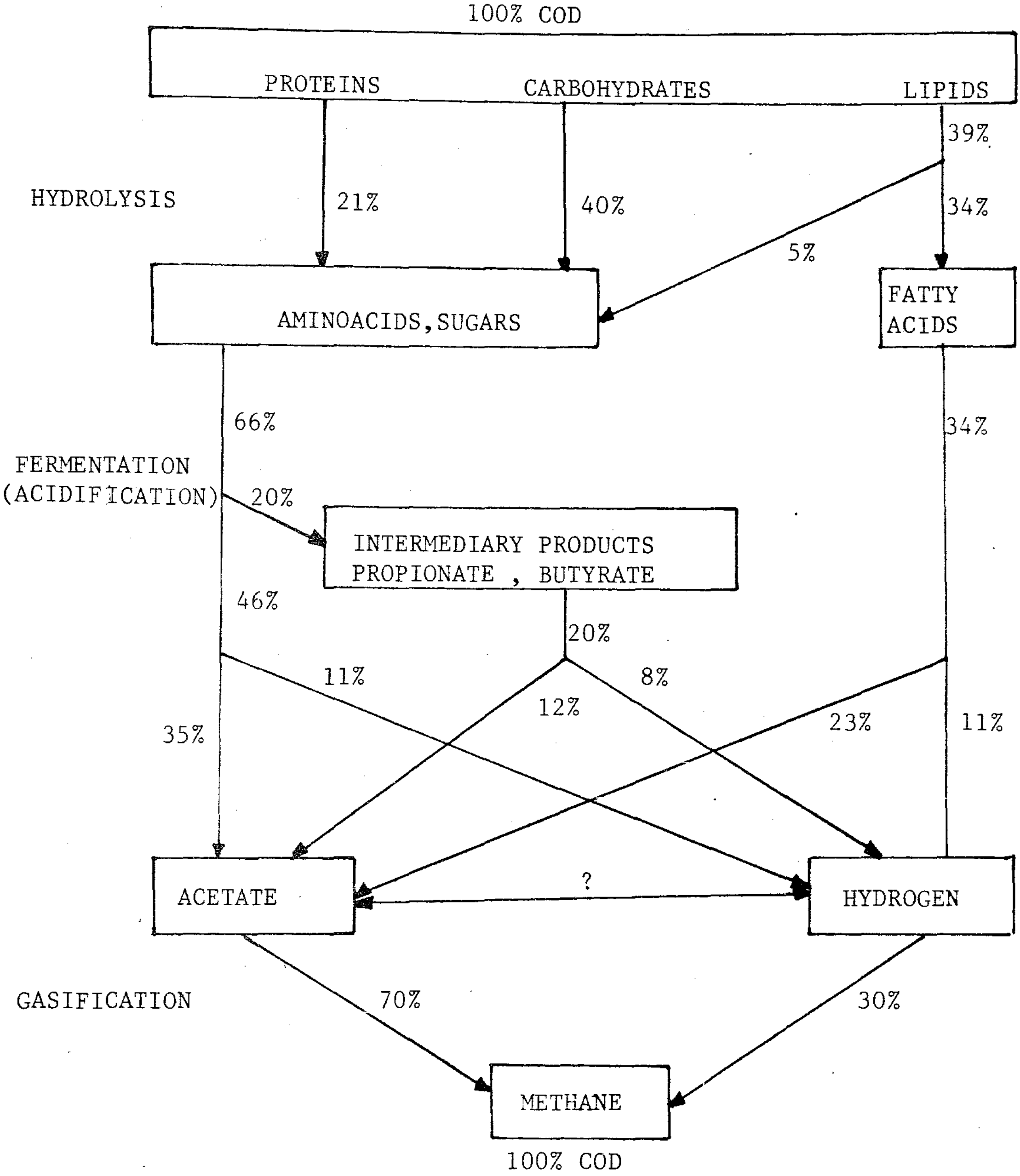


Figure 2.1 Proposed Reaction Scheme for Anaerobic Digestion . Adopted from Kaspar and Wuhrmann (1978). % numbers indicate substrate flow (stoichiometrically) in form of COD or CH_4 equivalents. Only net flow of substrates (degradation minus biomass formed) through cell external are indicated

2.3 Biological Growth Kinetics

There are two general approaches used to mathematically model biological processes which are Monod Model (a rational fundamental approach based on the understanding of microbial growth) and first order model (on empirical approach which is dependent upon laboratory or full scale analyses of the substrate). Monod Model (Monod,1949) is expressed as :

$$S_{b1} = \frac{K_s(1 + K_d\,\Theta_c)}{\Theta\,(\mu_m - K_d) - 1} \qquad \text{.... Monod Equation}$$

where, K_d : Endogenous Decay Coefficient (1/day)

μ_m : Maximum Spesific Growth Rate (1/day)

K_s : Half-Velocity Constant (g /L)

θ : Hydraulic Retention Time (day)

θ_c : Solid Retention Time (day)

S_{b1} : Effluent Biodegradable Volatile Solids Concentration(g

Monod Model is based on pure bacterial culture enzyme kinetics and assumes that the microbial growth rate is a function of substrat concentration in contact with the microorganisms and the concentration of microorganisms in the reactor. Keeping this fact in mind this model is difficult to apply.First order model assumes the rate of substrate removal to be proportional only to the substrate concentration (S).

In this model, it is assumed that the influent flow rates and effluent flow rates are equal,therefore the reactor volume remains constant. Liquid residence time in the reactor is:

$$\theta = V/Q$$

where , Q : Flow Rate (L/day)

V : Reactor Volume (L)

θ : Hydraulic Retention Time (days)

In a completely mixed single staged system where recycle of solids is not practiced.

$$\theta = \theta_c$$

where , θ_c is the Solid Retention Time (days)

A mass balance relationship describing the change in substrate concentration can be written in the following way:

$$\left[\begin{array}{c}\text{Change in Substrate}\\ \text{Concentration in}\\ \text{Reactor}\end{array}\right] = \left[\begin{array}{l}\text{Influent Substrate}\\ \text{Concentration}\end{array}\right] - \left[\begin{array}{l}\text{Effluent Substrate}\\ \text{Concentration}\end{array}\right] - \left[\begin{array}{l}\text{Substrate}\\ \text{Removal}\end{array}\right]$$

Assuming first order substrate utilization kinetics, the change in biodegradable volatile solids can be expressed as:

$$V\frac{dS_b}{dt} = QS_{bo} - QS_{b1} - KVS_{b1} \qquad \text{.... Equation 1}$$

where , $V\frac{dS_b}{dt}$ Change in Biodegradable Volatile Solids (BVS) With Time (g/day)

S_{bo} : Influent Biodegradable Volatile Solids Concentration (g/L)
S_{b1} : Effluent Biodegradable Volatile Solids Concentration (g/L)
K : Substrate Removal Coefficient (L /day)

At steady state dS_b/dt will equal zero, and $V/Q = \theta$, so Equation 1 takes the following form:

$$S_{bo} - S_{b1} = K\, S_{b1}(\theta) \qquad \text{.... Equation 2}$$

Rearranging terms and solving for the effluent biodegradable volatile solid concentration (Faree and Mc Carty, 1968). The following first order mode is obtained;

$$S_{b1} = \frac{S_{bo}}{1 - K(\theta)}$$

From Equation 2,K, the substrate removal coefficient is shown to be:

$$K = \left[S_{bo} - S_{b1}\right] / \theta\ (S_{b1})$$

K can be determined by plotting $(S_{bo} - S_{b1}) / \theta$ versus S_{b1} (Figure 2.2)

The efficiency of biodegradable volatile solids (BVS) removal, E_b, can be described by:

$$E_b = 100\ (S_{bo} - S_{b1})/S_{bo}$$

and efficiency of total volatile solids removal, E_T :

$$E_T=100(S_o-S_{b1})/S_o$$

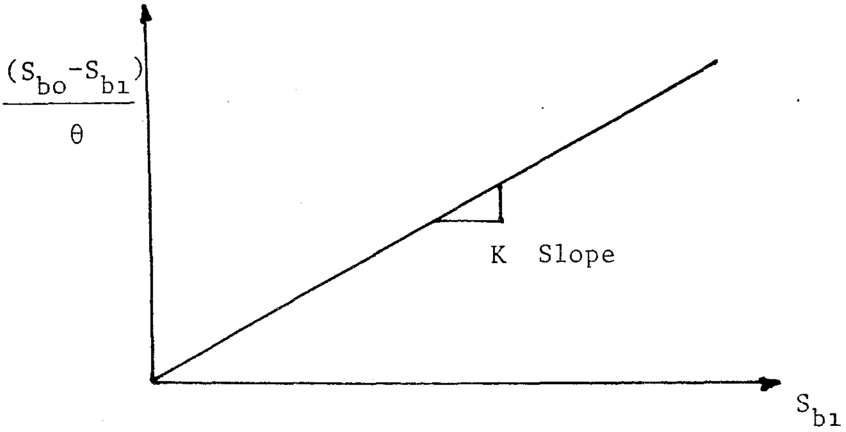


Figure 2.2 Graphical Determination of Substrate Removal Coefficient

2.4 Reactor Performance Based on the Empirical Model

For semi-continuous tank reactors the following equation (3) may be used (Jewell,et.al.,1978) :

$$S_{b1} = \frac{S_{bo}(t)\exp(-Kt)}{\theta\left[1-(1-t/\theta)\exp(-Kt)\right]} \qquad \text{.... Equation 3}$$

where, t is Incremental Time Period in Semi-Cotinuous Mode. Jewell(1978) showed that a semi-cotinuous reactor could be considered equivalent to a completely mixed tank reactor (CSTR) when operated at long hydraulic retention times (t<<HRT) (Equation 4).

$$S_{b1}(CSTR) = \lim_{t\to 0}\left[\frac{S_{bo}(t)\exp(-Kt)}{\theta(1-(1-t/\theta)\exp(-Kt))}\right] = \frac{S_{bo}}{K(\theta)+1} \qquad \text{.... Equation 4}$$

2.5 Biodegradability

Biodegradability describes the anaerobic fermentation of dairy manure.Its theory is developed by Jewell(1976) and applied by Morris(1976). Highly concentrated animal manures such as dairy cow manure contains a large fraction of nonbiodegradable or refractory material.The total volatile solids (TVS) are comprised of two fractions:Biodegradable volatile solids (BVS) and refractory volatile solids (RVS).Equation 5 and 6 describe the two fractions in effluent and influent.

$S_o = S_{bo} - S_{ro}$ .... Equation 5

$S_1 = S_{b1} - S_{r1}$ .... Equation 6

where, S_o: Influent Total Volatile Solids (g/L)

S_{bo}: Influent Biodegradable Volatile Solids(g/L)

S_1: Effluent Total Volatile Solids (g/L)

S_{b1}: Effluent Biodegradable Volatile Solids(g/L)

S_{ro}: Influent and Effluent Refractory Volatile Solids(g/L)

Since the refractory fraction of the total volatile solids is resistant to microbial attack, the influent and effluent refractory solids concentrations remain constant.

$S_{ro} = S_{r1} = S_r$ .... Equation 7

If R is determined refractory fraction of the total volatile solids in the influent becomes ,

$R = S_1/S_o$

To determine R, a graphical plot (Figure 2.3) of experimentally determined S_1/S_o versus $1/S_o(\theta)$ is prepared. The result is a straight line, the ordinate intercept of which represent the refractory fraction of the organic matter.

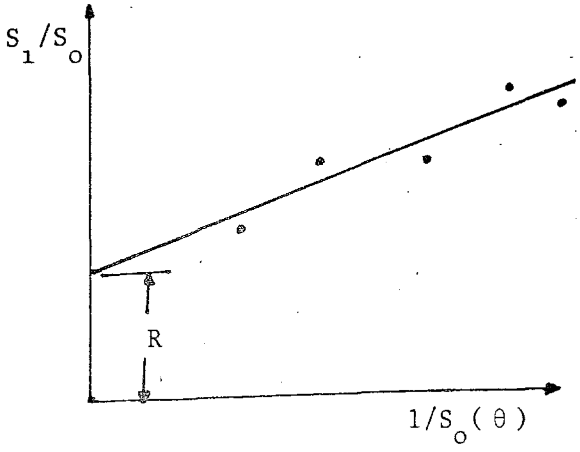


Figure 2.3 Refractory Fraction (Anthonisen,et.al.,1968 and Wood,et.al., 1974 and Morris,1976)

In this method, the manure is placed in a batch reactor. Samples are withdrawn at various intervals and analyzed for total volatile solids. When hydraulic residence time ,θ, goes to infinite time, S_b (effluent volatile solids concentration) will lead to zero. Substituting $S_{bi} = m/\theta$ into Equation 7 gives :

$$S_1 = \frac{m}{\theta} + S_{ro} \qquad \text{.... Equation 8}$$

m is the Proportionality Constant (or slope of straight line). Dividing both sides of Equation 8 by S_o yields (Jewell, et. al., 1978).

$$\frac{S_1}{S_o} = \frac{m}{S_o(\theta)} + \frac{S_{ro}}{S_o} = \frac{m}{S_o(\theta)} = R \qquad \text{.... Equation 9}$$

2.6 Methane Production

Methane production from an anaerobic treatment process can be calculated based on the amount of total volatile solids stabilised. The amount of methane produced is proportional to the total volatile solids digested as indicated in the following equation:

$$G_t = 0.35\ M(S_o - S_1)/\theta \qquad \text{(based on the total volatile solids)}$$

where, G_t : Methane Production (Volume gas/reactor volume-time)

θ : Hydraulic Retention Time (day)

M : Chemical Oxygen Demand to Total Volatile Solids Ratio of the Biodegradable Feed Material

0.35 : Theoretical Volume of Methane in Liters/g Chemical Oxygen Demand Removed.

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

As can be determined from the above relationship 2 mole of oxygen or 64 grams of chemical oxygen demand is equivalent to one mole (or 22.4 L at STP) of methane, and 22.4 L/64 g = 0.35.

It is assumed that the ratio between biodegradable chemical oxygen dema reduction and biodegradable total solid reduction remains constant.

through the anaerobic fermentation process and knowing that the ratio of COD to TVS for most complex organics is 1.4,the quantity of gas production per unit volume of reactor can be predicted (Jewell,1978) by

$$G_t = 0.5(S_o - S_1)/\theta$$

where , S_o : Influent total volatile solids concentration, mg/L
S_1 : Effluent total volatile solids concentration, mg/L

2.7 Factors Affecting Methane Generation

The following parameters effect the generation of methane.

2.7.1 pH, Alkalinity, and Volatile Acids

pH of a digester is a measure of the acidity or alkalinity of its contents.It is an extremely important parameter to control the optimal digestion conditions.pH effects the rate of reaction,the end products of fermentation and the solubility of metals.All anaerobic digestion process can be operated successfully within the pH range of 6 to 8.Jewell (1978) states that "Alkalinity in these units provides the 'buffering capacity' so that if there is a small volatile acids accumulation the pH of the reactors will not be adversely effected.The volatile acid concentration in the system is an important parameter which should be monitored.If the volatile acid concentration increases,this indicates that the system is not in equilibrium and the methane forming bacteria in the system may be inhibited."

Under steady-state conditions,pH is relatively constant.However, sudden drops in temperature,shock loads,and toxic substances unbalance the volatile acid concentration.Thus, if the volatile acid concentration continues to accumulate, a drop in pH will eventually result and the reactor will fail.

If a drop in pH occurs the following precautions should be taken to prevent the failure in the decomposition process.

1. Feeding may be stopped and the methanogenic population is allowed to reduce the volatile acid concentration.When volatile acid concentration reach low levels(e.g. 10% of normal), feeding can start again.

2. If pH still continues to drop, chemicals can be added.Usually lime is used to increase the alkalinity of the reaction.It must be noted,however that calcium bicarbonate is not a very soluble compound and precipitates usually above a pH value of 6.7 according to the following equation.

$$CO_2 + Ca(OH)_2 \longrightarrow CaCO_3\downarrow + H_2O$$

3. Instead of using calcium bicarbonate,hydroxide and carbonate salts of sodium or calcium may be used to overcome the disadvantages of the bicarbonate insolubility.

2.7.2 Temperature

The anaerobic digestion process can take place over a wide range of temperatures,5^{0}C to 60^{0}C. In reality variation of temperature has an effect on the type of bacteria.Operation of the process can take place within three separate temperature ranges having different characteristics. These are thermophilic fermentation,mesophilic fermentation and psychrophilic fermentation.

a) Thermophilic Fermentation (Temperature Range,47^{0}C to 55^{0}C)

Sludge digesters in this range give faster reaction rates than mesaphilic range and provide a more efficient process.Daily gas production is around 2.5 m^3/m^3 of digester(UNEP, 1981) However,digesters are not commonly operated at these temperatures for the following reasons:

- Thermophilic bacteria are very sensitive to any temperature change in the digester.
- Cost of the external heat energy is too high.
- The quantity of fertilizer produced by thermophilic bacteria is low less than the other temperature ranges).

b) Mesophilic Fermentation (Temperature Range, 5^0C to 25^0C)

Operation of the digesters at this temperature range is usually common. Residence time are around 20 to 40 days. Daily gas production is 1-1.5 m^3/m^3 of digester volume depending upon concentration of substrate (UNEP,1981).

c) Psychrophilic Fermentation(Temperature Range, 5^0C to 25^0C)

This reaction rate is the lowest among others and residence time of the microorganisms vary between 100 and 300 days. Daily gas production vary between 0.1 and 0.3 m^3/m^3 of digester volume depending upon substrate concentration(UNEP,1981).

The effect of temperature on anaerobic digestion can be expressed in two different ways. These are Arrhenius Equation (1889) and temperature coefficient, θ_{10}(Stuckey, 1983).

1. Arrhenius Equation(1889)

Temperature has an extremely important effect on anaerobic digestion since it alters the activity of enzymes,and hence the microbial growth rate. This effect can be described by the following equation (Arrhenius,1889).

$$r = A.e^{-\Delta H/R^0 T} \qquad \text{.... Equation 10}$$

where , r : Rate of the Reaction
R^0: Gas Constant (1.987 cal/^{0}K mol)
T : Absolute Temperature (^{0}K)
ΔH : Activation Energy
A : Frequency Factor

By taking the logarithm of both sides of Equation 10,the rate of reaction can be expressed as :

$$\log r = C - E/T \qquad \text{.... Equation 11}$$

where , C is a constant.

E : $\Delta H/2.303.R^0$ (8400 to 84000 Joulle/mole)

As can be seen in Equation 11, when log r is plotted against 1/T, the Equation 11 gives a straight line of slope E and intercept C. If the temperature range is limited, most chemical (biochemical) reactions give a straight line plot (Figure 2.4)

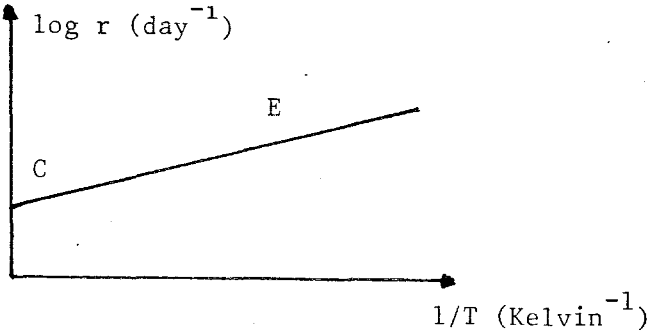


Figure 2.4 Microbial Growth Rate versus 1/T

2. Temperature Coefficient (θ_{10})

Another common way to express the effect of temperature on a biological system is by use of the term θ_{10} or "temperature coefficient". This coefficient gives the increase in reaction rate for every 10^0C rise in the temperature of the reactor. Novak(1974) states that the θ_{10} is not only a function of temperature,but also is a function of the substrate concentration. This concentration increases as θ_{10} decreases (Figure 2.5).

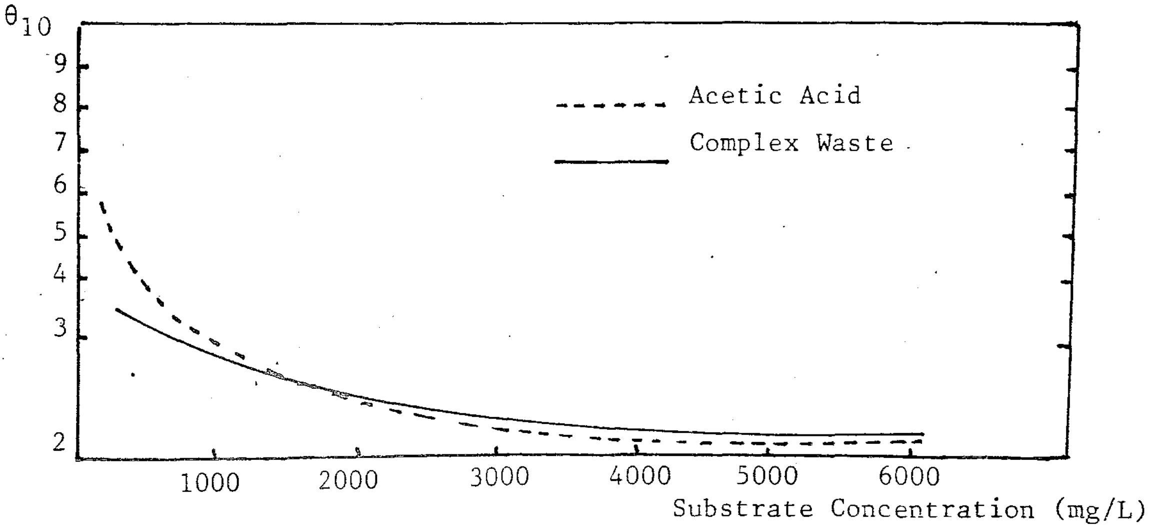


Figure 2.5 Variation θ_{10} With Substrate Concentration under Anaerobic Conditions (Stuckey,1983)

θ_{10} can be expressed as (Stuckey,1983) :

$$\theta_{10} = \frac{\text{rate at}(T^0C + 10^0C)}{\text{rate at } T^0C} \qquad \text{.... Equation 12}$$

2.7.3 Substrate Concentration,Retention Time,and Organic Loading Rate

The three parameters are intimately related to each other. Figure 2.6 illustrates the relationship between these three parameters. The substrate concentration is expressed as total solids (percent solids) of the influent material. The organic loading rate is presented as the quantity of organic material supplied to the reactor per day (grams of volatile solids added per liter of reactor per day).

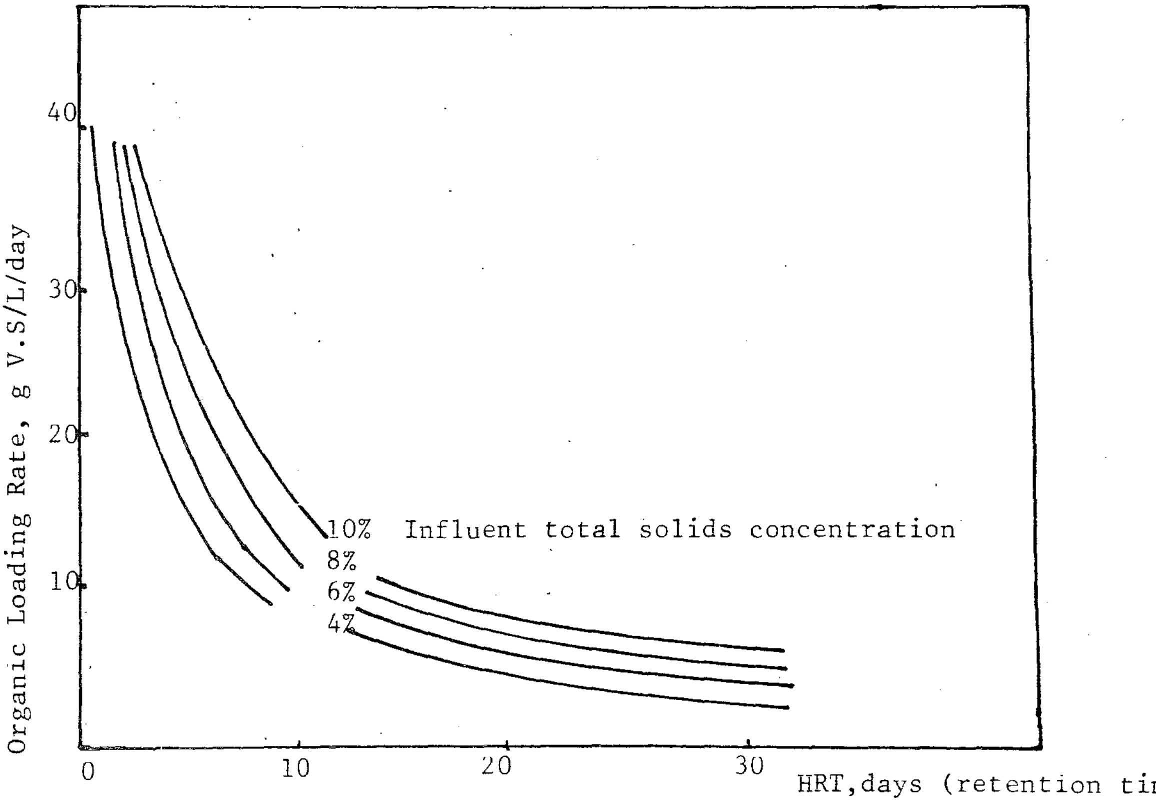


Figure 2.6 Organic Loading Rate as a Function of Hydraulic Retention Time (HRT) in a Completely Mixed Fermentor. Assuming VS/TS (Volatile Solids/Total Solids) Equals 0.88 (Jewell,1978)

All organic substances except mineral,oil and lignin are suitable for anaerobic digestion process. Stalks and leaves are rich in cellulose which is a highly polymerized linear matrix tightly wrapped with a surface layer of wax. Therefore,it is very difficult for bacteria to destroy and digest them. Such substances should be pre-treated before use in a digester. There are two methods of pre-treatment:

In the first method weeds,stalks and leaves are crushed and then used as fodder. Then by passing through the digestive system of livestock, especially through the rumen,these raw materials become more quickly digestible in the anaerobic digestion process with increased biogas production.

In the second method stalks are cut into small pieces,a little lime water and excreta are added,and the mixture is piled into a heap for composting. After a short time,the wax disintegrates and the cellulose becomes soft and loose. Precomposting raises the temperature of the compost to 60-70^{0}C and kill off the insects. The second method has a weak point that part of the raw material decomposed by aerobic bacteria and thus its energy content is wasted (UNEP,1981). On the other hand,without pre-treatment the process will be too slow.

2.7.4 Mixing

It is necessary to mix the digester slurry continuously to prevent thickening and caking of scum. Thickening and caking of scum on the surface of the slurry prevent the gas from escaping into the gas-holder.Mixing also ensures distribution of raw katerials,extends the contact surface of raw materials with bacteria and speeds up the reaction (UNEP,1981). Studies showed that the gas yield in stirring digester is 10-15% higher than the unstirred digester(UNEP,1981).

2.7.5 Pressure

Xu Vi-Zhong stated that "if the internal pressure of digester is too high, the rate of gas production slows down" (UNEP, 1981). When the internal pressure is at 40-50 cm (water column), it has no effect on gas production, but if it increases to 60-90 cm (water column) gas production decreases. In order to avoid a high internal pressure, it is better to use a gas holder with a water pressure type of structure.

2.7.6 Toxic Substances

There are many materials, both organic and inorganic, which may inhibit the anaerobic waste treatment process. When volatile acid content increases to 200 ppm, fermentation is inhibited. When the ammonia nitrogen concentration exceeds to 1500 ppm, the fermentation bacteria are killed. Table 2.2 shows the inhibiting concentrations of these substances (Mc Carty, 1964).

TABLE 2.2 INHIBITING CONCENTRATION OF SUBSTANCES (MC CARTY,1964)

Cation	Stimulatory	Concentration in mg/L Moderately Inhibitory	Inhibitory mg/L
Sodium	100-200	3500-5500	8.000
Potassium	200-400	2500-4500	12.000
Calcium	100-200	2500-4500	8.000
Magnesium	75-150	1000-1500	3.000
Sulfides	-	200	>200
Soluble Heavy Metals		1	> 1
Ammonia		1700	4000
(ABS) Detergents		15	23

2.7.7 C/N Ratio (Carbon to Nitrogen Ratio)

Carbon (in the form of carbohydrates) and nitrogen (as protein, nitrates, ammonia, etc.) are the chief nutrients for anaerobic bacteria. Bacteria are utilizing carbon in order to obtain the energy needed for their metabolism. However, nitrogen is essential for bacterial life for the following reasons :

1- Growing cells need nitrogen to form protein either for cell mass or for enzymes.

2- The free form of ammonia (NH_4) regulates the pH in the digester acting as a buffer.

Experiments have shown that a carbon to nitrogen (C/N) ratio of 25-30/1 will permit the fermentation process (UNEP,1981). If the carbon to nitrogen ratio is high, nitrogen is exhausted first, and the remaining carbon should not regulate the pH in the digester and should not supply protein for cell structures. In short, reactor falls down. If the ratio (C/N) is low (e.g. C/N 2),carbon is utilized first and the remaining nitrogen changes to ammonia (NH_3). Ammonia exceeding 150 mg/L becomes toxic (UNEP,1981).

2.8 Previous Work on the Anaerobic Digestion of Animal Waste

Table 2.3 summarizes the physical and pollutional characteristics of animal wastes. Operation and performance data from anaerobic digestion of cow manure are given in Table 2.4. As it can be seen in Table 2.4, studies usually performed at 35^{0}C and various detention times,ranging from 2.5 to 30 days. However, a remarkable reduction in volatile solids and increase in gas production were obtained when reactors were operated at hydraulic retention times longer than 10 days. Unfortunately it is difficult to make direct comparisons between the anaerobic digesiton studies of cow manure due to many external factors such as type and size of the animals,stage of lactation,type and location of digester, and time of the year,etc.

The Environmental Engineering Programme which is developed within the Civil Engineering Department of Boğaziçi University supported several studies related to biogas among which the studies of Alpaslan (1979), Baban (1981) and Kocasoy(1982) should be mentioned. Alpaslan (1979) and Baban(1981) were constructed some experimental sets for biogas generation and the effect of yeast addition to cow manure was researched. According to Alpaslan (1979), yeast addition to the cow manure improved the rate of biogas production. This increase in biogas production was not due to an increase in the substrate of slurry. The yeast being added in very small amounts had a catalytic effect. Also,Baban(1981) stated that "A 10% increase in biodegradability and 75-100% increase in gas production were observed when yeast (5 g. yeast per liter of reactor) addition was practised". Kocasoy(1982) was researched the effects of vitamin on cow manure. Kocasoy(1982) stated that "the addition of vitamine B_{12} to cow manure had a definite accelerating effect on the reaction".

TABLE 2.3 PHYSICAL AND POLLUTIONAL CHARACTERISTICS OF ANIMAL WASTE
(Barnett,et.al.,1978)

Parameters	Hens(1.8-2.3 kg)	Swine(45 kg)	Cattle(450 kg)
Wet Manure (kg/day-animal)	0.1	3.2	29.0
Total Solids (% Wet Basis)	290	16.0	16.0
Volatile Solids (%Dry Basis) kg/day	76.0(0.025)	85.0(0.43)	80.0(3.7)
Nitrogen (% Dry Basis)	5.6	4.5	33.7
P_2O_5 (% Dry Basis)	4.3	2.7	1.1
K_2O (% Dry Basis)	2	4.3	3.0
BOD (kg/day)-(kg/kgVS)	0.008-0.320	0.15-0.349	0.58-0.156
COD (kg/day)-(kg/kgVS)	0.026-1.04	0.57-1.32	4.76-1.29
BOD/COD (%)	30.8	26.3	12.2

2.9 Biogas Technology in the World

The need for energy has contributed to the development of different types of digesters and digester techniques. Among these the most important ones are summarized below.

2.9.1 Fixed Dome (Chinese) Digesters

The reactor consists of a gas tight chamber,or poured concrete. Both the top and the bottom of the reactor are hemispherical,and joined together by straight sides. The digester is fed semi-continuously (Figure 2.7).

TABLE 2.4 OPERATION AND PERFORMANCE DATA FROM ANAEROBIC DIGESTION STUDIES

Feed	T°C	Loading kg VS/ m^3-day	θ days	Methane content (%)	m^3 of Gas Produced per kgTVS added	VS Reduction (%)	References
Dairy Cow Manure	35	4.00	20	62	1.20	-	Jewel,et.al., 1976
	22	6.67	12	62	0.268	13.7	Jewel, et.al., 1978
	22	2.67	30	62	0.368	28.3	"
	35	8.00	10	62	1.298	27.9	"
	35	6.67	12	62	1.367	28.9	"
Dairy Cow Waste	32.5	27.9	2.5	59	0.01	8.6	Morris et.al., 1978
	32.5	6.9	5	65	0.06	23.2	"
	32.5	10.4	5	60	0.05	20.8	"
	32.5	13.9	5	60	0.06	19.2	"
	32.5	17.4	5	61	0.06	18.8	"
	32.5	3.5	10	66	0.18	35.0	"
	32.5	5.2	10.	65	0.16	33.7	"
	32.5	7.0	10	65	0.13	39.1	"
	32.5	8.7	10	64	0.14	29.0	"
	32.5	1.7	20	66	0.23	37.8	"
	32.5	2.6	20	63	0.20	37.1	"
	32.5	3.5	20	63	0.19	36.2	"
	32.5	4.4	20	63	0.18	35.1	"
	32.5	1.2	30	65	0.24	39.8	"
	32.5	1.7	30	64	0.21	37.7	"
	32.5	2.5	30	63	0.19	36.0	"

This type of digester has no moving parts. The gas chamber and the digester are combined in one unit. The pressure equilization in digester tank is very interesting. Increasing gas pressure pushes slurry up the feed inlet and outlet pipes and decreased pressure allows the slurry to flow back in the digester (UNEP,1981). There are approximately 5 to 6 million of these digesters in China. The typical feed to these digesters is not homogenous and is usually comprised of a mixture of animal manure,night soil,and agricultural residues. Typical gas productions are around 0.1-0.2 Volume/Volume of digester,day with detention times 60 days at 25^{0}C (UNEP,1981

2.9.2 Floating Cover (Indian or KVIC Design) Digesters

The KVIC design consists of a cylindirical reactor with on height to diameter (H/D) ratio of between 2.5 and 4.1 (Figure 2.8). The reactor is usually constructed of brick,although chicken wire reinforced concrete has been used. The construction does not have to be as strong as the fixed dome type since the only pressure on the wall is the hydrostatic pressure from the liquid contents (Barnett.et.al.,1978)

The gas holder volume is approximately 50% of the total gas production The pressure usually varies between 4-8 cm of water pressure. Typical detention vary from 30 days in warm climates to 50 days in colder climates. Gas yields vary between 0.2 and 0.3 Volume/Volume of digester-day (Total solid concentration is about 9%).

2.9.3 Bag Design (Taiwan) Digesters

This digester consists of a manure inlet, a fermentation and gas storage chamber,and a manure outlet (Figure 2.9). The digester is essentially in the form of a long cylinder (length to diameter ratio varies between 3 and 14) made of either PVC, nylon, or red mud plastic (RMP). The feed pipe is arranged in such a way that a maximum water pressure at about 40 cm is maintained in the bag. The digester acts essentially as a plug flow reactor and the gas produced is usually stored in the reactor under flexible membrane, although it can be stored in a separate gas bag.

Typical detention times in bag digester vary from 60 days at 15-20^{0}C to 20 days at 30-35^{0}C. One advantage of the bag is that its walls are thin

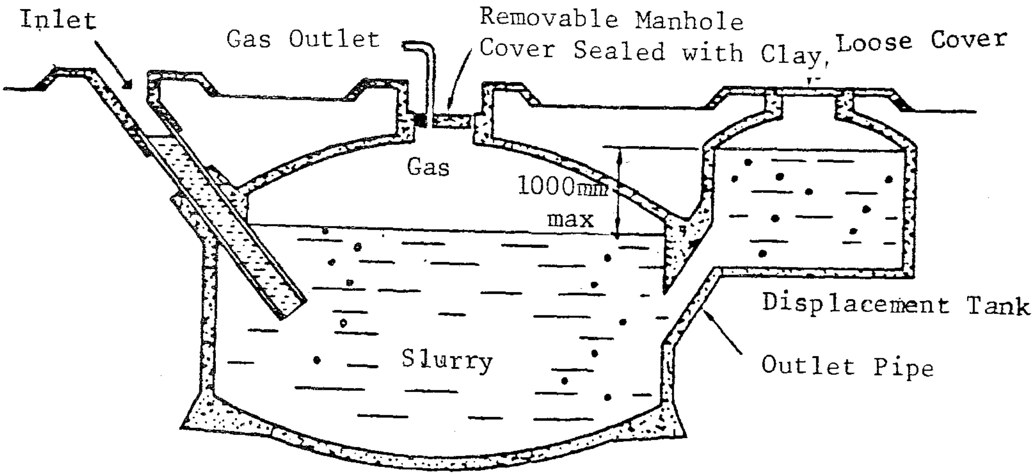


Figure 2.7 Fixed Dome Digester

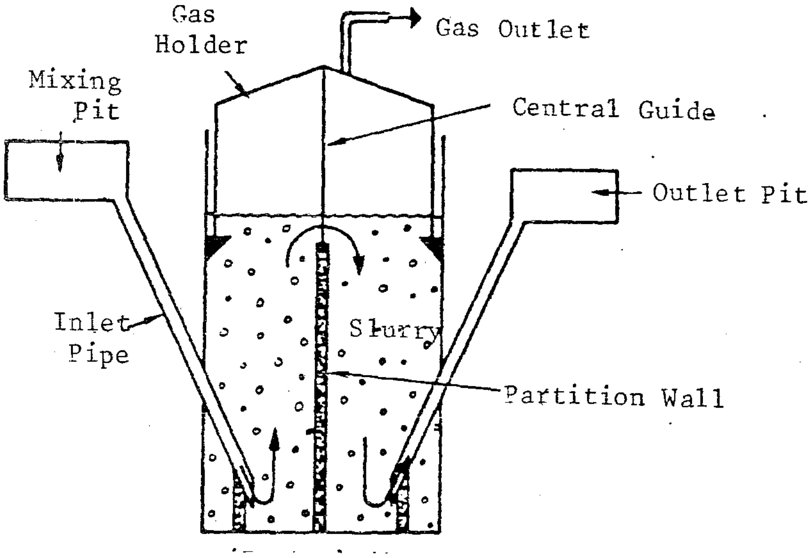


Figure 2.8 Floating Cover

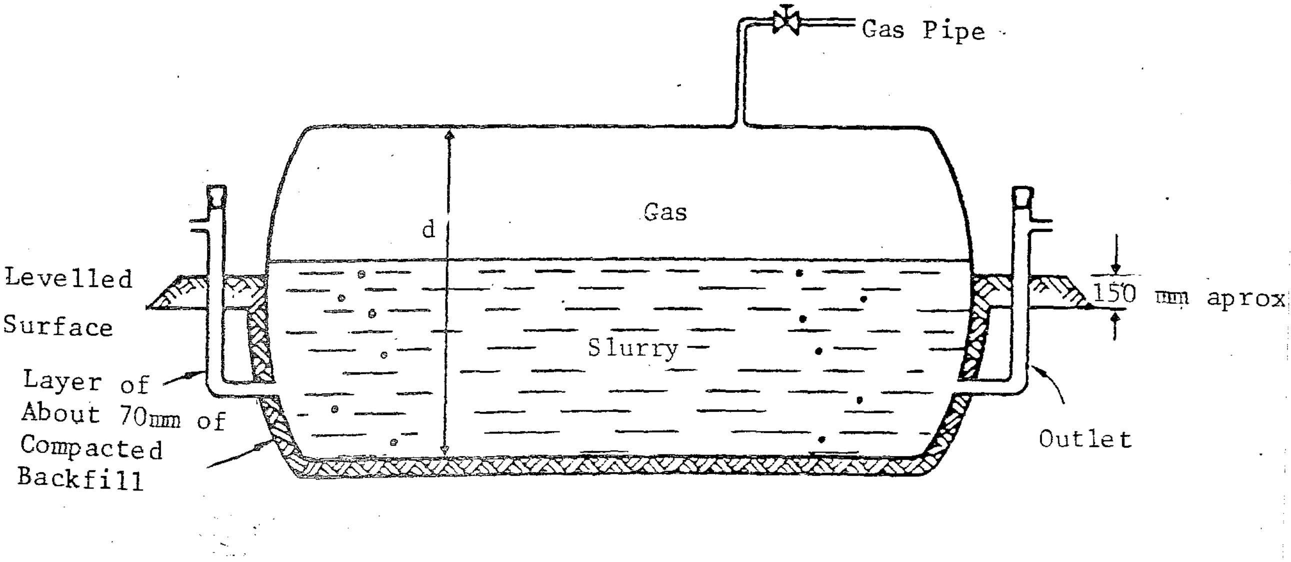


Figure 2.9 Bag (Taiwan) Digester

hence the digester contents can be heated easily if an external heat source is available(e.g. Sun). Volumetric gas production varies from 0.14 in winter (8^0C) to 0.7 Volume/Volume of digester-day in summer (32^oC) (Stuckey,1983).

2.9.4 Batch and "Dry" Digesters

This digester consists of a manure outlet and an airlight fermentation chamber. This is the simplest equipment of biogas types. The slurry is placed in the reactor, then the reactor is sealed, and the fermentation is allowed to proceed for 30-180 days. During this period, the daily gas production builds up to a maximum and then decreases (Figure 2.10) (Stuckey, 1983).

2.9.5 Plug Flow Fermentation Digesters

A typical plug flow reactor is similar to the bag reactor, consisting of a trench cut into the ground and covered with either concrete or on impenmeable membrane. Ensuring true plug flow conditions, the length has to be considerably greater than the width and depth (Figure 2.11).

The plug flow reactor gives higher gas production rates than the completely mixed one. Detention time vary from 15 days to 30 days. Gas production at 35^0C (Total solids,13%) is around 2.32 Volume/Volume of digester-day for 15 days detention time (Stuckey,1983).

2.9.6 Anaerobic Filter Fermentation Digesters

This reactor consists of a tall chamber (e.g. height to diameter ratio (H/D) 8-10) filled with a media (Figure 2.12). Media have varied from river pebbles(void volume 0.5) to plastic dump media (0.9), although any material which provides a high surface area per unit volume is suitable. The media of choice depends on considerations such as cost, void volume, and weight. The slurry to be treated is usually passed upwards through the filter, and exits through a gas syphon,although downflow configurations can be used. The organisms growing in the filter consist of two sorts :

- The organisms can grow on the media,
- The organisms become enterraped within the media.

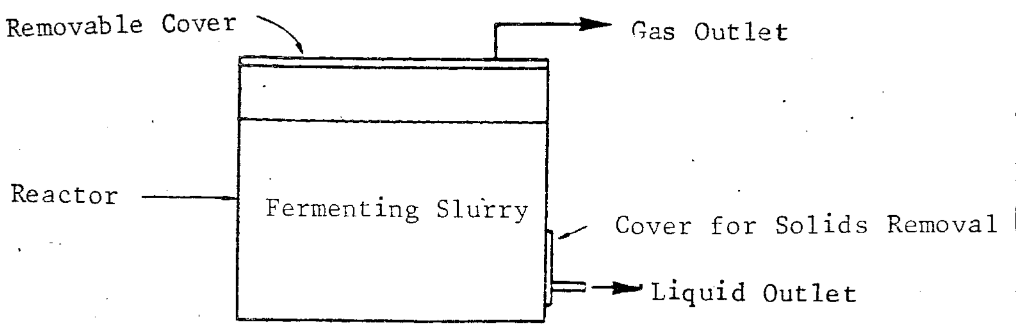


Figure 2.10 Batch Digester

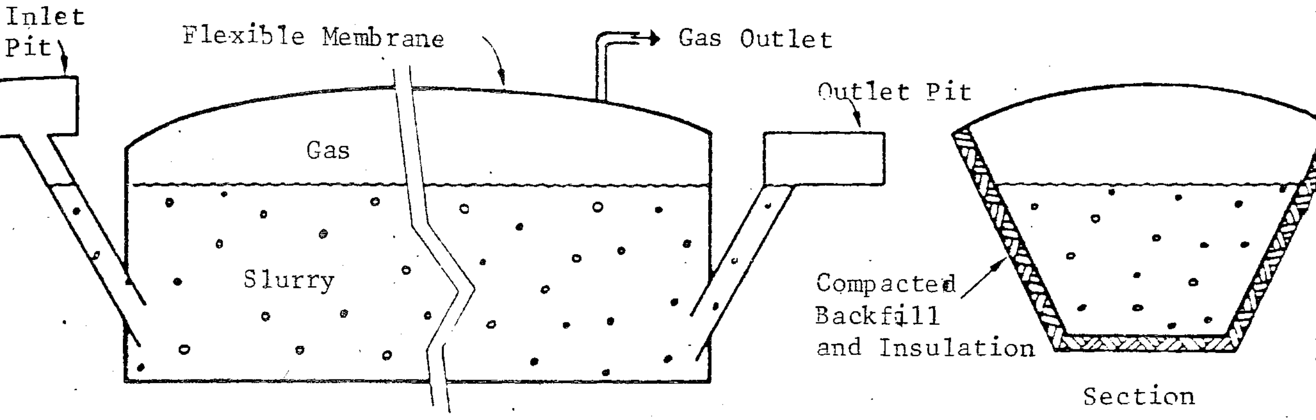


Figure 2.11 Plug Flow Digester

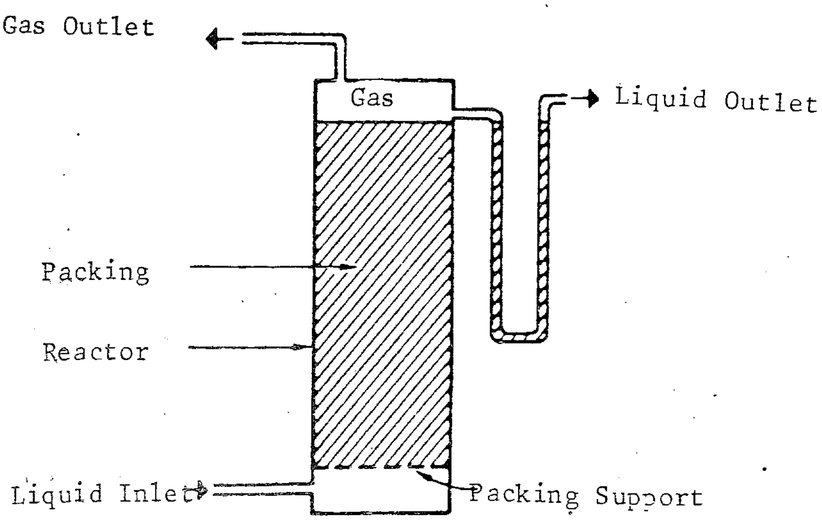


Figure 2.12 Anaerobic Filter

At low hydraulic loading rates both sorts are prevalent, while at high hydraulic loads the suspended organisms are washed out leaving only the attached forms.

The typically detention times are in order of 1-2 days (Arora and Chattopadhyo,1980), and at these times over 90% COD removals are possible. Daily gas production is around 4 Volume/Volume of digester-day at 7 kg COD/m^3-day loading rate.

2.9.7 Anaerobic Baffler Reactors (ABR)

The reactor is a simple rectangular tank, with physical dimensions similar to a septic tank, and is divided into 5 or 6 equal volume compartments by means of walls from the roof and bottom of the tank (Figure 2.13) (Bachmann,et.al.,1982). The liquid flow is alternatively upwards and downwards between the walls. When the liquid pass upward, the waste flows through an anaerobic sludge blanket. Thus the waste is in intimate contact with the active biomass. Bachmann,et.al.,(1982) obtained 80% COD removal efficiency. With a volumetric gas production of 2-9 Volume/Volume of digester-day at 35^0C (Influent waste containing 7.1 g/L COD).

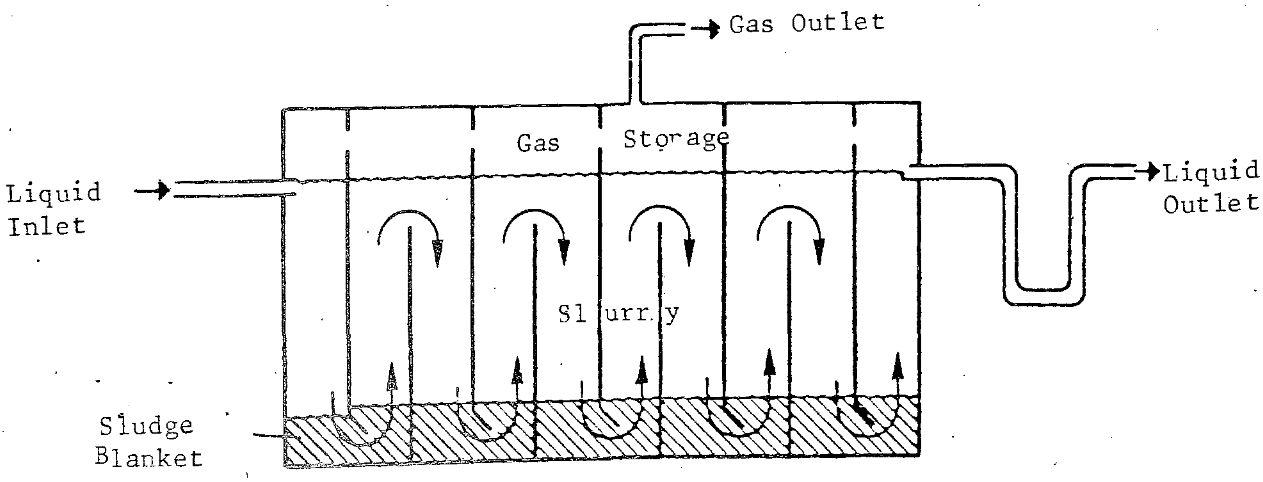


Figure 2.13 Anaerobic Baffled Reactor (ABR)

CHAPTER III

EXPERIMENTAL SET-UP AND MATERIALS

3.1 Experimental Set-Up

Three anaerobic digesters, each of different size, were used in the present study, in order to examine the effect of the digester size on the efficiency of the system which consisting of two main parts, the digester and the gas holder. Details about the different systems are given in the following sections.

3.1.1 The Small Digester

The smallest of the three digesters used in this study was a tin can 13x15x26 cm in size having a volume of 5 liters of working capacity (volume of slurry in the digester). A 2 cm hole which was opened at the lower part of one of the sides of the can and to which a small valve was installed, served as the outlet of the digester. A 2 cm ID pipe which was inserted to the can from a hole opened at the top, which was extending till the middle of the can was the inlet of the digester. Another 0.5 cm ID pipe located also at the top was acting as the gas outlet. Both the inlet pipe as well as the gas outlet pipe were inserted in such a way that intrusion of air to the can was prevented entirely. A mixer was also inserted in the digester so as to enable mixing of the slurry. During summer times, the outside surface of the digester was dyed with a black paint to permit the absorbtion of sun heat. Details about this system are given in Figures 3.1 and 3.2. During winter times, the digester was covered with an insulating material (e.g. izocam) for keeping the digester at a constant temperature. The system was fed semi-continuously (i.e. twice a week). Feeding and withdrawal of the waste was done manually.

The generated gas was collected in a separate gas holder (Figure 3.1) which was consisting of two containers. The smaller one of these which had a diameter 12 cm and height of 12 cm was located upside down within the outer one which was slightly larger,(20 cm in height, 24 cm in diameter). Two 0.5 cm holes opened at the small container (Figure 3.1) were acting as the gas inlet and outlet. In order to prevent the absorption of carbon dioxide, the outer cup was filled with acidified water (Geisser and Preffer,1977 and Baban,1981). The cover of the gas holder was connected to a counter weight, in order to regulate the gas pressure in the reactor (as biogas was produced the gas holder was expanding thus preventing any increase in pressure in the system). Amount of gas produced was determined by observing the displacement of the inner cup.

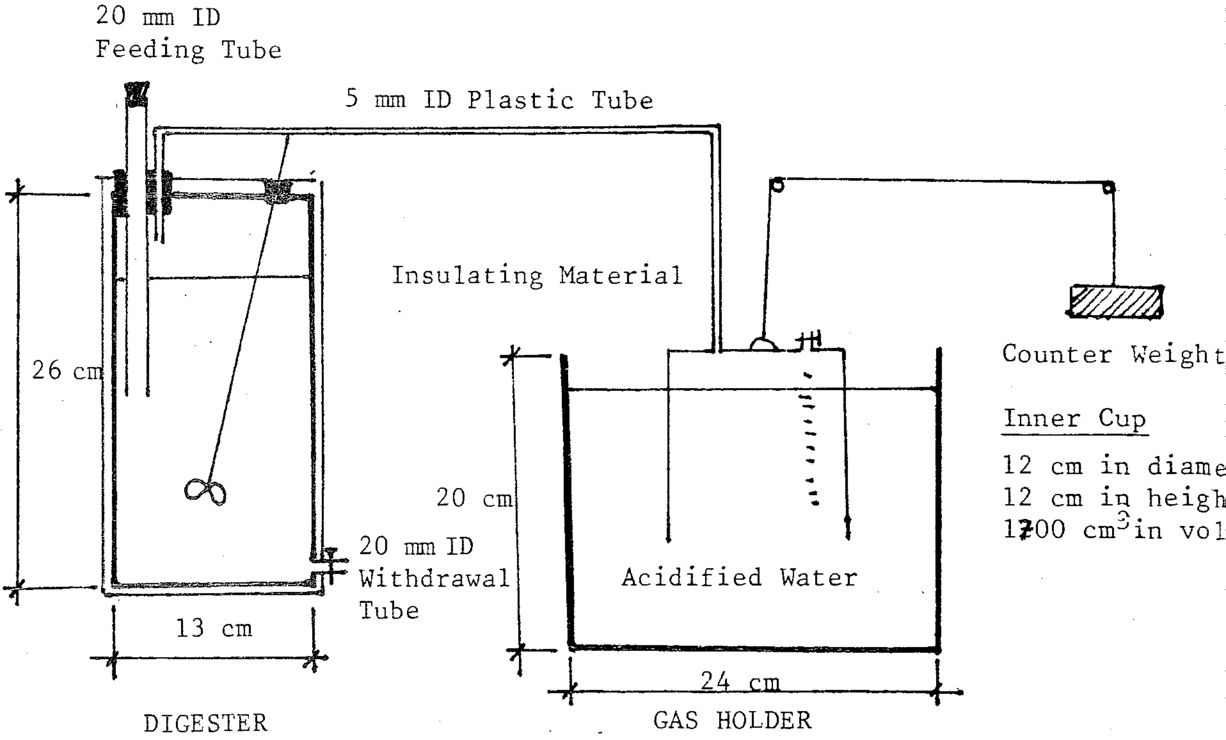


Figure 3.1 Schematic Diagram of the Small Digester

3.1.2 The Medium Size Digester

The medium size digester consisted of a cylindrical steel barrel having a diameter of 55 cm, a height of 85 cm and a volume of 200 liters with 180 liters working capacity (slurry volume in the digester). A 2 inches valve installed at the lower part of the barrel, served as the outlet of the digester. A straight pipe having a diameter of 10 cm and made of PVC (Polyvinyl chloride) was inserted to the barrel from a hole opened at the top which was ended at the bottom of the digester. This pipe was serving as the inlet of the system. Another pipe 1 cm ID located also at the top was acting as the gas outlet. A partitioning steel wall 40 cm in height from bottom and 3 mm in thickness was installed in the inside of the digester to prevent short-circuiting and to mix slurry. The exterior of the barrel was dyed with a black paint to increase the absorption of sun rays during summer times. During winter times, the digester was covered with an insulating material (e.g. İzocam) for keeping the digester at a constant temperature (Figures 3.2, 3.3, 3.4).

The gas holder was consisting of two parts (Figure 3.4). The inner reactor tin cup having a size of 24x24x33 cm and a volume of 19 liters was inverted in the outer cup. Two holes of 1 cm were opened at the inner container which were acting as the gas inlet and outlet. The delivery pipe was 1 cm in diameter and made of plastic. The outer steel cup 40x40x40 cm in size was filled with acidified water to prevent the absorption of carbon dioxide. In order to determine the amount of gas produced the displacement of the inner cup was measured.

3.1.3 The Large Size Digesters

The system consisted of a cylindrical steel digester having a diameter of 100 cm and a height of 200 cm. At the lower part a conical hopper of 30 cm in height was connected at the main body. The tank was made of 5 mm steel. The volume of the digester was 1.70 m^3 and the working capacity 1.4 m^3. A 5 cm valve was installed at the lower part of the conical hopper. This opening acted as the digested slurry outlet. A steel lid hermitically covered the top of digester. The inlet of the system was a straight pipe of diameter 12 cm made of PVC which was inserted to the lid from a hole extended till the middle of the tank. Another pipe of 1.2 cm ID located also at the top served as the gas outlet pipe were placed in such a way that intrusion of air to the digester was prevented entirely. A mixer operating by hand was also inserted in the digester in order to enable complete mixing of the slurry. The inside wall of the digester was dyed by a special dye, not containing pesticides, to prevent corrosion due to hydrogen sulphur (H_2S). The digester was located within a chamber made of a two-lined wall 'Ytong' which had a thickness of 40 cm with a space of 10 cm between them in such a way that a complete thermal insulation was achieved. The top

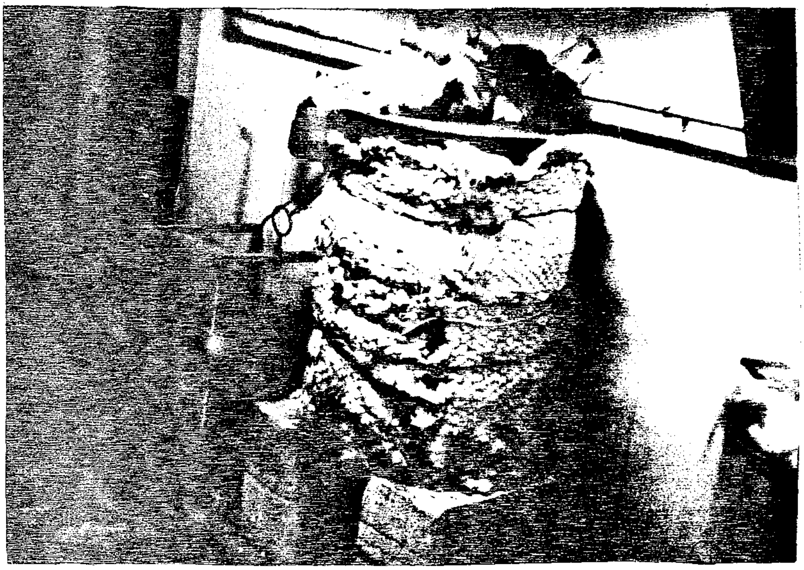


Figure 3.2 Small and Medium Digester

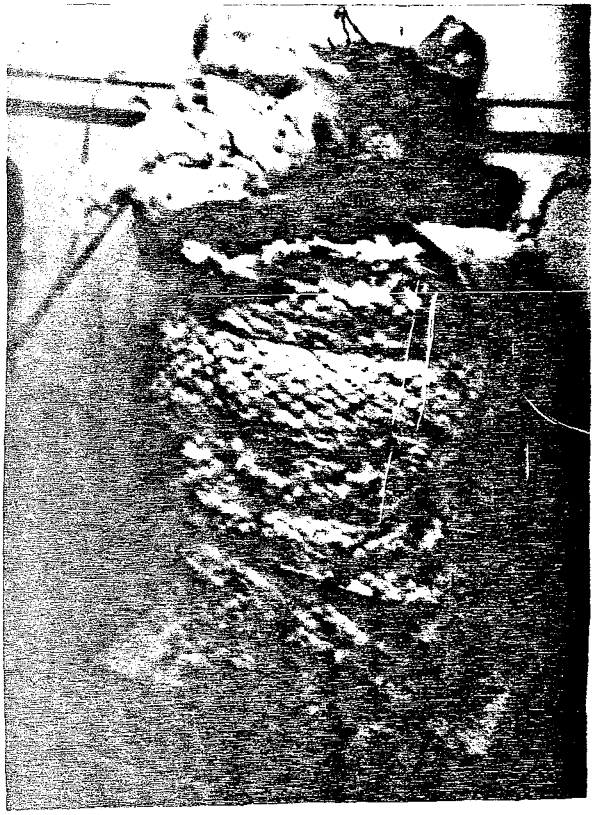
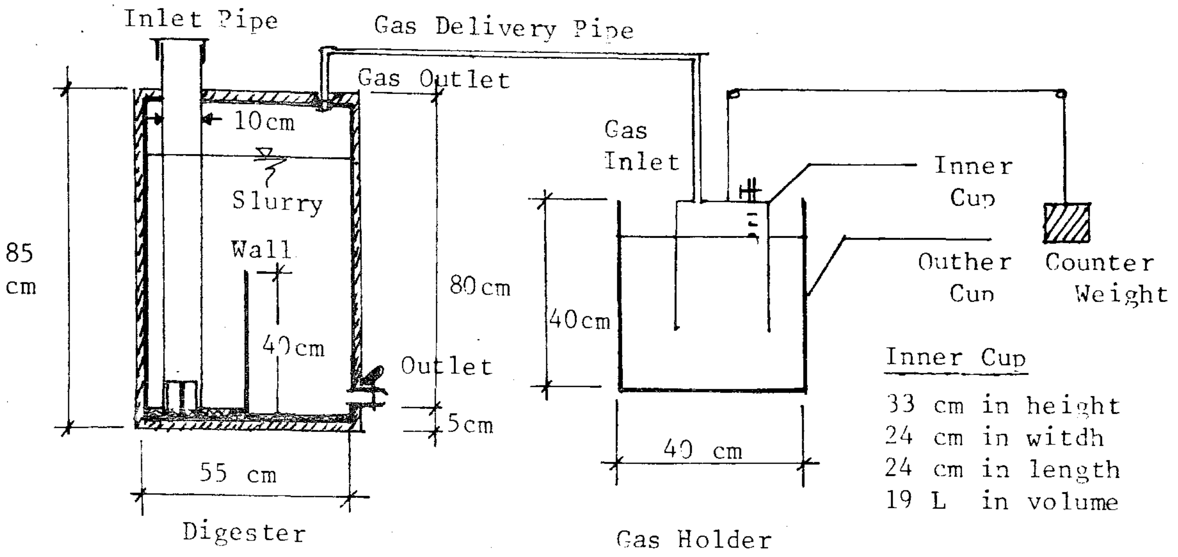


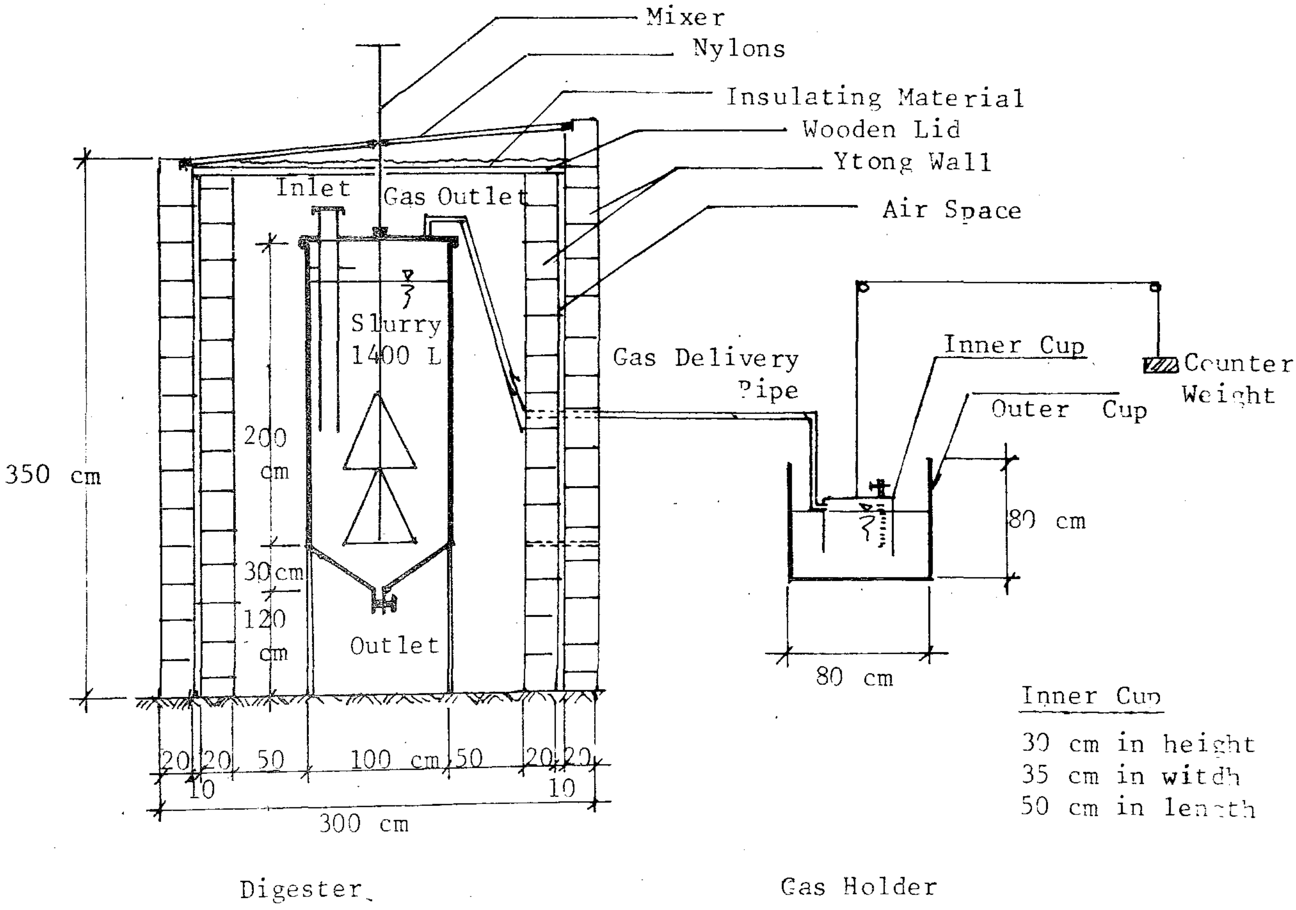
Figure 3.3 Medium Digester



Inner Cup

33 cm in height
24 cm in witdh
24 cm in length
19 L in volume

Figure 3.4 The Medium Size Digester



Inner Cup

30 cm in height
35 cm in witdh
50 cm in length

igure 3.5 The Large Digester

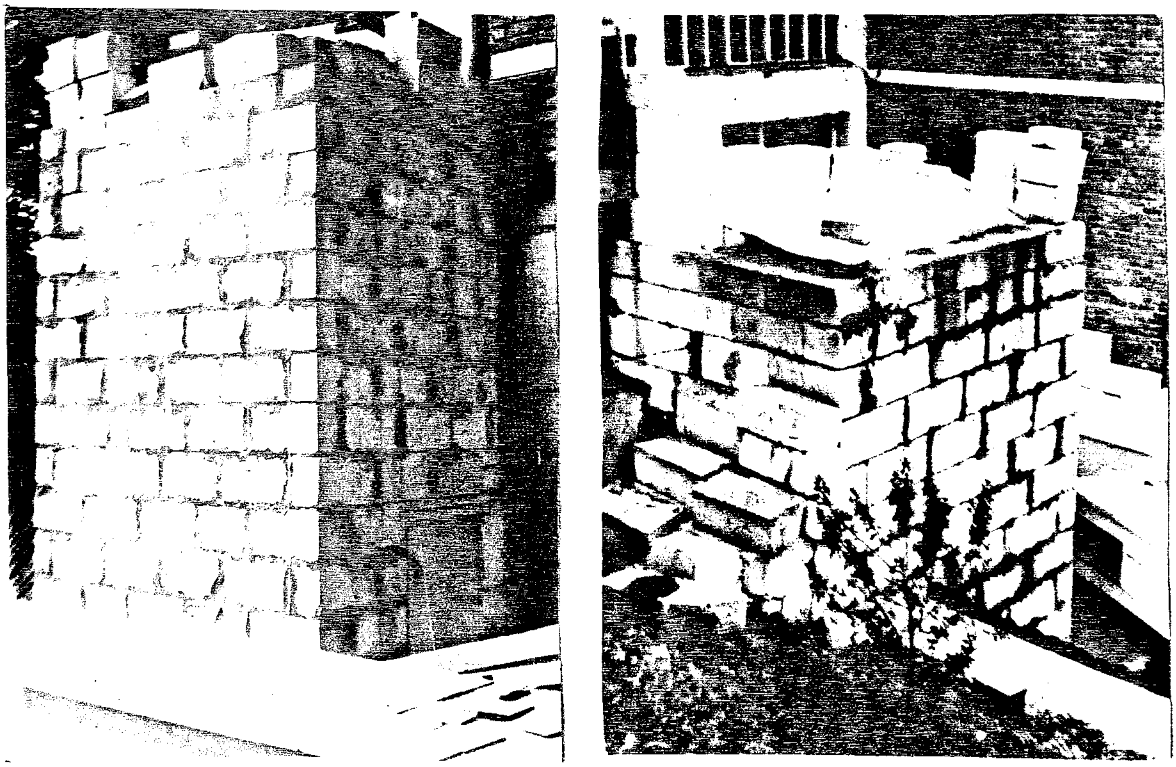


Figure 3.6 Large Digester

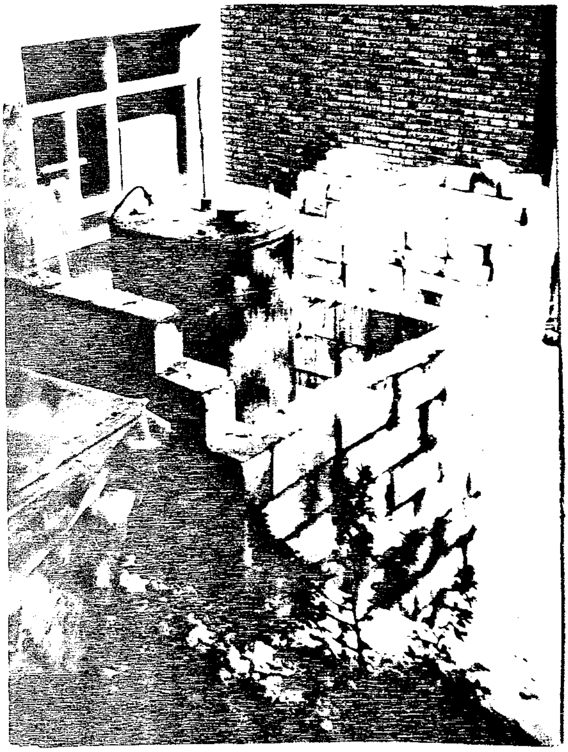


Figure 3.7 Large Digester (View during construction)

of the 'Ytong' chamber was covered by a lid made of a wooden frame and two-lined nylon with a 5 cm space between them. During winter times, especially at nights, an extra insulating material (e.g. İzocam) is used to prevent loss of heat in the reactor. Details about this system are shown in Figures(3.5, 3.6 and 3.7).

The generated gas was collected in a separate gas holder consisting of two main parts. The smaller cup 50x35x30 cm in size which was made of fiberglass was inverted in the outer cup. Two holes having a diameter of 1.2 cm opened at the top and at the higher part of the inner cup, served as the gas inlet and outlet. The outer cup having a size of 80x80x80 cm made of fiberglass was filled with acidified water as previously mentioned in Sections 3.2.1 and 3.2.2. A plastic pipe having a diameter 1.2 cm and made of plastic was used for gas transportation.

3.1.4 Batch Reactor

The batch reactor consisted of two main parts, a flask having a volume of 2 liters with 1.5 liters of working capacity (slurry volume in digester) and a gas collection unit similar to the one explained in Section 3.1.1 (Figure 3.8).

The batch reactor was operated to determine the biodegradability of cow manure at 19.5^{0}C and 23^{0}C.

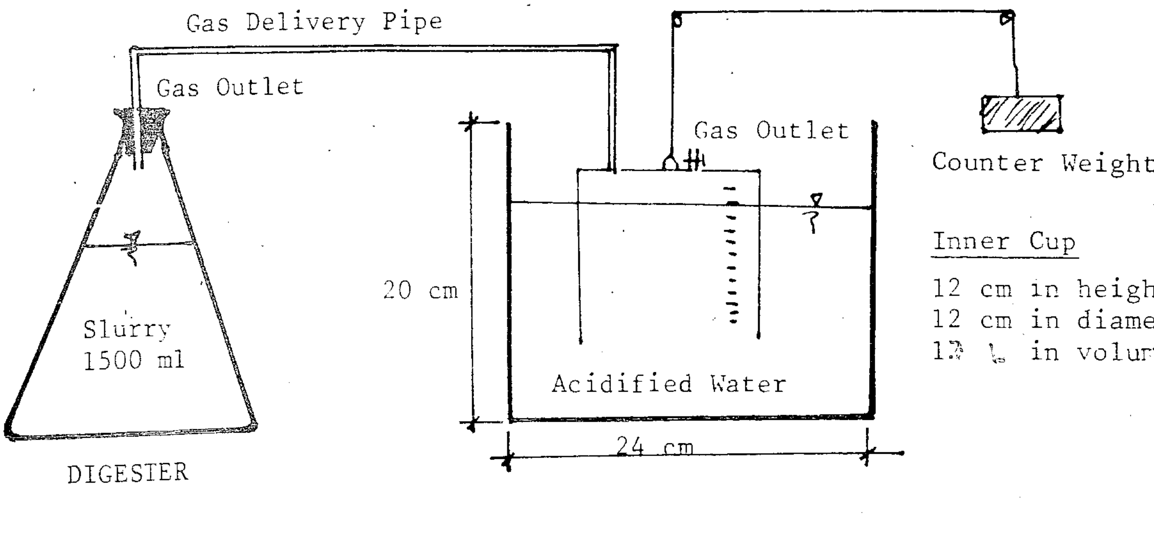


Figure 3.8 Schematic Diagram of Batch Reactor

3.2 Substrate and Other Material Used in the Study

3.2.1 Cow Manure

Cow manure supplied from a nearby farm at Rumelihisarüstü was used as subsrate in the present study. Fresh cow dung had a moisture content of about 80%. Chlorine free tap water was used to arrange the required moisture content of the cow manure. It was desired to feed the reactor always with a substrate which had the same moisture content, approximately 93.6%. Because of that after determining the initial moisture content of the dung, the appropriate amount of water was added in order to adjust the final moisture content. This adjustment was made with the assistance of the nomograph given in Figure 3.9.

3.2.2 Yeast

The effect of the yeast on cow manure under anaerobic conditions was investigated by Alpaslan (1978) who showed that, in batch reactors, addition of small amount of yeast to cow manure accelerated the gas production significantly. Furthermore, Baban (1981) investigated whether Alpaslan's (1979) finding could be extended to continuous digester systems or not. Baban (1981) stated that yeast (5g yeast per liters of digester) addition to cow manure improved the gas generation in semi-cotinuous reactors as well as an increase of about 10% in the biodegradable fraction could be achieved. Keeping this fact in mind, in the present study, yeast* addition to cow manure was performed. The yeast using in the present study produced from beet molasses which contained 70% water and 30% cells.

3.2.3 Seed Material

To accelerate the initiation of the decomposition, sludge taken from a septic tank of Boğaziçi University was used as seed. In order to increase the bacteriological activity of the seed, the sludge was kept in an incubator at 37.5°C for a week before being added into the digester. This sludge was added as seed material to each digester at a rate of 5 mL per liter of digester volume.

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* Mayadağ, Yaş ve Kuru Maya Fabrikası, Kağıthane, İstanbul

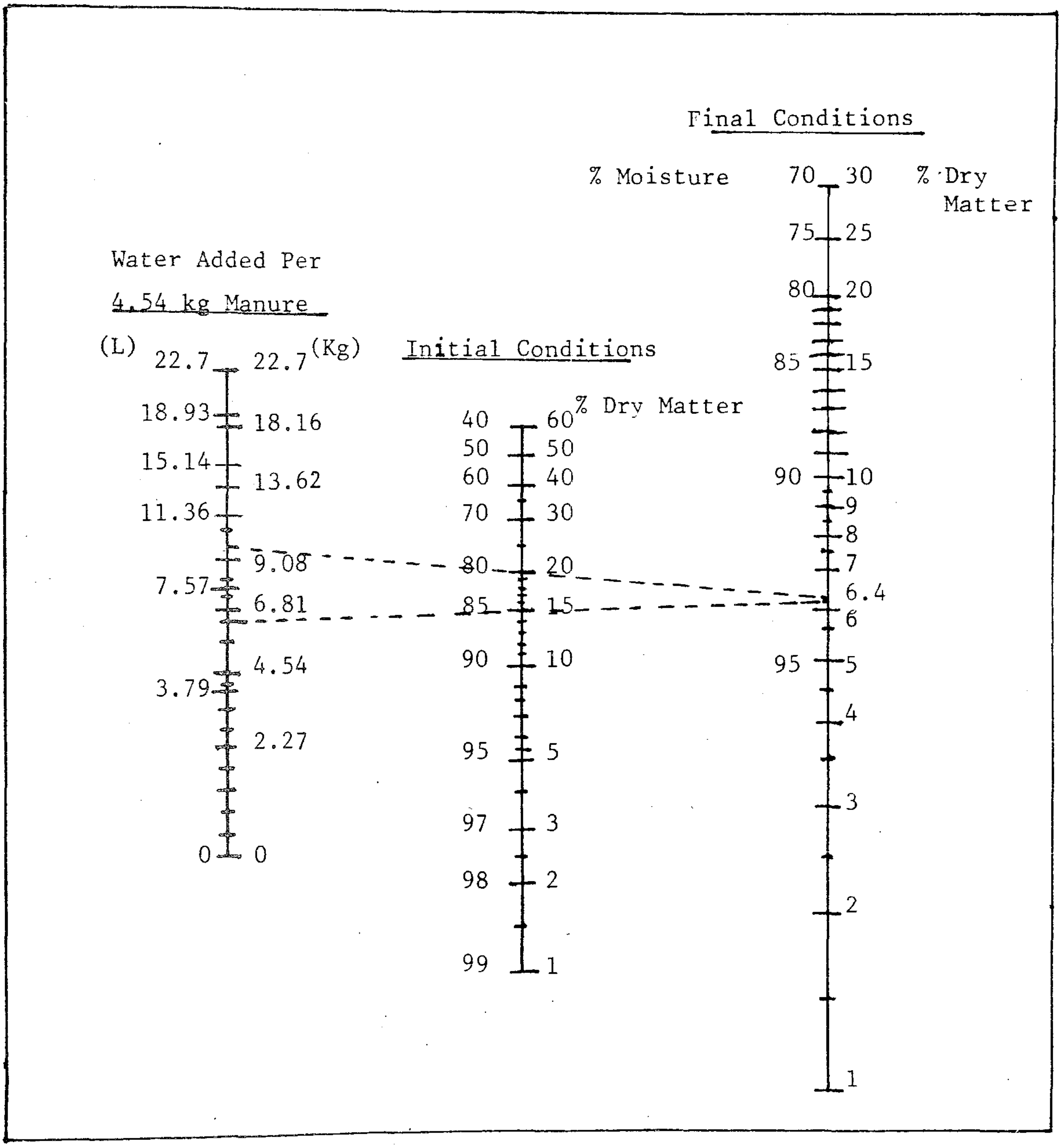

Figure 3.9 Nomograph Giving the Amount of Water to Be Added in order to Adjust the Moisture Content (Colorado State University, 1975)

3.3 Equipment

3.3.1 Incubator

An incubator* was used in this study in order to provide constant temperature to the batch reactor during the biodegradability test. The internal volume of this incubator was 85 dm^3. Temperature range : 20^0C to 60^0C with a deviation of $\pm$ 0.4^0C at 20^0C.

3.3.2 Gas Partitioner

The characteristics of the generated gas were determined by a gas partitioner**. Nitrogen was used as a carrier gas. This gas has the ability to separate and measure carbon dioxide, oxygen, methane and carbon monoxide. Before the analysis, the instrument was calibrated for each possible component by using a standard gas (e.g. pure carbon dioxide, pure methane). Standard gas is necessary for each gas component to obtain the respective concentrations of the components in the sample. The concentration of a particular gas component is obtained by the evaluation of the peaks recorded by the recorder. The following equation helps to calculate the unknown gas concentration:

$$C_u = \frac{C_s . H_u}{H_s}$$

where , C_u : Concentration of Unknown Gas
C_s : Concentration of the Standard Gas
H_u : Peak Height of the Unknown Gas
H_s : Peak Height of the Standard Gas

3.4 Determination of the Characteristics of Substrates and End Products

The following parameters are determined related to the characteristics of the substrate and of the end products:

- pH
- Total Solids (TS) and Total Volatile Solids (TVS)

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* Fisher- Isotemp Incubator

** Fisher- Hamilton Gas Partitioner (Model 29, Litho, 1967)

- Chemical Oxygen Demand (COD)
- Nitrogen (Total Kjeldahl Nitrogen, TKN)
- Volatile Acids (VA)
- Ortho-phosphate(Stannous Chloride Method)
- Composition of the Generated Gas (Determined by Using the Gas Partitioner Explained in Section 3.3.2).

The experiments were conducted according to the "Standard Methods" (1981).

CHAPTER IV

EXPERIMENTAL PROCEDURE

The experimental procedure followed in this study can be considered in two groups :

- Preliminary procedure, and
- Procedure followed after gas production started.

The details of which are given below.

4.1 Preliminary Procedure

The preliminary procedure followed before the initiation of biogas production is given below.

1- All three reactors were covered hermitically so that intrusion of air to the reactors was prevented entirely.

2- The moisture content of the dung was accurately determined as soon as it was brought from the farm. Then the moisture content was adjusted to be 93.6% in accordance with the principles explained in Section 3.2.1.

3- The pH, total solids, total volatile solids, chemical oxygen demand, nitrogen,volatile acids, and ortho-phosphate of the prepared slurry were determined. This information was essential in order to determine the efficiency of the system.

4- The water in the gas holder was acidified to a pH value of 2 by using hydrochloric acid. Thus the absorption of the carbon dioxide present in the gas produced by the water is prevented.

5- Due to the fact that sufficient dung was not available,it was not poss to fill the reactors completely at the same time. Because of that only one third of each reactor was filled with dung at the beginning the experiments. This was repeated on the 17th and 25th day, when the reactors were filled completely. During this period the slurry wa not removed from any of the reactors.

6 - Throughout the whole experimental period, record of temperature variations of the slurry was kept. This was done in the following way:

a) During the working hours (day period) temperature readings were taken every two hours.

b) During the night the minimum and maximum temperature of the slurry was determined with the help of a "minimum-maximum thermometer".

Temperature variations, between day and night were recorded to be around 3-5°C in summer, and between 6 to 8°C in winter. Values reported in this study are the average daily temperatures.

4.2 Procedure Followed After Gas Generation Started

After the initiation of biogas generation, the procedure given below was followed:

1- The hydraulic retention time (θ) for all the three reactors was adjusted to be 35 days. Hence daily volatile solids loading rate was calculated to be 1.49 g/L digester-day according to the following equation:

$$\frac{S_o}{\theta} = F$$

where, S_o : Initial Total Volatile Solids ($S_o = 52.2$ g/L of slurry) (Table 5.1)

θ : Hydraulic Retention Time (35 days)

F : Volatile Solid Loading Rate (g/L of slurry-day)

2- The reactors were fed regularly with cow manure, prepared as mentioned in Section 3.2.1, at 3-4 days intervals. Feeding and withdrawal volumes were calculated according to the following equation:

$$\frac{V}{\theta} . t = V'$$

where, V: Working Capacity Volume/of the Reactors (3.5 L, 180 L, and 1400 L respectively for the three reactors used)

θ : Hydraulic Retention Time (35 days)
t : Feeding Day Intervals (i.e. 3 or 4 days)
v : Feeding and Withdrawal Volume (liters)

The influent and the effluent volumes were kept equal during the feeding period.

3- The chemical oxygen demand, total solids, total volatile solids, volatile acids, nitrogen, pH, and phosphate concentration of influent and effluent samples were determined in order to detect the initiation of steady-state, as well as the efficiency of the system.

4- The composition and volume of the generated gas was determined periodically.

5- The temperature variations were recorded at two hours intervals except at nights, during which "maximum - minimum thermometer" was used to determine to lowest temperature.

6- Two batch reactors having a volume of 1500 mL were fed with diluted slurry having a moisture content of 93.6% and placed for a period of 65 days in two separate incubator adjusted to 19.5^{0}C and 23^{0}C respectively. Samples were collected at different time intervals and total solids and total volatile solids tests were performed in order to determine the biodegradability of the slurry used.

7- Yeast was added (0.5 g/L of slurry) to the slurry on the 73th and 78th day. The effect of yeast on anaerobic decomposition was observed by determining the efficiency of the system.

CHAPTER V

RESULTS AND DISCUSSIONS

The experimental study mainly covered,

- The determination of biodegradability of slurry at 19.5°C and 23°C,
- The variation of cow dung characteristics with time,
- The determination of substrate utilization coefficient,
- The effect of temperature on substrate utilization coefficient.

The results of the experiments are given in the following section.

5.1 Biodegradability

The biodegradable fraction at the feed material (i.e. cow manure) was determined according to the theoretical consideration given in Section 2.5 using a batch reactor having a volume of 1500 mL. The diluted slurry which had a total solids content of 6.4% (or moisture content 93.6%) was used as substrate in this study. Two batch reactors were placed for a period of 65 days in two separate incubator adjusting to 19.5°C and 23°C respectively. At the end of the period, gas generation virtually came to a halt. Samples from batch reactors were gathered at different time intervals and the total volatile solids were determined. Results are given in Table 5.1. In order to determine the refractory fraction (R) of the total volatile solids, a graphical plot (Figure 5.1) of experimentally determined $R = S_1/S_0$ versus $1/S_0(\theta)$ was prepared. The ordinate of this graph was known to be the refractory fractions. As can be seen in Figure 5.1, the biodegradable fraction of cow manure at 19.5°C and 23°C varied from 33% to 35%, respectively. These values are in agreement with the study of Baban (1981) who reported biodegradable fraction of 40% at 37.5°C.

TABLE 5.1 VARIATIONS OF TOTAL VOLATILE SOLID REDUCTION RATE WITH TIME AND TEMPERATURE IN THE BATCH REACTOR

Influent

Initial Total Volatile Solids (S_o) TVS, g/L	52.2

Effluent

Temperature T^0C		19.5		23		—
Parameter		S_1, Effluent Total Volatile Solids, g/L	S_1/S_o	S_1, Effluent Total Volatile Solids, g/L	S_1/S_o	$1/S_o \times \theta$
Hydraulic Retention Times, θ Days	10	49	0.94	48.00	0.94	$19x10^{-4}$
	22	44.80	0.86	43.95	0.84	$8.7x10^{-4}$
	30	42.66	0.82	40.77	0.78	$6.4x10^{-4}$
	40	39.67	0.76	37.58	0.72	$4.8x10^{-4}$
	60	35.50	0.68	33.93	0.65	$3.2x10^{-4}$
	65	35.40	0.68	33.90	0.65	$2.9x10^{-4}$

5.2 The Variation of Cow Manure Characteristics With Time

The variation of daily gas productions with time for the three reactors used in this study is given in Figures 5.2, 5.3, 5.4. In the same figures information about some other parameters such as pH, temperature, total volatile solids, chemical oxygen demand, yeast and biogas generation, etc. are given. The detail discussion of these parameters is given sub-section which follows :

5.2.1 Temperature Variations With Time

As can be seen in Figure 5.2, the daily average temperature in the

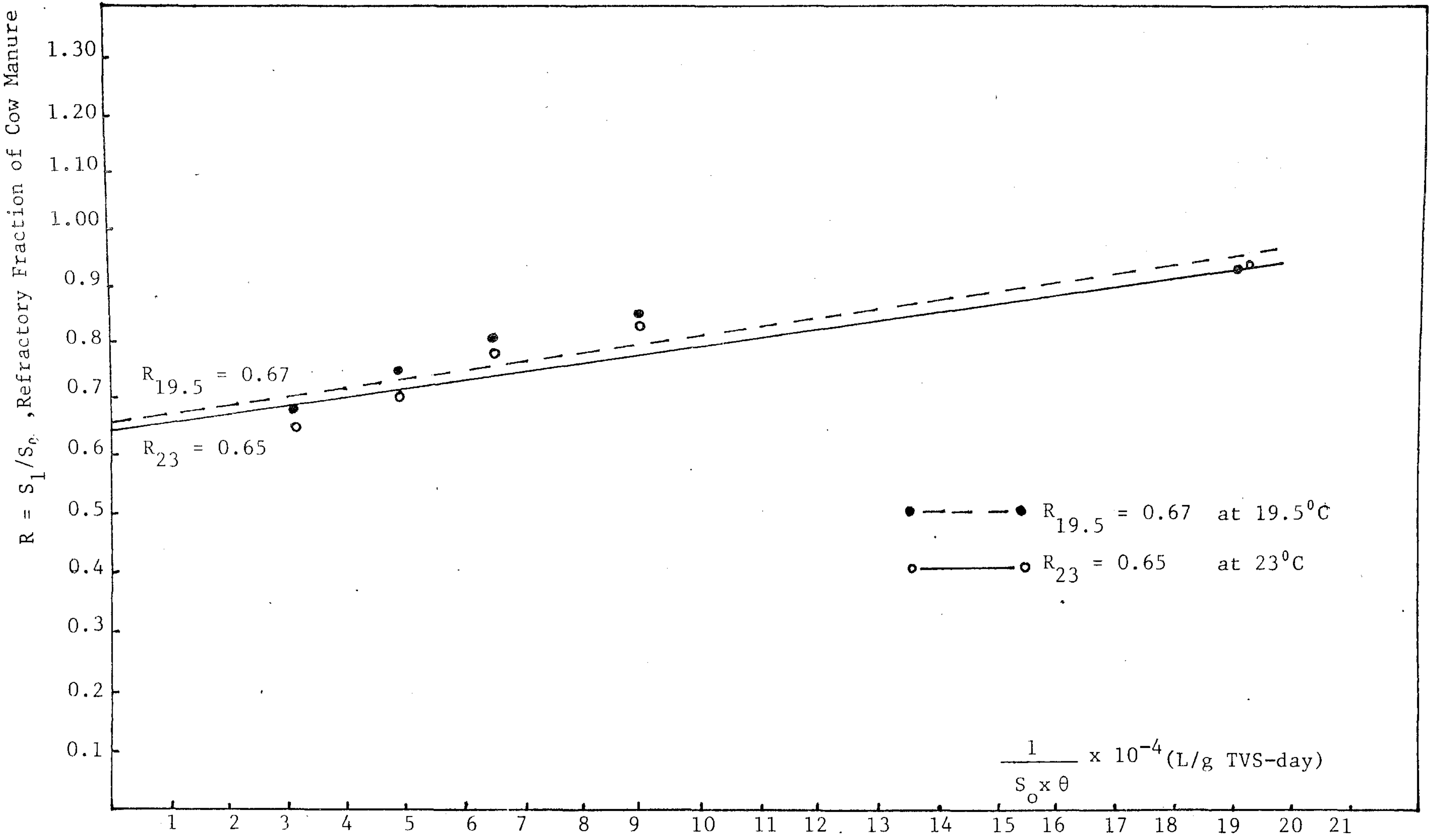


Figure 5.1 Biodegradability Determination of Daily Cow Manure

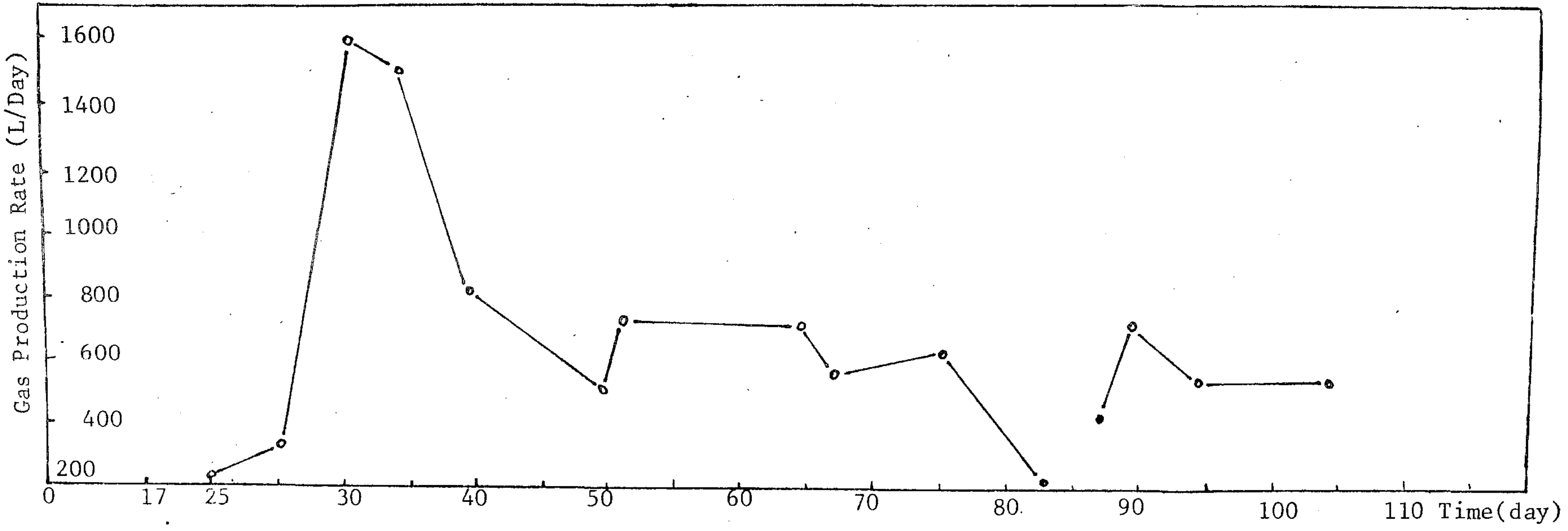
small digester for a period of 50 days varied between 25^{0}C and 26^{0}C, then dropped to 23^{0}C (from 50 th to 65th day). From the 65th day on, a decrease in temperature was observed reaching to a value as low as 13^{0}C. At this point, gas generation slowed down to a great extent. In order to avoid the detrimental effects of low temperature, after the 90th day the reactor was moved into the Engineering Building where after being covered with insulating material, the temperature rised again to a value of 19.5^{0}C. The temperature variation in the medium digester was similar to the temperature variation in the small digester. However, temperature in the large digester for the first 65 days varied between 25^{0}C and 26^{0}C, then dropped to a value of 23^{0}C. In this temperature remained for 15 days. After the 80th day the temperature dropped to 19.5^{0}C. The relatively smaller temperature variations observed in the large digester, are due to the better insulation as well as due to the large mass of substrate involved.

5.2.2 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand is one of the most important parameters by which the treatment efficiency of a digester can be determined. Because of that the variation of this parameter for all the reactors was investigated. Results obtained are given in Figures 5.2, 5.3 and 5.4. As can be seen in these figures the influent chemical oxygen demand for all the reactors was 45.05 g COD/L. The variation of COD removal efficiency with time is given in Figure 5.5. As can be seen in this figure, there was not an effective COD removal at any of the reactors in the first days. This can be attributed to the acidification stage of the anaerobic waste utilization as evidenced by on decrease in the pH as can be seen in Figures 5.2, 5.3 and 5.4. After the 30th day, a sudden increase in the COD removal efficiency was observed as a natural result of the initiation of the methanification stage. The variation of effluent COD of removal with time and the COD removal rate with time are given in Figures 5.6 and 5.7, respectively. As can be seen in Figure 5.5, the COD removal efficiency of the reactors varied from 36% to 44% were in agreement with the studies of Welsh (1977).

5.2.3 Total Volatile Solids (TVS)

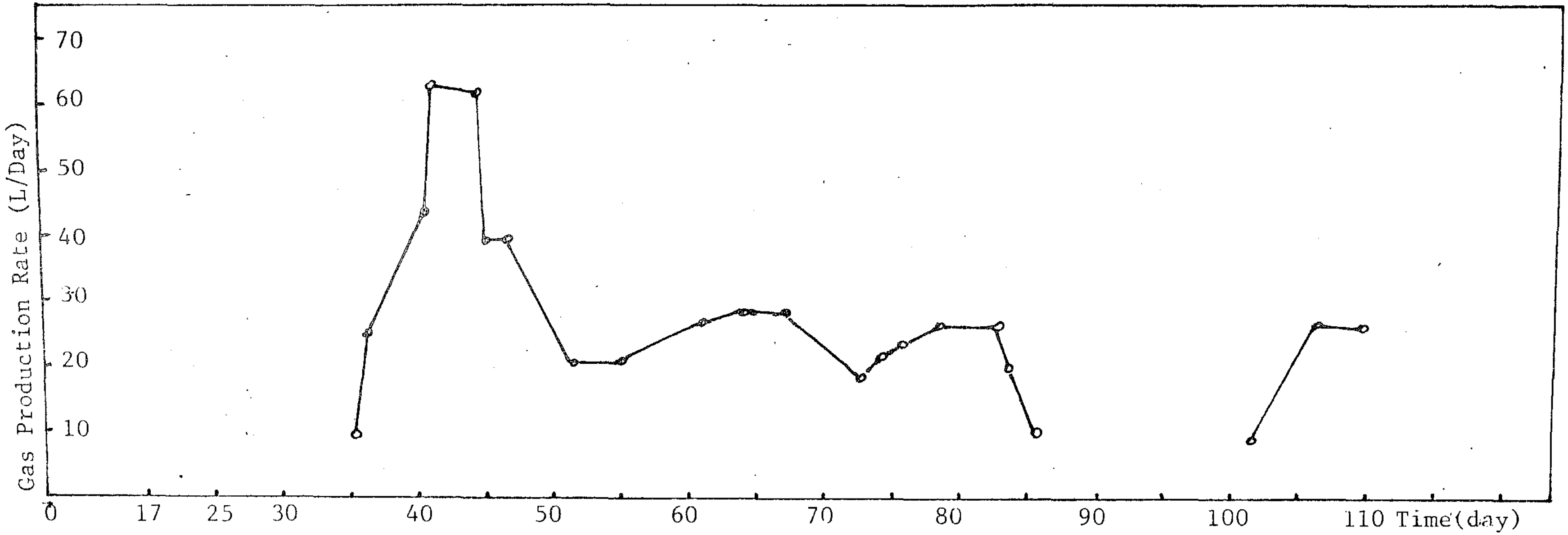
The variation of the effluent total volatile solids of reactors with time are presented in Figure 5.8 while, the total volatile solids reduction



Variation of Other Parameters Within the Same Time Intervals

T°C	29	26	26.6	25.5	26	25	25	25	23	23	23	23	17	19	21	16	13	18	20	19.5
Feeding Volume (L)	1167	1167	1167		100	300	400	300	400	300	600	500	400	500	500	400		400		
Yeast Addition (g)														0.8	0.8					
Total Volatile Solids (g/L)	53	52	51.18		46.90		46.76		42.66	40.10		41.51			40.50					
Chemical Oxygen Demand (g/L)	45		42					33.08			29.80		27.88		28.60					
pH	6.4	6	6.8		7.1		7.1						7.1							
Volatile Acids (g/L)	1.5												0.5							
Nitrogen(g/L)	0.34					0.35							0.37		0.369					
Phosphorous (g/L)	0.65												0.5							

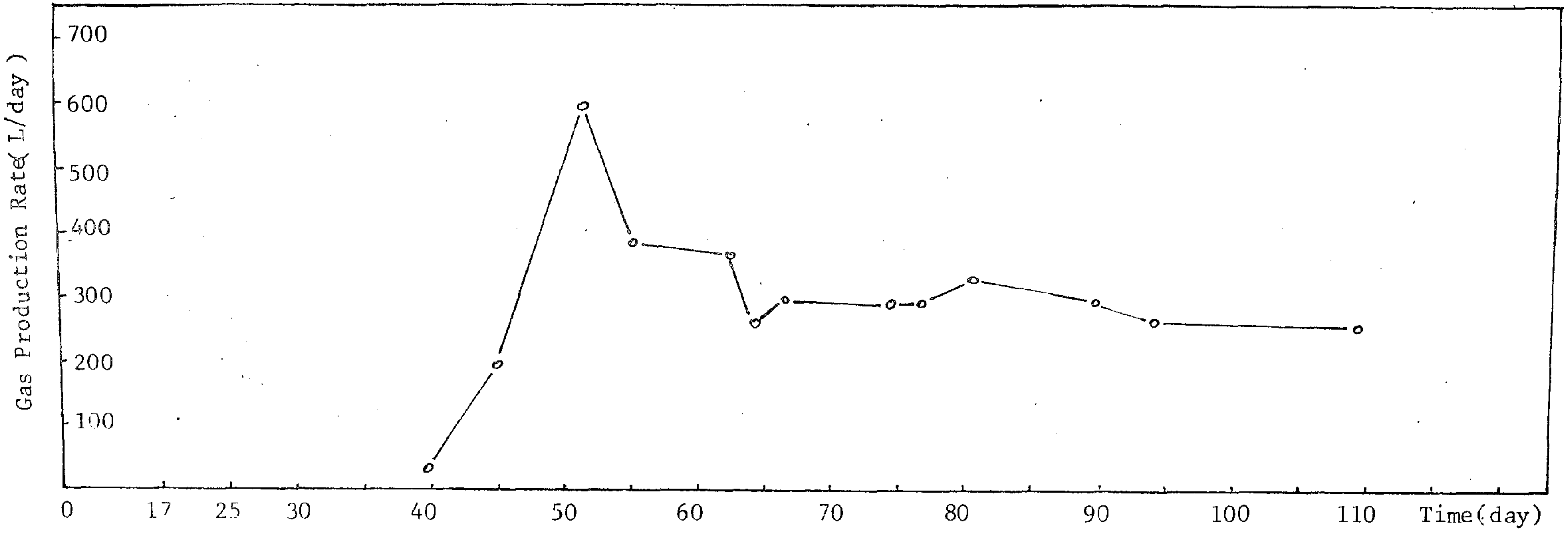
Figure 5.2 Variation of the Small Digester Gas Production Rate With Time



Variation of Other Parameters Within the Same Time Intervals

29 26 26.5 24.5 26.5 25 25 23 22 23 23 17 19 20 15 13 20 19.5 19	T^0C
60 60 60 5 20 15 20 15 30 26 20 26 26 20 20	Feeding Volume(L)
45 45	Yeast Addition(g)
53 51.90 45.67 43.28 41.10 42.76 42	Total Volatile Solids(g /L)
45 44 33.73 31.68 28.90	Chemical Oxygen Demand (g /L)
6.4 5.2 6.5 6.7 6.7 6.7 6.7	pH
1.5 0.66	Volatile Acids (g /L)
0.34 0.34 0.35 0.349	Nitrogen (g /L)
0.65 0.55	Phosphorous (g /L)

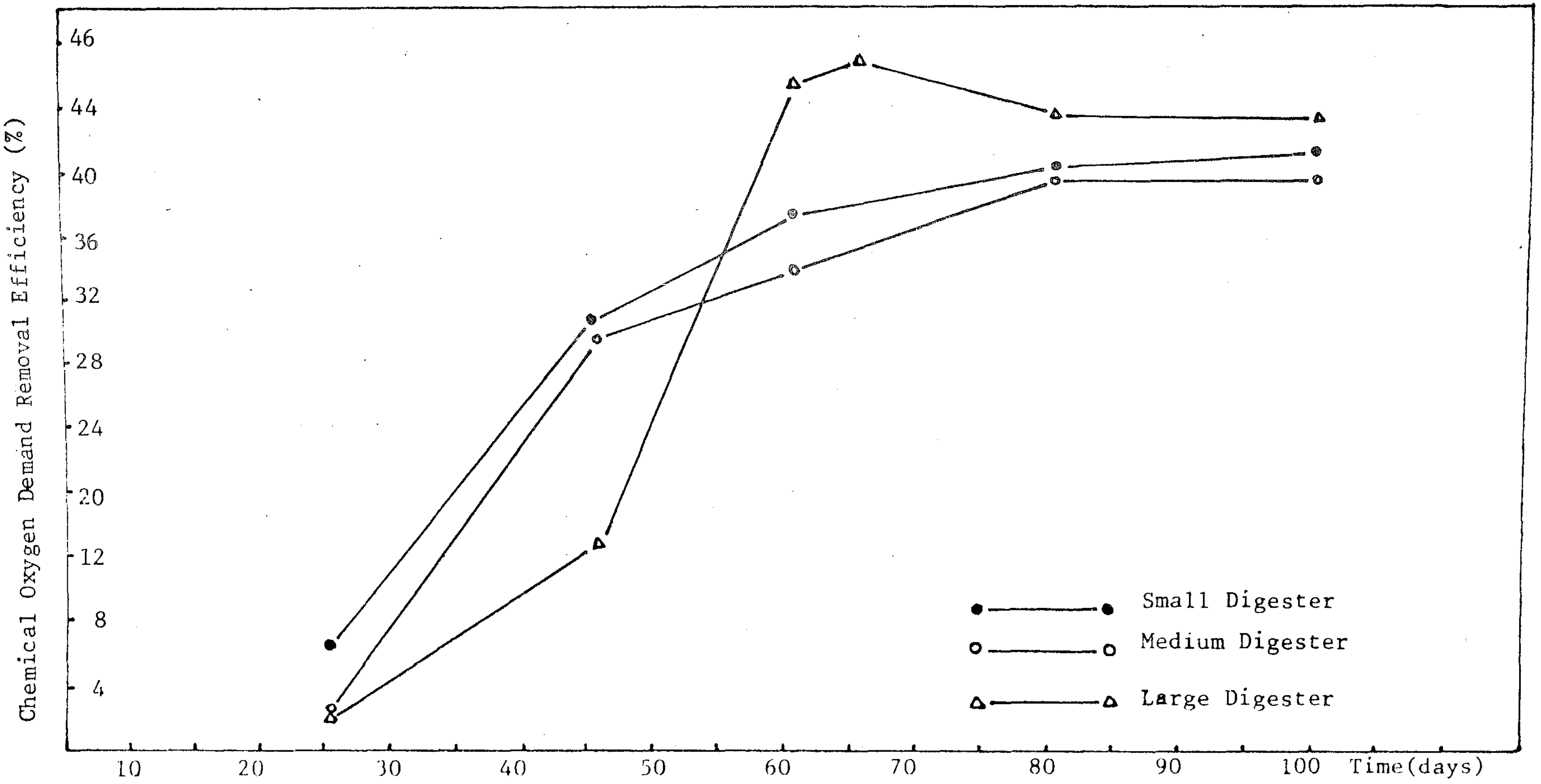
Figure 5.3 Variation of the Medium Digester Gas Production Rate With Time



Variation of Other Parameters Within the Same Time Intervals

T°C	29	26	26	26	26	26	26	26	26	25	24	23	23	23	20	19.5	19.5	19.5	20	19.5
Feeding Volume (L)	466	466	466	40	160	120	160	120	240	200	160	200	200	160	200	200	200	200		
Yeast Addition (g)	350	350																		
Total Volatile Solids (g/L)	53	52.86	50.02	40.77	39.00	39.42	39.50													
Chemical Oxygen Demand (g/L)	45	44.03	39.08	26.08	25.28	26.80														
pH	6.4	5.4	5.4	6.0	6.3	6.7	6.6	6.6												
Volatile Acids (g/L)	1.5	0.50																		
Nitrogen (g/L)	0.34	0.34	0.345																	
Phosphorous (g/L)	0.65	0.60																		

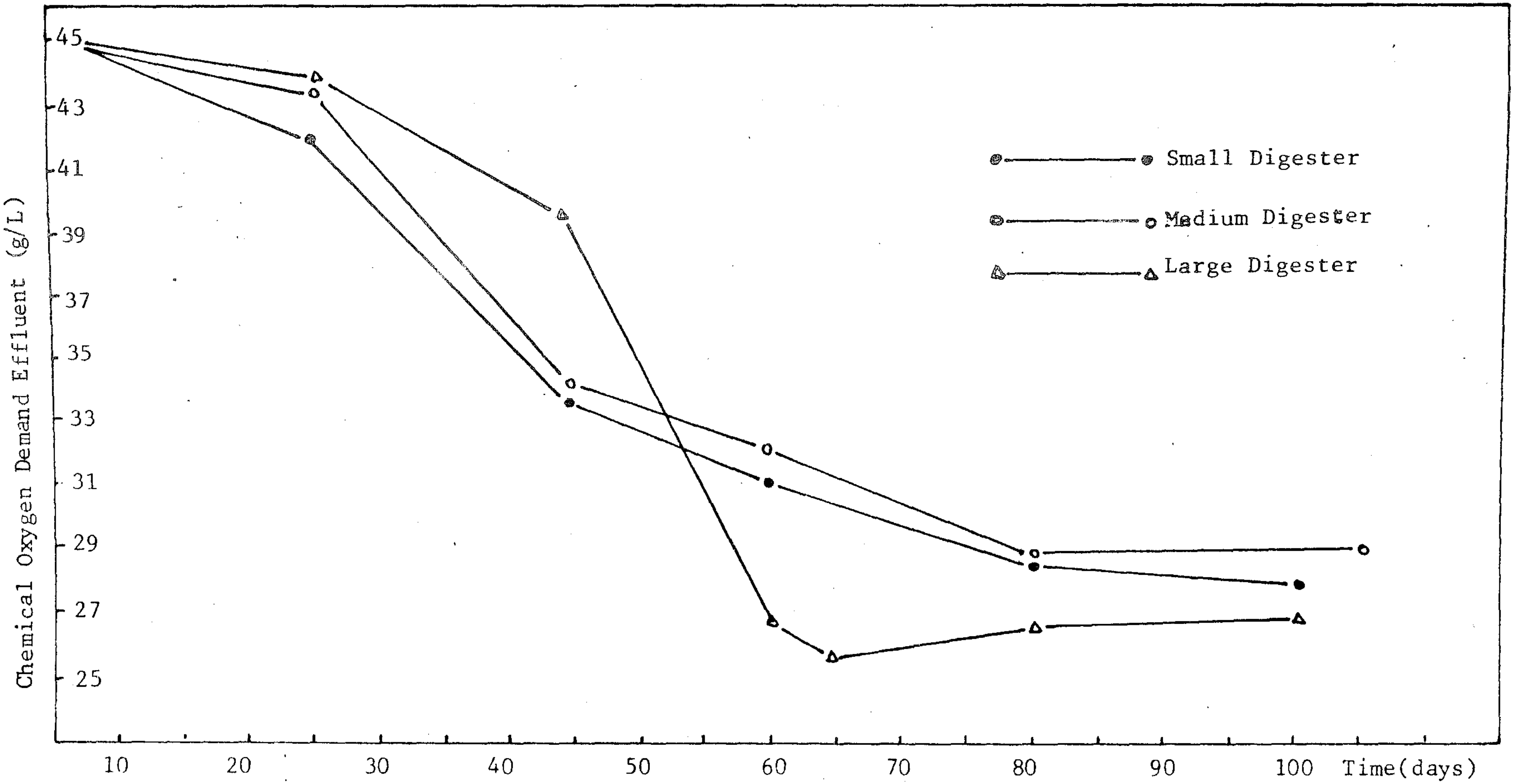
Figure 5.4 Variation of the Large Digester Gas Production Rate With Time



Variation of Temperature Within the Same Time Intervals

26.6	26	25	23	17	21	13	Small Digester (T^0C)
25.5	25.5	25	23	17	20	13	Medium Digester (T^0C)
26	26	26	25	23	23	19,5	Large Digester (T^0C)

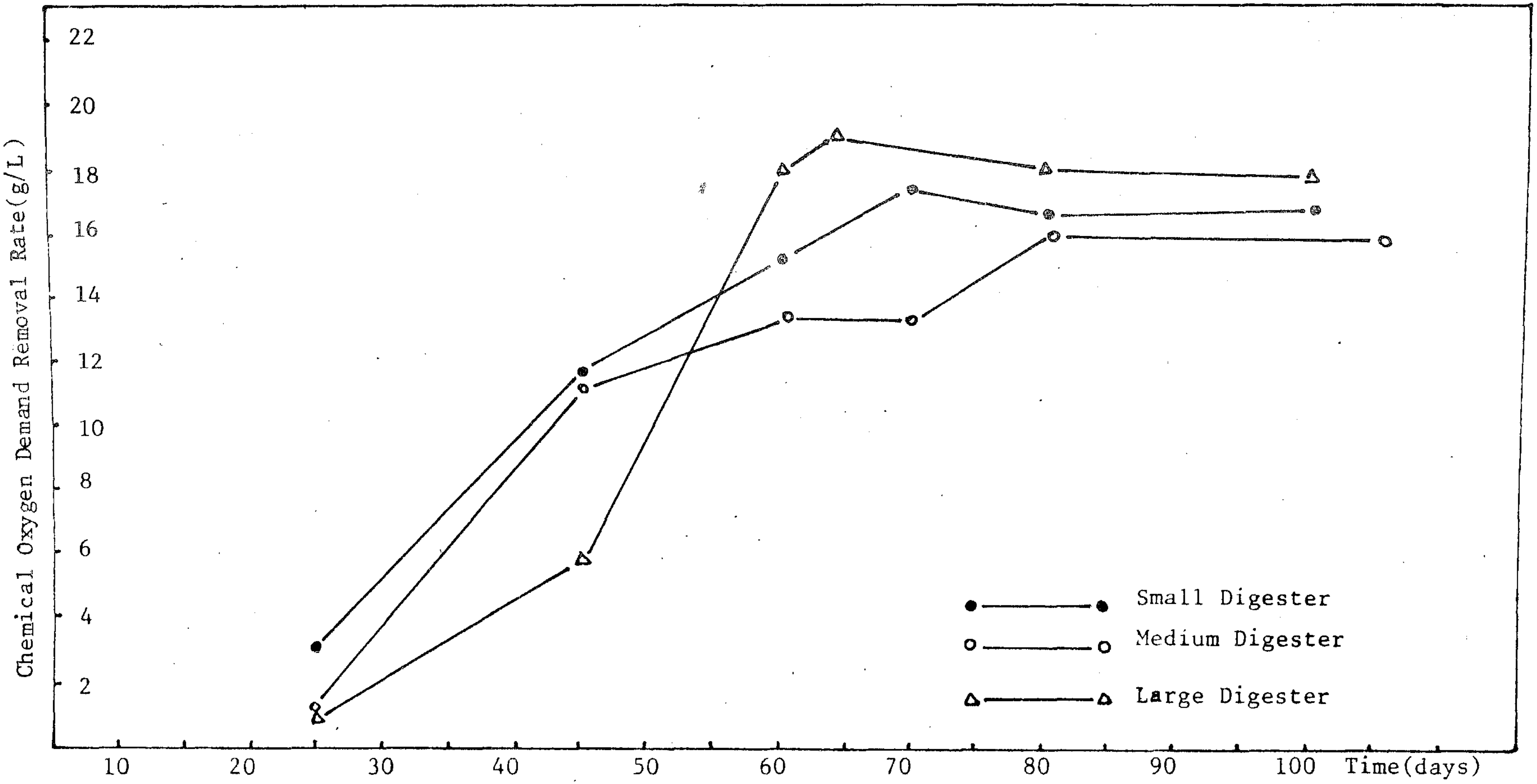
Figure 5.5 Variation of the Chemical Oxygen Demand Removal Efficiency With Time



Variation of Temperature Within the Same Time Intervals

26.6	26	25	23	17	21	13	Small Digester (T°C)
25.5	25.5	25	23	17	20	13	Medium Digester (T°C)
26	26	26	25	23	23	19.5	Large Digester (T°C)

Figure 5.6 Variation of the Reduction of Chemical Oxygen Demand With Time



Variation of Temperature Within the Same Time Intervals

26.6	26	25	23	17	21	13	Small Digester (T^0C)
25.5	25.5	25	23	17	20	13	Medium Digester (T^0C)
26	26	26	25	23	23	19.5	Large Digester (T^0C)

Figure 5.7 Variation of the Chemical Oxygen Demand Removal With Time

rate, and reduction efficiency are given in Figures 5.9 and 5.10,respectively. As can be seen in Figure 5.8,total volatile solids, showed a variation similar to the variation of Chemical Oxygen Demand,namely for the first 20 days, no change took place in its initial value. After that date a decrease started which continued till the 60th day, and after that it remained constant. The reduction of the total volatile solids with time are shown in Figure 5.9. Total volatile solids removal efficiency, on the other hand, varied between 0.20 and 0.23 (Figure 31). These results are in agreement with the studies of Jewell(1978) where the values reported were around 0.30 in continuously-fed reactors in series with 10% total solids concentration for a 30 days detention time at 22^{0}C. The comparison of the results obtained in this study with the results of earlier studies are given in Table 5.3. Also, a comparison between the influent and effluent values after the steady-state conditions is reached, are given in Table 5.9 ,Table 5.2 on the other hand, gives the removal efficiency of solids obtained at the same period.

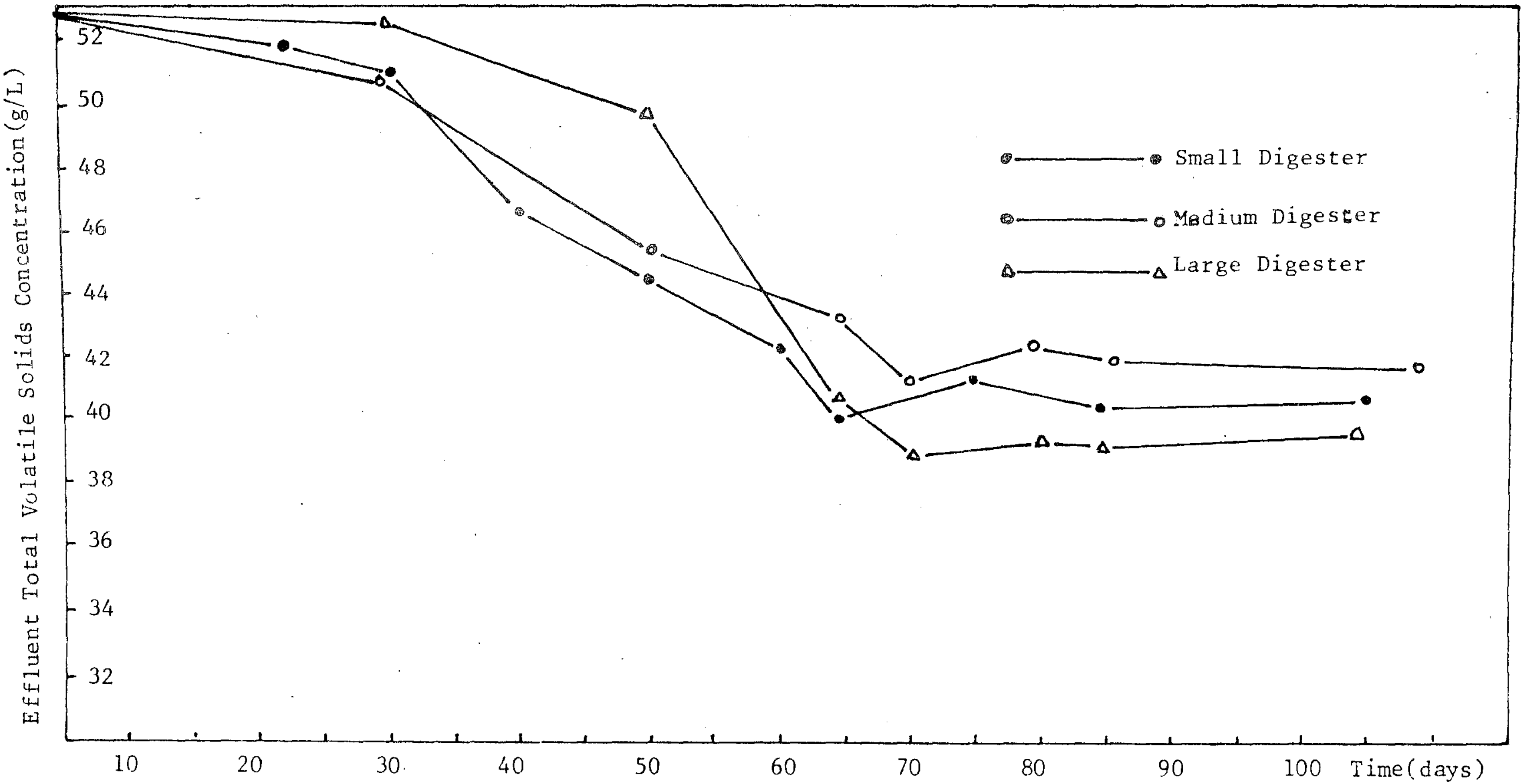
The substrate utilization coefficient, K , for the different digesters was determined by using the method explained in Section 2.3 and 2.4. Table 5.4 is prepared using the data given in Table 5.9 and in Section 5.1. Since all the three digesters were operated on a semi-continuous fed reactors basis, K , substrate utilization coefficient was obtained using Equation 3. These values varied from 0.04 day^{-1} to 0.06 day^{-1}.

TABLE 5.2 TOTAL SOLIDS AND TOTAL VOLATILE SOLID REDUCTION DURING THE STEADY-STATE CONDITIONS

Parameter	Small Digester	Medium Digester	Large Digester
Temperature, ^{0}T	23 ± 1	23 ± 1	23 ± 1
Biodegredable Tot.Vol. Sol.Reduction, %	0.66	0.61	0.72
Total Volatile Solid Reduction, %	0.23	0.21	0.24
Total Volatile Solid Reduction, g/L	12.10	11.07	12.75
Total Solid Reduction, %	0.19	0.17	0.24
Total Solid Reduction,g/L	12.21	11.00	15.57

TABLE 5.3 THE COMPARISON OF THE RESULTS OBTAINED IN THIS STUDY WITH THE RESULTS OF EARLIER STUDIES

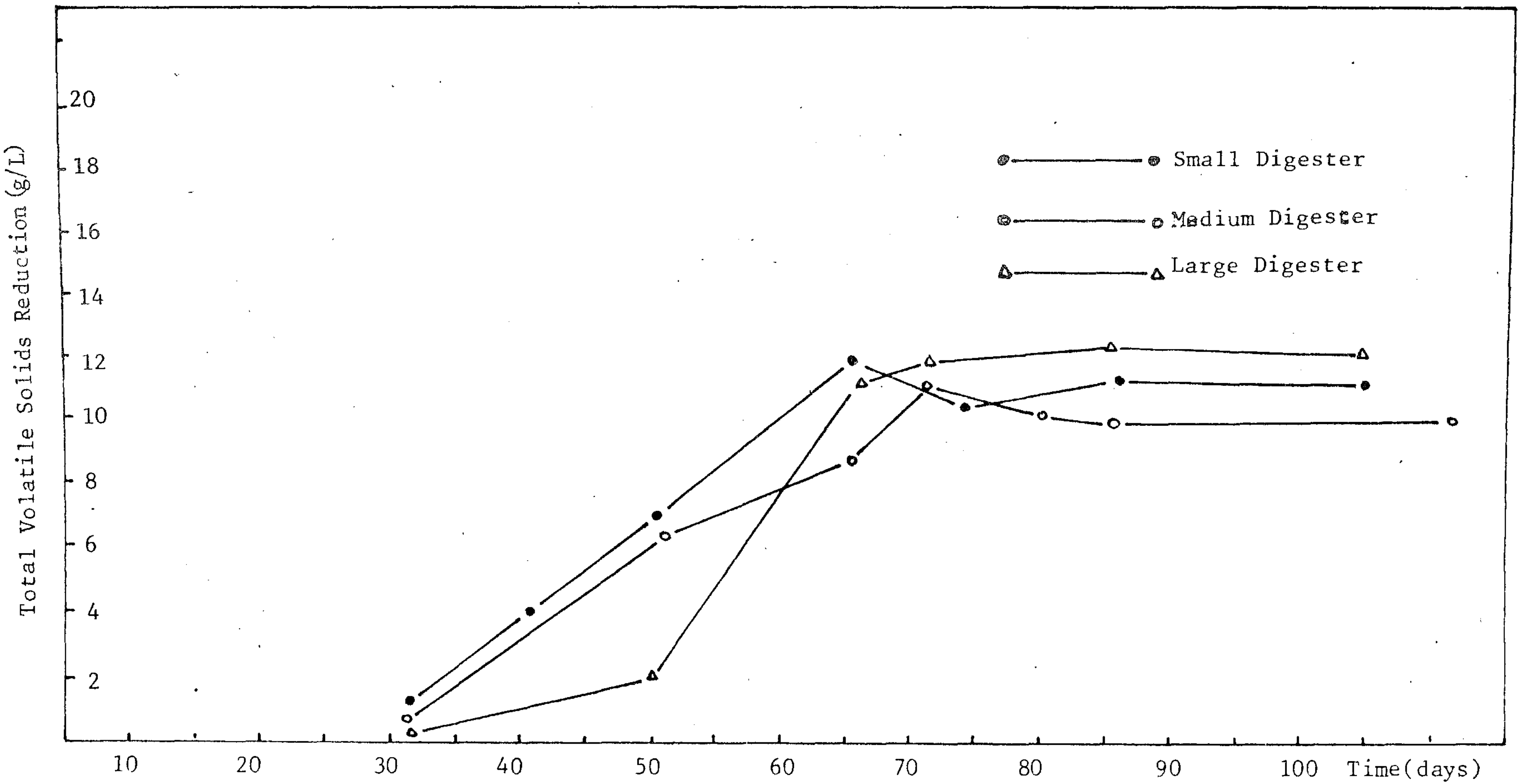
References	In this study	Jewel et.al (1978)	Baban (1981)	Jewel et.al. (1978)
Parameters				
Temperature (T^0C)	23^0C	22^0C	35^0C	22^0C
Hydraulic Retention Time, (Days)	35	30	15	12
Types of Reactor	Semi - CSTR	CSTR	Semi - CSTR	CSTR
Influent Total Solids, TS (g/L)	64	80	60	70
Influent Total Volatile Solids, TVS (g/L)	52.18	71.18	-	71.69
Total Solids Reduction g TS/L of Digester	15.57	20.17	16.30	10.13
Total Solids Reduction, (%)	0.27	0.38	0.27	0.13
Total Volatile Solids Reduction, g TVS/L of Digester	13.17	20.91	14.90	9.83
Total Volatile Solids Reduction, (%)	0.25	0.26	0.31	0.14
Gas Production, (L gas/day)	300	4.41	-	3.21
Gas Production (L gas/g TVS added)	0.13	0.16	0.09	0.04
Gas Production (L gas/g TVS Destroyed)	0.53	0.55	0.29	0.33
Gas Production (L gas/L reactor-day)	0.20	0.37	0.30	0.27



Variation of Temperature Within the Same Time Intervals

26.6	26	25	23	17	21	13	Small Digester (T°C)
25.5	25.5	25	23	17	20	13	Medium Digester (T°C)
26	26	26	25	23	23	19.5	Large Digester (T°C)

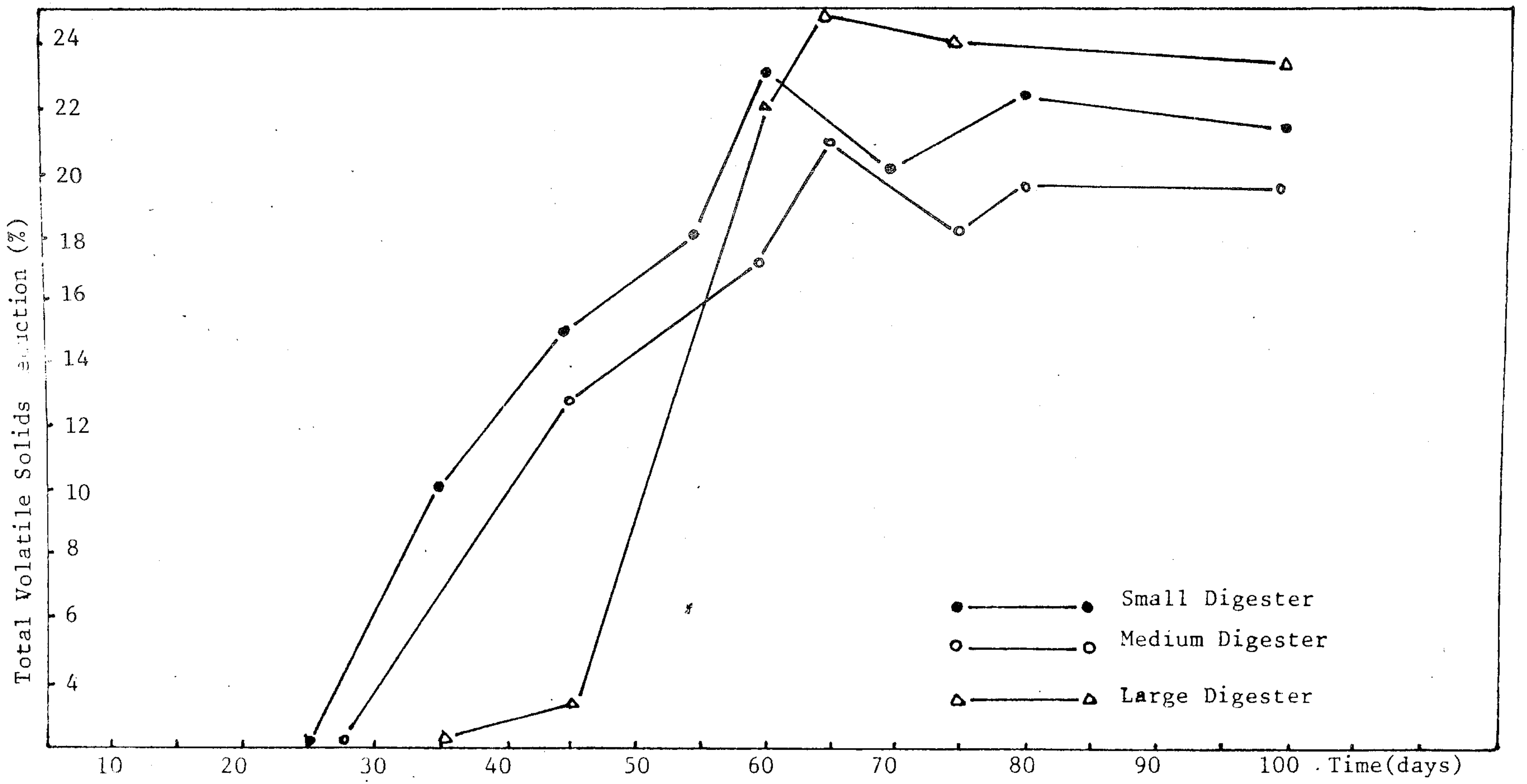
Figure 5.8 Variation of the Effluent Total Volatile Solids With Time



Variation of Temperature Within the Same Time Intervals

26.6	26	25	23	17	21	13	Small Digester (T°C)
25.5	25.5	25	23	17	20	13	Medium Digester (T°C)
26	26	26	25	23	23	19.5	Large Digester (T°C)

Figure 5. 9 Variation of the Total Volatile Solids Reduction With Time



Variation of Temperature Within the Same Time Intervals

	26.6	26	25		23	17	21	13	Small Digester (T^0C)
	25.5	25.5	25		23	17	20	13	Medium Digester (T^0C)
	26	26	26		25	23	23	19,5	Large Digester (T^0C)

Figure 5.10 Variation of the Total Volatile Solids Reduction With Time

TABLE 5.4 SUBSTRATE UTILIZATION COEFFICIENT , K

Parameters	Small Digester	Medium Digester	Large Digester
Influent Total Volatile Solids, S_0,(g /L)	52.20	52.20	52.20
Biodegradable Fraction, B (%)	0.35	0.35	0.35
Refractory Fraction, R' (%)	0.65	0.65	0.65
$S_{b_0} = S_0\ (1-R)$ (g /L) Influent Volat.Biodeg.Fraction	18.27	18.27	18.27
Effluent Total Volatile Solids, S_1 (g /L)	40.10	41.10	39.42
$S_{r1} = S_{r0} = R \times S_0$ (g /L) Effl. and Infl.Refract.Fraction	33.93	33.93	33.93
θ,Hydraulic Retention Time(day)	35	35	35
$S_{b1} = S_1 - S_{r1}$, (g /L)	6.17	7.17	5.49
Incremental Time Period,t (days)	3.5	3.5	3.5
1-t/θ	0.9	0.9	0.9
$S_{b1} = \dfrac{S_{b0}(t) \times \exp(-Kt)}{\theta\left[1-(1-t/\theta)\exp(-Kt)\right]}$ [Solved with trial and error K (1/day)]	0.051	0.04	0.06

5.2.4 Effect of Yeast Addition

Previous studies conducted by Alpaslan (1979), Baban (1981) and Kocasoy (1982) indicated that the addition of yeast into the slurry accelerates the decomposition rate. To verify this result, yeast was added in the reactors on the 73rd and 78th day. The amount of yeast added was 0.5 g/L of slurry. As can be seen in Figures 5.2,5.3 and 5.4,the addition of yeast accelerated the generation of gas, ranging from 10% to 18%. This is in agreement with the findings of previous work conducted at Boğaziçi University.

5.2.5 Gas Generation

Rate of gas production was another parameter determined during this study. The data obtained are given in Figures 5.2, 5.3, 5.4, 5.11, 5.12 and 5.13 and in Table 5.5.As can be seen in these figures, an unusual maximum gas generation was observed at all the three reactors as soon as the gas production started. This unexpected rise in gas generation may be due to the following reasons :

a) Effect of pH

As can be seen in Table 5.5,the pH value, especially for the medium and large digester, was low for a relatively long time, at the beginning of the experiment, finally, the pH was adjusted to a value around 7 by adding NaOH.

The long acidification period may support the assumption that an accumulation of acidified substrate took place during the initial period. When appropriate conditions for methanification were established, this material immediately completed its decomposition giving rise to the production of large amounts of gas.

b) Temperature Effect

In the first days, as can be seen in Table 5.5 the temperature in all three reactors was higher than in the periods which followed. Although this difference in temperature was small, still it may be the reason of the unexpected gas generation pattern observed.

The variation of the gas production rate per total volatile solids added with time are given in Figure 5.11 while the gas production rate per liter of slurry are presented in Figure 5.12.Careful observation of this figure indicates that, the time required to elapse for the initiation of gas generation increases as the size of the reactor increases. This may be due to the fact that longer time is required to increase the temperature of a larger mass of slurry.

In order to make a better comparison of the performance of the three digesters, the curves given in Figure 5.12 were shifted the one on the other, so that the points of initiation of gas generation coincide for all the three reactors. The results obtained can be seen in Figure 5.13. As can be seen in this figure, the pattern of gas generation is the same for all digesters. However, the gas generation per liter of slurry is slightly higher in the large digester. On the other hand, the reactor which has shown the lower gas generation was the medium one.

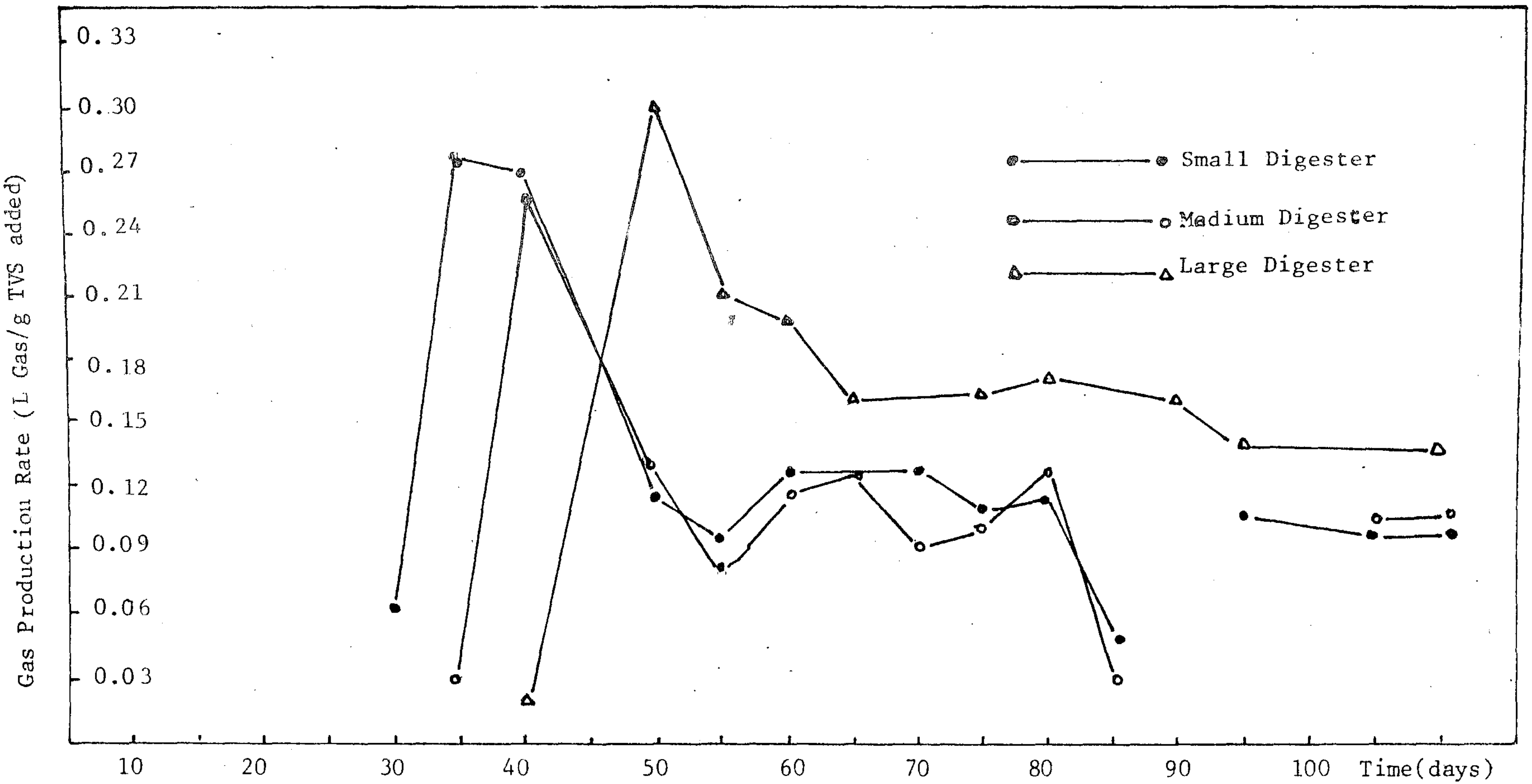
Possible reasons for this performance are :

a) Temperature was relatively stable in the large reactor. Temperature variations in this reactor were very small in comparison to the other two reactors, and because of that the efficiency of this reactor was higher than that of others.

b) Mixing of the slurry as mentioned in Section 2.7.4 has a positive effect on gas generation rate reaching to an increase of 15%. As it is explained in Section 3, although the small and large digesters were mixed with the assistance of a mixer, such a facility was not available in the medium size digester. This may be the reason of the lower amount of gas produced by the medium digester.

After steady-state conditions are reached the gas production rates obtain are given in Figures 5.11 and 5.12 and are tabulated in Table 5.6. The comparison of the results obtained from Table 5.6 with the results of earlier studies are given in Table 5.3.These values are in agreement with the studies of Jewell (1978) and Baban (1981).

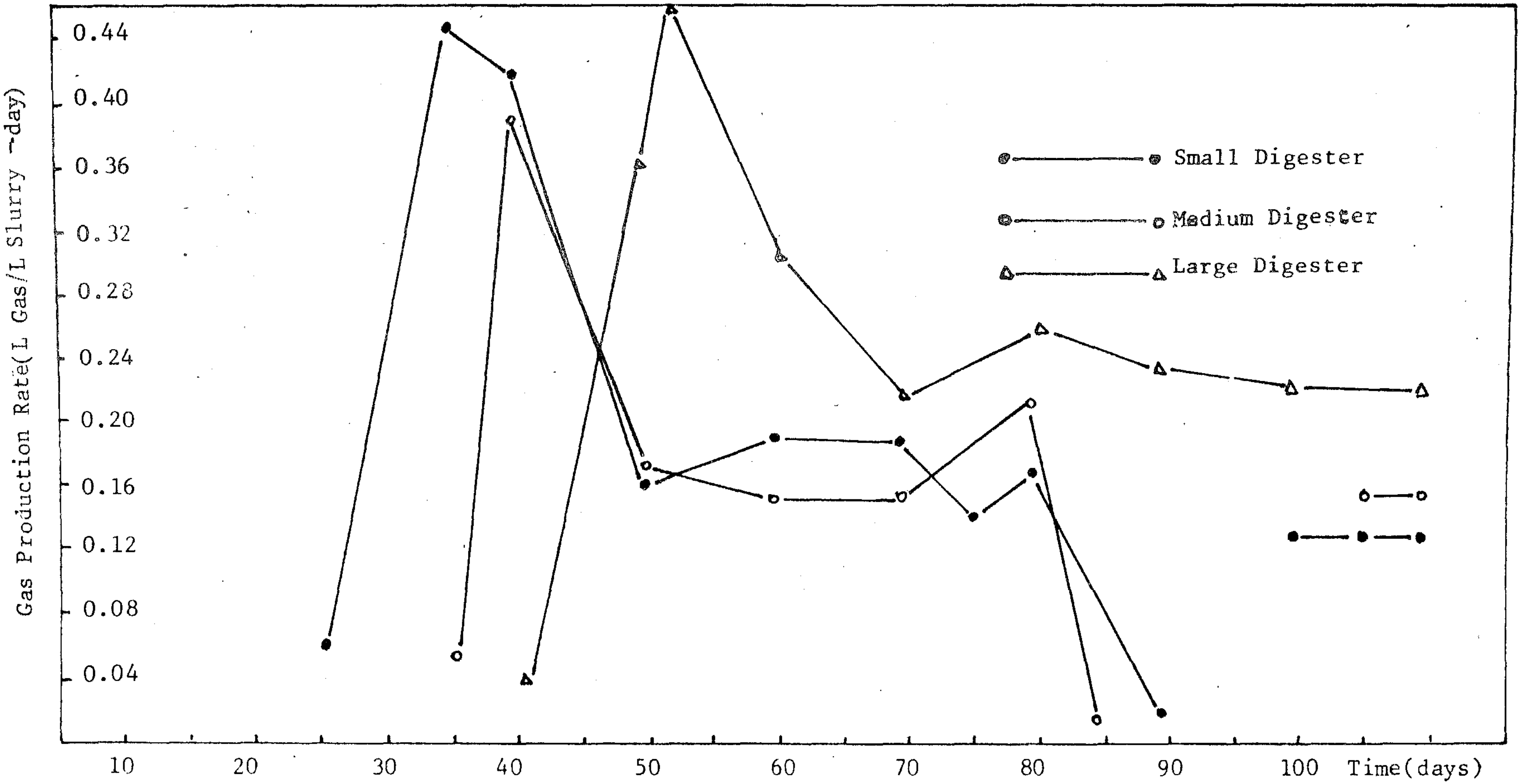
Composition of the generated gas was determined by using the gas par-



Variation of Temperature Within the Same Time Intervals

26.6	26	25	23	17	21	13	Small Digester (T°C)
25.5	25.5	25	23	17	20	13	Medium Digester (T°C)
26	26	26	25	23	23	19.5	Large Digester (T°C)

Figure 5.11 Variation of the Gas Production Rate With Time (L gas/g TVS-added)



Variation of Temperature Within the Same Time Intervals

26.6	26	25	23	17	21	13	Small Digester (T°C)
25.5	25.5	25	23	17	20	13	Medium Digester (T°C)
26	26	26	25	23	23	19.5	Large Digester (T°C)

Figure 5.12 Variation of the Gas Production Rate With Time (L gas/L reactor-day)

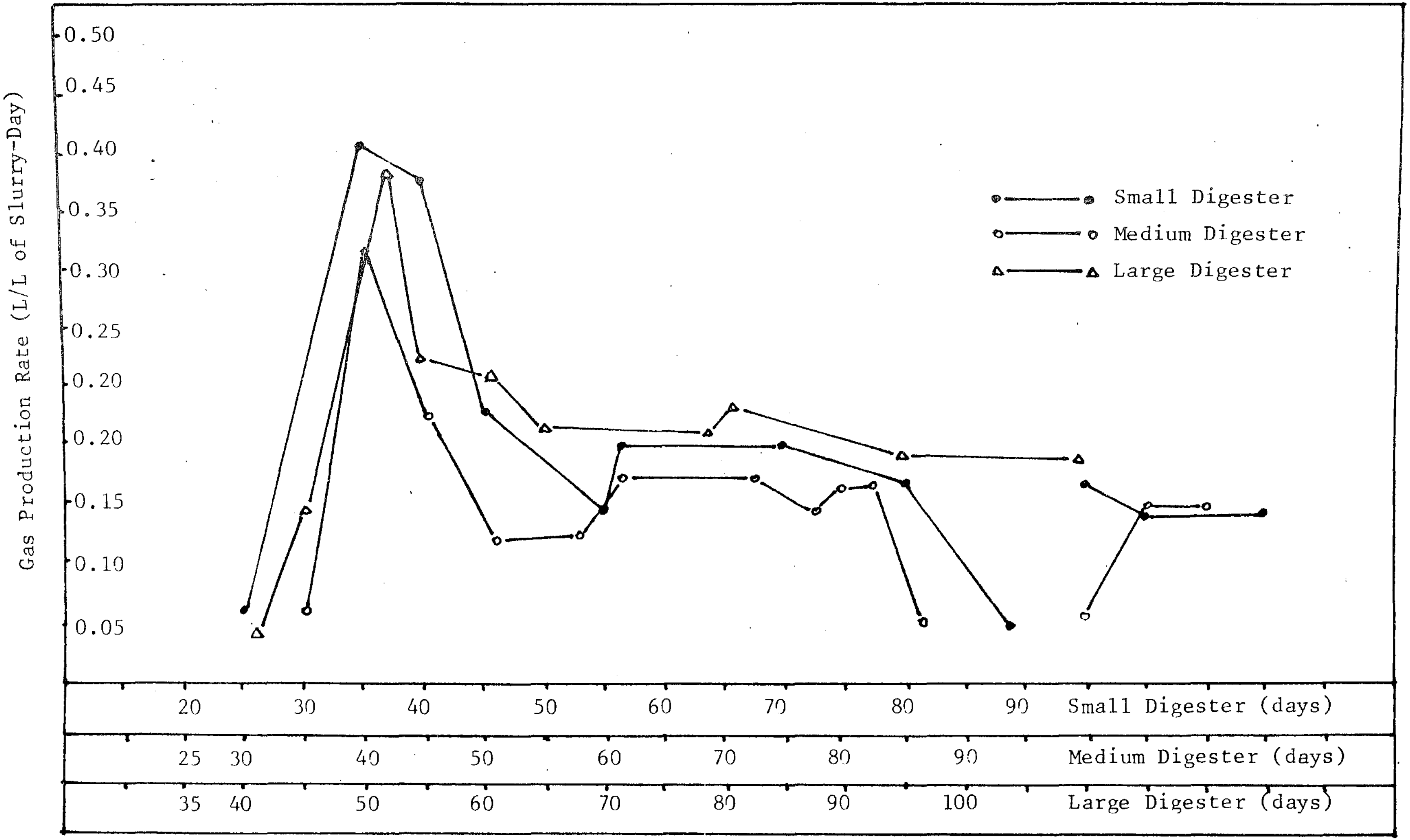


Figure 5.13 Variation of the Daily Gas Production Rate of the Reactors and Their Comparison

TABLE 5.5 THE VARIATION OF pH, TEMPERATURE AND GAS GENERATION OF THE REACTORS WITH TIME

Operation Days	Temperature in Air, T	Small Digester			Medium Digester			Large Digester		
		pH	Temp.	Gas Gen (L/day)	pH	Temp.	Gas Gen (L/day)	pH	Temp.	Gas Gen. (L/day)
0	29	6.4	29	-	6.4	29	-	6.4	29	-
5	28	6.4	27	-	6.4	26	-	6.0	27	-
15	255	6.0	25	-	5.8	24.5	-	5.8	25	-
25	28	6.8	26.6	200	5.2*	25.5	-	5.4*	26	-
30	27	6.8	25.5	270	6.5*	24.5	-	5.4*	26	-
35	27.8	7.1	26	1600	6.6*	25.5	9	6.0*	26	-
40	27	7.1	25	1450	6.7	25	30	6.3*	26	50
45	27	7.1	25	800	6.7	25	65	6.7	26	200
50	26	7.1	25	630	6.7	23	20	6.7	26	600
55	24	7.1	23	570	6.7	22	20	6.7	26	380
60	25	7.1	23	700	6.7	23	28	6.7	25	360
65	23	7.1	23	680	6.7	23	30	6.6	24	260
70	16	7.1	17	580	6.7	17	22	6.6	23	290
75	20	7.1	19	590	6.7	19	22	6.6	23	300
80	22	7.1	21	600	6.7	20	27	6.6	23	320
85	18	7.1	16	400	6.7	15	8	6.6	20	300
90	14	7.1	13	200	6.7	13	-	6.6	19.5	280
95	19.5	7.1	18	700	6.7	-	-	6.6	19.5	260
100	21	7.1	20	580	6.7	20	10	6.6	19.5	255
105	20	7.1	19.5	570	6.7	19.5	26	6.6	19.5	250
110	20	7.1	19.5	560	6.7	19.5	25	6.6	19.5	250

* NaOH Addition

titioner explained in Section 3.3.2. Biogas, in this study mainly contained 55% to 60% methane and 35% to 45% carbon dioxide.

TABLE 5. 6 GAS PRODUCTION FROM SEMI-CONTINUOUSLY FED REACTOR

Parameter	Small Digester	Medium Digester	Large Digester
Temperature, T^0C	23 ± 1	23 ± 1	23 ± 1
TVS Loading Rate, g/L day	1.49		
Hydraulic Retention Time, θ, day	35		
Total Volatile Solid Destroyed , %	0.23	0.21	0.25
Gas Production L gas/g TVS Destroyed	0.58	0.61	0.64
Gas Production L gas/g TVS Added	0.13	0.13	0.16

Also, the following equation is given in Section 2.6 can be used to calculate daily gas generation rate per liter of slurry (Jewell,1978).

$$G_t = 0.5\ (S_{bo} - S_{bi})/\theta$$

where , G_t: Gas Production Rate, L/L of digester-day
θ : Hydraulic Retention Time, day
S_o : Influent Total Volatile Solid Concentration, g/L
S_i : Effluent Total Volatile Solid Corcentration, g/L

G_t values of the small, medium and large digesters were calculated to be 0.17, 0.16 and 0.18 L gas/L of slurry-day, respectively. These values are in agreement with the values given in Table 5.9.

5.2.6 Volatile Acids and pH

As can be seen in Table 5.7, after the digesters reached to a steady-state, volatile acids concentration for all the three reactors dropped to a value varying between 500-660 mg volatile acids/L. The effect of the reduced volatile acid content was enhanced by the increase in pH. The reduction efficiencies of volatile acids were between 58% and 68%. These values are i agreement with the studies conducted by Welsh (1977) indicated that this value was around 71%.

TABLE 5.7 VARIATION OF VOLATILE ACIDS CONCENTRATION

Digester	Volatile Acids, g/L		% Reduction
	Influent	Effluent	
Small Digester	1.576	0.530	66.75
Medium Digester	1.576	0.660	58
Large Digester	1.576	0.500	68

5.2.7 Nitrogen and Phosphorus

End products of anaerobic decomposition are known as good fertilizers. To verify this belief, the nitrogen (as TKN) and phosphorus concentration of the slurry were determined. The results obtained after steady-state was reached are given in Table 5.8.

TABLE 5.8 NITROGEN AND PHOSPHORUS VALUES AFTER STEADY-STATE CONDITION

Digester	Nitrogen, g/L			Phosphorus, g/L		
	Influent	Effluent	% Variation*	Influent	Effluent	% Variation
Small Dig.	0.343	0.370	+7.87	0.650	0.500	-23.07
Medium Dig.	0.343	0.350	+2.04	0.650	0.550	-15.38
Large Dig.	0.343	0.345	+0.58	0.650	0.600	-7.69

* (- : Reduction, + : Increase)

As can be seen in this Table, the concentration of nitrogen increase by 0.58% to 7.87% . This increase is in agreement with the results reported by Welsch (1977). Another observation however, which can be done is that, the increase of nitrogen concentration becomes smaller and smaller as the digester becomes larger.

Phosphorus concentration has shown a decrease varying between 7.69% to 23.07 %, as can be observed in Table 5.8. Furthermore, similarly to nitrogen, the percent decrease of phosphorus was inversely proportional to the volume of the digester.

The concentration of nitrogen and phosphorus remaining at the effluent are an indication that this slurry can be characterized as a good quality fertilizer.

CHAPTER VI

CONCLUSIONS

The present study as mentioned in the previous section, has been conducted with the intention to determine the size effect on the performance of an anaerobic digester model, as well as the performance of such a digester under ambient conditions. The main conclusions which have been reached are the following :

a) The large digester was the one which has shown slightly better performance than the other digesters as long as the substrate utilization coefficient, the COD removal, the volatile solids removal and the gas production are concerned.

b) As can be seen in Table 5.9 , the size of the digester has also an effect on volatile acids, nitrogen, phosphorus and pH variations.

c) Any digester can operate under ambient conditions if proper insulation precautions are taken.

d) It is verified that mixing has a positive effect on biogas generatio

e) The positive effect of yeast on anaerobic decomposition is verified once more.

The results obtained in this study are a clear indication that size has an effect on the overall performance of anaerobic digesters using dung as a substrate and aiming to produce biogas. Because of that,

- Attention should be paid in the size effect when the results obtained by relatively small models are interpreted,
- Further investigations should be made in order to understand

TABLE 5. 9 STEADY-STATE DATA OF SEMI-CONTINUOUSLY MIXED REACTOR (SEMI-CSTR) (HYDRAULIC RETENTION TIME 35 DAYS AT 23 ± 1°C)

Parameter	Small Digester	Medium Digester	Large Digester
Influent			
Total Solids (g /L)	64.41	64.41	64.41
Total Volatile Solids (g /L)	52.18	52.18	52.18
Chemical Oxygen Demand (g /L)	45.05	45.05	45.05
Nitrogen, TKN (g /L)	0.343	0.343	0.343
Phosphorous (g /L)	0.650	0.650	0.650
pH	6.4	6.4	6.4
Volatile Acids (g /L)	1.576	1.576	1.576
Effluent			
Total Solids (g /L)	52.20	53.41	48.84
Total Volatile Solids (g /L)	40.10	41.10	39.42
Chemical Oxygen Demand (g /L)	27.88	28.90	25.28
Nitrogen, TKN (g /L)	0.370	0.350	0.345
Phosphorous (g /L)	0.500	0.550	0.600
pH	7.1	6.7	6.6
Volatile Acids (g /L)	0.530	0.660	0.500
Gas Production L/L of Slurry-Day	0.19	0.16	0.20
% Variation *			
Total Solids	-19	-17	-24
Total Volatile Solids	-23	-21	-24
Chemical Oxygen Demand	-38	-36	-44
Nitrogen ,TKN	+8	+2	+0.6
Phosphorous	-23	-15	-8
Volatile Acids	-66	-58	-68

* -:Reduction, +: Increase

better and give a dependable explanation to the size effect. Furthermore, a mathematical model should be derived by which the size effect can be predicted easily.

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APPENDIX A

Digester Design

The number of animals must be known while designing a biogas reactor. In this study, the manure of a cow and a sheep is used in all the three reactors. The following Table summarizes the daily dung and corresponding urine efficiency of this the kind of animal (UNEP,1980).

TABLE A.1 DAILY DUNG AND CORRESPONDING URINE EFFICIENCY

Types of Animals	(Dung %) x A	(Urine %) x A
cow	5-6	3-4
sheep	4-5	1-2

Where A is the living weight of the animal (kg). This table helps to find out the daily manure obtainable from a sheep and a cow:

1 sheep x 50 kg of living weight x (0.04 + 0.01) + 1.cow x 250 kg of living weight x (0.05 + 0.03)   23 kg organic waste/day.

The water added : 4.5 kg of dung per day is found to be around 8.4 kg/day (Figure 3.9).

Hence water added to the dung

(23 kg/4.5 kg) x 15 kg/day = 76 kg/day water added.

Total mass of water and dung :

23 kg dung + 76 kg water = 99 kg/day

Total mass for a period of day is :

99 x 35 days = 3.47 ton.

The living period of animals in shed is assumed to be 16 hours per day. Hence the total manure collected:

3.47 ton x 10/24 hours = 1.54 ton organic waste.

Manure density is accepted to be 0.96 ton/m^3.

The volume of 1.54 ton of manure is,

$1.54\text{ton}/(0.96\ \text{ton/m}^3) = 2.4\ \text{m}^3$.

This volume is equal to the total volume of the three reactors with a total working capacity of (1400 +180 + 3.5) = 1583.5 L.

Total gas production per day at a temperature of 23^0C at steady-state conditions, was around 0.32 m^3/day.
This produced gas is able to burn for about an hour using 5.1 cm burner, or can light a mantel lamp for about 4.5 hours.