DEVELOPMENT OF TECHNIQUES FOR BIOGAS GENERATION FROM ANIMAL DUNG FOR HOUSEHOLD USES

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CERTIFICATION

I certify that this project was carried out under my supervision by **ADEYEMI**, Aderonke Abidemi (Mrs) with registration number CVE/96/8416 of the Civil Engineering Department, Federal University of Technology, Akure.

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DEDICATION

This project work is specially dedicated to my loving husband, Engr. A.A. Adeyemi for his encouragement, patience, understanding, moral and financial support throughout the study period, God bless and reward you richly.

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ABSTRACT

In this study a simple technique of producing biogas from animal dung under measurable conditions is investigated. The specific objectives are to design, construct and test (using a chosen waste as substrate) a suitable mobile transportable biogas system (digester) which can be easily utilized for the production of biogas. The study aims at determining the amount of gas produced under 15, 25 and 35 days retention time using abattoir waste at ambient temperature.

Results achieved from the study indicated that the mobile biogas plant used can be fabricated and operated successfully with 100% local materials using the batch process. Abattoir waste used as a substrate in this study was found to have an average gas yield of $2.057m^3/m^3$ of waste per day. This is good compared to yields from other organic wastes. The gas can also be cleaned to obtain pure methane which has several industrial applications such as in the manufacture of methanol.

Since the gas produced from the experiment is combustible and can be used as fuel, which makes it valuable, the use of the gas is expected to offset to some extent the cost of managing the waste, which was used as a substrate in producing it.

Chapter One

INTRODUCTION

1.1 General

Biogas is a relatively cheap fuel produced from the anaerobic digestion of organic matter. Natural vegetation or organic residues and wastes from materials such as fruit peelings, cow dung, kitchen wastes, agricultural and crop wastes, etc., are decomposed under anaerobic conditions to produce a mixture of gases. These gases are methane (CH_4), Carbon dioxide (CO_2), nitrogen (N_2), oxygen (O_2), hydrogen (H_2), carbon monoxide (CO), hydrogen sulphide (H_2S) and sulphur IV oxide (SO_2) which are jointly referred to as biogas. Of the above, methane is the useful biogas. The combustible part of methane is usually present in sufficient quantities (40-87%) to allow the gas burn normally with a blue flame. This property has made biogas an attractive alternative source of energy.

1.2 Statement Of The Problem Of Wastes Conversion To Energy

Rapid urbanization all over the world has created a serious problem of solid waste disposal. The post independent period in Nigeria from 1960 to date has witnessed various levels of socio-economic and political development. According to the 1991 census, Nigeria had a population of 88.5 million with an average growth rate of

3.3% and 30% of growth of this figure is estimated to live in urban cities (National Population Commission, 1992). While the major cities continue to grow generally, there is a highly disproportionate movement to big cities like Lagos, Ibadan and Kano. These changes, i.e. demographic expansion and increased commercial and industrial activities have brought phenomenal increase in the volume and diversity of wastes being generated (Longe and Salau, 1997).

In the Lagos metropolis, with an estimated current population of about 9.5 million people (Lagos State Ministry of Information, 2001), there are over 15 existing abattoirs, (recognized and unrecognized) serving this teeming population. Results of field investigations conducted by this author revealed that in each of these abattoirs cattle slaughtered on a daily average ranges from 20-40 heads for the smaller abattoirs to about 400 heads at the larger ones. A common feature of most of the abattoirs is their nearness to water bodies such as lagoons, and natural and man-made canals. It was discovered that wastes from these abattoirs, which are mainly paunch and belly contents/blood mixture, are either dumped in heaps near the abattoir or discharged raw into the water bodies leading to serious contamination of the receiving water body. The resulting economic costs of the environmental degradation cannot be quantified. This has necessitated the need to look critically at these wastes and investigate how they could be converted to useful products.

A waste-to-wealth possibility is the recovery of energy from these putrescible (decomposable) organic wastes using a bio-digester. The gas thus produced could be suitably used for various purposes such as cooking and lighting and the resulting digested slurry which is rich in nutrients, can be used as organic manure in crop agriculture. Presently there are large-scale, medium-scale and small-scale biogas plants in use world-wide especially in Asia (Brown, and Tata, 1994).

Available records world-wide show that the following countries are the leading users of biogas in especially rural and semi-urban areas, with China blazing the trail since 1920 (Brown, and Tata, 1994):

i. China – over 7.5 million plants

ii. India – over 800,000 plants

iii. Taiwan – over 75,000 plants.

Nigeria has no known or publicized functioning biogas plants outside the laboratory scale and demonstration units of a few research centers notably the Sokoto Energy Research Center (SERC) and the Federal Institute of Industrial Research, Oshodi-Lagos

(FIIRO). Although, FIIRO has constructed a $20m^3$ digester biogas plant at Oko-Oba, Agege intended to utilize wastes from the abattoir nearby, the project is yet to be completed and commissioned due to lack of finance (Lawal, 2000). Despite the fact that the nation could benefit immensely from the advantages of biogas generation namely waste management in the urban areas and waste management, sanitation improvement, crop production and energy supply in the rural and semi-urban areas, the nation has not seriously considered the options.

Presently, experiments on biogas generation in Nigeria as deduced from available literature have been carried out at laboratory level. With its controlled environment and attendant modifications, it is believed that results obtained from such experiments might not differ significantly from what obtains in reality. From these works, prototype biogas plants can be developed for full scale commercialization.

1.3 Aims and Objectives of the Study.

The objectives of this research was to devise a simple technique of producing biogas from animal dung under measurable conditions. These are:

(i) To design, construct and test a suitable transportable biogas system (digester) using a selected abattoir waste as substrate.

(ii) To determine the amount of biogas using abattoir waste as substrate under 15, 25 and 35 days retention time at ambient temperature.

(iii) To examine the possibility of using a fabricated biogas units in rural/semi-urban areas of Nigeria using readily available local substrates.

(iv) To proffer suggestion for modifications or outright re-design of suitable plants bearing in mind the socio-cultural beliefs of rural people in Nigeria to enhance the sustainability of any proposed biogas plant.

1.4 Scope and Limitations of Study:

The study was carried out using the paunch and belly contents/blood components of wastes from slaughtered cattle as substrate. This organic matter is easily available in large quantities. It has been described to have a rapid production of gas, than other organic materials such as poultry droppings, pig and goat wastes, and vegetative wastes.

Although temperature plays an important role in the rate of gas production, the study was limited to the prevailing ambient temperature, as no external heating of the chamber was done. The interest of this work is towards the production of small scale plants that can be operated at household level, without additional sources of energy.

The research was focused mainly on investigating the feasibility of producing adequate biogas from the selected substrate and not on the actual design of a full scale bio-digester plant system.

Chapter Two

Literature Review

2.0 Historical Background:

Over the centuries, various sources of energy have been used by man in order to meet his basic life essentials such as food, water and shelter. Starting with his own energy and sunlight, he progressed to wood fuel, draft-animal power, water and wind power, then developed engine power fuelled by wood, coal, petroleum and nuclear energy (Abubakar, 1990). Man has utilized energy in modifying and manipulating land, water, plants and animals to obtain food, clothing and shelter. In primitive agricultural systems, the processes of providing food proceed in their natural state, with solar energy being the principal energy source, augmented only slightly by human or animal energy inputs. Thus in order to achieve greater levels of output, other energy inputs (mostly derived from fossil fuel reserves) have been used by man to enhance solar energy transformation.

Presently, fossil fuels provide the bulk of the world's primary energy. With hydro-electricity providing about 2% and nuclear fission, wood and other sources each probably accounting for less than 1% of the primary industrial energy used in the world

(Abubakar, 1990). Since fossil fuels are non-renewable natural resources and man has done little to conserve the earth's supply, supply of fossil fuels (especially oil and gas) may very soon get completely depleted. There is thus a need to develop alternative energy sources to replace fast depleting fossil fuels. In Nigeria, fuel wood, petroleum, gas, kerosene and electricity constitute important sources of energy. However, the majority of Nigerians living in rural areas do not have access to gas or electricity. Developing countries generally rely on wood, dung, straw and animal and human power to meet most of their basic needs. The recent global energy crisis has generated interest in the use of organic wastes for energy to substitute for fossil fuel. Biogas production is the biological method through which organic waste materials can be converted to fuels.

Biogas results from the anaerobic digestion of organic materials such as vegetation, animal wastes and marsh gas. Marsh gas was discovered by Shirley in 1667. Undoubtedly, it was known much earlier because of its universal appearance from decaying vegetation in swamps and lakebeds. As early as 1630, Van Helmont mentioned, among 15 different kinds of gas, an inflammable gas that evolves during putrefactions and also is contained in intestinal gas. Priestly reported in 1790 of "Air produced by substances putrefying in water" in his "Observation on Inflammable Air". He confirmed the work of Volta, who in 1776 recognized a close relationship between the appearance of combustible gas and the decaying vegetation in the sediment of lakes and streams. Volta gave the first eudiometric analysis of methane, the constitution of which was first developed by Dalton in 1804 (Jewell, 1977).

It was in 1808 that Humphrey Davy collected methane in his experiments with strawy cattle manure kept in a retort in a vacuum. This might be considered the beginning of manure gas research, but Davy was not interested in solving energy problems with natural fuel gas. His experiments was directed toward an evaluation of rotted and unrotted manure for crop production. It was not until 1868 that Bechamp first defined his reaction as a microbiological process. This process, the biological decomposition of organic matter with the liberation of methane gas, is the anaerobic digestion process (Jewell, 1977).

Gayon, a pupil of Pasteur, also recorded a success in his experiments with animal manure in 1883-1884. The volume of gas collected at 35^0C was so great that Louis Pasteur concluded that anaerobic manure fermentation might supply gas for heating and illumination under special circumstances. But the proposal, reported in the newspaper, Le Figaro to improve the street illumination of Paris by manure fermentation from the numerous horses being used as taxis and in public works was not executed (Jewell, 1977). Ethane was first recognized as having practical and commercial value in 1896 in Exeter, England, where a specially designed septic tank was used to generate the gas for the purpose of lighting a street (Sambo and Garba, 1992).

In the following decades, experimental work with manure gas production never really stopped and the process has been used many times when conditions of reduced energy supplies existed (Sambo and Garba 1992). Municipalities were able to further the development using taxpayers' money. The next step was sewage treatment in a heated digester, which accelerated the fermentation process, improved the treatment efficiency, reduced the retention time and thus the digester volume requirement. The increase in release of sewage gas by heating was regarded only as a valuable by-product until the next critical state in energy supply. That occurred during and after World War II (Jewell, 1977).

In 1951, 48 sewage treatment plants in West Germany provided more than *16 million* m*3 of* sewage gas, *3.4% of which was utilized* for power production, 16.7% for digester heating, 28.5% was delivered into the municipal gas supply system and 51.4% was converted to vehicle motor fuel (Jewell, 1977).

In China and India, biogas technology has been used for more than 60 years. In China biogas has been successfully used to provide cooking fuel and to conserve fertilizer and improve public health. This pioneering work stimulated interest in other countries (for example Korea, the Philippines and Taiwan). Although, most of the activity has taken place in Asia, a number of African and Latin American countries are currently engaging in biomethanation projects (Brown and Tata, 1994).

2.1 Biogas as Energy:

Mankind has passed from a period of affluence for many to global environmental quality degradation, food and energy shortages and natural resource depletion (Jewell, 1977). Concern that known fossil fuels are being rapidly depleted, the need for the evolution of sustainable waste management strategies, the possibilities of improvement in sanitation in rural and urban areas of third world countries and the increasing deforestation resulting partially from the use of firewood for cooking have focused attention on the feasibility of economical recovery of energy and plant nutrients from most organic wastes through anaerobic digestion. The large concentration of organic matter contained in such wastes may, if broken down by anaerobic bacteria in a controlled environment, yield significant quantities of methane gas (Kroeker et al, 1975).

Bhavan (1988) defines energy, as the capacity of doing work and that it is necessary for all the processes of growth. He went further to assert that "Energy is now recognized as one of the factors of production. It furnishes the base to quality of life and it is a barometer of future potentials".

In third world countries, demands for fuel wood and energy for house-holds have steadily increased due to a booming human population (Kroeker et al, 1975). Mallan (1997) posited that energy is a basic need to survive and therefore the need for sustainable energy supply cannot be over-emphasized. The question thus is how and where to find the energy?

Biogas is a fuel which can be used for a variety of purposes (Superflex, 1997). At the first instance, biogas is used for cooking food by utilizing special types of burners and for lighting or heating purposes (Bhavan, 1988). In Tanzania, biomass is the main source of energy for domestic use. It accounts for over 90% of the total energy consumed in the country while oil, electricity and coal accounts for less than 10% (Mallan, 1997).

Due to its anti-knock characteristics, Biogas is an outstanding fuel for combustion engines and in principle, all combustion engines are suitable if adapted to biogas. Biogas can easily be stored to provide energy for various uses such as refrigeration and running of engines that may help in water pumping and related operations (Abubakar, 1990). One gallon (4 litres) of petrol is approximately equivalent to 5 to $7m^3$ of biogas, so that it can be used to power automobiles plying short distances. Ethane has an octane rating of around 130 and is thus suitable for modern high compression, high performance engines. If used alone, about $3m^3$ of methane is equivalent to a gallon of petrol (Hobson et al, 1978). The ignition temperature of methane is higher (704°C) than many other fuels, and a hot spark is necessary to ignite it. The advantages of methane gas as a fuel include the freedom from pollution emission on combustion; this clean burning results in longer spark plug and engine component lives (Hobson et al, 1978).

2.2 Biogas Plants

A typical biogas plant consists of two main parts:

i) a digester – where fermentation occurs, and

ii) a gas holder – where the gas produced is stored.

However, the heart of a biogas plant is the digester. Different types of digesters exist:

(i) **Batch Digester:**

The waste to be treated is placed in the digester and the vessel is closed and sealed to achieve an anaerobic environment, and left until digestion is completed. Under these conditions, gas production should start in 3 to 4 days. When gas production tapers off or ceases, digestion is assumed to be completed so the contents are then removed from the tank and preparations are undertaken to repeat the cycle. The simplest arrangement of this batch – loading principle is the vertical drums type (Fig. 2.1). Waste is placed into the outer drum and seeded with digester contents from previous fermentation. The inner drum is pushed down in the waste with gas taps opened to exclude air. When fermentation begins, the inner drum is forced upwards by digester gas thereby giving visual indication of gas generation.

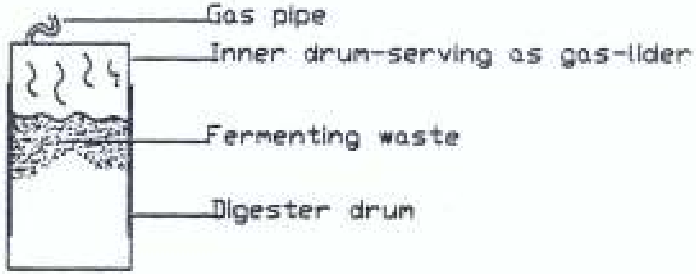


Fig 2.1:Batch Digester

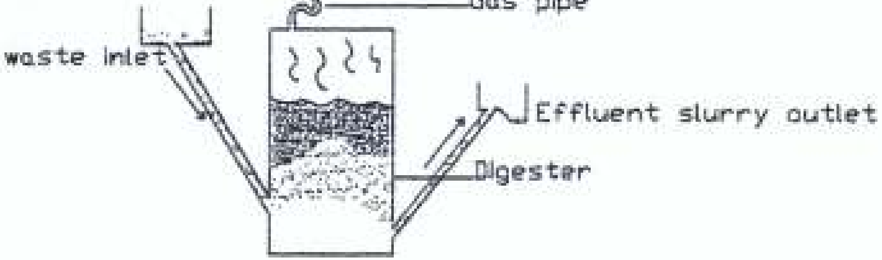


Fig 2.2:Continually Fed Digester

Source: Roy,1981

(ii) **Continually Fed Digester**:

This category of fermenting reactor requires the feed as influent to be deposited into the vessel at regular intervals. The rate of feeding should be continuous for maximum efficiency, probably once a day. The design is a vertical displacement type (Fig. 2.3) where the waste matter is mixed with water and introduced down the in let pipe (usually at daily intervals) into the digester. This in turn displaces an equal amount of contents into the slurry outlet.

(iii) High Rate Digester

By definition, a high rate digester is a design which incorporates stirring or agitation of the contents to achieve good mixing and which also has a means of heating to ensure that the reaction takes place at stable optimum temperature. The digester is insulated and stirred intermittently via a double paddle agitator, the upper rotor serving as a scum breaker. Heat is supplied via a sludge re-circulation system passing through a conventional gas-fired heat exchanger *(Fig. 2.3)*.

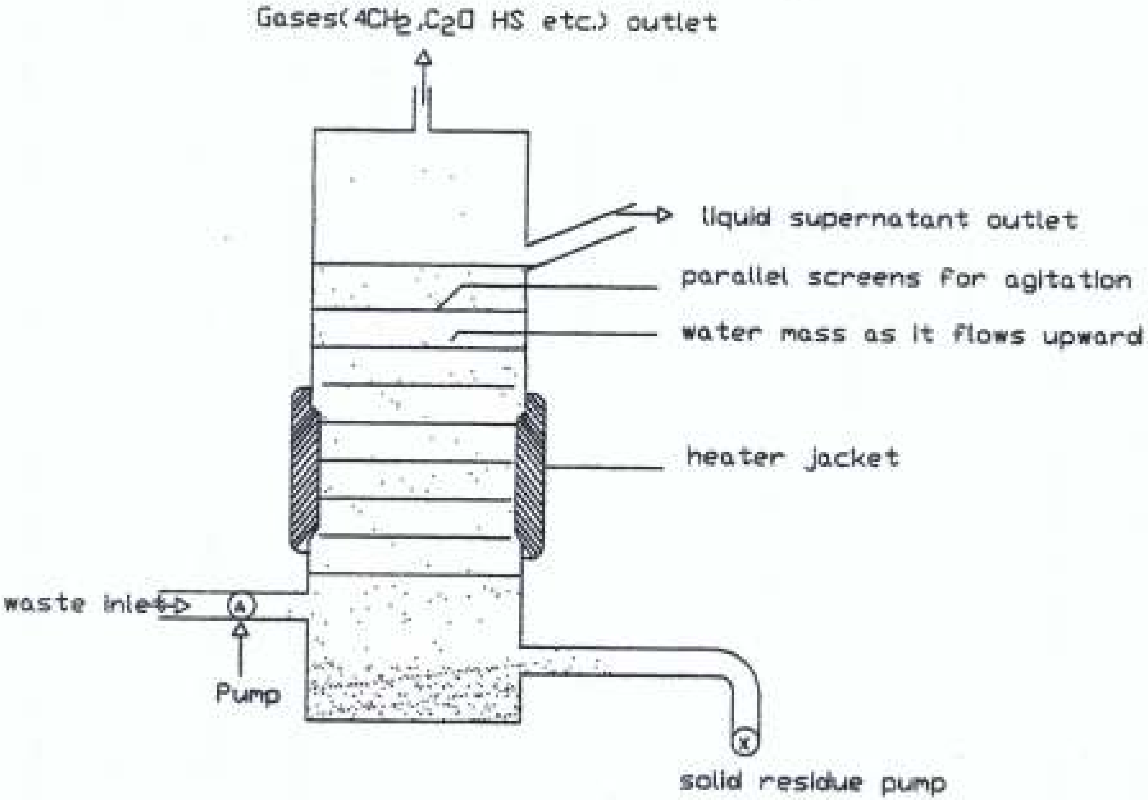


Fig 2.3 : High rate digester

Source: Roy,1981

(iv) **Anaerobic Filtration Digester**

In this type of digester, the tank contains materials, which are suitable for the bacteria to attach themselves to the bacteria adhering to the fitter particles absorb nutrient from the surrounding flow of influent, as the growth becomes larger or dies, it sloughs off and passes out as sludge. The filter material can vary from stone granules or chips to plastic pieces of various shapes and sizes.

(v) **Other types of digesters:**

These types are simply described by their processes. They are:

a) Anaerobic contact process, Digester

b) Multistage Digesters (Saubolle, 1987).

c) Plug flow digester.

2.2.1 Plant Design

For full-scale digesters, which are expected to serve for a reasonable length of time, only appropriate designs will perform satisfactorily and will have a favourable cost benefit ratio. Existing basic designs of biogas systems have to be adapted to the following frame-work conditions (G.A.T.E., 1999):

i) Climatic and soil conditions,

ii) The quality of substrate to be digested,

iii) The quantity of substrate,

iv) The prioritization of expected benefits,

v) The capital available, and

vi) The availability of skills for operation, maintenance and repair.

Problems usually associated with bad design include (Pfeiffer, 1973);

a) **Scum**:- If a digester is not adequately stirred, a scum – which consists of the lighter fractions, such as animal hair, feathers, straw and other fibrous material, depending on the waste being digested can form on the surface. This layer can build up and if not broken can form a thick mat, dry on the surface, which eventually prevents the liberation of gas and a proper functioning of the digester. The worst problem is that in which the scum causes a blockage in the gas outlet pipe with a corresponding pressure build up. There have been notable explosion, especially of research equipment, which have been traced to this cause.

b) **Explosions**:- Explosions are one possible hazard when dealing with a digester gas composed of about 70% methane. They can occur either due to excess pressure build-up or ignition of the gas when it is in an explosive condition i.e. a mixture of 1 part of digester gas with 7 to 19 parts of air. Care must be taken therefore, to avoid the possibility of leakage e.g. through badly worn or incorrectly designed stirrer shaft glands or gas pump bearings.

c) **Feeding**:- the most common problem is clogging with rags or large solid particles. This is especially likely in a digester plant in which the feed material is altered. This can occur with the addition of more sewage into a sewage/factory waste combination or with an alteration in a manufacturing process to give a change in waste composition.

d) **Economic**:- One of the most common of the "operational problem" found with anaerobic digesters is in the field of economics. Many digesters which were designed to produce "free" energy have, in fact, proved to be expensive when the true costs are evaluated. Lack of digester design experience or lack of attention to details can result in costly mistakes. For example, it is common to take a figure of one third of the gas produced for the digester heating requirements. This can be quite inaccurate for some conditions and may give a falsely optimistic view of the economics of the system. Similarly, it may be felt that a residue could be sold as a fertilizer and the overall economics calculated accordingly. However, this would involve extra handling costs as well as specialized de-watering and bagging equipment. Marketing and distribution would perhaps be other sources of trouble, and in many cases what may have begun by being a solution to the problem of waste disposal could easily become a large financial commitment. These aspects need to be considered from the onset as part of the design rationale.

2.2.2 Recent Advances in Biogas Plant Design

Perhaps the most advanced biogas plant ever designed to date, with the poorer third world countries in mind, is the supergas/superflex biogas digester invented in 1996-1997 by scientists in Sweden as an ecologically and socially sustainable solution to long term problems in the energy sector in the developing countries.

The superflex biogas system, illustrated in Fig. 2.4, is designed with no mechanical parts for stirring, utilizing instead, the pressure from the generated gas to achieve an automatic forced stirring via a *pressure equalizing system. Expected to cost between US $ 100-150* (about 250 Euro) when the product goes into full commercialization. This innovative design has combined aesthetics and durability in the production of the most simple, relatively cheap and yet most technologically sophisticated system ever produced in the field of biogas (Superflex, 1997).

2.3 Chemistry of Biogas Production

In the anaerobic digestion process, a complex mixture of interacting microorganisms, mainly bacteria, carries out the complete degradation of organic materials to biogas. The decomposition of the complex organic compounds occurs in a 3-stage process where 3 main groups of microorganisms – fermentative, proton reducing acetogenic and methanogenic bacteria – are acting interdependently. These processes can be summarized thus (Lawal, 2000):

A – Fermentative Step:

The fermentation of complex organic molecules comprises two stages:

i. The hydrolysis of compounds such as polysaccharides proteins and lipids to corresponding monomeric units.

ii. The further fermentation of simple compounds to short-chain fatty acids, alcohols, hydroxyl acids, co_2, H_2 etc.

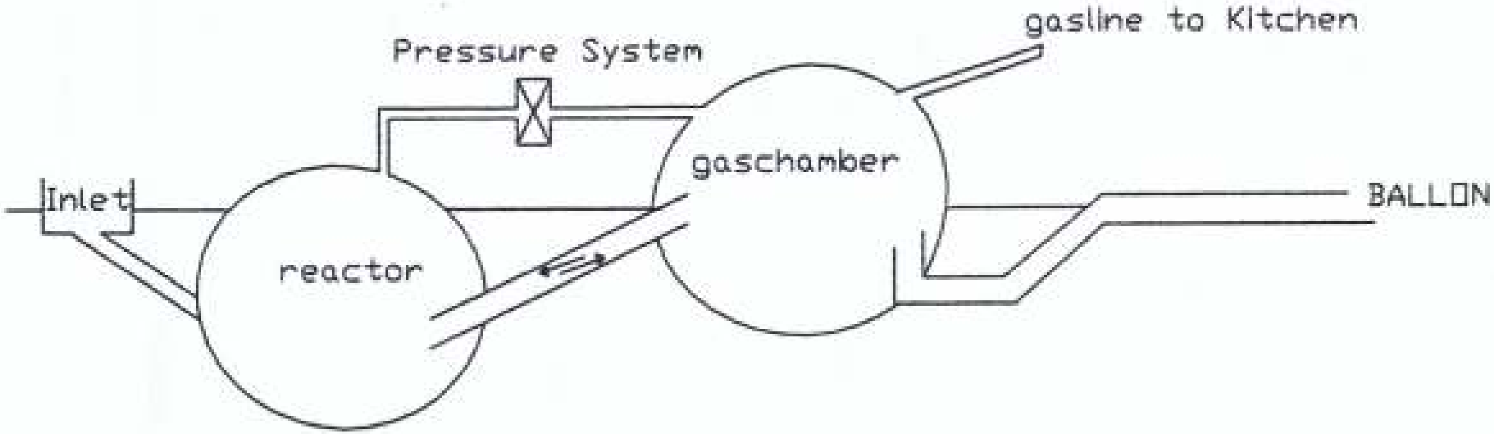


Fig 2.4.Principle diagram for superflex Biogas system

(Source:Superflex,1997)

Acetate, formate, methanol and methylamines. In natural environments and practical applications acetate is the most important precursor of methane accounting for 70% of the methane. The biology of methanogenic bacteria is discussed below: Acetate production from H_2/Co_2 :- Carbon dioxide is reduced by hydrogen, mainly to form methane:

$$4H_2 + Co_2 \longrightarrow CH_4 + 2H_2O$$

$$4H_2 + 2Co_2 \longrightarrow CH_3\ COOH + 2H_2O$$

The acetate produced from H_2 + Co_2 will then be used by methanogens

$$CH_3\ COOH \longrightarrow CH_4 + CO_2$$

The biogas production process can be illustrated thus:

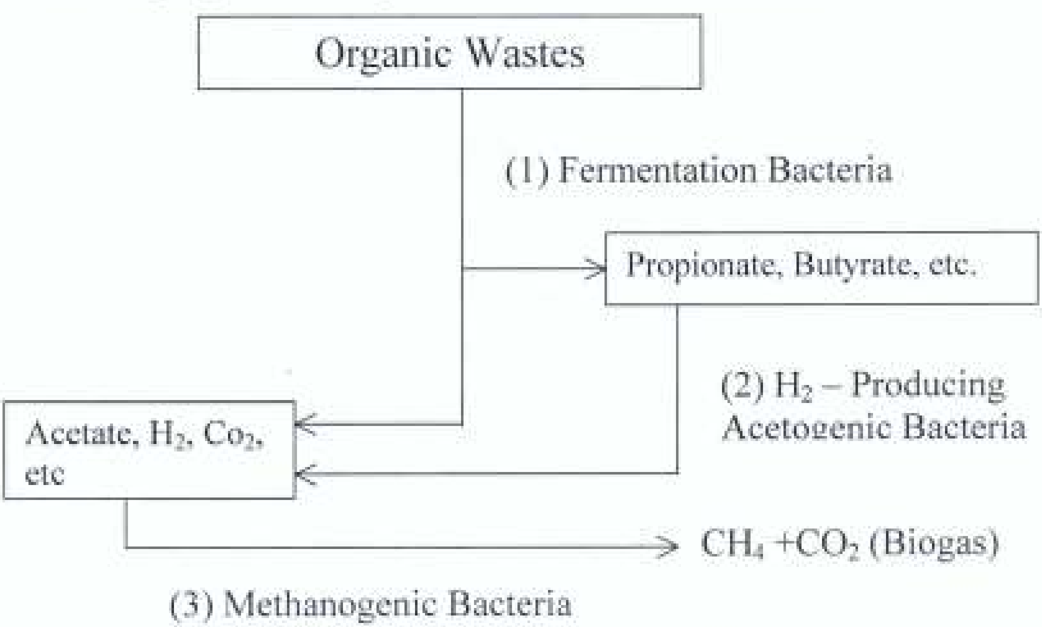


Fig. 2.6 – Fermentation of Organic Wastes to Biogas.

(Source: Lawal, 2000)

Certain parameters affect biogas production and these include according to Lawal (2000), temperature, pH, nutrient concentration and loading rate:

(1) **Temperature**

There are three temperature levels existing within the biogas process under which the growth of bacteria is possible. For each temperature range, it is thought that a known bacteria strain exists. The three different ranges are:

a) ***Pyschophilic (0 – 15^{0}C)*** :- At low temperature the anaerobic process occurs very slowly, but however, if it is given sufficient retention time the total accumulated gas should be the same as in the other temperature ranges with shorter retention time. Psychophilic plants are always run with very long retention time especially when the solid content is high.

b) ***Mesophilic (15^{0C} –45^{0}C):-*** The optimal mesophilic temperature is regarded to be 35^{O}C, however, increase in temperature increases the rate of polysaccharide hydrolysis and fermentation.

c) ***Thermophilic (55^{0} – 60^{0}C)*** :- The optimum range is about 55^{O}C to 60^{O}C and it could be increased up to 70^{O}C but not higher.

(2) **pH**

The pH value has a profound effect on biological activity. Microorganisms are highly sensitive to pH changes. The optimum pH for methane production is 7.0 – 7.2 though gas production is satisfactory between 6.6 and 7.6.

(3) **Nutrients Concentration**

Various research results have testified to the fact that when sufficient amount of nutrients are available, fermentation proceeds very fast. Sewage sludge and animal wastes generally contain sufficient amount of nutrients, however, this may not be the case of all types of biomass. For example, urban organic solid wastes may require nutrient addition as the wastes may be deficient in nitrogen and phosphorus. The addition of these nutrients is essential to microbial growth and gas production.

(4) **Loading Rate**

This plays a significant role in biogas plants and for plants utilizing cattle waste as substrate, it is taken as roughly 12kg of cattle dung per m^3 of digester capacity. If the loading rate is increased, the retention time is decreased and consequently, fermentation is curtailed.

(5) **Others factors**:

These are:

i. Feed concentration (Solid content)

ii. Retention time

iii. Inhibitors.

2.3.1 Digester Gas Characteristics

The gas produced during anaerobic digestion of natural organic materials consists of a mixture of gases, notably methane (CH_4) and carbon dioxide (Co_2) with small amounts of other gases, in particular hydrogen sulphide (H_2S) and hydrogen (H_2), all in very small quantities. Methane is the simplest and most abundant hydrocarbon and the chief constituent of natural gas (Bryant, 1979).

Typically, digester gas, or biogas as it is sometimes called, has between 60 to 70% methane with 40 to 30 % carbon dioxide, the remaining gases are in very small quantities and are often difficult to detect. The gas is combustible with a calorific value of about $26MJ/m^3$. The physical constants of the principal gases CH_4 and CO_2 are listed in tables 2.1 and 2.2 respectively.

The physical properties and general characteristics of the various gases sometimes found in digester gas are discussed below (Ludwig, 2000).

(1) **Hydrogen Sulphide**

Data available show wide variations in the amount of hydrogen sulphide present in digester gas, however, normally, the expected value for a digester that is working well on sewage sludge is between 100 to 3000mg H_2S per m^3. The gas is very toxic and even in low concentration can be hazardous. The physiological effects are itemized in Table 2.3.

Table 2.1: ***Some Physical Constants of Methane***

Physical Property	Value
Molecular weight	16.04
Boiling point at 1 atm	- 164.0^{oc}
Freezing point at 1 atm	- 182.5^{oc}
Density at 0^{oc} , I atm	0.7172 kg/m^3
Critical Temperature	- 82.5^{oc}
Critical pressure	$4.628MN/M^3$
Heat capacity Cp at 15^{oc}, I atm	2.219 KJ/Kg^{oc}
Ratio CP/CV	1.307
Flammable limits in air	5.3–14% by volume
Calorific value at 15^{oc} & 101.325kpa	37.71 MJ/M^3

Table 2.2: ***Some Physical Constants of Carbon Dioxide***

Physical Property	**Value**
Molecular weight	44.01
Triple point at 5.11 atm	- 56.6^{oc}
Sublimation point at I atm	- 78.5^{oc}
Density at 0^{oc}, I atm	1.976kg/m^3
Critical Temperature	31.0 ^{oc}
Critical pressure	72.8 atm
Heat capacity Cp at 0^{oc}, I atm	0.822 KJ/Kg^{oc}
Ratio CP/CV	1.303

(Source: Ludwig, 2000)

Table 2.3: ***Concentration of H_2S in Air and its Physiological Effects***

Concentration of H_2S (% by volume)	Physiological Effects
0.0002	Just detectable by smell
0.002	Maximum allowable concentration for prolonged exposure at this concentration it causes eye irritation.
0.007 – 0.015 0.017 – 0.03	Slight symptoms such as headache can be inhaled for 1hr without serious lasting effect.
0.04 – 0.06	Dangerous if inhaled for ½ to 1hr.
0.06	Fatal after ½ hr
0.1	Paralyses sense of smell and causes instant unconsciousness.

(Source: Ludwig, 2000)

(2) **Hydrogen**

Usually, no more than 1 to 2% maximum is to be found in digester gas. This is probably because there are many bacteria present in the sludge, which can utilize it readily, particularly the methanogenic bacteria. Although hydrogen gas is highly inflammable, the small concentrations present have little effect on the calorific value of digester gas. Hydrogen is not poisonous, but if present in large quantities in air, it may cause asphyxiation (suffocation) due to a reduction in the percentage of oxygen present.

(3) **Carbon Monoxide**

This is a toxic gas since it has a higher affinity for haemoglobin in the blood than oxygen. The proportion in digester gas is usually well under 1% and often more like 10 to 100ppm. The physiological effects of carbon monoxide in air are shown in Table 2.4.

Table 2.4: **Concentration of Carbon Monoxide in Air and its Physiological Effects.**

Concentration of CO (% by Volume)	**Physiological Effects**
Less than 0.001	No effects.
0.01	Slight headache after some time.
0.05	Severe headache and mental illness, troubled vision, fainting, tendency to collapse.
0.06	Headache in less than 1hr, unconsciousness in 2hrs
0.10	Unconsciousness in just over 1hr fatal in 4 hrs

(Source: Ludwig, 2000)

(4) **Nitrogen**

Any appreciable quantity of nitrogen showing up in routine gas analysis is usually indicative of a leakage of air into the system. There will always be a mall quantity present since the raw organic waste will usually contain some due to its previous contact with air. Usually less than 4% is present in digester gases and often much smaller concentrations are present.

(5) **Oxygen**

This is a dangerous gas when present in digesters because of the risk of explosion when mixed with methane. It is usually a sign of leakage and, hence, also of the possibility of methane leaking into the surrounding air, which is a more hazardous situation since, with only just over 5% methane in air a mixture occurs in which a flame is self propagating.

(6) **Ethane and other low molecular weight hydrocarbons**

Because of the reactivity of methane with carbon dioxide and hydrogen and because of its small potentials for polymerization, other paraffin gases will be produced, such as ethane, propane and butane in small quantities. Ethane, propane and butane are found also in natural gas and all will react to some extent with chlorine to produce a dichloroethane, chloroform, carbon tetrachloride and choloroethanes. It is important that chlorine-producing substances do not come into contact with these lower molecular weight hydrocarbons, due to their co-reactivity, forming chlorine derivatives as well as for the explosive mixtures they can produce.

2.3.2 Gas Collection and Measurement

One of the simplest methods of collecting the gas produced during anaerobic digestion is by means of a flexible bag such as a balloon or bladder (Stafford, 1974) (Fig. 2.7). This method clearly has serious limitations, the main one being that with an elastic type of material, the pressure of the gas varies with the amount collected and the volume is difficult to determine. Fig. 2.8 (a) shows a common gas collection method using a floating lightweight holder (Stafford, 1974). As the gas is collected, the gas holder rises, and this can be calibrated prior to use. A different version is shown in Fig. 2.8 (b). One problem with this one is that the gas holder tilts as it rises in the water, but some form of restraint can be easily added.

If a heavy container is used, then a counter balance weight needs to be added. The first of these two has the advantage that changes in pressure due to feeding or withdrawing digester contents can be accommodated since the container merely sinks or rises in the water. In the version shown in Fig. 2.8 (b), any reduction in pressure in the digester will cause water from the collection device to be sucked back, so the tube must be clipped off when withdrawing the digester contents.

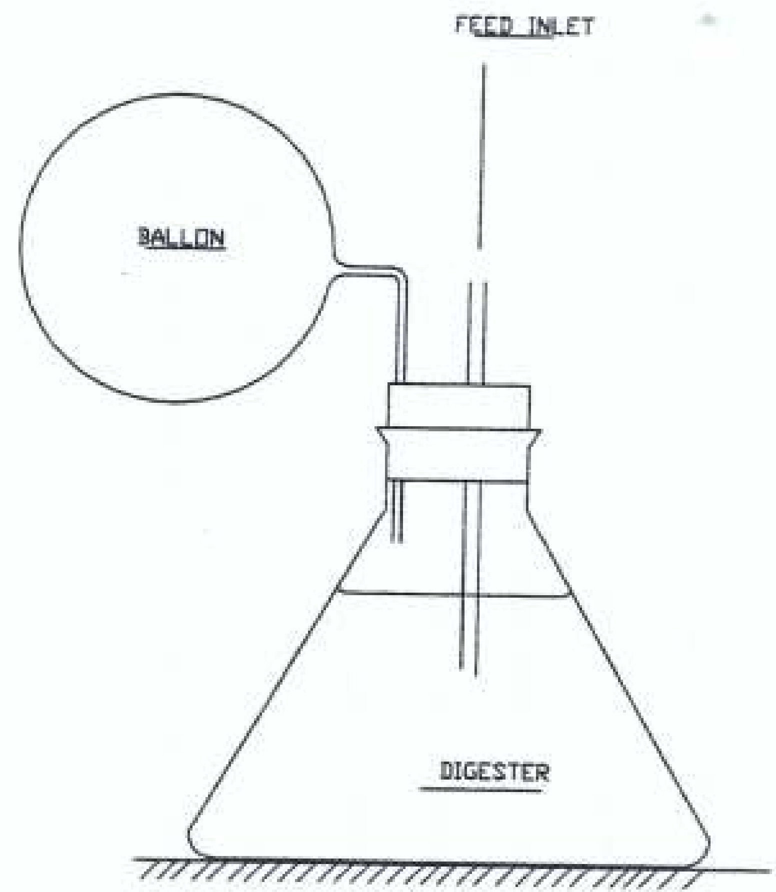
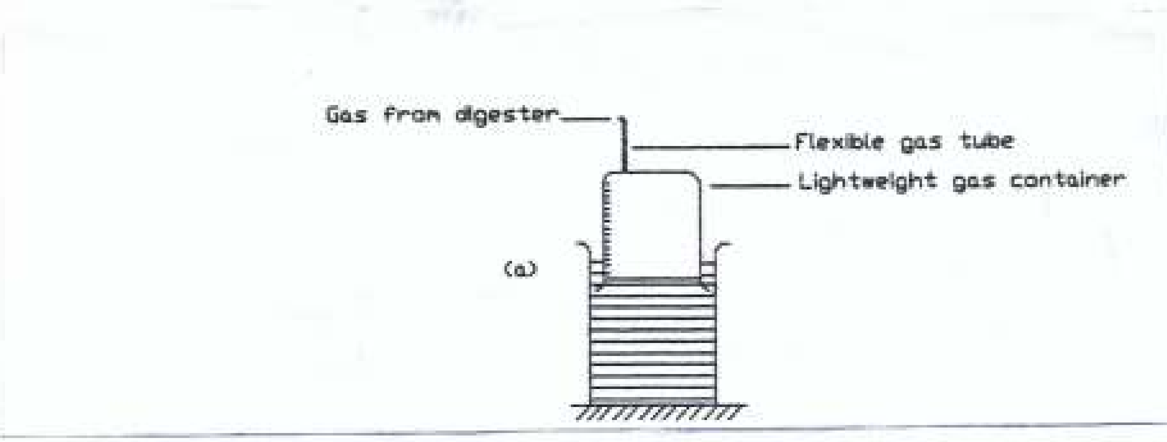


Fig 2.7. Gas collection method-ballon

(Source:Stafford,1974)

Another method, which uses displacement, is shown in Fig. 2.9. In this one, the top of the upper aspirator is opened slightly, and the water runs out until the pressures are balanced. Any production of digester gas will allow a similar quantity of water to escape, and this can be collected in a measuring cylinder as shown (Stafford, 1974). One disadvantage is that a gas leak will allow the aspirator to empty, giving the illusion of a greater gas production. With the gasometer method, however [Fig. 2.8 (a) & (b),] a gas leak will lead to an apparent cessation of gas production. Fig. 2.9 shows an improved version of this displacement method in which a siphon is used to accommodate any reduction in pressure in the digester. A direct connection between two aspirator is sometimes used (Fig. 2.11), and a manometer tube used for measuring the pressure can be incorporated. This is necessary so that the volume can be converted to standard temperature and pressure. Care must be taken to ensure that there is no excess pressure in the digester when feeding is commenced.

A gas production measuring device is useful for automatic recording, especially if the digester is to be operated continuously. Fig. 2.12 shows one such method. Here, the production of gas increases the pressure in the digester, causing the flexible membrane to deflect and the liquid in the manometer tube to rise. Photoelectric cells switch a solenoid – operated value on and off, allowing some gas to escape. Each operation of the valve can be recorded, and this gives an indication of the volume given off.



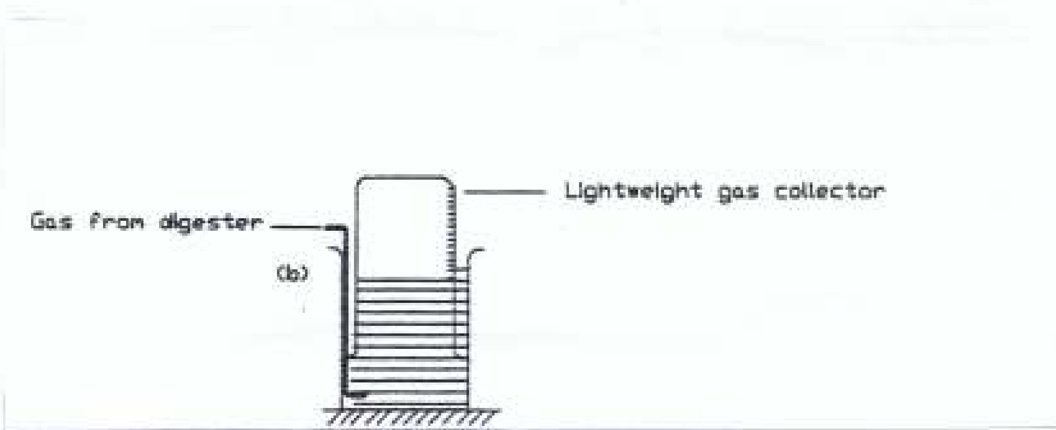


Figure 2.8: Gas collection method – floating gas holder.

(Source: Stafford 1974)

One method which cannot be left out and perhaps the most common, although fairly expensive, is the accurate wet gas meter. These are very convenient and can record large quantities of gas over long periods without much attention. It will usually be necessary to collect samples of gas for analysis, and therefore some method of collection will be employed, since this only accurately measures the amount given off (Stafford, 1974).

2.4 Cleaning Biogas

If biogas are to be cleaned prior to use, then the main requirements will be for the removal of the acid gases; carbon dioxide and hydrogen sulphide for corrosion prevention, the removal of hydrogen sulphide being necessary to also meet statutory regulations on allowable levels, usually around 1 to 15ppm by volume (Stafford, 1974). Hydrogen sulphide as one of the trace gases gives problems in 2 aspects:

(a) It is a very toxic gas to humans and animals even in low concentrations.

(b) It leads to corrosion during combustion while forming $H_2 SO_4$ (Brown and Tata, 1994).

Providing the levels of hydrogen sulphide are low, then it can be removed simply by passing the gas through heated iron oxide sponge. The carbon dioxide will be removed if the digester gas is bubbled through a solution of calcium hydroxide when the carbon dioxide forms calcium carbonate and is precipitated thus:

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

A better option of removing carbon dioxide from biogas will be to use a chemical, notably sodium hydroxide, which will form a by-product i.e. sodium carbonate which is easily more marketable than calcium carbonate. This way, cost effectiveness would be achieved while scrubbing unwanted gases. The equation of reaction for this can be represented thus:

$$CO_2 + 2NaOH \longrightarrow Na_2CO_3\downarrow + H_2O$$

Other methods can be used to remove unwanted gases, and some are more suitable for digester gas, which has high levels of CO_2 as the main contaminant. In the carbonate process, for example, potassium carbonate or an organic carbonate is used with added catalysts or activators and operates mainly by physical absorption.

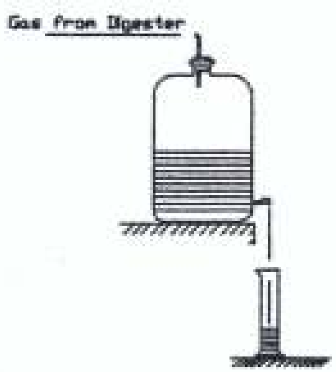


Fig 2.9. Gas collection method using displaced water

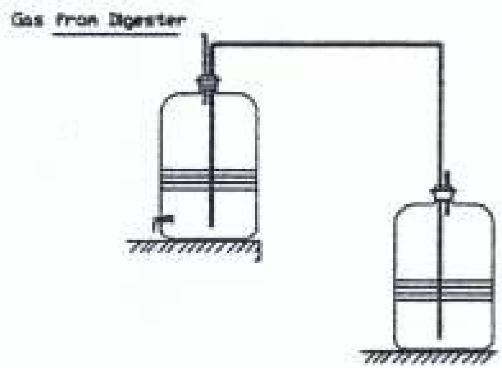


Fig 2.10. Gas collection method using displaced water syphon

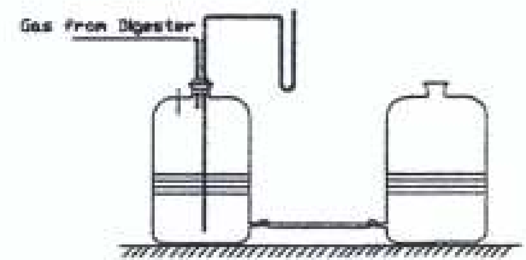


Fig 2.11. Gas collection method using displaced water pressure

(Source:Stafford,1974)

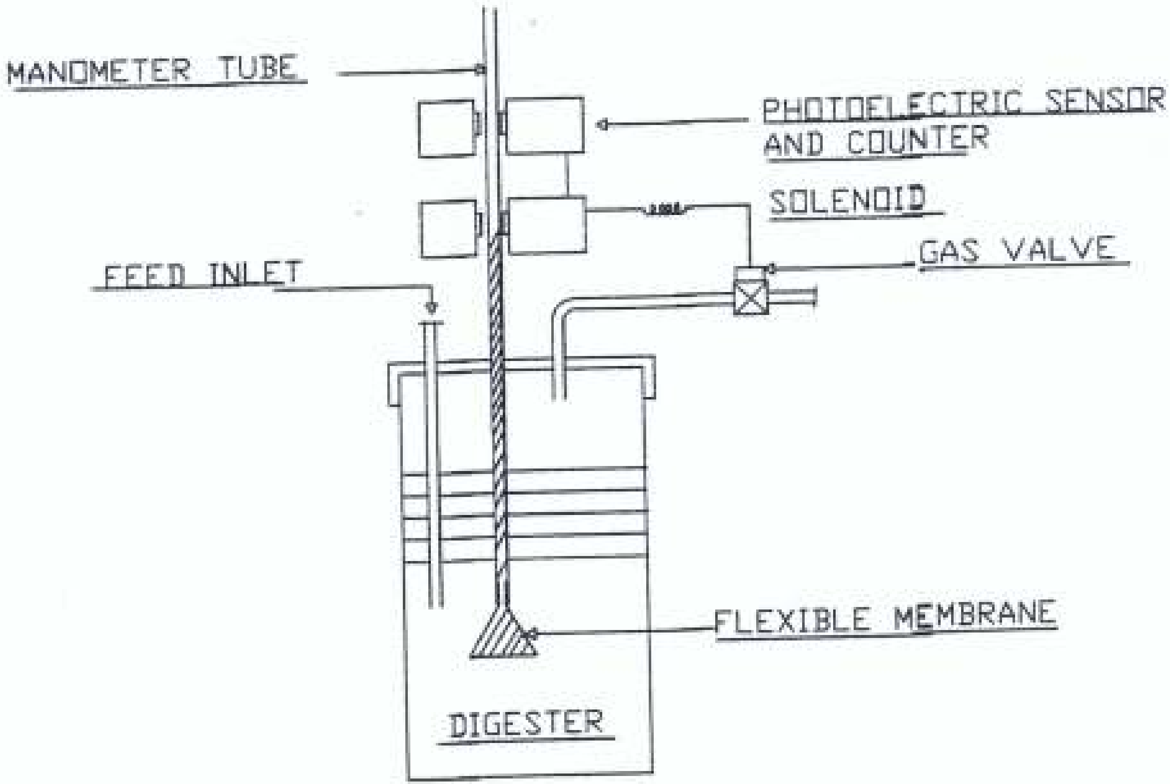


Fig 2.12 .GAS PRODUCTION MEASURING DEVICE

(Source:Stafford,1974)

Molecular sieve absorbents could be used for simultaneous CO_2 removal and drying. Synthetic zeolites, such as sodium or calcium alumino-silicates, absorb the CO_2 and water vapour and are re-generated by heating. The cost of such equipment, however, would make it uneconomical for most small applications involving anaerobic digestion processes.

Ferrumoxid filter could also be used as a chemical treatment of the effluent gas. The filter consists mainly of a steel cube, which is filled with wood chips to increase the surface area and to act as sponge to take the steel cube. The reaction is as follows:

Step 1: $2Fe_2O_3 \text{ x } H_2O + 6H_2S \longrightarrow 2Fe_2S_3 + 6H_2O$ + heat.

After a period of time the sponge can be regenerated by exposing it to the atmosphere. Due to the reaction of the spent sponge with atmospheric oxygen, the sponge is regenerated for reuse. The regeneration reaction is:

Step 2: $2Fe_2S_3 + 3O_2 \longrightarrow 6Fe_2O_3 + 6S$ + heat.

With such a treatment, the H_2S content of biogas can be reduced from about 2500 ppm to around 200ppm (Pfeiffer, 1973).

CHAPTER THREE

MATERIAL AND METHODS

3.1 Field Apparatus

The Field apparatus consists of 2 major equipments, the digester and the gas holder.

3.1.1 The Digester

The digester is made of a 200 litre capacity drum. The top of the digester drum was cut away to make an opening that is slightly larger than the uncut portion. Lengths of 25mm wide and 2mm thick, flat steel bars were welded to the underside and along the cut portion to reinforce it. A 2mm thick steel plate was cut into a semi-circular shape in such a way that it covers and overlaps the cut portion by about 20mm along its circumference. The cover was welded to the top of the drum using 2 hinges (Fig. 3.1).

Six number holes of 5mm diameter were drilled at approximately equal distances along the circumference of the cut portion. Nuts that would take 5mm bolts were welded to the underside of the cut circumference taking care that they align perfectly with the drilled holes. Hard but flexible 3mm thick rubber material was cut into the shape of the cut area and about 40mm wide. This rubber would serve to make this portion airtight when the digester is sealed.

A steel handle was welded on to the cover plate for easy opening. At the uncut portion of the top of the drum, 4 holes were cut for the gas outlet, stirrer shaft inlet, pressure gauge inlet and gas meter inlet. The hole for gas outlet was filled with a 20mm connector nipple by welding and a 20mm gate value screwed onto it to serve as a gas tap. To the stirrer shaft inlet a pair of detachable, machined, high-grade steel flange with 20mm diameter center holes was welded with the top part removed.

At the inside bottom of the drum, a plate of about 100mm diameter was welded to protect the base of the drum from being punctured due to the grinding effect of the stirrer shaft when it is being turned. Also, a 40mm stump of 14mm diameter rod was welded on to the plate for the stirrer shaft to fit in and thus prevent it from moving about when it is being turned. A pair of detachable paddles each having a short and long arm was bolted on to the shaft near the top and near the bottom to act as stirrers as illustrated in Fig. 3.1.

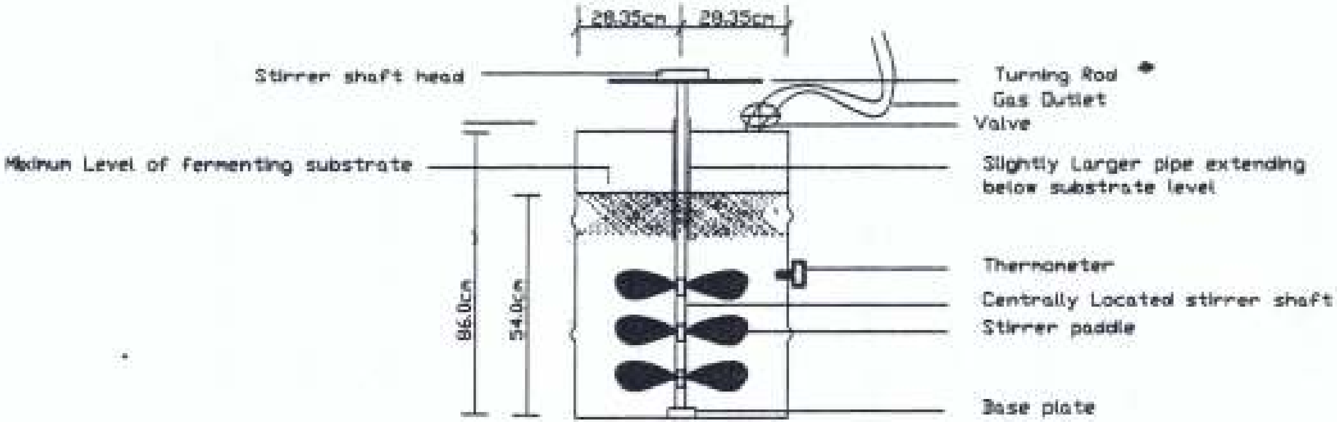
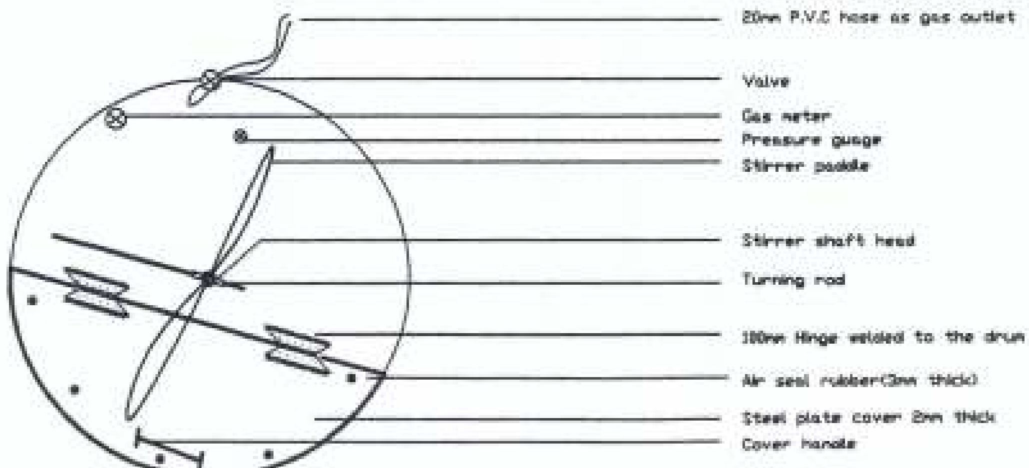


FIG 3.1 LONGITUDINAL SECTION OF DIGESTER



PLAN

3.1.2 The Gas Holder

The gasholder is made up of a 200ℓ drum. At two opposite ends on the top of the gasholder, holes were drilled and 20mm nipples were welded on to them. 20mm taps were screwed on to the nipples to serve as gas inlet and outlet. 20mm reinforced P.V.C. hoses were attached on to the gas taps to serve as gas carriers (Fig. 3.2).

3.2 Method

From various research experiences using animal wastes as substrate, the optimum water/waste mix ratio has been found to be 1kg of waste to 1 litre of water (B.O.R.D.A., 1991). Thus, for this experiment, the mixing ratio: dung: water = 1:1 was adopted.

The volumetric ratio of waste to water was estimated as follows:

Feed material: cattle dung (Dd) amount = 30kg

mixing ratio: dung: water = 1.1

Fermentation slurry (Sd) amount = 30kg manure and 30ℓ water = 60ℓ

3.2.2 Field Set Up

The mix ratio obtained as above was used to fill the digester in each case (plate 3.1), while turning the stirrer to achieve a homogenous mix. The digester was then sealed up and connected to the gas holder. The contents of the digester were stirred at least once a day after sealing.

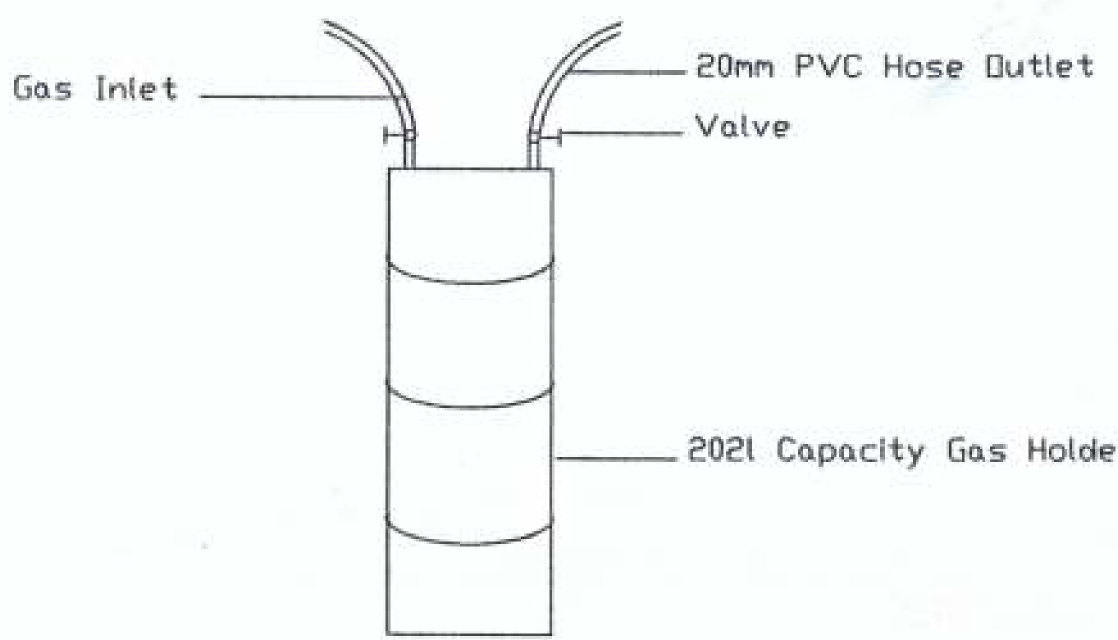


Fig. 3.2 – ***Illustration of Gas Holder.***

3.2.3 Gas Production and Measurement

The aim of a measuring and test programme is to determine the specific gas production obtained at specific retention times.

The research study consists of a set of three (3) biogas plants. A given filling volume results in different retention times (15,25 and 35days), in turn yielding different amounts of gas production for one and the same filling volume.

Filling volume: 30kg dung and 30ℓ water = 60ℓ

Retention times (RT) chosen: 15,25 and 35days. 15 days was chosen as the minimum retention time because at the start of the experiment, gas production of significant quantity was noticed at about 6 – 10 days retention. At 25 days retention gas production progressed satisfactorily, and at 35 days retention the rate of gas production gave a confirmation that length of retention period has a significant effect on the rate of gas production as recorded from the experimental procedure.

Requirement digester volume:

RT (15): VD = 15 x 60 = 900ℓ ($0.9m^3$)

RT (25): VD = 25 x 60 = 1500ℓ ($1.5m^3$)

RT (35): VD = 15 x 60 = 2100ℓ ($2.1m^3$)

The gas production measurement was taken using the dry gas meter method (direct reading type). Also a pressure gauge was used to take pressure reading in the digester.

3.3 Experimentation Process

The process of pouring the substrate slurry mixed in the ratio 1:1 i.e. 30kg dung: 30 litres of water into the digester prior to mixing is illustrated in plate 3.1.

Plate 3.2 – Illustrates the thorough and uniform mixing of substrate in the digester to hasten anaerobic digestion.

Plate 3.3 – Illustrate the connection of gas hose from the digester to the gas holder, for transporting produced gas from the digester to the gas holder.

Plate 3.4 – Illustrates the reading of the substrate/digester temperature with a simple thermometer.

Plate 3.5 – Illustrates taking pressure reading using a pressure gauge.

3.4 Correlation of Yield with Time, Temperature and Pressure using SPSS Subprogram Regression.

The data obtained were subjected to various statistical analyses, based on the statistical package for social sciences (SPSS).

Outputs from the SPSS subprogram regression models include the following:-

(1) regression coefficients and their standard errors,

(2) t – values or f – values for testing whether individual coefficients are significantly different from zero, the t – value to the ratio of a regression coefficient to its standard error, t – values can be tested against the student's t – distribution with degrees of freedom the same as for the residual sum of squares. The F – value for testing the significance of individuals regression coefficients are equal to the square of the t – values (i.e. $F = t^2$). The overall significance of the regression model can be determined from the F – Value for the analysis of variance, the F – value can be tested against the F – distribution with degrees of freedom equal to those attributable to the regression and those of the residual term.

(3) Multiple correlation coefficient "R", measures the correlation between the dependent variable and the set of independent variables and takes a value between zero and unity.

(4) Coefficient of determination "R^2" (square of multiple correlation coefficient) measures the proportion of variance in the dependent variable explained jointly by the independent variables included in the regression equation. It is also a

measure of goodness of – fit of the regression. It takes a value between zero and unity. Thus, a high value of "R^2" indicates a good fit and a low value, a poor fit (National Engineering Conference Series, 1999).

Generally, the value of R^2 increases with increasing number of independent variable.

(5) Adjusted coefficient of determination "R^2" accounts for the number of coefficient estimated (independent variables and constant, if used) in relation to the number of observations. As the value of R^2 must increase with increase in the number of independent variables it becomes tempting to choose a regression overloaded with independent variables. Therefore, R^2 serves to compromise a good fit and the number of independent variables, in which case further addition of variables to a regression causes R^2 to decrease.

The SPSS computes R^2 from the relation:

$$R^2 = R^2 - \left\{\frac{C-1}{N-C}\right\} [1- R^2]$$

Where "C" is the number of coefficients estimated (independent variables and constant if used). "N" is the number of observations.

(6) Standard Error of Estimate: "SEE", measures the standard deviation of the residuals, that is, the standard deviation about the regression line established.

(7) Coefficient of variability "Cv" measures the standard deviation of dependent variable given the independent variable (say Y at a given X) expressed as a percentage of the mean of the dependent variable.

In other words, Cc is the ratio of "SEE" to the mean of the dependent variable and it is unitless.

(8) Elasticity is the percentage change in Y divided by the percentage change in X, where the change is measured from the mean of each variable.

PLATE: 3.1 – Pouring substrate slurry into the digester

PLATE 3.2: Mixing substrate in the digester

PLATE 3.3: Connecting gas hose from the digester to the gas holder

PLATE 3.4 – Reading substrate/digester temperature

PLATE 3.5 – Taking pressure reading.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Performance Of Apparatus

The "field" digester was found to perform satisfactorily. No leakage of gas was noticed, consequently enough pressure was generated, gas production was measured and stored. Also the stirring mechanism designed for the digester was found to be adequate.

4.1.2 Temperature

Daily minimum and maximum ambient temperatures were recorded throughout the duration of the experiment and are as presented in Fig. 4.1a - c and Table 4.2 - 4.4.

The average daily minimum temperature for case 'A' (RT = 15days) was 26.2^{O}C and the average maximum temperature was 31.6^{O}C while the average daily temperature for the entire 15days period for case A was 28.9^{O}C

The average daily minimum temperature for case 'B' (RT = 25days) was 25.7^{O}C and the average maximum temperature was 33.6^{O}C while the average daily temperature for the entire 25days period for case B was 29.7^{O}C.

The average daily minimum temperature for case 'C' (RT = 35 days) was $24.8^{O}C$ and the average maximum temperature was $37.2^{O}C$ while the average daily temperature for the entire 35 days period of experiment 'C' was 31 ^{O}C.

4.1.3 Substrate Analysis

The substrate was analysed for its biological and chemical properties before and after the experiment and the results are as presented in Table 4.1.

Substrate type: Abattoir waste.

Weight of 1 liter of unmixed substrate: 930g mixed substrate slurry composition: water mixed with cattle paunch contents made up of partially digested animal feed with some blood, animal fat and hair traces.

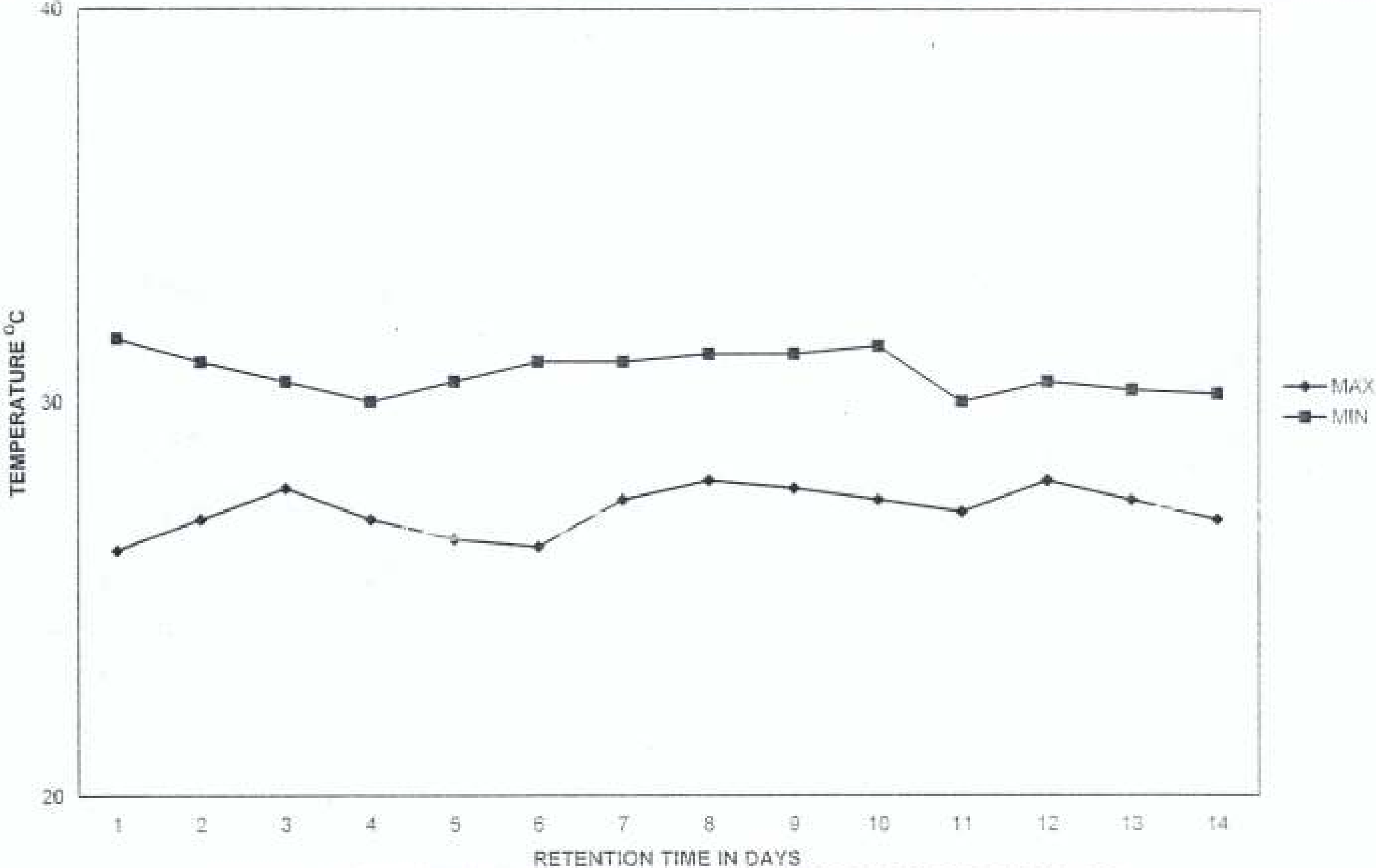


FIGURE 4.1A:DAILY MINIMUM AND MAXIMUM TEMPERATURE RANGES CASE 'A'(RT = 15D)

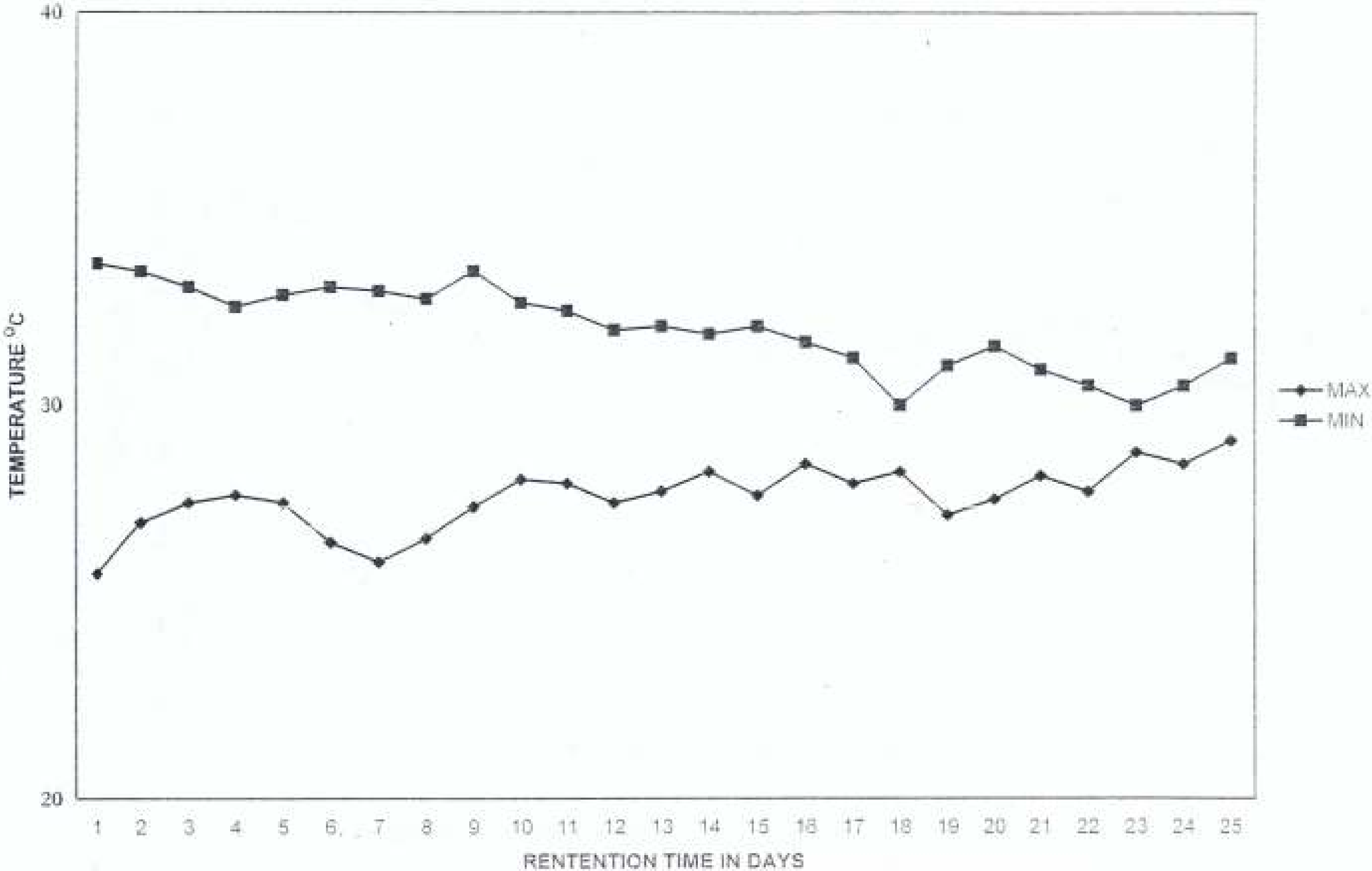


FIGURE 4.1B:DAILY MINIMUM AND MAXIMUM TEMPERATURE RANGES (CASE'B' RT =25D)

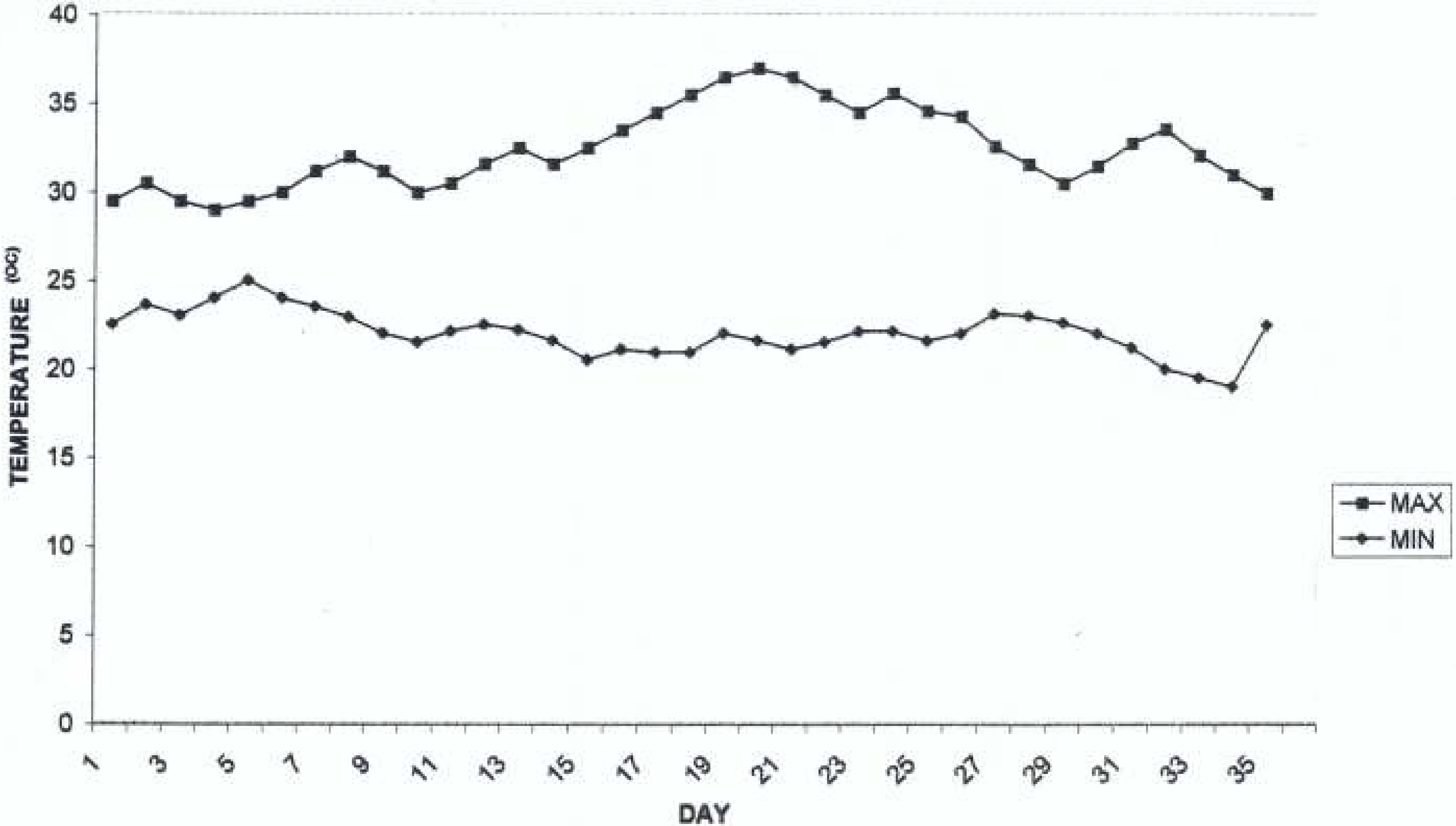


FIGURE 4.1C:DAILY MINIMUM AND MAXIMUM TEMPERATURE RANGES (CASE 'C'- RT =35D)

Table 4.1 SUBSTRATE ANALYSIS

	Start of Experiment	End of Experiment
Date	6th March, 2003	25th April, 2003
Volume of Slurry	0.9 litre	0.74litre
pH	6.42	7.86
$B.O.D_5$	4,980mg/l	2,988mg/l
C.O.D	11,650mg/l	5,243mg/l
Volatile Suspended Solids (V.S.S)	107,260mg/l	24,670mg/l
Ammonia Nitrogen (NH_3)	180.3mg/l	233.6mg/l

4.1.4 Gas Yield

Using a dry gas meter, the daily gas yield from the substrate was recorded throughout the duration of the experiment. This is presented in Table 4.2 - 4.4 and *Figs. 4.3a - c*.

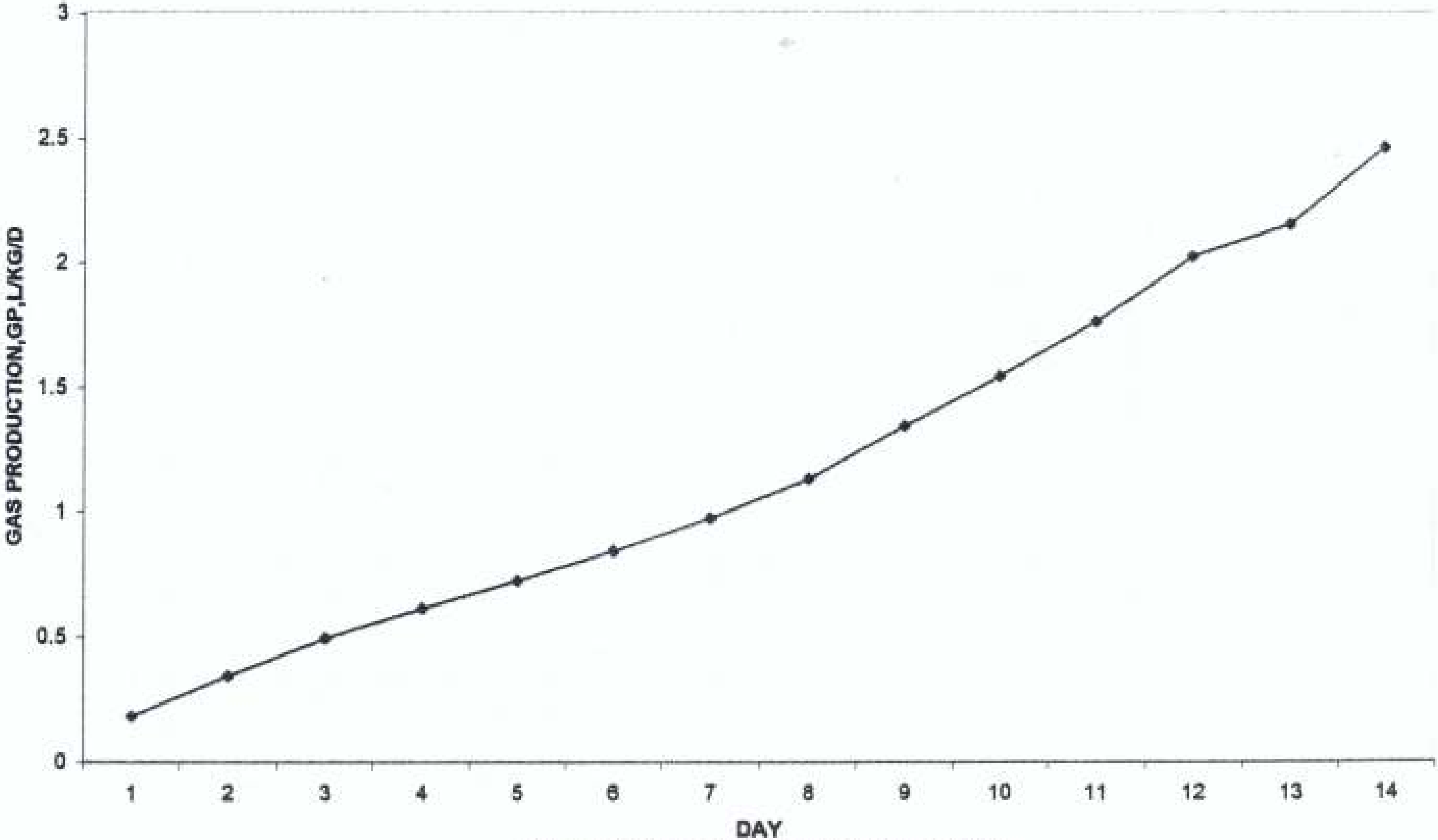


FIGURE 4.3A DAILY GAS PRODUCTION CHART

(RT=15D)AVERAGE TEMPERATURE 28^{OC} - 32^{OC}

TABLE 4.2 (RT = 15D) DAILY GAS YIELD, TEMPERATURE AND PRESSURE TABLE.

DAY	GAS YIELD (liters)	SAMPLING TIME	TEMPERATURE 0^c			PRESSURE (Bar)
			MIN O^C	MAX O^C	AVG	
1	-	13.00	26.2	31.6	28.9	
2	0.18		27.0	31.0	29.0	
3	0.34		27.8	30.5	29.15	
4	0.49		27.0	30.0	28.5	
5	0.61		26.5	30.5	28.5	
6	0.72		26.3	31.0	28.65	
7	0.84		27.5	31.0	29.25	
8	0.97		28.0	31.2	29.60	
9	1.13		27.8	31.2	29.50	
10	1.34		27.5	31.4	29.45	
11	1.54		27.2	30.0	28.60	1.0
12	1.76		28.0	30.5	29.25	1.15
13	2.02		27.5	30.3	28.90	1.25
14	2.15		27.0	30.2	28.60	1.85
15	2.46		28.5	31.0	29.75	2.50

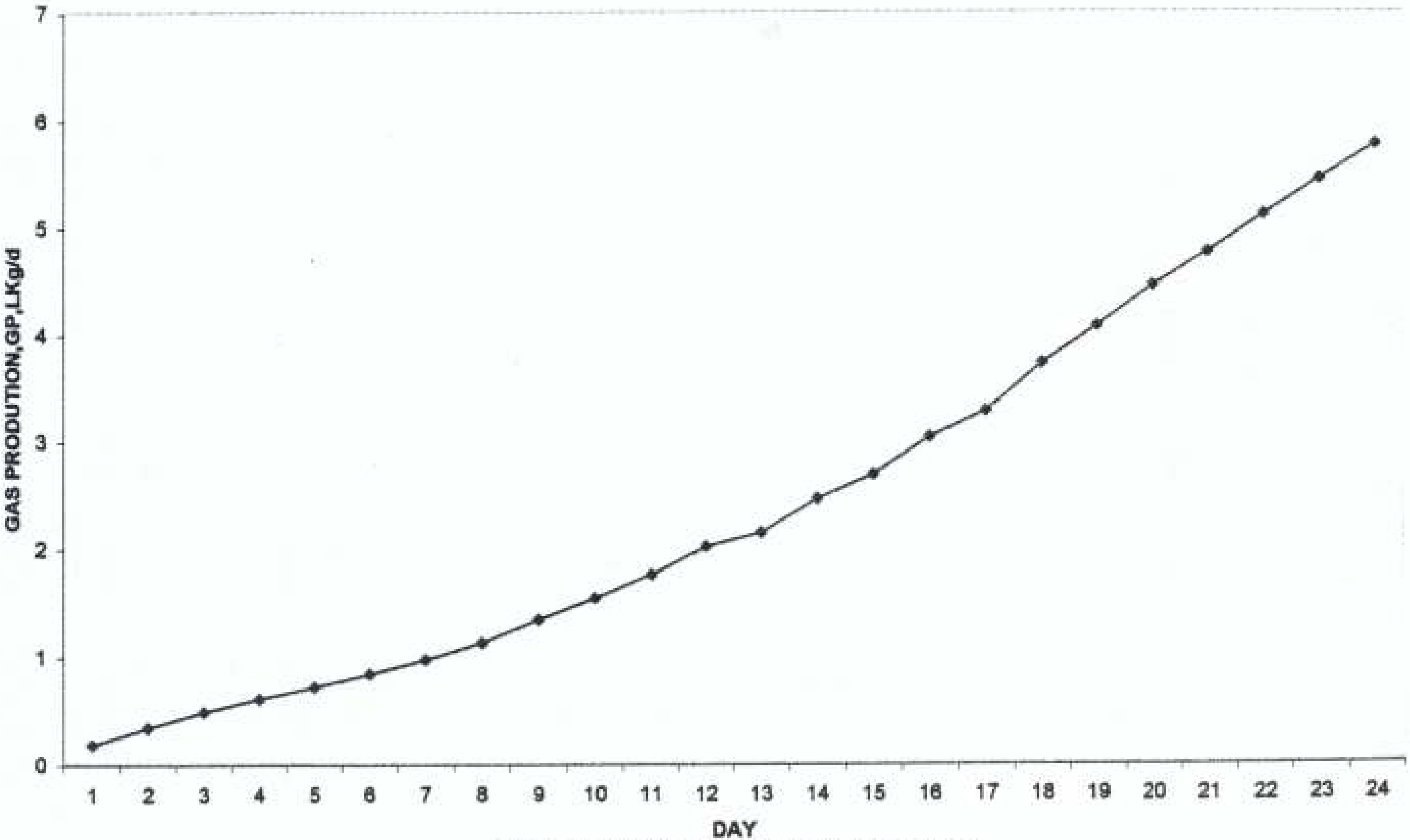


FIGURE 4.3B- DAILY GAS PRODUTION CHART

4.3B (RT = 25D)AVERAGE TEMPERATURE 26^{OC} -33.6^{OC}

TABLE 4.3 (RT = 25D) DAILY GAS YIELD, TEMPERATURE AND PRESSURE TABLE.

DAY	GAS YIELD (liters)	SAMPLING TIME	TEMPERATURE			PRESSURE (Bar)
			MIN O^C	MAX O^C	AVG	
1	-	13.15	25.7	33.6	29.65	
2	0.18		27.0	33.4	30.20	
3	0.34		27.5	33.0	30.25	
4	0.49		27.7	32.5	30.10	
5	0.61		27.5	32.8	30.15	
6	0.72		26.5	33.0	29.75	
7	0.84		26.0	32.9	29.45	
8	0.97		26.6	32.7	29.65	
9	1.13		27.4	33.4	30.40	
10	1.34		28.1	32.6	30.35	
11	1.54		28.0	32.4	30.20	1.0
12	1.76		27.5	31.9	29.70	1.15
13	2.02		27.8	32.0	29.90	1.25
14	2.15		28.3	31.8	30.05	1.85
15	2.46		27.7	32.0	29.85	2.50
16	2.69		28.5	31.6	30.05	2.62
17	3.04		28.0	31.2	29.60	2.84
18	3.28		28.3	30.0	29.15	2.93
19	3.73		27.2	31.0	29.10	3.08
20	4.07		27.6	31.5	29.55	3.17
21	4.45		28.2	30.9	29.55	3.27
22	4.76		27.8	30.5	29.15	3.39
23	5.11		28.8	30.0	29.40	3.47
24	5.44		28.5	30.5	29.50	3.56
25	5.76		29.1	31.2	30.15	3.71

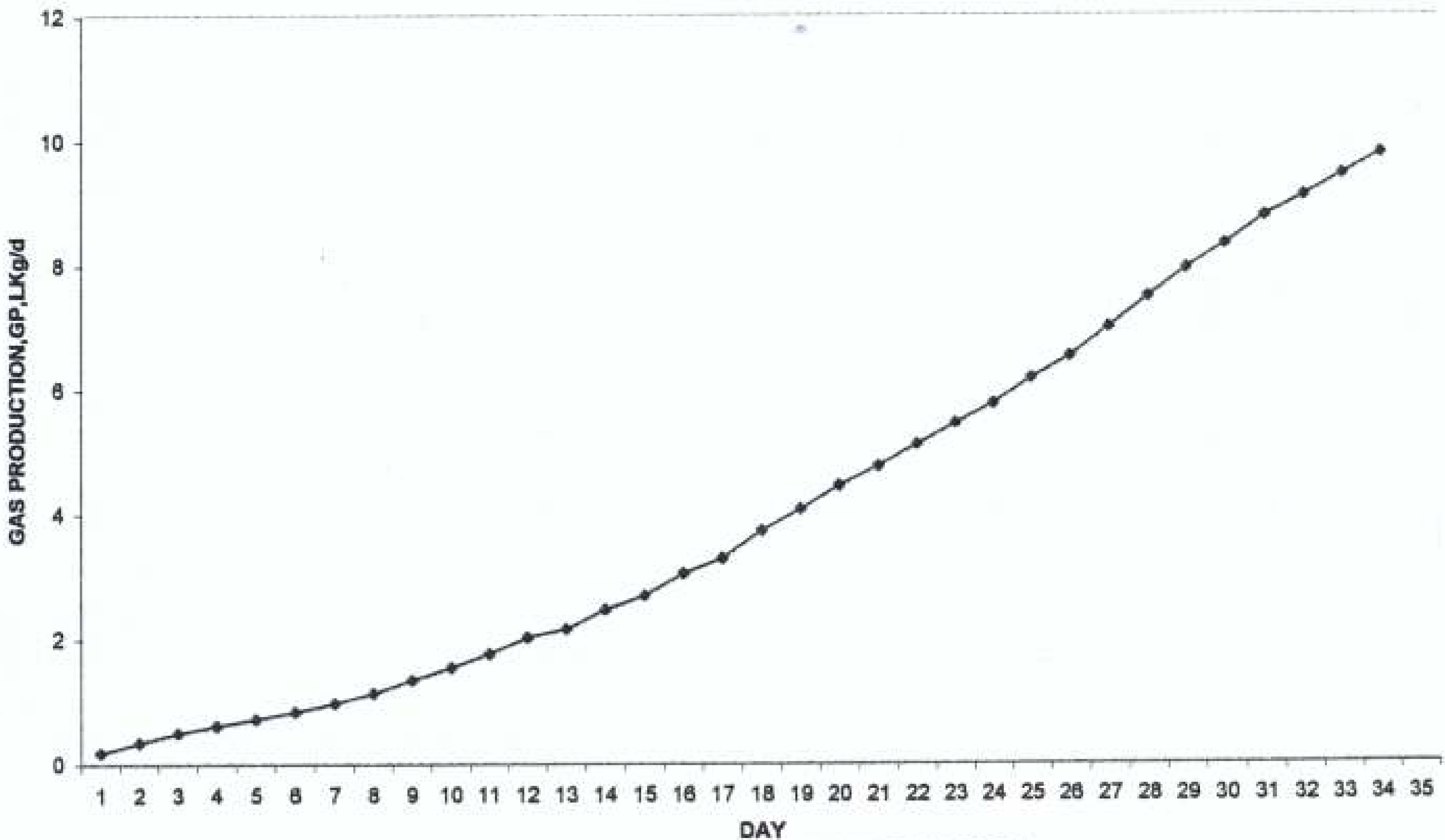


FIGURE 4.3 C- DAILY GAS PRODUCTION CHART

(RT=35D) AVERAGE TEMPERATURE 25^{OC} -37^{OC}

TABLE 4.4. (RT = 35D) DAILY GAS YIELD, TEMPERATURE AND PRESSURE TABLE.

DAY	GAS YIELD (liters)	SAMPLING TIME	TEMPERATURE			PRESSURE (Bar)
			MIN O^C	MAX O^C	AVG	
1	-	13.35	22.5	29.5	26.00	
2	0.18		23.6	30.5	27.05	
3	0.34		23.0	29.5	26.25	
4	0.49		24.0	29.0	26.50	
5	0.61		25.0	29.5	27.25	
6	0.72		24.0	30.0	27.00	
7	0.84		23.5	31.2	27.35	
8	0.97		22.9	32.0	27.45	
9	1.13		22.0	31.2	27.05	
10	1.34		21.5	30.0	25.75	
11	1.54		22.1	30.5	26.30	1.0
12	1.76		22.5	31.6	27.05	1.15
13	2.02		22.2	32.5	27.35	1.25
14	2.15		21.6	31.6	26.60	1.85
15	2.46		20.5	32.5	26.50	2.50
16	2.69		21.1	33.5	27.30	2.62
17	3.04		20.9	34.5	27.70	2.84
18	3.28		20.9	35.5	28.20	2.93
19	3.73		22.0	36.5	29.25	3.08
20	4.07		21.6	37.0	29.30	3.17
21	4.45		21.1	36.5	28.80	3.27
22	4.76		21.5	35.5	28.50	3.39
23	5.11		22.1	34.5	28.30	3.47
24	5.44		22.1	35.6	28.85	3.56
25	5.76		21.6	34.6	28.10	3.71
26	6.17		22.0	34.3	28.15	3.92
27	6.52		23.1	32.6	27.85	4.07
28	6.99		23.0	31.6	27.30	4.18
29	7.49		22.6	30.5	26.55	4.25
30	7.94		22.0	31.5	26.75	4.37
31	8.32		21.2	32.8	27.00	4.53
32	8.78		20.0	33.6	26.80	4.68
33	9.10		19.5	32.1	25.80	4.96
34	9.45		19.0	31.0	25.00	5.11
35	9.78		22.5	30.0	26.25	5.23

4.2 Discussion Of Results

4.2.1 Digester Design

The digester design was found to be adequate and the performance was satisfactory. The stirrer shaft, which was centrally located inside the digester, allowed the stirring blades to turn a full circle, to ensure uniformity of the substrate mix.

4.2.2 Substrate Analysis

As shown in section 4.1.3, the B.O.D and C.O.D of the substrate reduced drastically after undergoing anaerobic fermentation, an indication of the reduction in the microbial load of the substrate. pH, of the slurry changed from 6.42 to 7.86 that is, from being acidic to alkaline. Also there is considerable increment in the ammonia – nitrogen content of the residue slurry after the experiment. These are indications of improvement in the fertilizer value of the substrate after undergoing anaerobic fermentation. The odour of the substrate was found to be less offensive after the experiment than before commencement. This is most likely due to the microbial load reduction in the digested substrate.

Volatile suspended solids (V.S.S.) of the substrate decreased from 107,260mg/ℓ to 24,670mg1ℓ. Thus the waste can then be said to be 77% biodegradable. The biodegradability of the substrate can be further confirmed from a physical observation of the substrate before and after the experiment. While the substrate contained a lot of long, coarse fibers, which are partially digested feed materials, and seed grains at the beginning of the experiment, this long fibers had become broken down to much shorter and finer particles and the seed grains were no longer present in the residue slurry.

4.2.3 Gas Yield

Gas production was noticeable in the waste matter on collection from the abattoir and leaving in the container while preparing the digester, as there was a significant increase in its volume. This confirmed the fact that there were active acetogenic and methanogenic bacteria present in the abdominal contents of ruminants. It could therefore be said that biogas production process from abattoir wastes do not need innoculum to aid digester start up.

Gas production was encouraged by high, uniform temperatures (e.g. $28^{\circ}C$ – $35^{\circ}C$), long retention times and thorough mixing of the slurry. The biogas produced was odorous and was ignited after about 14days of sealing the digester. Gas production rate was usually higher in the afternoons when daily temperature was highest and slows to a minimum at night when temperature was lowest.

For case 'A' (RT = 15D), a total of 17litres of gas was produced from the 60litres substrate in a retention time of 15 days at an average temperature of 28.9°c, representing an average of 1litre per day.

For case 'B' (RT = 25D), a total of 59litres of gas was produced from the 60litres substrate in a retention time of 25 days at an average temperature of 30°c, representing an average of 2.36litres per day.

For case 'C' (RT = 35D), a total of 140litres of gas was produced from the 60litres substrate in a retention time of 35 days at an average temperature of 33°c , representing an average of 4litres per day.

This result confirms that gas production is enhanced by uniform high temperature, long retention times and thorough mixing of the slurry.

4.3 Statistical Analysis

The result of the SPSS are presented in table 4.5 and fig 4.4 which represent curve fitting.

3.1 Summary of Finding from Computer Output

Based on the computer program output shown in table 4.5, the result of the models are as described below in equation 4.1 – 4.3.

YIELD (1) – RETENTION TIME 15 DAYS

$Y = a + b_1x_1 + b_2x_2 + b_3x_3$ ……………(4.1)

Where

The b's = are the regression coefficients

X_1 = Time

X_2 = Pressure

X_3 = Temperature

The regression coefficients indicate the rate of change in Y(Yield) as a result of unit change in x's.

$Y_1 = - 3.24 + 1.40x_1 + 1.82x_2 + 0.0007480x_3$ ---- (4.2)

Prediction Ability of the Model:

- Coefficient of correlation "R"

  R = 0.999 which means that there is 99.9% linear relationship between the dependent and independent variables;

- Coefficient of determination "R^2"

  R^2 = 0.997 which means that 99.7% of the dependent variable is explained by the independent variables and that only 0.3% is explained by other variables not included in the model or captured by the field work.

- The conclusion that can be drawn is that retention time is the major factor contributing positively to the yield more than the temperature as shown in table 4.2 (RT = 15D) and curve fit yield 1.

YIELD (2) – RETENTION TIME 25 DAYS

Y_2 = - 4.74 + 2.01x_1 + 1.89x_2 + 2.33x_3 ----(4.3)

Prediction Ability of the Model:

- Coefficient of correlation "R"

  R = 0.984 which means that there is 98.4% linear relationship between the dependent and independent variables;

- Coefficient of determination "R^2"

  R^2 = 0.968 which means that 96.8% of the dependent variable is explained by the independent variables and that only 3.20% is explained by other variables not included in the model or captured by the field work.

- It appear that time is the major factor contributing positively in this case to the yield more than the temperature as shown in table 4.3 (RT = 25D) and curve fit yield 2.

YIELD (3) – RETENTION TIME 35 DAYS

$Y_3 = 7.285 + 2.90x_1 + 0.004815x_2 + 2.35x_3$ ----(4.4)

Prediction Ability of the Model:

- Coefficient of correlation "R"

  R = 0.990 which means that there is 99.0% linear relationship between the dependent and independent variables;

- Coefficient of Determination "R^2"

  R^2 = 0.980 which means that 98.0% of the dependent variable is explained by the independent variables and that only 2% is explained by other variables not included in the model or captured by the field work.

- Time is the major factor contributing positively in this case to the yield more than the temperature as shown in table 4.4 (RT = 35D) and curve fit yield 3.

4.3.2 Sensitivity Analysis of Computer Output

Sensitivity analyses were performed on the equation from computer output as shown in Tables 4.6 - 4.8.

$Y_1 = - 3.24 + 1.40x_1 + 1.82x_2 + 0.0007480x_3$

$Y_2 = - 4.74 + 2.01x_1 + 1.89x_2 + 2.33x_3$

$Y_3 = 7.285 + 2.90x_1 + 0.004815x_2 + 2.35x_3$

Table 4.6 – Correlation of Yield with Time, Pressure and Temperature.

Variable / Model	Constant	$X_1 = 14$ Time	$X_2 = 2.5$ Pressure	$X_3 = 28.5$ Temperature	$Yield_1$
Eqn 1	-3.24	$1.40x_1 = 19.6$	$1.82x_2 = 4.55$	$0.0007480x_3 = 0.021318$	20.93
Eqn 2	-4.74	$2.01x_1 = 28.14$	$1.89x_2 = 4.725$	$2.33x_3 = 66.405$	94.53
Eqn 3	7.285	$2.90x_1 = 40.6$	$0.004815x_2 = 4.55$	$2.35x_3 = 66.975$	114.87

Table 4.7 – Correlation of Yield with Time, Pressure and Temperature.

Variable / Model	Constant	$X_1 = 23$ Time	$X_2 = 3.47$ Pressure	$X_3 = 29.65$ Temperature	$Yield_2$
Eqn 1	-3.24	$1.40x_1 = 32.2$	$1.82x_2 = 6.3154$	$0.0007480x_3 = 0.0221782$	35.3
Eqn 2	-4.73	$2.01x_1 = 46.23$	$1.89x_2 = 6.56$	$2.33x_3 = 69.09$	117.13
Eqn 3	7.285	$2.90x_1 = 66.7$	$0.004815x_2 = 0.0167$	$2.35x_3 = 69.68$	143.68

Table 4.8 – Correlation of Yield with Time, Pressure and Temperature.

Variable / Model	Constant	$X_1 = 32$ Time	$X_2 = 4.68$ Pressure	$X_3 = 26.5$ Temperature	$Yield_3$
Eqn 1	-3.24	$1.40x_1 = 44.8$	$1.82x_2 = 8.518$	$0.0007480x_3 = 0.019822$	50.1
Eqn 2	-4.74	$2.01x_1 = 64.32$	$1.89x_2 = 8.8452$	$2.33x_3 = 61.745$	130.16
Eqn 3	7.285	$2.90x_1 = 92.80$	$0.004815x_2 = 0.02253$	$2.35x_3 = 62.275$	162.38

Remarks: The result of the sensitivity analysis performed on the models as shown in the Tables 4.6 – 4.8 reveals that as yield (Y) increases, the independent variables (time, pressure and temperature) increases, which indicates that the correlation derived from the models do not have biased coefficients.

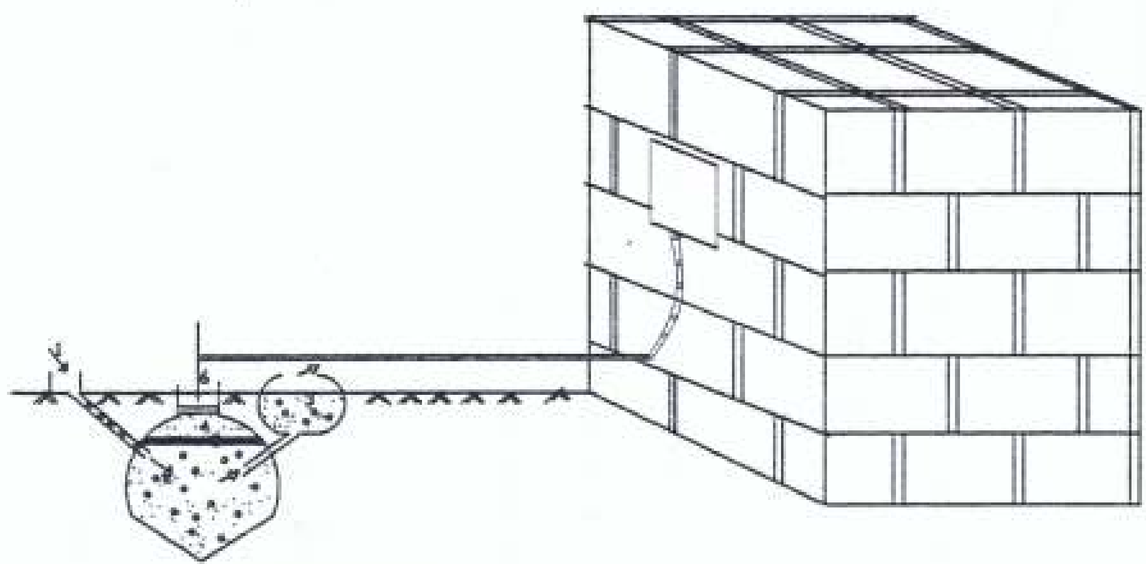
CHAPTER 5

RECOMMENDED BIOGAS PLANT FOR HOUSE HOLD USES

5.1 Recommended Biogas Plant For Household Uses (The Fixed – Dome Plant)

The fixed-dome plant is recommended for use by households because of the ease in construction, operation and maintenance. It consists of an enclosed digester with a fixed, non-movable gas space. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the outlet pipe and compensating and removal tank. It also consists of a mixing tank with inlet pipe, gas pipe connected to household appliances and supernatant scum level.

The fixed dome plant (Fig 4.6) has the advantages of low construction cost, no moving parts, no rusting steel parts, hence long life (20 years or more), underground construction, affording protection from cold weather and saving space, fed continuously and creates employment locally.



1 MIXING TANK WITH INLET PIPE
2 DIGESTERMADE OF BRICKS,SAND & CEMENT)
3 OUTLET PIPE,OVER FLOW OR REMOVAL TANK
4 GASHOLDER
5 SUPERNATANT SCUM
6 GAS PIPE CONNECTED TO HOUSEHOLD APPLIANCES
7 DIGESTER VOLUME(8-10M^3)

Fig 4.6:-Fixed Dome Plant

.2 Daily Gas Production/Daily Household Gas Requirement

The size of the digester – the digester volume (VD) is determined by the length of the retention time (RT) and by the amount of fermentation slurry supplied daily (sd). The fermentation slurry consists of the feed material (cattle dung) and the mixing water (Tam, 1982). For the fixed dome plant recommended for household use the daily feed material amount is 60kg.

A simple 8-10m^3 biogas plant can produce 1.5 – 2m^3 and 100 litres digested slurry fertilizer per day from cattle dung. With that much biogas, a 6-8 person family can cook 2-3 meals, operate one refrigerator all day and also operate two lamps for 3 hrs, since the gas requirement for cooking is 0.1-0.3m^3/person, 0.1 – 0.15m^3/hr for 1 lamp and 0.1 – 0.65m^3/hr for a refrigerator. The data below can be used for the design of such biogas plant.

Feed material: cattle dung, amount (Dd) = 60kg

Mixing ratio: dung: water = 1:1

Fermentation slurry amount (Sd):

= 60kg/day x 2 = 120 lit./day

Retention time (RT): 80 days

Digester volume (V_D)

= 120 lit/day x 80 days = 9600 litres

Digester Temperature (t): 26 – 28^{0C}

Specific gas production (Gd) for a retention period of 80 days at average temperature of 26 – 28^{0C} from Chart is 40 lit/kg.

Daily gas production (G)

= 40lit/kg x 60kg/day = 2400 lit./day.

Gasholder capacity ©: 60%

Gasholder volume (V_G)

= 2400 x 0.60 = 1440 litres

Digester/gasholder ratio

V_D: V_G = 9600lit: 1440 litres = 6.67:1 (World Bank Technical Paper number 308).

5.3 Biogas Stoves

There are many different designs of biogas stove available. The biogas stove shown below illustrates the different aspects of a stove which is simple in design.

Cost of Construction

A simple fixed dome plant is estimated to cost about N10,000.00 to install, including all peripheral equipment, i.e. gas appliances, piping, etc.

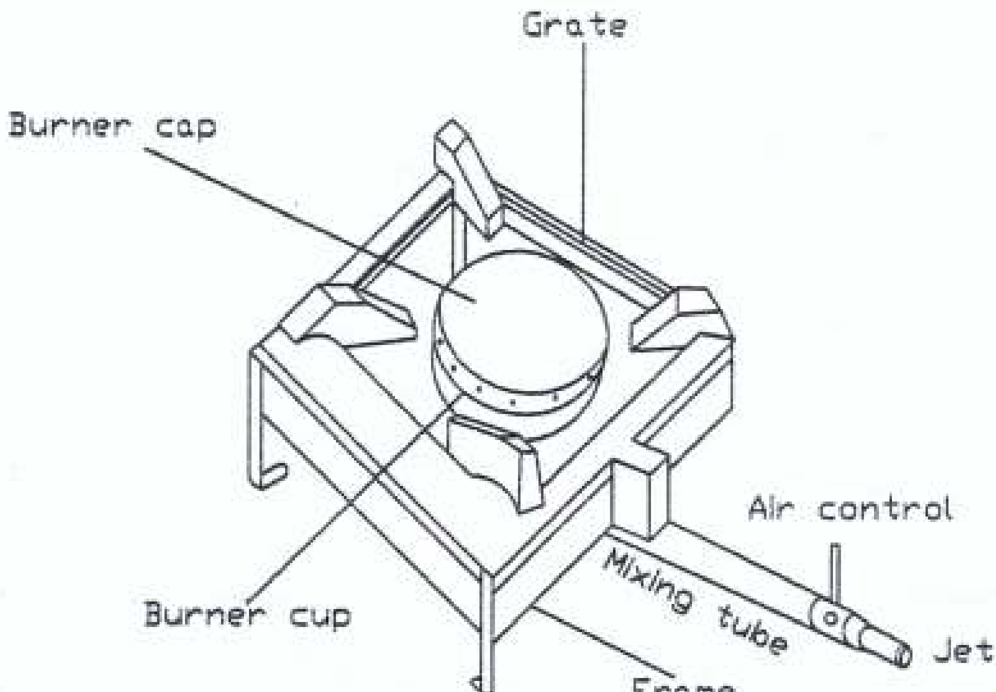


Fig 4.7(a):Biogas Stove

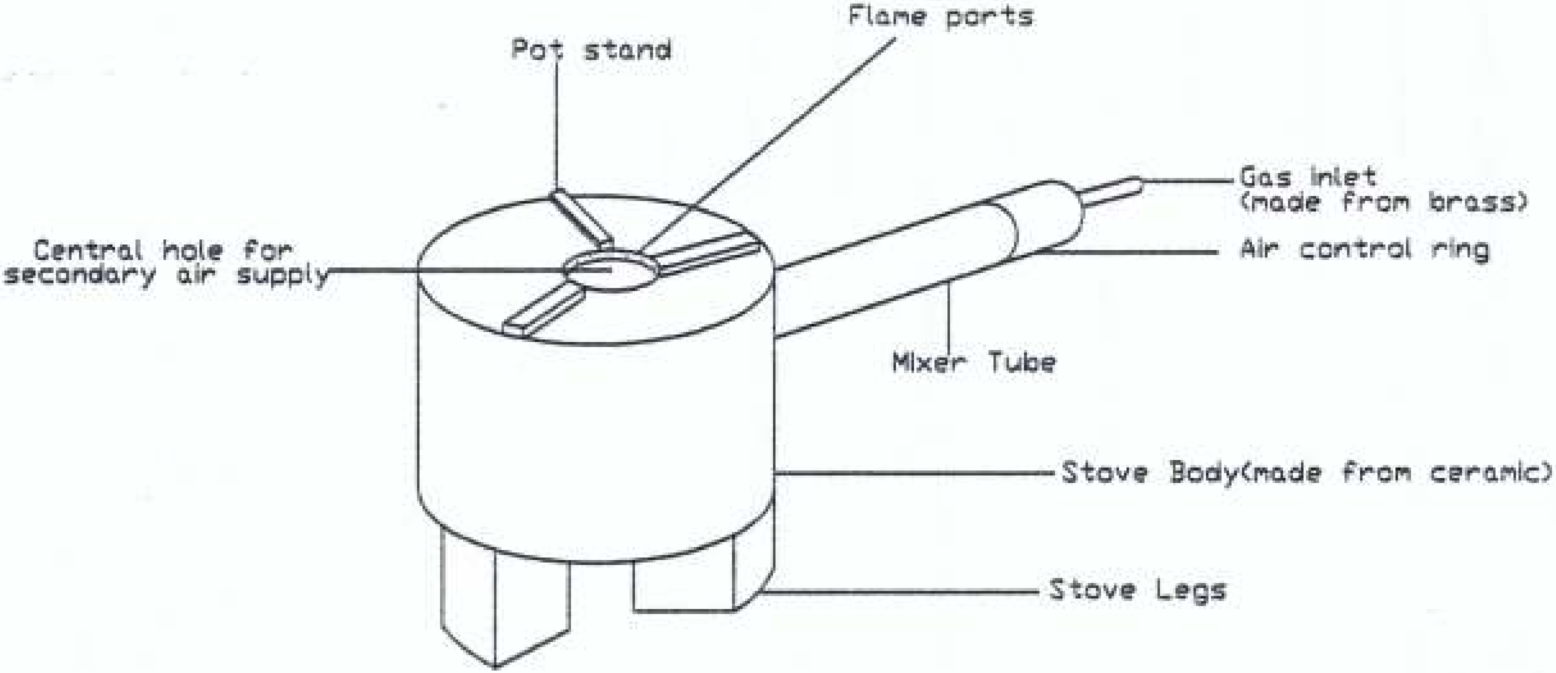


Fig 4.7(b): Ceramic Gas Stove

The Advantages of Biogas Technology

The advantages of biogas technology for the user consist chiefly of direct monetary returns, less work and various qualitative benefits.

The monetary returns consist mainly of:

- savings on kerosene, wood, charcoal and possibly bottled gas.
- savings on chemical fertilizers.

The qualitative benefits are:

- easier, cleaner cooking and better hygiene
- energy independence,
- good soil structure thanks to fertilization with digested sludge,
- less local deforestation,
- more work and income for local craftsmen,
- improved environment.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The digester designed for this research performed satisfactorily as the gas was produced as expected. On the average, the test substrate produced about 4litres of biogas per day. Thus, a much larger capacity digester would be required especially if the gas produced is intended for domestic or industrial use. Abattoir waste, with a gas yield of 2.05 litres per litre of waste per day, was found to be a very suitable substrate for biogas production comparing favourably with other suitable organic wastes and even better than some. For Lagos, where the rate of abattoir waste generation is estimated to be about 100 – 200m3/d (Oko-Oba abattoir officials), due to their high population, the use of high rate digesters would be more desirable in order to shorten considerably the retention time and the ability to handle more wastes.

6.2 Recommendation

There is an obvious need for the provision of a stirring mechanism for digesters using abattoir waste as substrate to prevent segregation of the material. A situation which if allowed to occur would affect the creation of an enabling environment for the multiplication and sustenance of valuable methanogenic bacteria within the substrate mass, thus leading to a reduction in the quantity of gas produced, the likelihood for the formation of scum and a consequent stoppage in the production of gas. A gentle but intensive stirring about every four hours is recommended.

The wastes situation of most of our abattoirs, where abattoir waste water is conveyed via surface drains to join municipal gutters flowing into natural water courses and with dire consequences for both surface and under ground water resources, could be changed for the better if such wastes are fed into biogas plants. The problem of health risk, waste disposal and environmental protection would be solved while at the same time recovering useful energy in the form of biogas and fertilizer for agricultural purpose.

For the acceptance of biogas technology it is recommended that:

- Biogas generation should be carried out in a controlled temperature to ensure maximum gas production (uniform temperature effect).
- The technology should be simple and affordable for the technical abilities and economic capacity of the intended users.

- Biogas technology should be made progressive by government intervention and involvement to make it a symbol of social advancement.
- The biogas plant must not be primitive, must be well made, attractive, tidy and well constructed.

In this study, a linear regression model was formulated to relate the biogas yield to the substrate and process parameters, that is, temperature, pressure and time of retention. The equations obtained in the model can be used to compute the maximum rate of biogas generation from these parameters.

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dix A – Table 4.5: Descriptive Statistical Model for Y1, Y2 & Y3 (RT = 15D, RT = 25D & RT = 35D)

	N	Minimum	Maximum	Mean		Std.
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
YIELD1	15	.00	2.46	1.1033	.1947	.75409
TIME1	15	1.00	15.00	8.0000	1.1547	4.47214
PRES1	15	.00	2.50	.5167	.2133	.82606
avertem1	15	28.50	29.75	29.0667	.1132	.43861
YIELD2	25	.00	5.76	2.3552	.3573	1.78658
TIME2	25	1.00	25.00	13.0000	1.4720	7.35980
PRES2	25	.00	3.71	1.5917	.2999	1.49926
avertem2	25	29.10	59.30	30.9800	1.1825	5.91257
YIELD3	35	.00	9.78	3.9834	.5206	3.08013
TIME3	35	1.00	35.00	18.0000	1.7321	10.24695
PRES3	35	.00	5.23	2.4311	.3142	1.85867
avertem3	35	25.00	29.30	27.2343	.1727	1.02180
Valid N (listwise)	15					

Regression

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	avertem1, PRES1, TIME1[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: YIELD1

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.999[a]	.997	.996	.04588

a. Predictors: (Constant), avertem1, PRES1, TIME1

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.938	3	2.646	1256.814	.000[a]
	Residual	.023	11	.002		
	Total	7.961	14			

a. Predictors: (Constant), avertem1, PRES1, TIME1

b. Dependent Variable: YIELD1

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-.324	.837		-.387	.706
	TIME1	.140	.005	.827	28.043	.000
	PRES1	.182	.026	.200	6.903	.000
	avertem1	7.480E-03	.029	.004	.257	.802

Coefficients[a]

Model		Correlations		
		Zero-order	Partial	Part
1	(Constant)			
	TIME1	.992	.993	.456
	PRES1	.879	.901	.112
	avertem1	.194	.077	.004

a. Dependent Variable: YIELD1

Regression

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	avertem1, PRES1, TIME1[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: YIELD1

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.999[a]	.997	.996	.04588

a. Predictors: (Constant), avertem1, PRES1, TIME1

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.938	3	2.646	1256.814	.000[a]
	Residual	.023	11	.002		
	Total	7.961	14			

a. Predictors: (Constant), avertem1, PRES1, TIME1

b. Dependent Variable: YIELD1

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.324	.837		-.387	.706
	TIME1	.140	.005	.827	28.043	.000
	PRES1	.182	.026	.200	6.903	.000
	avertem1	7.480E-03	.029	.004	.257	.802

Coefficients[a]

Model		Correlations		
		Zero-order	Partial	Part
1	(Constant)			
	TIME1	.992	.993	.456
	PRES1	.879	.901	.112
	avertem1	.194	.077	.004

a. Dependent Variable: YIELD1

Regression

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	avertem2, TIME2, PRES2[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: YIELD2

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.984[a]	.968	.963	.34136

a. Predictors: (Constant), avertem2, TIME2, PRES2

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	74.157	3	24.719	212.132	.000[a]
	Residual	2.447	21	.117		
	Total	76.604	24			

a. Predictors: (Constant), avertem2, TIME2, PRES2

b. Dependent Variable: YIELD2

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.474	.418		-1.135	.269
	TIME2	.201	.034	.829	5.997	.000
	PRES2	.189	.168	.159	1.125	.273
	avertem2	.233	.013	.003	.856	.824

Coefficients[a]

Model		Correlations		
		Zero-order	Partial	Part
1	(Constant)			
	TIME2	.983	.795	.234
	PRES2	.954	.238	.044
	avertem2	.237	.560	.024

a. Dependent Variable: YIELD2

Regression

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	avertem3, TIME3, PRES3[a]		Enter

a. All requested variables entered.

b. Dependent Variable: YIELD3

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.990[a]	.980	.978	.46107

a. Predictors: (Constant), avertem3, TIME3, PRES3

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	315.973	3	105.324	495.435	.000[a]
	Residual	6.590	31	.213		
	Total	322.564	34			

a. Predictors: (Constant), avertem3, TIME3, PRES3

b. Dependent Variable: YIELD3

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	7.285	2.325		3.134	.004
	TIME3	.290	.039	.964	7.495	.000
	PRES3	4.815E-02	.215	.029	.224	.824
	avertem3	.235	.083	.286	.564	.001

Coefficients[a]

Model		Correlations		
		Zero-order	Partial	Part
1	(Constant)			
	TIME3	.984	.803	.192
	PRES3	.955	.040	.006
	avertem3	.524	.024	.024

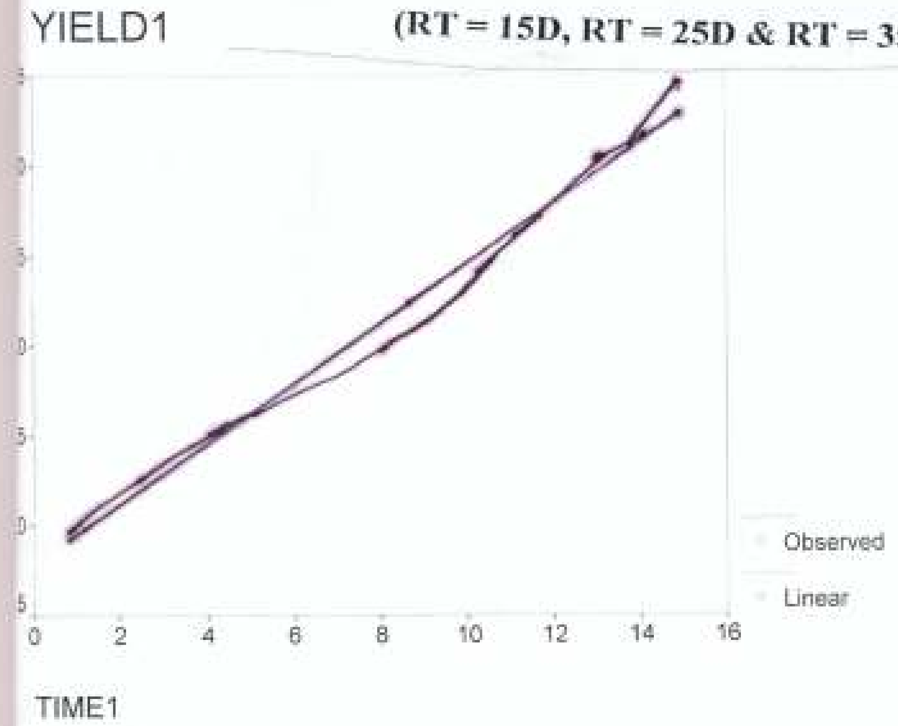
a. Dependent Variable: YIELD3

ppen dix – B

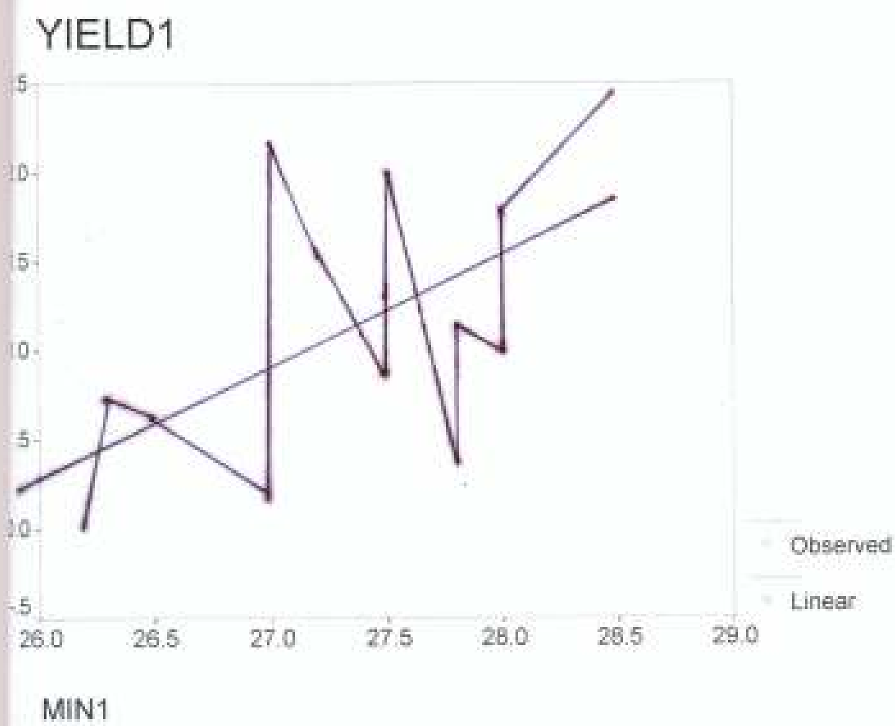
ve Fit

Figure 4.5: Curve Fitting for Y_1, Y_2 & Y_3

(RT = 15D, RT = 25D & RT = 35D)

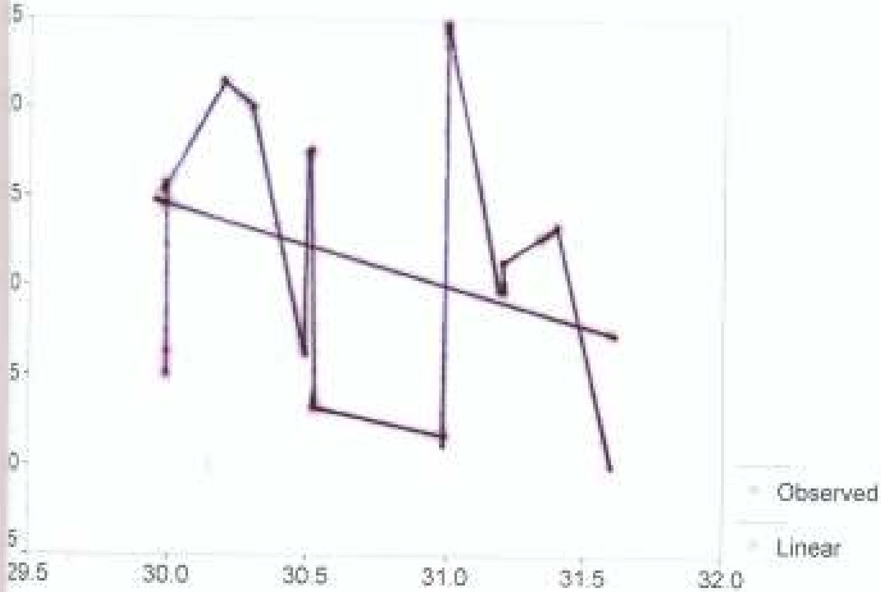


rve Fit



rve Fit

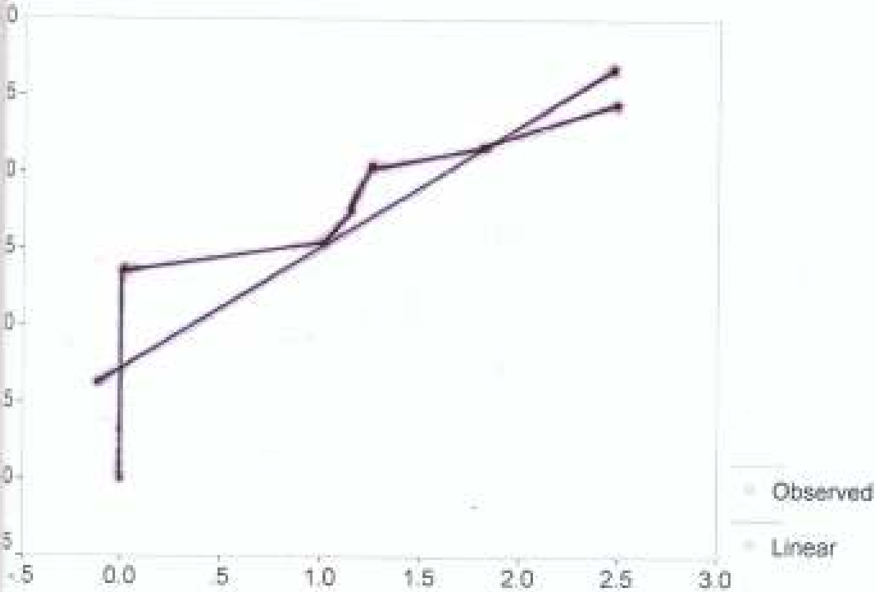
YIELD1



MAX1

ve Fit

YIELD1

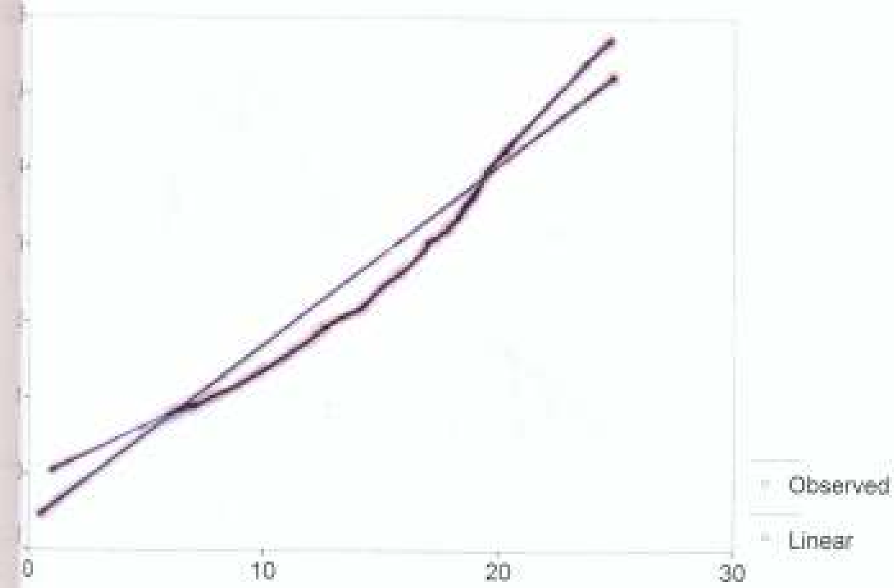


PRES1

ve Fit

89b

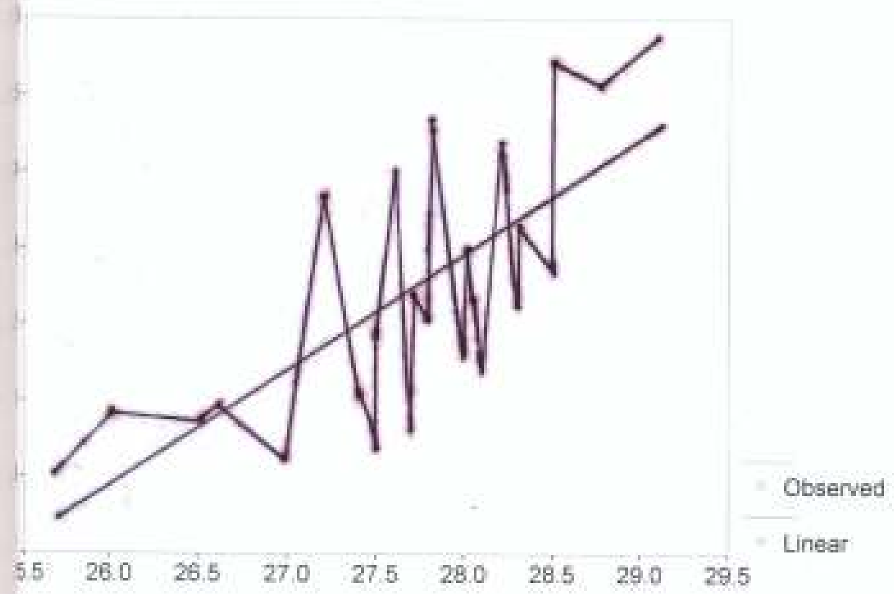
YIELD2



TIME2

ve Fit

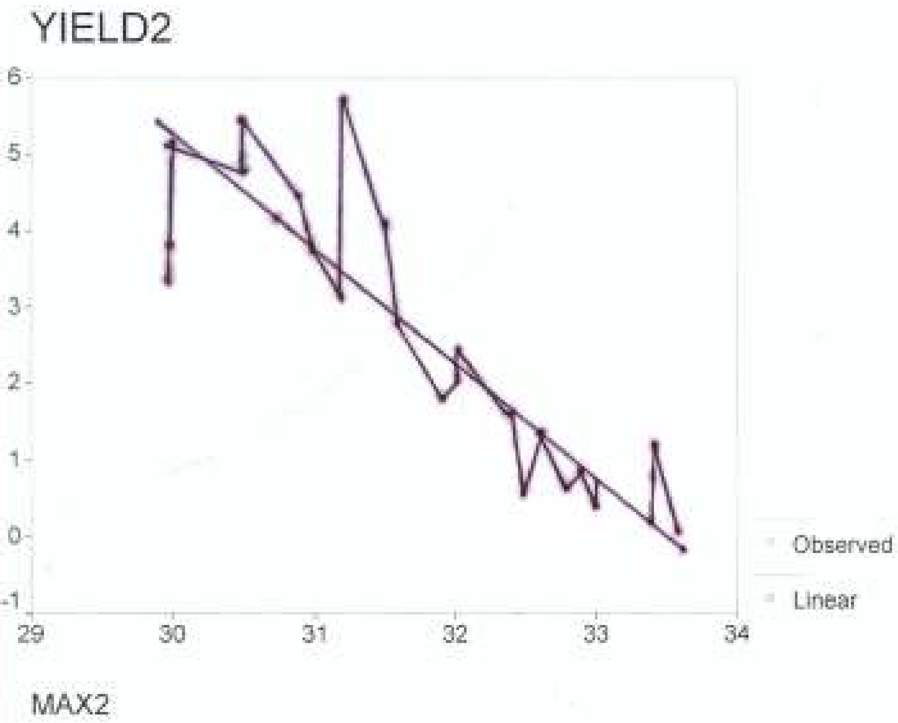
YIELD2



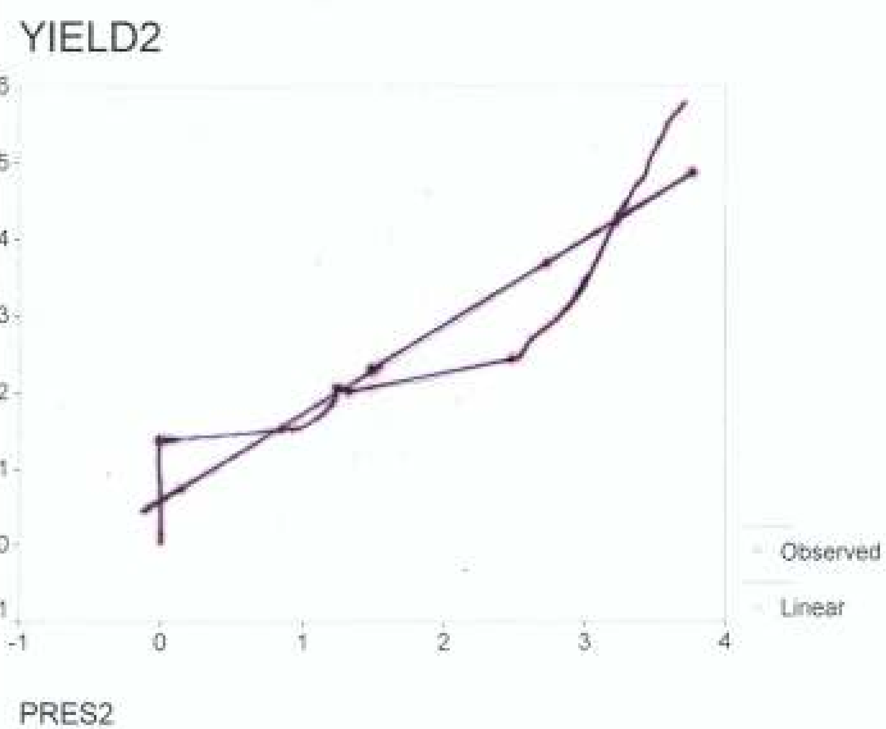
MIN2

ve Fit

89c

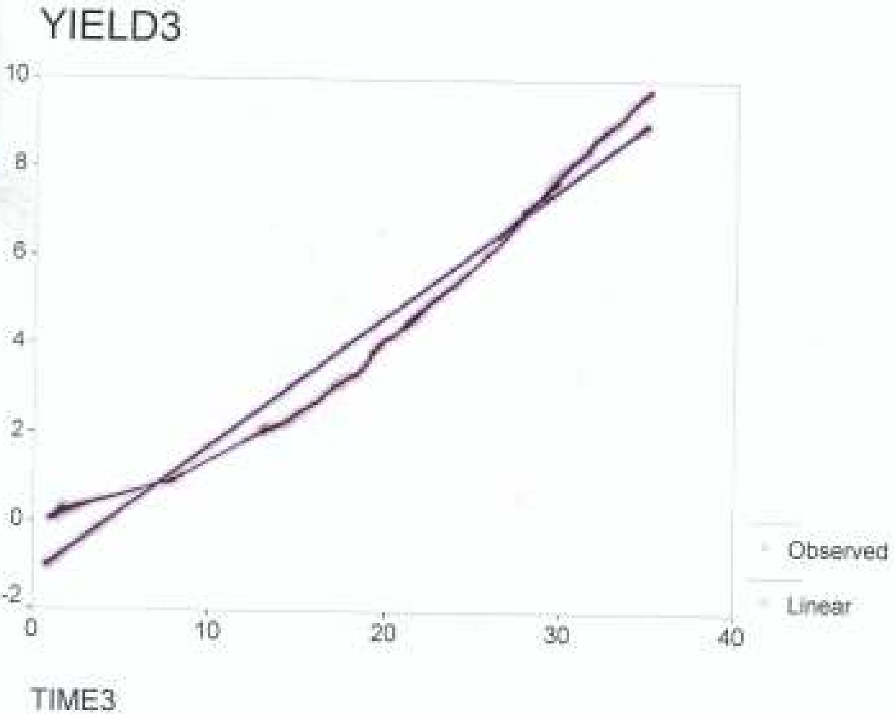


Curve Fit

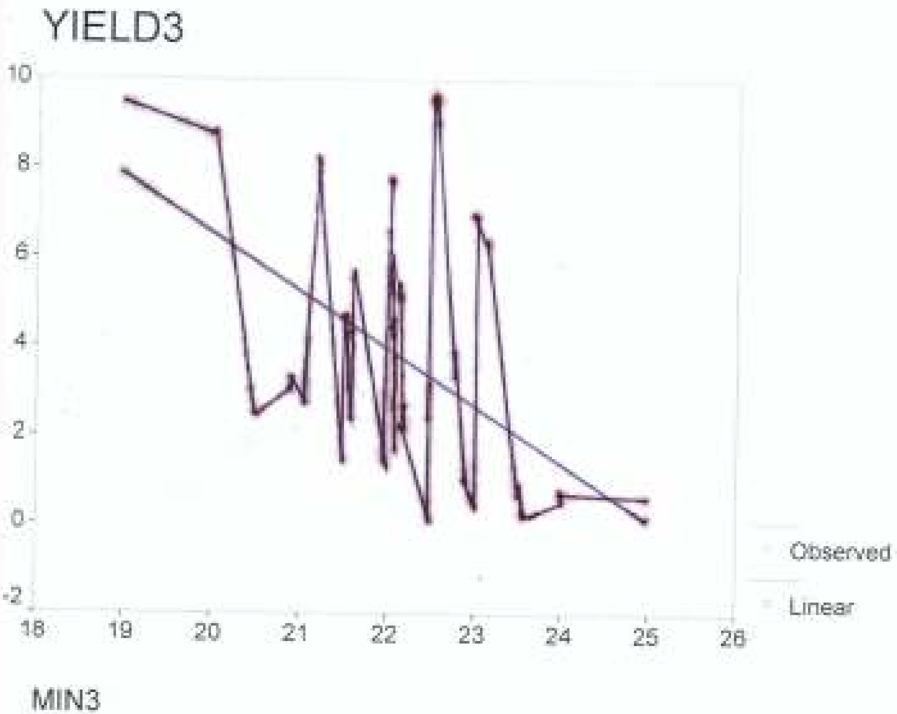


Curve Fit

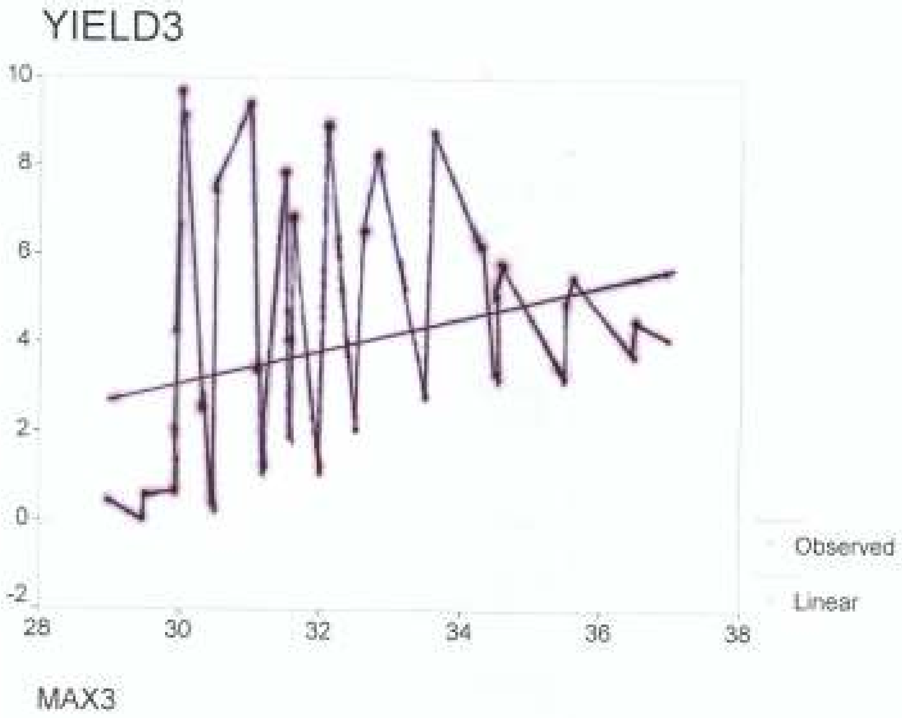
89d



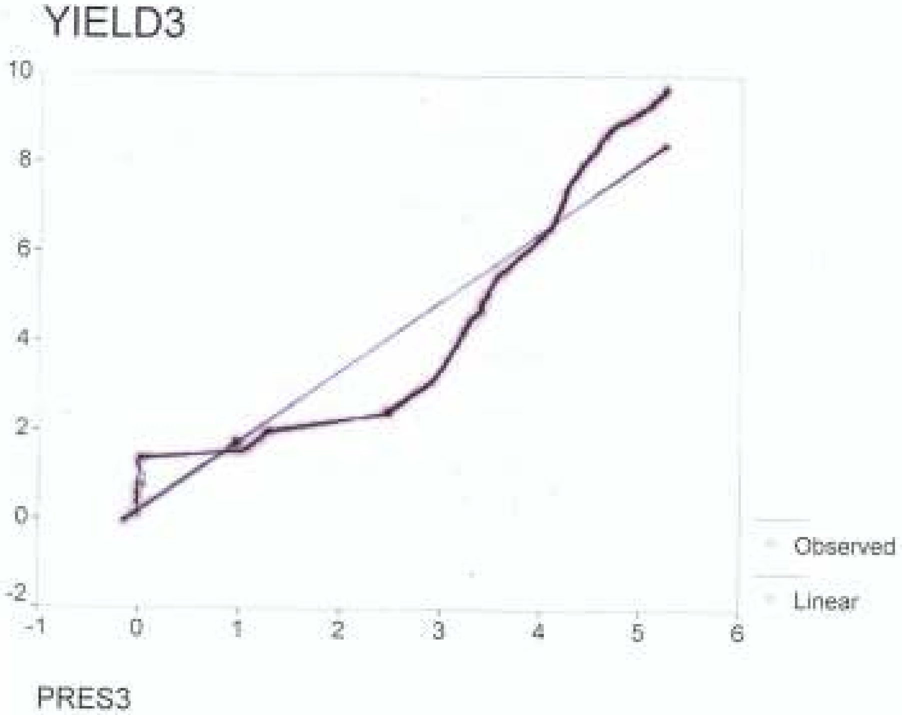
Curve Fit



Curve Fit



Curve Fit



89f

Appendix C – Stepwise Regression Analysis

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	TIME1	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	PRES1	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: YIELD1

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.992[a]	.984	.983	.09824
2	.999[b]	.997	.997	.04406

a. Predictors: (Constant), TIME1

b. Predictors: (Constant), TIME1, PRES1

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.836	1	7.836	811.853	.000[a]
	Residual	.125	13	.010		
	Total	7.961	14			
2	Regression	7.938	2	3.969	2044.253	.000[b]
	Residual	.023	12	.002		
	Total	7.961	14			

a. Predictors: (Constant), TIME1

b. Predictors: (Constant), TIME1, PRES1

c. Dependent Variable: YIELD1

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-.235	.053		-4.401	.001
	TIME1	.167	.006	.992	28.493	.000
2	(Constant)	-.109	.030		-3.682	.003
	TIME1	.140	.005	.829	30.337	.000
	PRES1	.181	.025	.198	7.254	.000

a. Dependent Variable: YIELD1

Excluded Variables[c]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	avertem1	-.016[a]	-.440	.668	-.126	.955
	PRES1	.198[a]	7.254	.000	.902	.326
2	avertem1	.004[b]	.257	.802	.077	.926

a. Predictors in the Model: (Constant), TIME1

b. Predictors in the Model: (Constant), TIME1, PRES1

c. Dependent Variable: YIELD1

Regression

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	TIME2		Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: YIELD2

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.983[a]	.966	.964	.33869

a. Predictors: (Constant), TIME2

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	73.966	1	73.966	644.787	.000[a]
	Residual	2.638	23	.115		
	Total	76.604	24			

a. Predictors: (Constant), TIME2

b. Dependent Variable: YIELD2

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.746	.140		-5.340	.000
	TIME2	.239	.009	.983	25.393	.000

a. Dependent Variable: YIELD2

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	avertem2	-.024[a]	-.611	.548	-.129	.970
	PRES2	.169[a]	1.290	.211	.265	8.514E-02

a. Predictors in the Model: (Constant), TIME2

b. Dependent Variable: YIELD2

Regression

90c

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	TIME3	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	avertem3	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: YIELD3

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.984[a]	.969	.968	.55047
2	.990[b]	.980	.978	.45418

a. Predictors: (Constant), TIME3

b. Predictors: (Constant), TIME3, avertem3

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	312.564	1	312.564	1031.504	.000[a]
	Residual	10.000	33	.303		
	Total	322.564	34			
2	Regression	315.963	2	157.981	765.859	.000[b]
	Residual	6.601	32	.206		
	Total	322.564	34			

a. Predictors: (Constant), TIME3

b. Predictors: (Constant), TIME3, avertem3

c. Dependent Variable: YIELD3

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.343	.190		-7.061	.000
	TIME3	.296	.009	.984	32.117	.000
2	(Constant)	7.066	2.078		3.401	.002
	TIME3	.298	.008	.992	39.122	.000
	avertem3	-.310	.076	-.103	-4.059	.000

a. Dependent Variable: YIELD3

Excluded Variables[c]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	avertem3	-.103[a]	-4.059	.000	-.583	.994
	PRES3	-.150[a]	-1.036	.308	-.180	4.505E-02
2	PRES3	.029[b]	.224	.824	.040	3.917E-02

a. Predictors in the Model: (Constant), TIME3

b. Predictors in the Model: (Constant), TIME3, avertem3

c. Dependent Variable: YIELD3