DEVELOPMENT AND EVALUATION OF A LABORATORY SCALE LANDFILL BIOREACTOR FOR TREATING MUNICIPAL SOLID WASTE

By

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Declaration

The Research work described in this thesis was carried out exclusively by me at Faculty of Agriculture, University of Peradeniya under the supervision of Prof. B.F.A.Basnayake. A report on this thesis has not been submitted to any other university, for another degree.

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DEDICATED TO MY
EVER LOVING
PARENTS, BROTHERS
AND FRIENDS.

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ABSTRACT

Urban waste management is one of the most complex environmental problems in Sri Lanka. Large quantities of wastes are generated day by day and there decomposition rate is low under anaerobic conditions. Landfill bioreactor is the most suitable system for waste degradation. The bioreactor landfills with the use of leachate recirculation as a method of leachate management is the modern approach for landfill design and operation. Most leachate recirculation operations performed to date have been conducted on traditionally designed landfills. In future, successful leachate recirculation system will be engineered as part of an integrated bioreactor landfill design. Thus, the design and operation of modern landfills involves many sciences and engineering disciplines, including the biology and chemistry of waste decomposition and leachate production, as well as the hydraulic, geotechnical, and materials engineering required for the design of liners, pipes and pumps.

To successfully operate the bioreactor landfills, it is necessary to control and monitor biological, chemical and hydrologic processes occurring within the landfill body. It is difficult to control the existing landfill bioreactors and it was found in an earlier study that leachate recirculation system should be maintained under anaerobic conditions. Therefore to obtain the process parameters for controlling the system, the leachate while being under anaerobic conditions, the TS, TSS, VS,VSS, TDS, salinity, conductivity, pH , leachate quantity, BOD and COD were monitored.

As reported in many of the literature, hydrolysis phase is the governing stage of the reactions to follow. It seems that this phase is prolonged at very low levels of microbial activity leading to large variations between BOD and COD values. Although VS and other parameters are fluctuating, there is an overall increase in the leachate strength. However, the BOD as expected seems to go through carbonaceous and nitrogenous phases, where the first phase had reached a peak at seven days. Also it could be concluded that acicogenesis has been delayed due to the evolution of acid forming gases, namely hydrogen. Thus amendments of the nutrients are essential to promote firstly acidogensis, followed by acedogenesis and finally methenogenesis. The delays in biochemical transformation may be due also to the type of the waste in this particular experiment because the quantity of paper was very high. Further analysis of the results is required to substantiate the conclusions and recommendations made in this study.

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CHAPTER I

INTRODUCTION

1.1 Back ground of the study

More than 90% of urban solid waste in Sri Lankan towns and cities are disposed in dumpsites. Only a small amount of solid waste is composted for producing organic manures/soil conditioners. Major portions of the solid wastes collected by the municipal authorities in the metropolitan cities are presently disposed in an indiscriminate manner in low lying marshy lands or on riversides.

Solid waste management is one of the major problems in developing countries. There are many waste disposal methods in Sri Lanka. However, open dumping has become a convenient method for most of the local authorities. The impact of the damage to the environment is considerable. The ground water and surface water contaminations by the leachate have permanently damaged the ecosystem. Next best alternative is to establish sanitary landfills and but the cost of construction and operation of such engineered landfills is sometimes prohibitive. It is economically feasible to pre-treat the waste and recycle some of it before final disposal in engineered landfills. Such integrated systems will reduce the organic loading on landfills and the impact on the environment will be less.

Another popular and a suitable method, very similar to landfill pretreatment is to construct and operate 'Landfill Bioreactors'. It is a suitable method, because it accelerates the decomposition and stabilization of solid waste usually under anaerobic conditions. Unlike sanitary landfills that are designed and operated to minimize contact between water and solid waste, the operation of a bioreactor relies on the addition of liquids to increase the moisture content of the solid waste to the optimal level for decomposition. The typical bioreactor will re-circulate all of its leachate and may still require the addition of supplemental liquids for its operation.

1.2 Justification and problem identification

Open dumping is the most common disposal method practiced in Sri Lanka. Sanitary landfills and landfill pre-treatment may be more costly than landfill bioreactors. Because the cost of construction of sanitary landfills and landfill bioreactors are very much the same with adequate liner materials to prevent groundwater pollution, but with the addition of leachate re-circulation system needed for landfill bioreactors. The cost of re-circulation can offset leachate treatment plants with the additional benefits of rapid decomposition of wastes and increased gas productions, thus it is a more efficient system for a tropical developing country like Sri Lanka.

However, very little research studies have been undertaken to establish landfill bioreactors and it is important to evaluate and optimize the performance of such landfills.

The design and operation of modern landfills involves many science and engineering disciplines, including the biology and chemistry of waste decomposition and leachate production, as well as the hydraulic, geotechnical, and materials engineering required for the design of liners, pipes and pumps.

To successfully operate the bioreactor landfill, it is necessary to control and monitor biological, chemical and hydrologic processes occurring within the landfill. As has been previously stated, a bioreactor landfill should be approached as a waste treatment system, thus requiring closer attention to system performance relative to traditional landfills.

1.3 Objectives:

i. To characterize the waste and determine the waste composition before commencement of the trial.
ii. To determine the leachate quality and quantity.
iii. To measure the volume and pressure of the gas emissions from the landfill bioreactor in relation to phases of anaerobic digestion.
iv. To evaluate the startup of the landfill bioreactor.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Definition of Municipal solid waste (MSW)

The term MSW refers to all waste collected and controlled by the local authority or municipality and is the most divers category of waste. It comprises of waste from several different source such as domestic or residential, waste, commercial waste and institutional waste, which makes MSW very heterogeneous in nature (Datta.M, 1997).

Solid waste management is one of the major problems in developing countries. There are many options available for the management of solid wastes such as,

- Direct dumping on approved sites.
- Sanitary land filling.
- Dumping in deep sea/land reclamation from sea.
- Elimination by incineration.
- Recycling.
- Composting.
- Anaerobic digestion.

2.1.1 Direct dumping on approved sites:

How ever, open dumping/direst dumping has become a convenient method for most of the local authorities. The impact of the damage to the environment is considerable in direct dumping sites.
It can cause,

- odour problems
- reduction in aesthetic value of the environment
- effects on sewers by solid wastes such as sedimentation, grease, odour
- effect on receiving water bodies/waters by solid wastes such as
  Deposits on river bed, sludge bank, benthal, anaerobic decomposition.
- reduction of available land for other uses due to accumulation of solid wastes in every subsequent disposal
- generation of extremely toxic chemicals such as toxin
- Depletion of resources such as metal resources and oil.

2.1.2 Sanitary landfill

The present disposal practices for large quantities of waste (especially garment waste) result in substantial loss in both resources. Therefore, disposal problems are ever increasing due to concentrated urban centers and industrialization. Open dumps and more recently the "controlled tipping" or "sanitary landfill" methods have been at least superficially the most attractive from an economic point of view, but in many places the cost of land for such sites and transport are becoming prohibitively high. Incineration prior to landfill is often necessary to reduce volume, but this contributes to air pollution and smoke emission. By practicing some alternatives such as pulverization or high pressure bailing before tipping , waste managers could reduce the volume and thereby reduce the required apace for land sites. How ever those methods are not practiced for various reasons. Landfills affect the ground water table due to changes in infiltration and deep percolation. Landfill involves space being occupied by plastic containers and drainage barriers being formed by plastic sheeting. The leachate from landfills could be hazardous since some of the unwanted elements could leach in to ground water and some of the leached chemicals could accumulate in the ground water reservoir over a period of time and become toxic. The construction cost of landfills could be very high so as to prevent leachate affecting ground water resources.

There should be additional provision to treat the leachate and the required extent of land for both landfill and system of effluent treatment may not be available within city limits. Sanitary landfill in marsh land is extremely costly and changes the entire ecosystem while causing floods. Indeed, it is not an acceptable solution to the problem.

2.1.3 Dumping in deep sea/land reclamation from sea.

It is an economically viable practice and reduces the visual pollution. But this is only a limited and short term solution because it will damage living organisms in the sea. Tropical countries, like Sri Lanka are more vulnerable to erosive action of the sea and therefore, such alternatives should not be considered.

2.1.4 Recycling:

The National Paper Cooperation (NPC) semi government cooperation, EMACE Sri Lanka a non-profit organization and Ceylon Glass Company (CGC) a private company are recycling paper, plastic polythyne and glass respectively in Sri Lanka (Allen, 2000).

2.1.5 Composting:

There are number of different ways of composting. Passive composting piles, windrow composting, passively aerated windrow composting, aerated static piles, in-vessel composting are few of the methods commonly used in Sri Lanka.

2.1.6 Incineration:

The disposal of urban waste by incineration offers advantages in volume reduction and the destruction of pathogenic micro organisms, and has not been used widely. Energy recovery incineration is one of the fully developed methods of utilizing the resources. At its worst, the process creates air pollution and leaves a residue of 40% of the original volume. Primary heat treatment is needed before incineration to reduce the available moisture content. In an incinerator the thermal energy can not be utilized, whereas in direct combustion, useful energy could be recuperated. Burning is, cheap and easy, but in many countries, atmospheric pollution controls have made this practice virtually illegal. Combustion generates hydrocarbons, carbon particles, and oxides of sulphur and nitrogen. Suitable in the near future, legislation in air pollution control is promoting a move a way from incineration and there is a tendency to promote landfills.

2.1.7 Anaerobic digestion:

There is an anaerobic digester that medium scale biogas and compost production from market garbage in Colombo. A pilot project been implemented by the Colombo Municipal Council uses organic waste from local city vegetable market to produce biogas and compost. The digester was developed by the national energy research and development center and accepts dry batches of organic waste. There are four 20-foot diameter floating dome digester each with a capacity of 40 tons dry waste. The residence time for the organic matter is 4 months and thus the four tanks are able to deal with a total of 480 tones of market waste each year. The wastes produce approximately 1 cubic meter of biomass per tone per day and these translate to a total of 7500-kiliwott hours of electricity of each year. The system also yields 30 tones of saleable fertilizer each year. The digester is made from concrete with a floating fiberglass cover. The gas is piped from the digester and is used to power a 220-vott, 5-killowatt converted engine.

2.1.7.1 Anaerobic digestion processes

This is biological engineering processes by which complex feedstock is converted in to a range of simpler compounds by microbes in the absence of air(oxygen). Anaerobic digestion is the consequences of a series of metabolic interaction among various groups of microbes. It occurs in four phases.

1. Hydrolysis / Liquefaction.
2. Acidogenesis.
3. Acetogenesis.
4. Methanogenesis.

Hydrolysis / Liquefaction:

This is the first stage of the anaerobic digestion, hydrolytic bacteria responsible for this stage. They catabolise saccaharides, proteins, lipids and other minor chemical constituents of biomass. Hydrolytic enzymes do these conversion, some of these enzymes are the lipases, proteases, celluloses, amylases etc.

Hydrolysis reactions:

Lipids ⟶ fatty acids

Polysaccharide ⟶ Monosaccharide

Protein ⟶ Amino acids

Nucleic acids ⟶ Purines and pyrimidines.

Acedogenesis:

In this stage, product of hydrolysis converts to simple oraganic acids, carbon dioxide and hydrogen. Acedogenic bacteria and homo acedogenic bacteria are the active microorganisms in this stage. Acetogenic bacteria catabolize certain fatty acids and neutral and products: homoacedogenic bacteria catabolize uni-carbon compounds (egg.H_2 ,CO_2 ,HCOOH) or hydrolyse multicarbon compounds to acetic acids. The principle acids produced are acetic acids, propionic acid(CH_3CH_2COOH), buteric acid(CH_3CHCH_2COOH), and ethanol(C_2H_5OH).

Methanogenesis:

Methanogenesis is final stage of anaerobic digestion process. Methanogenic bacteria are involved to produce methane by catebolizing acetate and one carbon compounds. Methane occur in two ways.

1. clevage of acetic and molecules to generate carbon dioxide and methane.
2. reduction of carbon dioxide by hydrogen.

Methane production is higher from reduction of carbon dioxide with hydrogen but limited hydrogen concentration in digesters results in that acetic acetate reduction is the primary producer of methane(Comstead et al, 1980). The methanogenesis reactions can be expressed as follows(Ref McCarthy),

$$CH_3COOH \xrightarrow{\qquad} CH_4 + CO_2$$

$$2C_2H_5OH + CO_2 \xrightarrow{\qquad} CH_4 + 2CH_2COOH$$

$$CO_2 + 2H_2 \xrightarrow{\qquad} CH_4 + H_2O$$

2.1.7.2 Important of anaerobic digestion products in future view:

In future, Sri Lanka has to face energy crises than present because limitation to the hydropower, social barrier for charcoal power projects and high cost involvement with diesel power etc. In future energy demand from villages will be increased rapidly. Simultaneously waste generation will be increased.

Biogas has the potential to fulfill energy demands at the village level because biogas plants can be easily installed with the use of available resources and also it is socially acceptable and economically viable. Anaerobic digestion will provide an alternate solution for waste and also energy crises with environmentally friendly, socially acceptable and economically friendly way.

2.1.7.3 Advantages of anaerobic digestion:

Anaerobic digestion contributes to reducing the green house gases. Well managed AD system will aim to maximize the methane production but not release any gases to atmosphere so can control the overall emissions. AD also is a source of energy but not cause to increase the carbon in atmosphere. The feedstock for AD is a renewable source, and therefore does not deplete finite fossil fuels. The use of digestate also participates to this reduction by decreasing synthetic fuels use in fertilizer manufacturing, which is an energy intensive process. AD reduce the soil and water pollution. Through this process can control odour and destroy weeds. In economic consideration the advantages of AD are: Biogas, Bio ethanol, soil conditioner, Liquid fertilizer.

2.1.7.4 Disadvantages of anaerobic digestion:

Anaerobic digestion involved with significant capital and operational costs. This will not be viable as energy source alone.

Another popular and a suitable method, very similar to landfill pretreatment is to construct and operate "landfill bioreactors". It is a suitable method because it accelerates the decomposition and stabilization of solid waste usually under Anaerobic conditions. Unlike sanitary landfills that are designed and operated to minimize contact between water and solid waste, the operation of a bio reactor relies on the addition of liquids to increase the moisture content of the solid waste to the optimal level for decomposition. The typical bioreactor will re-circulate all of its leachate and may still require the addition of supplemental liquids for its operation.

The primary goal in pursuing landfill bioreactor technology is the operation of solid waste land fills in a manner resulting in accelerated stabilization of the waste.

2.2 Features unique to bioreactor landfills

The bioreactor accelerates the decomposition and stabilization of waste. At a minimum, leachate is injected into the bioreactor to stimulate the natural biodegradation process. Bioreactors often need other liquids such as storm waterwaste water and waste water treatment plant sludges to supplement leachate to enhance the microbial process by purposeful control of the moisture content and differs from a landfill that simple re-circulates leachate for liquids management. Landfills that simply re-circulate leachate may not necessarily operate as optimized bio reactors.

Moisture content is the single most important factor that promotes the accelerated decomposition. The bioreactor technology relies on maintaining optimal moisture content near field capacity (approximately 35to 65%) and adds liquids when it is necessary to maintain that percentage. The moisture content, combined with the biological action of naturally occurring microbes decomposes the waste. The microbes can be either aerobic or anaerobic. A side effect of the bioreactor is that it produces landfill gas (LFG) such as methane in an anaerobic unit at an earlier stage in the landfill's life and at an overall much higher rate of generation that traditional landfills.

2.3 Special considerations of Bioreactor landfills.

Several considerations about bioreactor landfills must be examined and understood before the EPA can identify specific bioreactor standards or recommended operating parameters. Bioreactor landfill generally are engineered systems that have higher initial capital costs and require additional monitoring and control during their operating life, but are expected to involve less monitoring over the duration of the post-closure period than conventional "dry tomb" landfills. Issues that need to be addressed during both design and operation of a Bioreactor landfill include.

- Increased gas emission.
- Increased odors.
- Physical instability of waste mass due to increased moisture and density.
- Instability of liner systems
- Surface seeps.
- Landfill fires.

The unique design, operational and regulatory issues associated of the Bioreactor.

2.3.1 Leachate re-circulation.

A Bioreactor requires a large amount of leachate and supplemental liquid to be distributed evenly throughout the waste mass. The design and operation of leachate re-circulation systems requires careful attention so that the system can meet these operational requirement problems.

2.3.2 Landfill gas management.

The increased LFG generation over a reduced time period that comes with a bioreactor presents both opportunities and challenges. Design, installation and operation of an active LFG collection system will be an essential component of any bioreactor operation. Successful operation of an LFG collection system under wet landfill conditions is difficult. Particularly with the potential odor and clean air act compliance issues at stake.

2.3.3 Geotechnical stability.

While regulatory agencies are generally supportive of the landfill bioreactor concept due to its many benefits, existing landfill regulations do not always accommodate the features required for a bio reactor. Regulatory waivers or approval of alternate procedures may need to be pursued as part of the permitting of a landfill bioreactor.

2.3.4 Economic feasibility.

There are both additional costs and additional revenues associated with landfill bio reactors. Whether or not the additional revenues exceed the additional costs is dependent on a number of design and operational factors must be carefully evaluated.

2.4 Landfill bioreactor configurations.

2.4.1 Aerobic landfill

Aerobic processes require the presence of oxygen. In anaerobic bio reactor landfill, leachate is removed from the bottom layer, piped to liquids storage tank and re-circulated in to the landfill in a controlled manner. Air is injected in to the waste mass, using vertical or horizontal wells, to promote aerobic activity and accelerate waste stabilization under aerobic conditions, the CH_3COOH component act as a substrate in the aqueous phase for a reaction where oxygen is consumed to produced carbon dioxide, water and heat (Jakobsen, 1992).

$$CH_3COOH + 2O_2 \longrightarrow 2CO_2 + 2\,H_2O + HEAT$$

The aerobic micro organisms produce carbon dioxide levels as high as 90%, and the temperature rises to as high as 70 ^{0}C. The elevated carbon dioxide results in the formation of carbonic acid in the refuse, thus resulting in acidic p^H in the leachate.

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

2.4.2 Anaerobic landfill:

In an anaerobic bio reactor landfill, moisture is added to the waste mass in the form of re-circulated leachate and other sources to obtain optimal moisture levels. Bio degradation occurs in the absence of oxygen (an aerobically) and produces landfill gas. Landfill gas, primarily methane, can be captured to minimize greenhouse gas emissions and for energy projects. Under anaerobic conditions CH_3COOH biodegrades to carbon dioxide, methane and heat.(Popov and Power, 1999). The methanogenic bacteria utilize the products of the anaerobic acid stage, for example, hydrogen.

$$4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O$$

Consumption of the organic acids raises the pH of the leachate to the range of 7 to 8 organic acids that can not be used directly by the bacteria are converted to methane by an intermediate step. Volatile fatty acids act as a substrate for methanogenic bacteria, but high concentrations inhibit the establishment of a methanogenic community and at very high concentrations are toxic.

Hydrogen is produced during the none methanogenic stage but is consumed during the methanogenic stage.(Toerien et.al.,1969) reported that the latter reaction proceeds at a much more rapid rate than the former, therefore H_2 is generally not found in the presence of CH_4. The time require for the methanogenic stage to commence may be from six months to several years after placement. The shorter time period is associated with situations of higher water content and flow rate. It is noteworthy; however, that instability in the system or rapid variation in water movement may inhibit the methanogenic bacteria. During the methanogenic phase, leachate characteristically has a near neutral pH, low volatile fatty acid content, and low total dissolved solids.

2.4.3 Hybrid (Aerobic – Anaerobic)

The hybrid bioreactor landfill accelerates waste degradation by employing a sequential aerobic – anaerobic treatment to rapidly degrade organics in the upper sections of the landfill and collect gas from lower sections. Operation as a hybrid results in the earlier onset of methanogenesis compared to aerobic landfills.

2.5 Landfill bioreactor design:

The landfill bio reactor design components include the liner, leachate collection system, leachate management facilities, gas collection and management and final cap. The leachate re-circulation landfills include a leachate pumping station, leachate storage, leachate transmission piping and a reintroduction of the leachate.

2.5.1 Leachate system:

2.5.1.1 Liner/leachate collection system.

The landfill bioreactor requires a carefully designed liner system to accommodate extra leachate flow. The drainage system located above the liner is the most critical element of the collection system, and generally consists of highlypermiable natural materials such as sand or gravel or a geosynthatic net. The drain must be protected by a natural soil or geosynthetic filter to minimize clogging due to particulates in the leachate as well as biological growth.

- Leachate management options.
- Leachate re-cycling.
- Leachate evaporation.
- Treatment fallowed by disposal.
- Discharge to municipal waste water collection system.

2.5.1.2 Leachate reintroduction system:

A distinctive feature of a bioreactor landfill system is the re-circulation of leachate to the landfilled waste. The effective method for the treatment of leachate is to collect and re-circulate the leachate through the landfill. Bioreactors add additional liquid(leachate) to bring the waste to moisture content of 40% . The range of liquid addition to reach field capacity is 25,000 – 50,000 gallons per 1,000 tons of solid waste (Reinhart et al., 1974).

The addition and movement of moisture to the interior of the landfill creates and environment in which naturally occurring microbes degrade the waste at a much greater rate than they normally occur. During the early stage of the landfill operation the leachate will contain significant amount of TDS, BOD, COD, nutrients and heavy metals. When the leachate is re-circulated, the constituents are attenuated by the biological activity by other chemical and physical reactions occurring within the landfill. For example, the simple organic acids present in the leachate will be converted in to CH_4 and CO_2. Because of the rise in pH with in the landfill when CH_4 is produced, metals will be precipitate and retain within the landfill. The additional benefit of the leachate recycling is the recovery of landfill gas that contains CH_4.

The efficiency of leachate distribution and waste moisture absorption varies with the device used to re-circulate leachate. The methods currently employed include pre wetting of waste, spraying, surface ponds, vertical injection wells and horizontal infiltration devices.

The advantages of leachate re-circulation:

- Distribution of nutrients and enzymes.
- p^H buffering.
- Dilution of inhibitory compounds.
- Recycling and distribution of methanogens.
- Liquid storage.
- Evaporation opportunities at low additional construction and operating cost.

2.6 Waste degradation:

The ultimate goal of leachate recycling is to force the landfill to be a massive anaerobic reactor. As such the waste is reduced to methane and some other products.(Barlazetal, 1990) describes the processes that are involved during degradation.

2.6.1 The phases of degradation:

The generally accepted phases that leachate undergoes in a bio reactor landfill are as follows;

Stabilization of waste in a landfill occurs in five stages.

- Lag phase.
- Acid formation phase.
- Methane fermentation phase.
- Maturation phase.

Each phase is defined by its characteristic leachate and gas compositions. The lag phase is the period during which aerobic microbes are becoming established and moisture is building up in the refuse. Once moisture content is sufficient to support microbial growth, aerobic degradation of the refuse begins. This marks the beginning of the transition phase.

During transition phase, aerobic degradation consumes the molecular oxygen and conditions go from aerobic to anaerobic. Consequently, a transition toward a reducing environment in which chemical oxygen demand (COD) and volatile organic acids (VOA) being to form.

$$\text{Degradable waste + oxygen} \longrightarrow CO_2 + H_2O + \text{heat + biomass + Acetic acid + residuals.}$$

$$CO_2 + H_2O \longrightarrow H_2CO_3 \text{ (Carbonic Acid)}$$

Increase in COD and VOA signal the beginning of the Acid Formation phase. The VOAs formed during this phase are metabolic intermediates in the overall degradation of organic material in the refuse. These products form much faster than they are consumed, which leads to a build up of VOA. Therefore, the pH of the leachate is reduced and formerly insoluble metals are mobilized.

The methane fermentation phase begins when the organic acids produced in the Acid Formation phase are consumed. The end products of this anaerobic metabolism include CH_4, CO_2, and H_2O vapors.

$$4H_2 + CO_2 \longrightarrow CH_4 + 2\,H_2O$$

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

Consumption of acetic and carbonic acid results in an increase in the p^H around 8. This increase in hydroxide concentration is coupled with the reduction of sulfate to sulfide. Both, sulfide and hydroxide form insoluble complexes with metals. Therefore, metal concentrations in the leachate are significantly reduced.

Once all these reactions go to completion, there is a reduction in biological activity. This signifies maturation phase. A characteristic of this phase is very little gas production, because most of the readily degradable organic matter has been degraded. Nutrients and substrate are limited, but there is

still slow degradation of the remaining material, which resembles humic matter. The entire process can occur within 3 to 5 years under the optimal laboratory conditions.

2.7 Biological enhancement of reactor.

2.7.1 Buffering.

Methanogenes are only active between a pH of 6.8 and 7.4, thus Control of pH is important in establishing methanogenesis (Kasali et al., 1988). Buffering is particularly important early stages of degradation; when excess acid are produced and pH levels can drop quickly. Since low pH is typically the problem, the alkalinity is increased by adding lime or sodium hydroxide to the leachate during storage.

2.7.2 Sulfate.

Inhibition of methanogenesis by sulfate has been observed in a variety of environments. Sulfate-reducing bacteria compete with methanogenic bacteria for electron donors like acetate and H_2. Therefore, methanogenesis is hindered in sulfate rich environments like construction and demolition debris landfills, which contain gypsum.

2.7.3 Nutrients.

Nutrient requirements (both organic and inorganic) are typically met by the organic fraction of MSW. Phosphorus has been limiting in later phases of degradation. In most cases, nutrients do not increase degradation rates and therefore are not typically added.

2.7.4 Temperature control.

The microorganisms carrying out degradation rates increase with temperature up to an optimum temperature, specific for those particular microbes.(Gurijala, 1993) reported that 40^0C as optimum with significant inhibition over 55^0C. Temperature control is very difficult and is currently not widely practiced because of economic inefficiency.

2.7.5 Inoculation.

Inoculation has typically been done by adding biosolids from a wastewater treatment plant. Results from studies evaluating the effects of such additions have been inconsistent. Due to the varying effects and difficulty of handling, biosolids are not commonly added. Another method of establishing microbial populations is to place fresh waste over decomposed wastes. Studies have shown that the old refuse can stimulate methanogenesis and is more effective at treating leachate.

2.7.6 Gas collection:

Several laboratory and pilot-scale lysimeters have documented increased gas production rates and total yields as a result of moisture addition. The increase gas production results from accelerated waste stabilization as well as the return of organic material in the leachate to the landfill for conversion to gas. Gas production enhancement can have positive implication for energy production and environmental impact, however only if gas managed properly. Gas production rate in wet re-circulating landfill is around 0.023 m^3/kg/year and waste in dry areas 0.0096 m^3/kg/year (Reinhart et al, 1998).

Horizontal and vertical collection systems are used to collect the landfill gas. Horizontal collection systems are gaining in popularity as an efficient method of gas extraction for active landfill and in particular fore bio reactor landfills. The gas extraction trench is constructed in a similar manner to the horizontal injection trench for re-circulation.

Gas production has been observed to particularly enhanced near leachate reintroduction sites. Bioreactor landfills were found to have advantages of increased waste stabilization and landfill gas production over a shorter period of time. However landfill gas is not collected immediately, much of the advantage of energy recovery is lost, and environmental risks escalate. As a general characterization of methanogenic decomposition (Ham et al., 1987) presented the equation;

$$CaHbOcNd + (4a\text{-}b\text{-}2c\text{+}3d)/4H_2O \longrightarrow (4a\text{-}b\text{-}2c\text{-}3d)/8CH_4 + (4a\text{-}b\text{+}2c\text{+}3d)/8CO_2 + d\,NH_3$$

This equation assumes that substrate material chemical formula CaHbOcNd is decomposed anaerobically to CH_4 andNH_3.

2.7.6.1Benefits of active gas extraction:

Migration control:

Active gas extraction is the only effective method of controlling migration from a landfill site. This control is affected by used of a specifically designed gas well in order to prevent migration to specific high risk areas.

Odour control.

Odours are always a problem for landfill operators. Rapid compaction and cover can only control the normal odour associated with landfill gas is not the result of its major components CH_4 and CO_2 but trace volatile reduced sulphur, volatile fatty acids and volatile amines. Since landfill gas is the carrier for these compound and the mechanism of their dispersal management is active extraction and use of this gas as a thermal energy source.

Settlement:

The removal of landfill gas has resulted in settlements of 2m or more in a 30m deep landfill being recorded. This settlement arises as a result of the gas, leachate and condensate removal which allows elements in the waste is a not a homogeneous mixture.

Biological stability:

The amount of gas generated by any particular site is finite. This finite volume can be allowed to disperse naturally over a long period of time, namely 30 to 50 years, or can be actively extracted over 10 to 50 years. In both instances the waste mass can be considered stable once the finite gas volume has been generated. At this stage landfill no longer requires monitoring in terms of the permit to operate.

Energy replacement:

Landfill gas typically contains up to 50% CH_4 and has calorific value of 16 to 18 MJNm-3. The conversion of thermal energy to electricity via a reciprocating spark ignition engine has an efficiency of 33-38% depending on the degree of use of exhaust heat. The rates vary depending on the consumer and consumption.

Other environmental benefits:

Both CH_4 and CO_2 contribute to the greenhouse effect. Green house gases compare in terms of their radio active effect with that for CO2 as follows.

Component relative rating:

CH_4 is 20-30 times more efficient in radiating energy back to earth than CO2. There is normally a trace component of CFCs in landfill gas derived from the disposal of aerosol cans, CFC blown styrene foams, refrigerators and air conditioner leaks. Collection and combustion of landfill gas converts the CH_4 to CO_2 and water. The contribution of landfill gas to green house effect is thereby reduced. CFCs are destroyed in flares with the destruction efficiency depending on flare temperature and design.

Municipal solid waste contains almost 30% biodegradable carbon of which two third may be converted to landfill gas. If the gas is not collected and flared there is a very substantial contribution to the greenhouse effect from the CH_4/CFC component. There is a further reduction in greenhouse gas generation if the energy value of CH_4 replaces fossil fuel use. Global estimates for landfill CH_4 production are around 40x10 6 tons in 1995. The overall global production figure is estimated at 375 $\times 10^{6}$ tons. High efficiency gas collection and energy recovery schemes are essential in reducing CH_4 emissions.

Landfill gas properties:

Methane (CH_4) is a colorless, odorless, flammable, non-toxic gas that is lighter than air with a vapour density of 0.6 CH_4 is explosive between the concentrations of 5%-15% by volume in air.

Carbon dioxide (CO_2) is a colorless, odorless, non-flammable, toxic gas that is heavier than air with a vapour density of 1.53. At a level of 3% by volume in air breathing becomes laboured with resultant headaches. Generally, if the patient can be removed from the exposure recovery

will usually be rapid. At a level of 5-6% by volume in air these symptoms become sever and at 10% by volume in air visual disturbances, tremors and loss of

consciousness can occur. The accepted safety limit for CO_2 is 1.5% by volume in air and concentrations above this limit are regarded as hazardous.

2.7.6.2 Factors effecting gas generation:

Waste composition:

The waste consists of variable decomposable and non-decomposable materials. The waste contain more organic fraction, will be the landfill gas generation rate.

Moisture content of waste:

It provides the aqueous environment necessary for gas production and also serves as a medium for transporting nutrients and bacteria throughout the landfill. The overall moisture content of the refuse as received at a landfill typically ranges from 30 to 405 on a wet weight basis. The higher the moisture content, the greater the gas generation rate. Moisture movement through decomposing refuse increases gas production observed during the minimal moisture movement. In bioreactor moisture content is maintained by re-circulation of leachate.

Particle size of waste:

The smaller particle sizes of shredded refuse are believed to have a beneficial effect on landfill gas production. A reduced particle size exposes a greater surface area of the refuse to the important parameters affecting gas production, including moisture, nutrients and bacteria.

Age of the waste:

Gas generation vary with age of the waste.

pH:

The optimal pH range for most anaerobic bacteria is 6.7-7.5 or close to neutral (Mc Bean et al., 1995). With in the optimum pH range methanogens grow at a high rate. So that methane production is maximized. The pH of the refuse and leachate significantly influences chemical and biological processes. An acidic pH is generally the result of the formation of organic acids during the initial stages of anaerobic decomposition. These acids become the substrate for the methanogenic bacteria. As these organics begin to proliferate, the pH should rise as the acids converted to methane. If the pH is too low, methanogenesis will be inhibited.

Temperature:

Temperature conditions with in the landfill influence the type of bacteria that are predominant and the level of gas production. Optimum temperature range for mesophilic bacteria is 30 to 35°C, whereas thermophilic bacteria is 45 to 65°C. Thermophilic generally produce higher gas generation rates, however most landfills exist in the mesophilic range. Optimum temperature is in landfill range from 30 to 40°C. Landfill gas temperatures are reported to be typically in the range of 30 to 60°C (Emcon,1980 and 1981). Temperature also affects chemical solubility, because solubility increases with increasing temperatures.

Nutrient content:

Bacteria in a landfill require various nutrients for growth, primarily carbon, hydrogen, oxygen, nitrogen and phosphorus, but also small amount of sodium, potassium, sulfur, calcium, magnesium and other trace metals. The greater the quantity of easily digested nutrients, the greater will be the rate of gas generation. Numerous toxic materials, such as heavy metals, can retard bacterial growth and consequently tetrad gas production.

Oxidation-reduction potential:

Oxygen is toxic to methane forming bacteria; production of methane generally requires that the oxidation-reduction potential be less than 330mV (Fungaroli et al, 1979; Zehnder, 1978).

- Other factors.

Bacterial content, density of gas production, waste compaction, landfill dimensions, landfill operation and waste processing variables are affect the gas generation in landfill (Zehnder,1978;Fungaroli et al,1979;Mc Bean et al.,1995).

2.8 Potential advantages of landfill bioreactor:

Decomposition and biological stabilization of the waste in a bio reactor landfill can occur in a much shorter time frame than occurs in a traditional "dry tomb" landfill providing a potential decrease in long-term environmental risks and landfill operating and post closure costs. Potential advantages of bioreactor include.

- Decomposition and biological stabilization in years Vs decades in "dry tombs"
- Lower waste toxicity and mobility due to both aerobic and anaerobic conditions.
- Reduced leachate disposal costs.
- A 15 to 30 percent gain in landfill space due to an increase in density of waste mass.
- Significant increased LFG generation that, when captured, can be used for energy use on site or sold.
- Reduced post- closure care.

Research has shown that municipal solid waste can be rapidly degraded and made less hazardous due to degradation of organics and the sequestration of inorganics) by enhancing and controlling the moisture within the landfill under aerobic and/or anaerobic conditions. Leachate quality in a bioreactor rapidly improves which leads to reduced leachate disposal costs. Landfill volume may also decrease with the recovered air space offering landfill operators extend the operating life of the landfill.

LFG emitted by a bio reactor landfill consists primarily of methane and carbon dioxide plus lesser amounts of volatile organic chemicals and/or hazardous air pollutants. Research indicates that the operation of a bioreactor may generate LFG earlier in the process and at a higher rate than the traditional landfill. The bioreactor LFG is also generated over a shorter period of time because the LFG emissions decline as the accelerated decomposition process depletes the source waste faster than in a traditional landfill. The net results appears to be that the bio reactor produces more LFG overall than the traditional landfill does.

2.9 Disadvantages of landfill bioreactor:

- Potential for increased odours.
- Not fully proven technology as yet.
- Increased potential for slope stability problems.
- Higher capital and operating costs than sanitary landfills.
- Bio reactor technology is not currently being considered as a full scale technology by the Minnesto pollution control Agency. (MPCA).

CHAPTER 3

MATERIALS AND METHOD

3.1 Experimental site:

This experiment was carried out at Meewathura farm, Faculty of Agriculture, University of Peradeniya. The laboratory analysis was conducted at the Department of Agricultural Engineering and Agricultural Biotechnology Center.

3.2 Materials:

Following materials were used for the experiment.

- Concrete rings.
- Re-circulation pump.
- Leachate collection and re-circulation pipes.
- Leachate collection tank.
- Final cover-polythene, soil.
- Drainage materials-gravel.
- Gas collection pipe.
- Polythene bags to collect gases.
- Manometer
- Vacuumed tubes.
- Sensors(moisture and temperature)

3.3 Design of reactor:

The figure 3.1 illustrates the schematic diagram of the landfill bioreactor. It mainly consist of,

- Main reactor.
- Leachate collection system.
- Leachate re-circulation system.
- Gas collection system.

Main reactor was constructed with three 120cm diameter and 60cm length of concrete rings. Each concrete ring was placed on top of the other and pasted by cement.

The 50mm diameter sampling port was made at each ring at a height of 35cm, 85cm and 140cm from the top of the reactor.

The bottom of the cylinder is slanted with a cement paste to facilitate collection of leachate. 0.5 cm holes were made in leachate collection pipe. The leachate collection pipe was embedded in a 15 cm thickness of gravel pack to improve percolation. The outlet of the leachate collection pipe is connected to the leachate collection tank. The collected leachate is pumped in to the bioreactor using re-circulation pump. The leachate was re-circulated daily on top of the main reactor from the leachate collection tank. The spray consisted of 0.15 cm holes along with a 1.2 cm diameter in the re-circulation pipe.

The gas collection system was embedded in to the bioreactor. The 0.5 cm diameter holes were made in the PVC riser pipe 5 cm diameter of 1m length embedded to collect the gas. At the top of the pipe, a lid was placed with a hole to join with smaller diameter flexible gas collection tube. The gas collection system was embedded in to bioreactor to a depth of 153 cm from top of reactor. 20 cm diameter net was placed around the flexible collection pipe inserted into a thick polythene bag with 46 cm diameter. The quantity of the collected gas was measured 2 times per a day. The "U" tube was used to measure the pressure of the collected gas. After a day, this polythene bag was changed and the flexible gas collection tube was inserted into the new polythene bag.

3.4 Filling of waste:

The municipal solid waste was collected from Yatinuwara Pradeshiya Sabaha and sorted manually to remove large particles of polythene, plastic, glass, metal and other non degradable materials Then the composition of the waste was estimated by the following sampling procedure.
10 samples were taken in several places and mixed well.
Then, samples were divided into 4 groups and removed two samples from that.
Again residual samples were mixed well and were divided into 4 groups.
After that two groups were removed and residual samples were mixed well.
After that the sample was divided into several portions such as short term degradable waste, paper, polythene, textile, coconut shell.
Then the weight of each of the component was obtained and thus determined the composition of the waste, along with TS, VS and ash contents.

Once the composition study was completed, 1149.6 kg of waste was filled into the main reactor and compacted to a density of 527.486 kgm^{-3}. During filling of waste, sensors, gas collection pipe, leachate re-circulation system was placed. The four sensors were placed at a height of 153 cm, 110 cm, 65 cm and 20 cm. These sensors were used to measure temperatures and moisture contents in the main reactor. The gas collection pipe was placed 153cm and the leachate re-circulation system was placed 45 cm from the top of the reactor to prevent from overflowing of leachate during the period of re-circulation.

After filling of waste fine soil was placed and then 120 cm diameter and 100 cm length polythene placed above the soil layer and again fine soil was placed on top of the polythene to prevent any gas leakages. The other end (side) of polythene was fixed to the outer side of reactor by using no-leak paste, so that this reactor maintained anaerobic conditions.

3.5 Parameters measured:

The following parameters were analyzed from the reactor. All of the parameters were measured one time per a day. The VS of the filling waste was measured in first day.

Table 3.1 Method of tests.

Type of waste	**Method of test**	**Frequency**
Leachate quality		
TS	Oven Drying	2 samples/ Day
VS	Oven Drying, Muffle Furnace	2 samples/ Day
TSS	Oven Drying, Muffle Furnace	2 samples/ Day
VSS	Oven Drying, Muffle Furnace	2 samples/ Day
Conductivity	Conductivity Meter	2 samples/ Day
pH	pH meter	2 samples/ Day
BOD	Wrinkler Titration Method	2 samples/ Day
COD	Oxidizing Organic matter	2 samples/ Day
Waste quality		
Moisture	Oven Drying	2 samples/ Day
Temperature	Electronic sensor	2 samples/ Day
Settlement	Eye estimation	daily
Gas		
Gas volume	By the polythene cylinders (the gas collecting tube was inserted in to the polythene cylinder).	2 samples/ Day
Gas pressure	By the U tube.	2 samples/ Day

3.6 Calculation of parameters:

BOD5	(of leachate)
Moisture content	(of raw waste)
TS (total solid), VS (volatile solid)	(of leachate)
TSS (total suspended solid)	(of leachate)
VSS (volatile suspended solid)	(of leachate)

Were calculated following equations;

3.6.1 BOD5 = (BOD5sample – BOD5blank) x D

BOD5 = 5th day BOD value.
BOD5sample = 5th day BOD value of sample.
BOD5blank = 5th day BOD value of blank.
D = dilution factor.

3.6.2. Waste moisture:

The moisture content of the filling waste was measured in the first day by the oven method at 105°C, in 24 hours.

Percentage of Moisture content (wet basis) = (w1 x w2) / w1 x 100

W1 = Weight of fresh substrate (MSW).
W2 = Weight of oven dried sample.
W3 = Weight of ignited sample.

3.6.3 Total solid (TS) and Volatile solid (VS):

The known amount of leachate (Vml) was filled into known weight of oven dried crucible (W1g). It was oven dried till constant dry weight (W2g). After that oven dried sample was ignited at 550°C for 2 hours in muffle furnace and final weight (W3g) was measured.

$$TS = (W2 - W1) \; x\, /V g/l$$

$$VS = (W2 - W3) \; x\, /V g\, /l$$

3.6.4 Total suspended solid (TSS) and Volatile suspended solid (VSS):

A known amount of leachate (V ml) was filtered through the known weight of oven dried filter paper (W1g). This filter paper was placed on a known weight of empty oven dried crucible (W2g). Then these contents were measured (W3g) and placed in an oven until the sample reached a constant weight (W4g). Then the contents were ignited in a muffle furnace at 550°C for two hours and final weight was measured (W5g).

$$\text{TSS} = (W4 - W2 - W1) \times (1000 / V) \text{ g/l}$$

$$\text{VSS} = (W4 - (W5 + W1) \times (1000 / V)$$

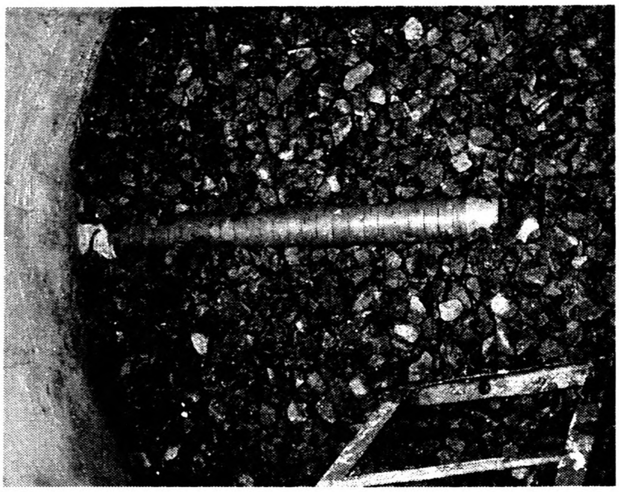

Plate 3.1: Gravel filling on the bottom of the reactor.

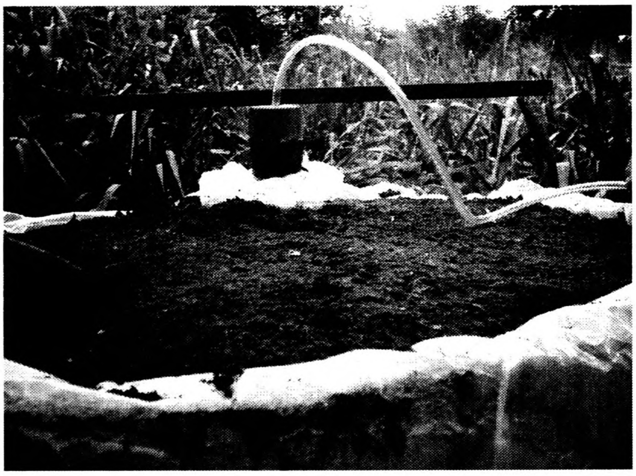

Plate 3.2: Clay filling on the top of the reactor.

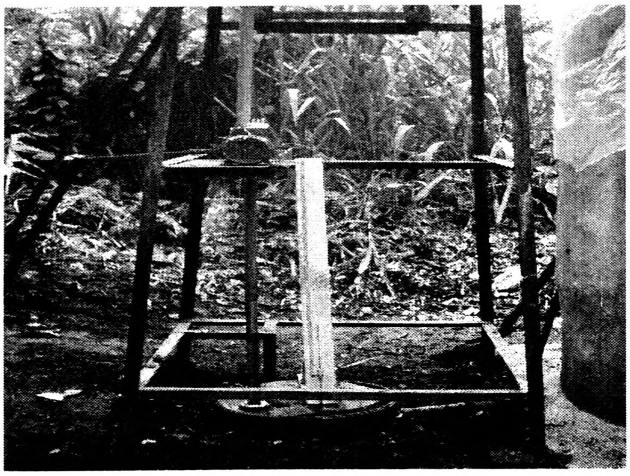

Plate 3.3: Quantity of Leachate measuring system.

Plate 3.4: Figure of the Landfill Bioreactor.

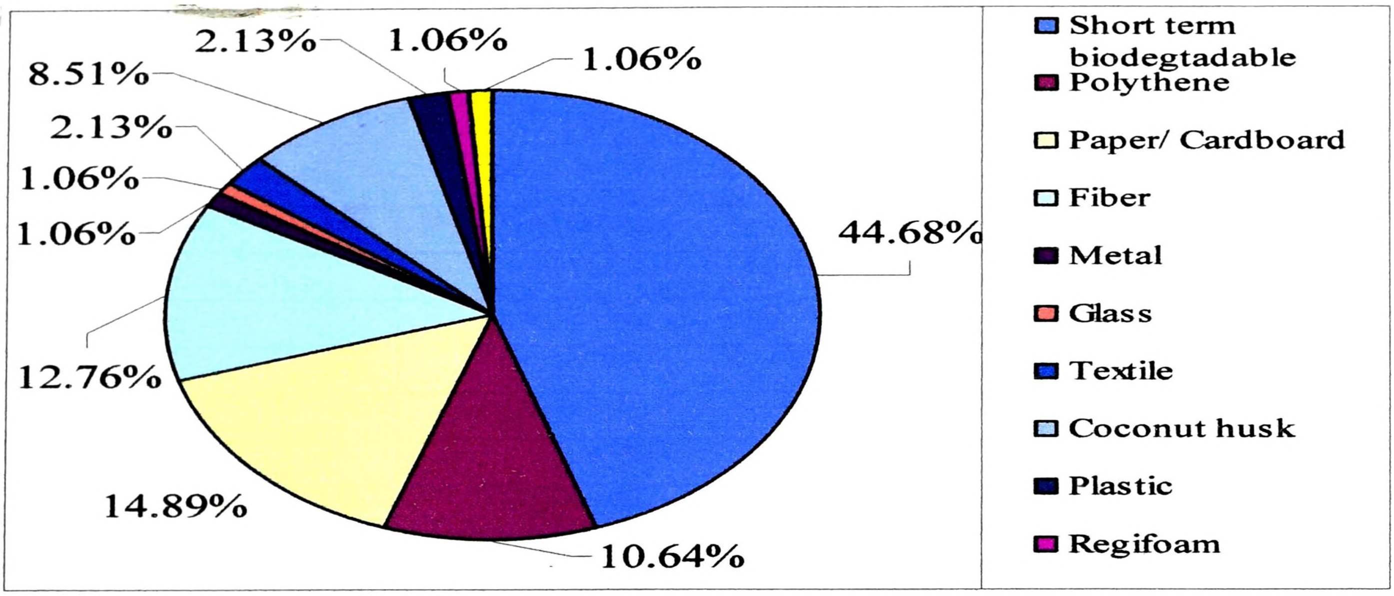

Figure 4.1 Composition of filling wastes.

Table 4.1 MC, TS, VS and Ash content of the filling wastes.

Type of waste	MC %(wet basis)	TS(%)	VS(%)	Ash(%)
Glass	0.109216359	99.89078364	0	99.89078
Wood	44.43128442	55.56871558	44.76336477	10.80535
Fiber	71.17167225	28.82832775	17.59448462	11.23384
Coconut shell	24.15673398	75.84326602	70.79534239	5.047924
Metal	0.8264	99.17355	0	99.17355
Plastic	4.575464456	78.52564103	76.89834007	18.5262
Polythene	50.21322819	49.78677181	45.02252977	4.764242
Paper	54.76093396	45.23906604	38.4171271	6.821939
Bio degradable short term	65.55292005	34.44707995	22.79391026	11.65317
MSW	60.2420079	39.7579921	20.88335538	18.87464

4.2 Landfill gas production:

The cumulative volume of gas production from the landfill Bioreactor with time is shown in Figure 4.2. In first day gas production rate increased with time. The gas production rate depends on the waste degradation rate and thus the type of wastes. The filled waste had 44.68% of short

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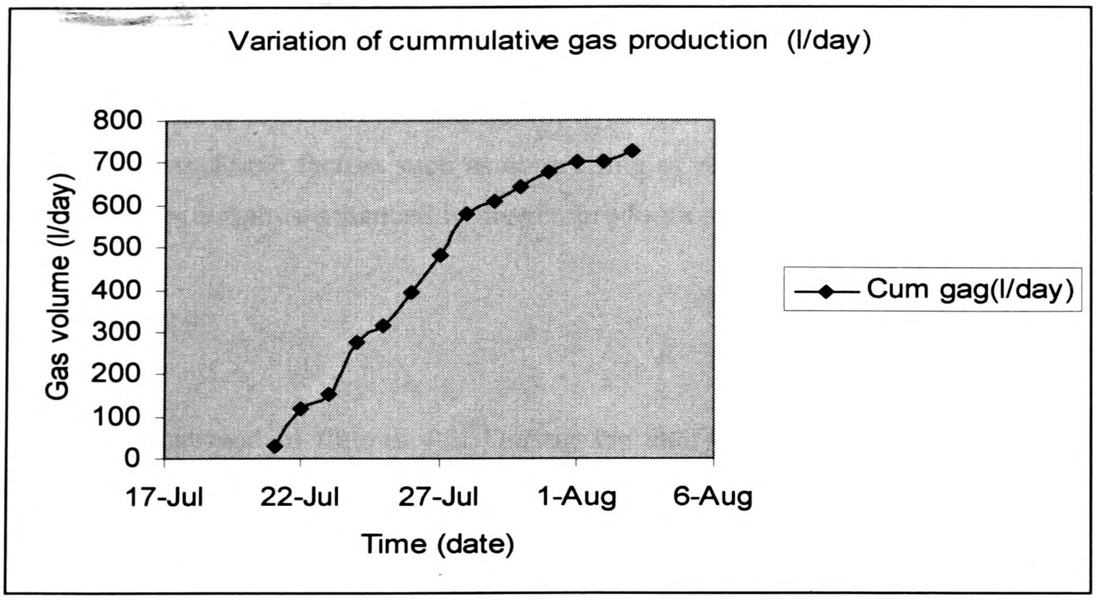
Unfortunately, the composition of gas was not analyzed. The generation of moisture might have been substantial and would have accounted for a large proportion. Another possibility may be the production of hydrogen that can occupy a large volume for a small quantity or else a combination of the gases with carbon dioxide evolution towards the end of hydrolysis phase.



The figure 4.2 gas production of the Landfill Bioreactor with time.

4.3 Variation of gas pressure.

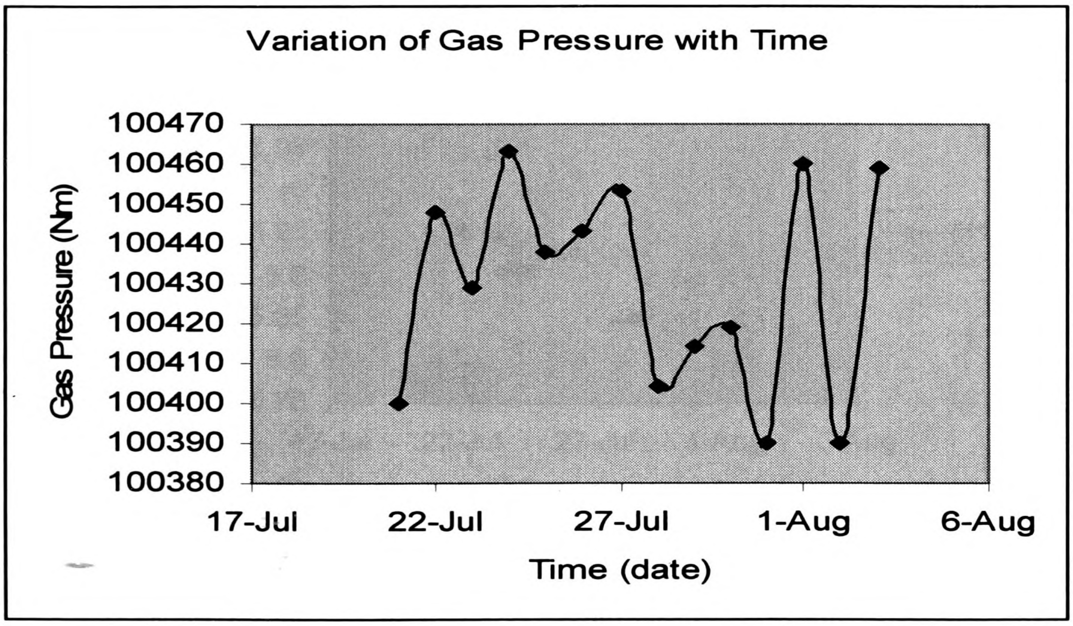


Figure 4.3 illustrates the correlation of gas pressure with time.

The anaerobic degradation is very complex multiphase and multi microorganisms process. In a second acidification phase amino acids, sugars and fatty acids are fermented to organic acids (mainly acetic, propionic and butric acids) and hydrogen. The main barrier to efficient conversion of dissolved organic matter in a waste water stream is prevention of interspecies hydrogen transfer that is to avoid consumption of hydrogen by other anaerobic microorganisms, notably methanogens. Some factors such as controlling of pH and temperature, that prevent the inter species transfer and thus enhanced hydrogen production (Toerien et al, 1969).

4.4 Variation of pH

pH variation is illustrated in figures 4.3. During the study period, the pH of bioreactor was found to vary from 5.8 to 6.1 and averaged at 5.94. Most methanogenic bacteria function in a pH range between 6.7 to 7.4, but optimally at pH 7-7.2 and the process may be failed if the pH is close to 6. Acidogenic bacteria produced organic acids, which tend to lower the pH of the bioreactor. Under normal conditions, this pH reduction is buffered by the bicarbonate, which is produced by the methanogenes. In this study the leachate was re-circulated, that dissolved the bicarbonate or even CO_2 in the bioreactor. These activities would have favored acidic conditions promoting more and more hydrogen to be produced and eventually inhibiting degradation as well as preventing methanogenesis for production of methane.

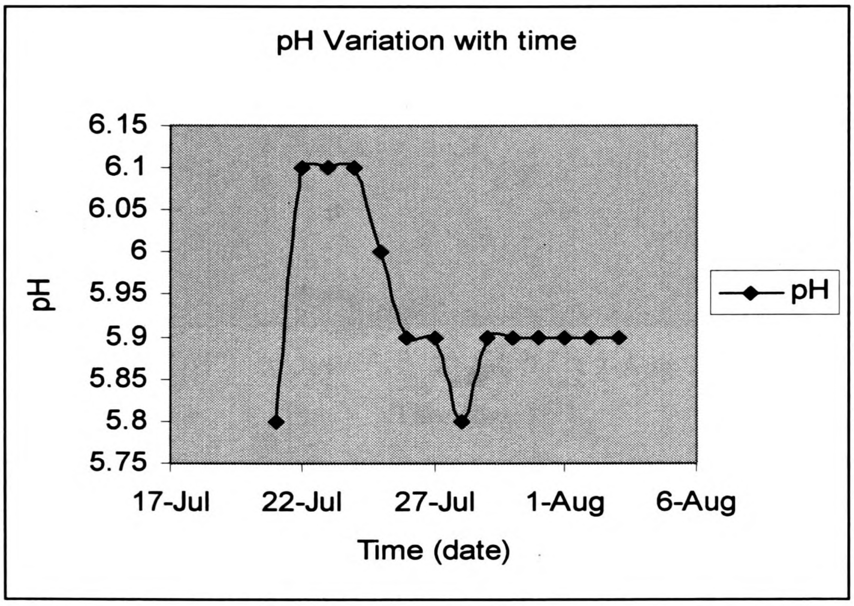


Figure 4.4 variation of elute p^H with time

4.5 Variation of temperature in the landfill bioreactor.

The table 4.3 the daily temperature variations obtained from the sensors placed at different heights of the reactor. The temperature variations are illustrated in figure 4.4. During this period, the temperature was slightly higher and then it was found to be within the range of 12 to 58°C. On the fifth day, water was added up to 10 liters, so as to create leachate. However, the temperature decreased and once again increased with the increasing in activity.

The methanogenic bacteria prefer temperatures between 30 to 40^{0}C. They are more sensitive to change in temperature and other organisms present in the bioreactor. This is due to faster growth rate of other groups such as acetogens, which can achieve substantial catabolism even at low temperatures (Schmid et al, 1969). This will retard the methane and enhance hydrogen production.

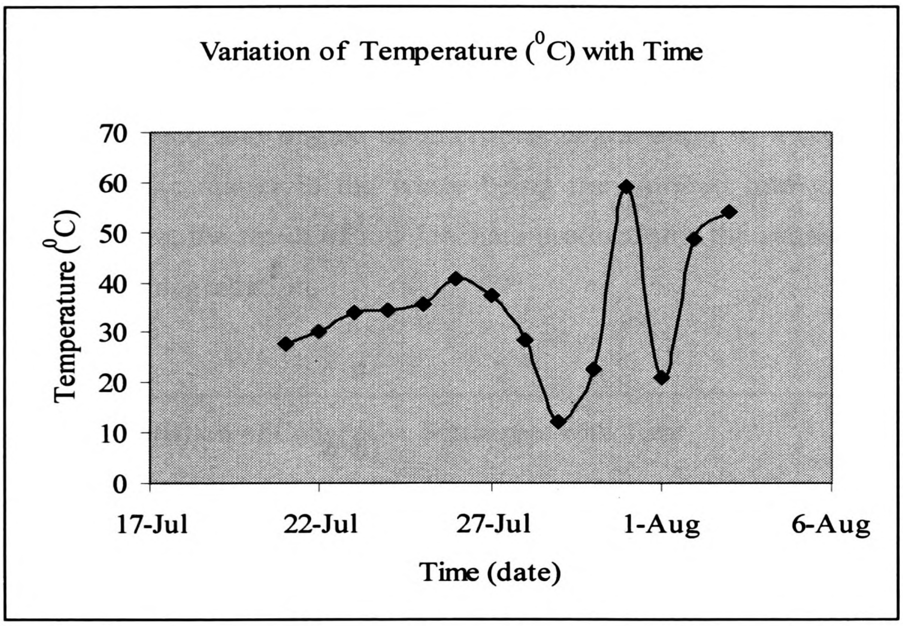


Figure 4.5 variation of temperature with time.

4.6 Daily moisture content of the reactor.

In this experiment, the moisture content had been maintained more or less within a narrow range throughout the study period by the action of leachate re-circulation. The moisture content ranged from 72.7 to 84.27 %. It seems that higher moisture contents are required to generate sufficient leachate for re-circulation.

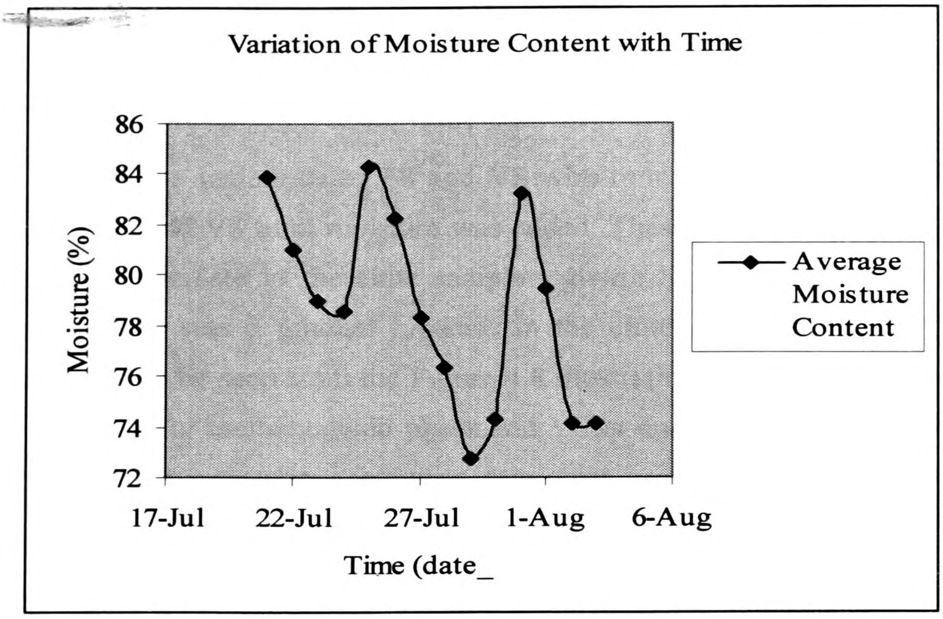


Figure 4.6 variation of moisture content with time.

4.7 Settlement of the bioreactor.

In the landfill bioreactor, faster degradation of waste is expected under daily leachate re-circulation. The enhanced speed and degree of microbial degradation in a bioreactor landfill results in more of the organic matter in the waste being transformed into gases and water. However, as mentioned before, the result of low leachate productions, the settlement rates were also low, indicating very low degradation.

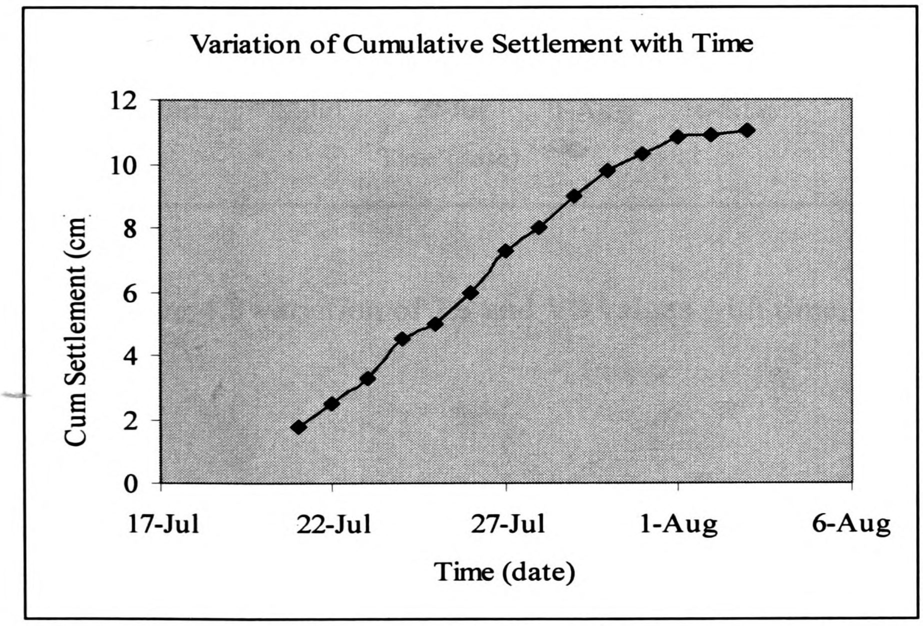


Figure 4.7variation of settlement of the reactor.

4.8 Variation of Total Solid (TS) and Volatile Solid (VS)

The Figure 4.7 show the variations of TS and VS with time. Unlike anaerobic reactors, there were decreases of TS and VS until moisture was added. These decreases could be attributed to initial presence of particulate in the elute samples, giving higher values. With the increased moisture content, there was a gradual increase in the elute concentrations. The difference between TS and VS can be seen from the Figure 4.8 illustrating cumulative values. VS indicate the available substrate for methanogenic phase and VS is one of indicative parameters, which can be used to express interactions between microbial growth and substrate utilizations in bioreactors.

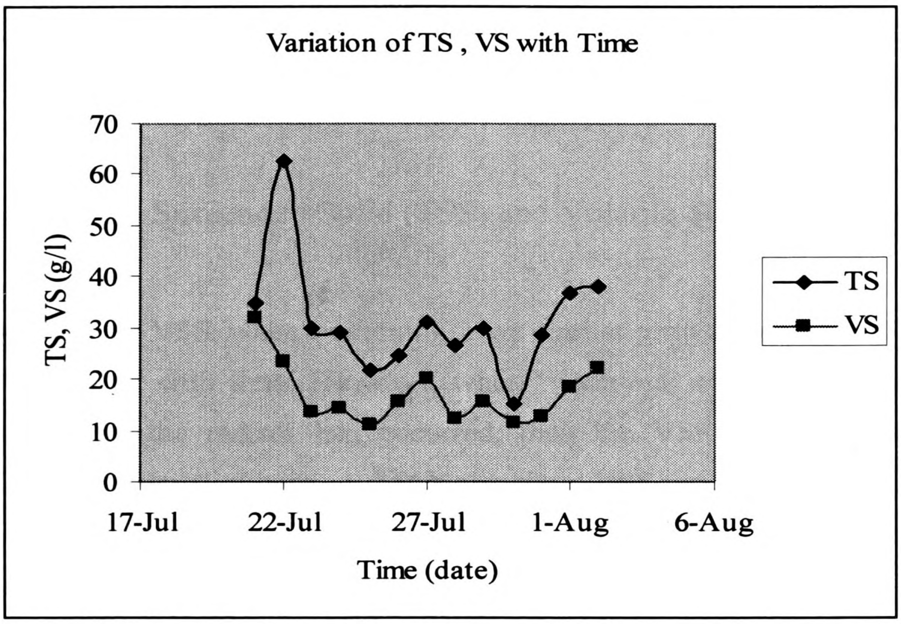


Figure 4.8 variation of TS and VS values with time.

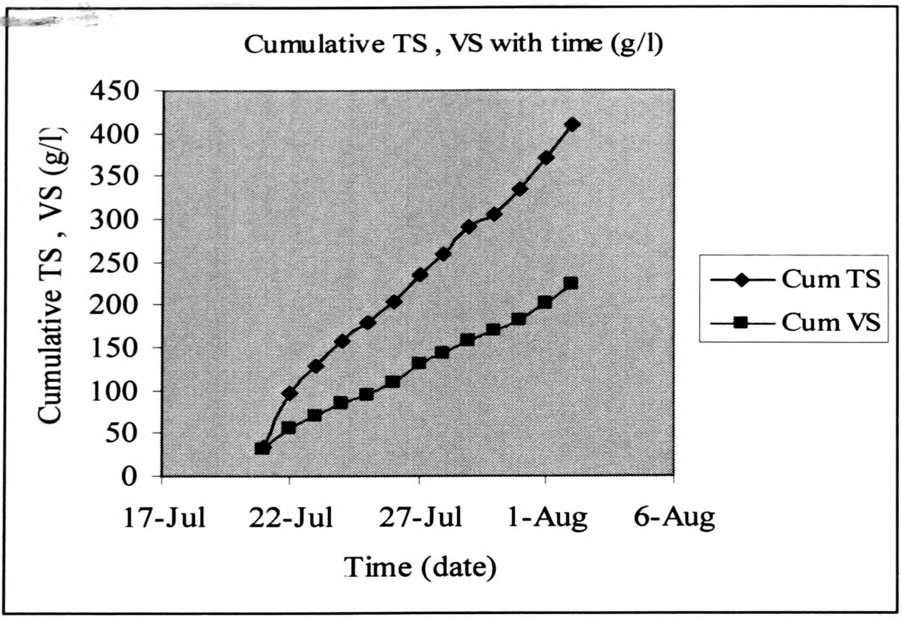


Figure 4.9 Variation of cumulative TS and VS with time.

4.9 Variations of Total Suspended Solid (TSS) and Volatile Suspended Solid (VSS).

In the results of TSS and VSS, when examining, have similar growth patterns to TS and VS, but TSS and VSS increased with time. However, when 'wash-out' or reduced transformation of suspended materials in the reactor had occurred, then the VSS value started to gradually decrease. VSS contain microbial biomass.. In bioreactors, VSS content is directly proportionate to the microbial biomass. The level of inorganic contents in these microbial mass seems to fluctuate with increase and decrease of active cells.

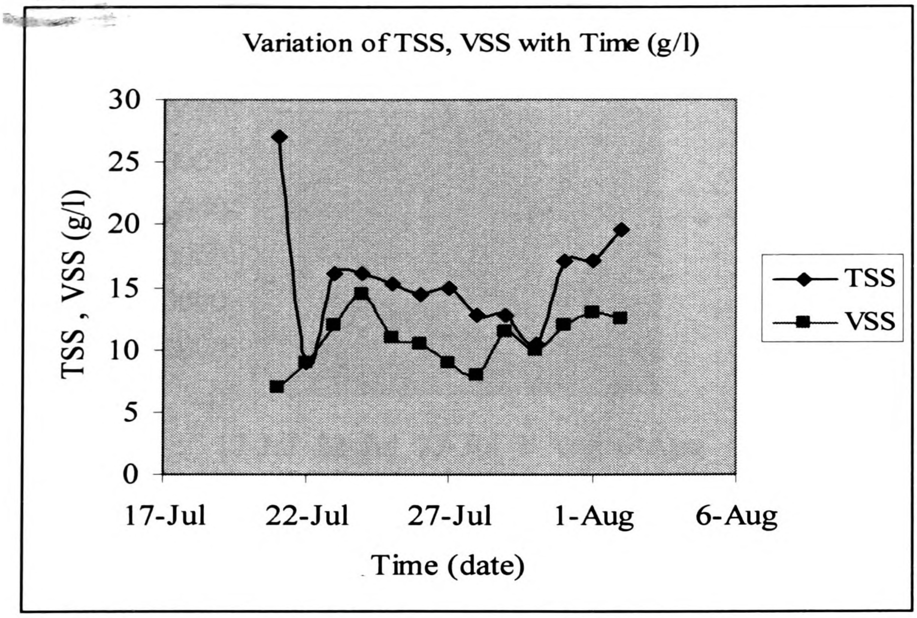


Figure 4.10 Variation of TSS and VSS with time.

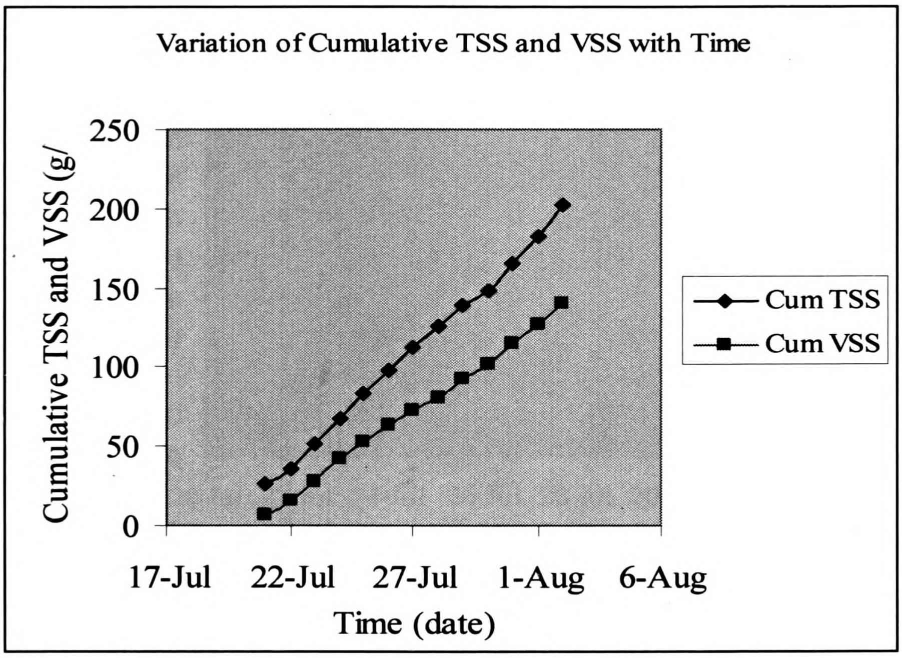


Figure 4.11 Variation of cumulative TSS and VSS with time.

4.10 COD and BOD variations with time.

BOD_5 is used to understand the maturity of the landfill which typically decreases with time(Qasim et al., 1994). The BOD_5 value of MSW landfill leachate ranges from 3.9 to 5700 mg/l. In this research BOD_5 varied from 600 to 10395 mg/l, indicating an inhibition since the COD values seems to increase while BOD_5 reached peak values.

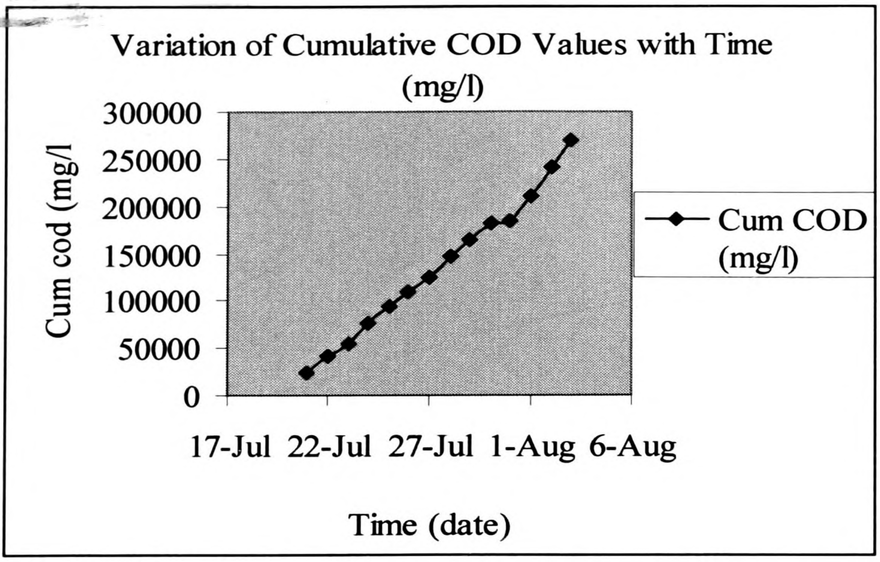


Figure 4.12 Variation of cumulative COD values with time.

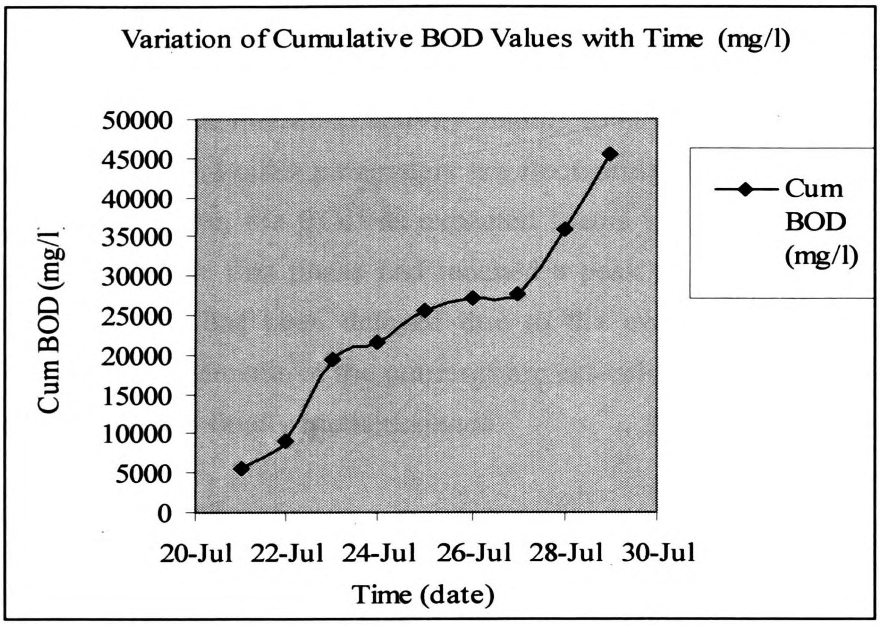


Figure 4.13 Variation of cumulative BOD values with time.

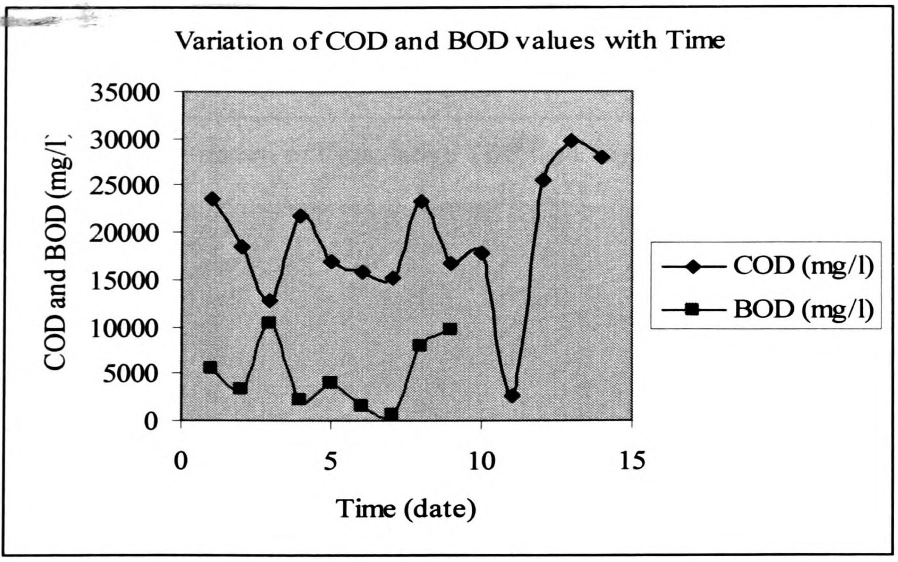


Figure 4.14 Variation of BOD and BOD values with time.

Hydrolysis phase is the governing stage of the reactions to follow. It seems that this phase is prolonged at very low levels of microbial activity leading to large variations between BOD and COD values. Although VS and other parameters are fluctuating, there is an overall increase in the leachate strength. However, the BOD as expected seems to go through carbonaceous and nitrogenous phases, where the first phase had reached a peak at seven days. Also it could be concluded that acetogenesis has been delayed due to the evolution of acid forming gases, namely hydrogen. Thus amendments of the nutrients are essential to promote firstly acidogensis, followed by acedogenesis and finally methenogenes

4.11 Variation of TDS and Conductivity in leachate.

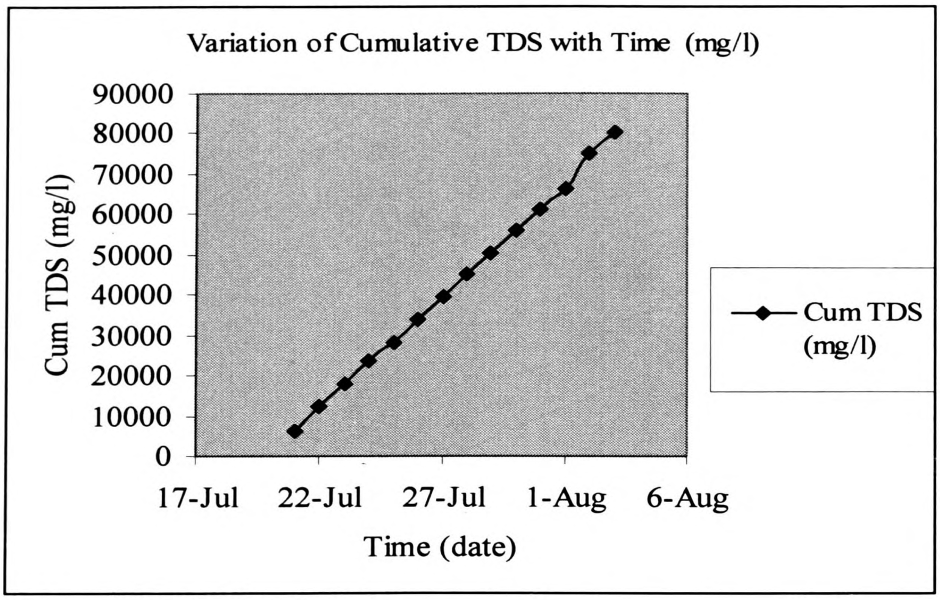


Figure 4.15 Variation of cumulative TDS values with time.

The TDS values increased with time and had a steady rate of increase. It is the product of the biochemical transformations; it is of utmost interest in the conversion processes, since the TDS becomes the substrate for the acedogenic and methanogenic microorganisms. The conductivity and TDS have very close relationship but with the difference of organic solutes as well in measuring TDS. Thus, the mineral composition of the TDS can be found by comparing the values. Also the mineral composition varies depending on microbial activities reflected with the values of TSS and VSS fluctuations.

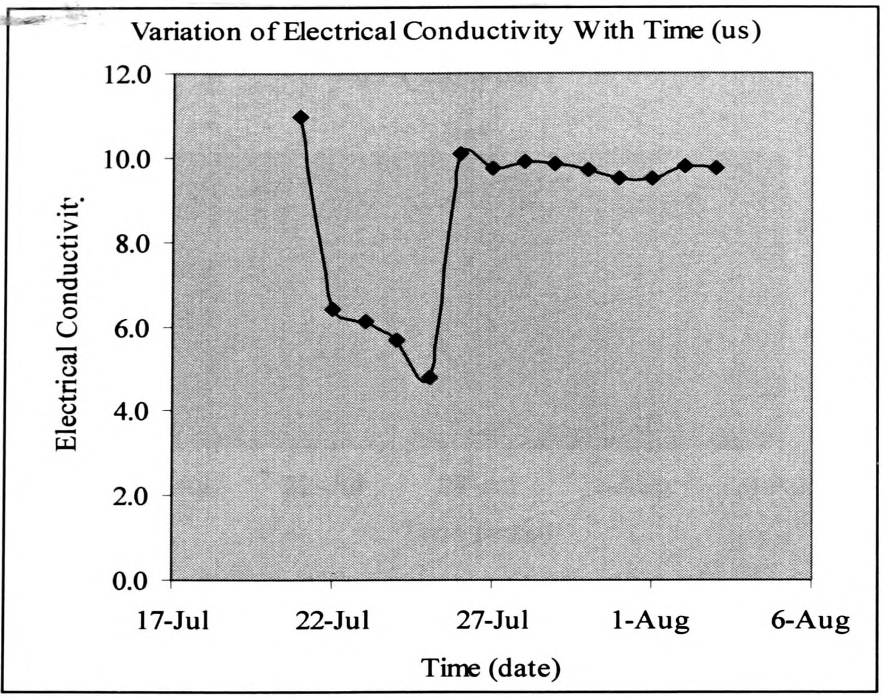


Figure 4.16 Variation of conductivity of leachate.

10.12 Leachate generation with time.

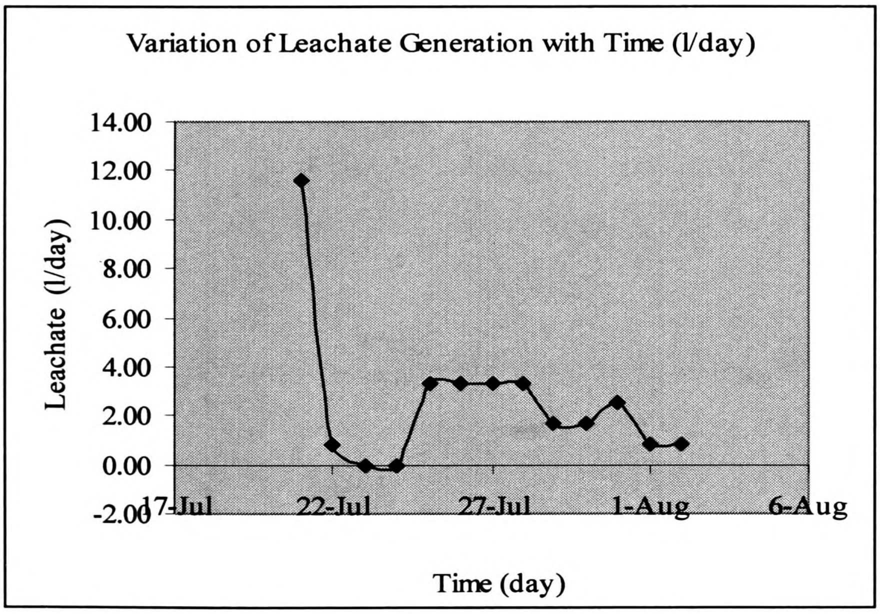


Figure 4.17 Variation of leachate quantity with time.

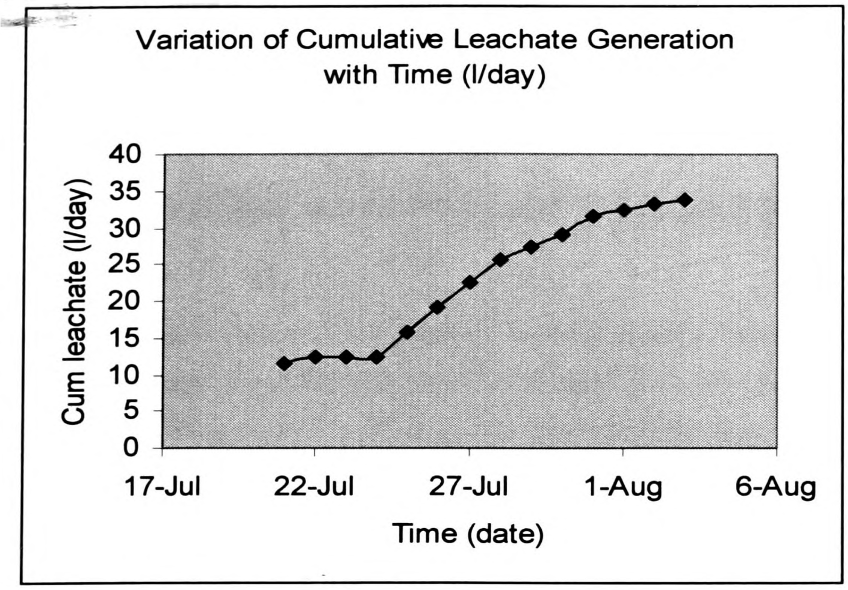


Figure 4.18 Variation of cumulative leachate quantity with time.

In first day, generation of leachate quantity was high but after three days, leachate generation became very low and in fifth day, it was decided to increase the moisture content in the landfill body. Thus after water was added to the reactor, again leachate quantity increased with time.

CHAPTER 5

CONCLUTION AND RECOMMENDATIONS.

The quantity of gas production rate differs from the reported values. Sometimes gas production rate was found to be more than 100 l/day and other times very low. The low gas production may be due to the initial stage of degradation that had been inhibited affecting microorganisms.

This resulted in the reduction of TS, VS, TSS, TDS and Conductivity. These indicative parameters reached stabilized levels since the microbial reactions were inhibited and exogenous food supply had become limiting. The wastes had not been de-polymerized transforming them as dissolved food for microbial activities.

The hydrolysis is the rate limiting phase of the reactions to follow. It seems that this phase is prolonged leading to large variations between BOD and COD values. Although VS and other parameters are fluctuating, there is an overall increase in the leachate strength. However, the BOD as expected seems to go through carbonaceous and nitrogenous phases, where the first phase had reached a peak at seven days. Also it could be concluded that acetogenesis has been delayed due to the evolution of acid forming gases, namely hydrogen. Thus amendments of the nutrients are essential to promote firstly acidogensis, followed by acedogenesis and finally methenogenesis. The delays in biochemical transformation may be due also to the type of the waste in this particular experiment because the quantity of paper was very high.

This lack of rapid waste degradation can be seen in the settlement values. Which were not very high over a period of 14 days. The p^H values did not vary between small to large values. Also the p^H values were not very low at the beginning so hydrolytic reactions were not taking place. Hydrolysis reactions perhaps would have been curtailed reducing the levels of TS and VS. There had been buffering action because of the high organic matter content along the flow path of re-circulating leachate.

A decision ~~has~~ to be made to first promote acid forming reactions and then inoculate with methanogenic bacteria or else to increase the p^H by amending the leachate and then introduce methane bacteria. Further research is needed to find out why inhibitory reactions are taking place at the commencement of these bioreactors and it seems to be an inherent problem of landfill bioreactors as reported by many researchers' operating and evaluating landfill bioreactors.

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