Long Term Emissions from Pretreated Waste: Lysimeter Studies

by

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ABSTRACT

Landfill emissions are the major environmental impact associated with the landfilling of solid wastes. These emissions which are mainly gases and leachate are a result of the anaerobic biochemical breakdown of the waste in landfills. The long term emissions from these solid wastes in landfills can be significantly reduced by Mechanical Biological Pretreatment of the waste prior to landfilling. Mechanical Biological Pretreatment of solid wastes is aimed at reducing the long term polluting potential from landfills through accelerated stabilization of the organic constituent material present in the waste body by biological degradation before the waste is placed in landfills.

This research is part of a broader investigation on the applicability of Mechanical Biological Pretreatment of solid wastes prior to disposal in the South Africa Waste Management context. General waste disposed at Bisasar Road Landfill Site in Durban which has been pretreated for 16 weeks in passively aerated windrows was collected and screened using a rotatory drum screen to generate an over-sieved waste fraction with particles of diameter greater than 50mm and an under-sieved waste fraction characterized by particles diameter less than 50mm. The long term behavior of these heavily pretreated wastes was then simulated using large anaerobic reactors (Lysimeter) in relation to grain size distribution. A third lysimeter containing general waste without pretreatment collected from Bisasar Road Landfill Site was also set up in order to study the effect of pretreatment on solid waste samples. The results of this research were then used to make recommendation on the appropriateness of Mechanical Biological in the South Africa Waste Management context.

DEDICATION

For

Mum, Dad and Mercy

PREFACE

The work presented in this dissertation was carried out at the School of Civil Engineering, Surveying and Construction, University of Kwa-Zulu Natal Durban South Africa under the Supervision of Dr Cristina Trois. This dissertation has been prepared in accordance with the Style Guide for Dissertations prepared by the Civil Engineering Programme, University of Kwa-Zulu Natal, Durban.

This dissertation was written by Babatunde Femi Bakare and it is the authors own work and has not been submitted in part, or in whole to any other University.

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Babatunde Femi Bakare.

This dissertation has been approved for submission by my supervisor, Dr Cristina Trois.

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Dr Cristina Trois.

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CHAPTER 1

INTRODUCTION

The modern society is faced with daily increase in the amount of solid wastes generated as a result of accelerated increase in urbanization, industrialization and population growth and as such are challenged with the problem of how to properly manage the increasing amount of solid wastes generated and how to eliminate the environmental and health impact associated with the high concentrations of waste to human beings and the environment. The disposal on or in the earth's mantle referred to as landfilling is, at present, the only viable method in South Africa for the long term handling of solid wastes collected from residential, commercial, institutional and industrial sources. Over 95% of all urban solid waste generated in South Africa is been disposed off in landfills (DWAF, 1998). Following the deposition of collected solid wastes on landfill sites and often before, the organic fraction of the waste begins to degrade. The degradation process occurs through microbial action and interrelated physical and chemical processes which result in biochemical breakdown products and the liberation of gases. The infiltration of rainfall, groundwater and surface water into the waste body in the landfill coupled with the biochemical and physical breakdown of the constituents material in the waste body results in the generation of highly polluted liquid containing soluble components of the waste, suspended solids, and microorganisms referred to as leachates (Williams, 1998).

These two emissions (gases and leachates) from the waste body in landfills are the major long term environmental problem associated with solid waste disposal. This has motivated research into the development of various technological options aimed at reducing the long term environmental impacts associated with solid waste. One such option is Mechanical Biological Pretreatment (MBP) of solid waste prior to disposal. Mechanical Biological Pretreatment is aimed at reducing the long term polluting potential from landfills through accelerated stabilization of the organic constituent material present in the waste body by biological degradation before the waste is placed in landfills. In South Africa, Mechanical Biological Pretreatment methods are not currently adopted and refuse is disposed untreated and unsorted. This

study is part of a broader investigation on the applicability of MBP in the South African waste management context. General waste disposed at the Bisasar Road Landfill Site in Durban was pretreated for 8 and 16 weeks in passively aerated windrows (Dome Aeration Technology). The use of Dome Aeration Technology is found appropriate within the South African waste management context in terms of low cost, low energy input and potential for labour intensive operations (Trois et al, 2006). The output of this process was screened to generate an oversieved sample (coarse) with particle diameter greater than 50mm and an undersieved sample (fines) characterized by particles of diameter less than 50mm. This was done in order to gain an insight into the effect of grain size on leachate contamination and to prove the hypothesis that it is the oversieved waste sample (coarse) which comprises the slowly or non degradable components of the waste that presents the long term emissions from pretreated waste. In this aspect of the research, the long term behaviour of waste which was heavily pretreated for 16weeks is simulated using large anaerobic reactors (Lysimeters) in relation to grain size distribution.

The objectives of the research were:
- To investigate degradation processes in anaerobic environment of heavily pretreated waste.
- To investigate the effect of grain size on leachate contamination.

The research and findings are presented in the following chapters of the dissertation. Chapter 2 is a literature review on landfill emissions and processes, leachate and biogas emission production. Chapter 3 focuses on literature review on waste pretreatment and its effect on landfill emissions with particular focus on aerobic pretreatment, composting operations, description of the Dome Aeration Technology, and behaviour of pretreated waste in anaerobic lysimeters with comparisons in terms of leachate quality and biogas production. Chapter 4 presents the methodological approach used in carrying out the research work, all the laboratory analysis carried out which includes the lysimeter set up, waste sampling and characterization, process monitoring and leachate characterization. Chapter 5 presents the experimental results with brief discussions. Chapter 6 concludes the dissertation by providing a summary of the findings and final comments on the results presented in chapter 5.

CHAPTER 2

LANDFILL EMISSIONS

2.1 INTRODUCION

Landfills are the oldest form of waste disposal. A landfill is an area which is used for the disposal of waste on land. Over 95% of all urban solid waste in South Africa is been disposed in landfills (DWAF, 1998). The major environmental hazards associated with the disposal of solid waste in landfills are gases generated from degradation of organics and the leachate generated from the moisture that percolates through the waste body. These gaseous and liquid emissions have been shown to have various impacts on the environment in relation to air, land, and water (Christensen *et al*, 1995). However, modern landfills are designed to contain the waste within the landfill site by managing the leachate and landfill gas in order to reduce the environmental impact associated with their operations (Williams, 1998).

2.2 LANDFILL EMISSION STAGES

Emissions from landfills are produced as a result of waste degradation processes. These waste degradation processes occurring in landfills involve not only biological processes but also interrelated physical and chemical processes (Christensen et al, 1996). Robinson (1989) described the characteristics of significant landfill emissions as a three stage process: Aerobic stage, Acid stage and Methanogenic stage.

AEROBIC STAGE

The aerobic stage occurs immediately after landfilling of the waste and for a short period of time, usually less than a month. This stage makes use of the available oxygen present within the waste. Large quantities of hydrogen, usually up to about 20% by volume, can be produced during this stage, particularly if the site is dry.

The duration of this stage depends on the amount of oxygen available for the process, the degree of compaction of the wastes in the landfill and how quickly the waste is covered either by incoming waste or by inert cover material.

ACID STAGE

The acid stage is characterized by the anaerobic and facultative microbes hydrolyzing and fermenting cellulose and other putrescible materials present in the waste to produce simpler soluble compounds such as volatile fatty acids and ammonia.

The leachates produced have high COD values commonly greater than 10000mg/l and BOD to COD ratios of 0.7 or more. The pH values of the leachates are usually in the acidic range, typically 5-6, with strong unpleasant odours and high concentrations of ammonical-N ranging from 500-1000mg/l. The aggressive chemical nature of the leachates assists in dissolution of other components of the waste resulting in high levels of iron, manganese, zinc, calcium, and magnesium in the leachate. Carbon dioxide is mainly produced during this stage with low quantities of methane and hydrogen. The time frame of this stage for warmer climates such as subtropical areas of South Africa and Australia is between six to nine months (Lombard, 2000).

METHANOGENIC STAGE

During this stage, the methanogenic microbes convert the soluble organic compounds in the absence of oxygen into methane and carbon dioxide which are emitted as landfill gas. The active production of gas can last for several years at a relatively high rate and might continue at a gradually reducing rate over a period of many decades.

The leachates produced during the methanogenic stage are characterized by low COD values, low BOD to COD ratio and pH values usually neutral/alkaline indicating the degradation of organic acids to methane and carbondioxide by the methanogenic microbes (Williams 1998). The concentration of ammonical-N in the leachates remains high. Inorganic substances such as iron, sodium, potassium, sulphate, and chlorides may continue to dissolve and leach from the landfill. The duration of the methanogenic stage lasts from years to decades depending on the waste composition and the type of landfill technology in place (Christensen *et al*, 1995).

2.3 LEACHATE AND LANDFILL GAS: (PRODUCTION AND QUALITY)

The stages of waste degradation discussed earlier produce characteristic leachate and landfill gas compositions. These leachate and landfill gas compositions change with time as waste degradation processes within the landfill progresses and it is generally used to define the age of the landfill.

2.3.1 LEACHATE PRODUCTION

Landfill leachate is the water which passes through the waste and water generated within the landfill site, resulting in a liquid containing suspended solids, soluble components of the waste and products from the degradation of the waste by the micro-organisms (Williams, 1998). For leachate to be generated from a landfill site, the waste must reach its field capacity. According to Novella (1995), the field capacity is defined as the maximum moisture content held in compacted waste in a landfill by capillary action. The quality of the leachate generated from the landfill site also depends on the volume of water that percolates through the waste body within the site. This process results in dilution of soluble compounds.

The liquid to solid ratio is a parameter used to give an indication of the degree of dilution in a landfill site and is calculated by dividing the total volume of water that has come in contact with the waste by the dry mass of the waste. The flux of moisture through the waste body in the landfill site depends on the site water balance. According to Blight et al (1992), the moisture contributions which form part of the landfill site water balance are as follows:

Water input
- Precipitation (P)
- Water contained in incoming waste/ daily cover (Uw)

Water output
- Leachate generated (L)
- Runoff (R)
- Evapotranspiration (ET)
- Biochemical Processes (G)

Water retained
- By waste retained (ΔUw)
- By the cover material (ΔUc)

Hence, the annual water balance is then expressed mathematically as follows:

$$P + Uw = ET + L + R + (\Delta Uw) + (\Delta Uc) + G \qquad\qquad 2.1$$

Couth (2000) states the parameters that affects the water balance model as:
- Rainfall (actual and effective)
- Infiltration through the capping system
- Waste absorptive capacity
- Waste input
- Phase area
- Liquid waste inputs

The performance of the landfill capping system and the absorptive capacity of the waste are the critical parameters of all. Various models have been derived to predict the quantity of landfill leachate based on available data describing the hydraulic behavior of the waste and local meteorological data. The most common model is the water balance which allows a proper leachate management plan at landfill sites. The water balance calculates the quantities of all liquids entering and leaving the landfill site at a specific period (Couth, 2000). The quantity of landfill leachate is greatly influenced by rainfall, the composition of the solid wastes disposed in the landfill site, water content in the cover soil layers, evapotranspiration and surface run off (Furuta *et al*, 1995). In South Africa, the water balance method is used to predict the volume of leachate generated at waste disposal sites, to determine co-disposal (liquid/solid) ratios and to specify site design and engineering requirements (Parsons, 1995).

2.3.2 LEACHATE QUALITY

Leachate quality depends on the type and composition of the waste, the stage of degradation reached by the waste, moisture content of the waste body and the operational procedures carried out at the landfill site (Williams, 1998). Table 2.1 shows typical compositions of landfill leachate.

Table 2.1 Typical landfill leachate compositions (Quasim et al, 1994)

Constituent	Value, mg/L[a]		Mature landfill (greater than two years)
	New Landfill (less than 2 years)		
	Range[b]	Typical[c]	Range[b]
BOD$_5$ (5-day biochemical oxygen demand)	2,000 – 30,000	10,000	100 – 200
TOC (total organic carbon)	1,500 – 20,000	6,000	80 - 160
COD (chemical oxygen demand)	3,000 – 60,000	18,000	100 – 500
Total suspended solids	200 – 2,000	500	100 – 400
Organic nitrogen	10 – 800	200	80 – 120
Ammonia nitrogen	10 – 800	200	20 – 40
Nitrate	5 – 40	25	5 – 10
Total phosphorus	5 – 100	30	5 – 10
Ortho phosphorus	4 – 80	20	4 – 8
Alkalinity as CaCO$_3$	1,000 – 10,000	3,000	200 – 1,000
pH	4,5 – 7,5	6,0	6,6 – 7,5
Total hardness as CaCO$_3$	300 – 10,000	3,500	200 – 500
Calcium	200 – 3,000	1,000	100 – 400
Magnesium	50 – 1,500	250	50 – 200
Potassium	200 – 1,000	300	50 – 400
Sodium	200 – 2,500	500	100 – 200
Chloride	200 – 3,000	500	100 – 400
Sulfate	50 – 1,000	300	20 – 50
Total Iron	50 – 1,200	60	20 – 200

[a] Except pH, which has no units.

[b] Representative range of values. Higher maximum values have been reported in the literature for some of the constituents.

[c] Typical values for new landfills will vary with the metabolic state of the landfill.

The leachates produced during the early stages of the anaerobic degradation are characterized by high concentrations of volatile fatty acids, acidic pH, high BOD to COD ratios, and high concentration of ammonical nitrogen and organic nitrogen. The high levels of ammonical nitrogen are a result of the degradation of amino acids of proteins and other nitrogenous compounds in the waste and also the high BOD to COD ratio indicates that high proportion of the organic materials in solution are readily biodegradable (Williams, 1998).

Methanogenic leachates are characterized by a neutral & alkaline pH values reflecting the degradation of organic acids to produce methane and carbon dioxide. As the leachate pH increases, the metal ions become less soluble and decreases in concentration. Ammonical nitrogen concentration in the leachate decreases slightly but remains high and the levels of BOD and COD decreases (Williams, 1998).

2.3.3 LANDFILL GAS

Various gases such as carbon dioxide, carbon monoxide, hydrogen, hydrogen sulphide, methane, nitrogen and oxygen are found in landfills with carbondioxide and methane been the principal gases produced during the anaerobic bacteria decomposition of the organic solid waste components in the landfill (Peavy, 1985). The composition of gas produced in landfills varies with time according to the stage of biodegradation reached.

The major constituents of landfill gas, methane and carbondioxide are odourless, but the minor components such as hydrogen sulphide, organic esters, and organosulphur compounds give the landfill a malodourous smell (Williams, 1998). Table 2.2 presents the characteristics of landfill gas components.

Table 2.2 Characteristics of landfill gas components (Couth, 2000)

Components	Density(g/l)	Odour	Colour	Flammable	Comments
Methane	0.71	Odourless	Colourless	Yes	Very low solubility in water at STP. Important green house gas.
Carbondioxide	1.98	Odourless	Colourless	No	Slightly acidic at high concentration. Very soluble in water, forming corrosive liquids of low pH.

Hydrogen sulphide	1.53	Rotten egg	Colourless	Yes	High odour which is toxic
Hydrogen	0.09	Odourless	Colourless	Yes	-
Oxygen	1.42	Odourless	Colourless	No	-
Nitrogen	1.25	Odourless	Colourless	No	-

During the initial degradation processes occurring within the landfill, significant levels of hydrogen and carbon dioxide are produced due to the process of hydrolysis and fermentation of the organic fraction. As acetogenesis begins the level of hydrogen and carbondioxide decreases. The low level of hydrogen at this stage promotes the methane generating microorganisms which generate methane and carbondioxide from the organic acid and their derivatives generated from the earlier stages of degradation (Williams, 1998).

The methanogenic stage is usually the main landfill gas generation stage with typical landfill gas composition of approximately 60% by volume methane and 40% by volume carbodioxide (Williams, 1998). The methanogenic stage often last for many years with the highest methane production rate expected to occur at the beginning of the stage which should decrease gradually and be negligible towards the end of the stage as the final degradation stage sets in (Christensen *et al*, 1995). The final stage marks the end of the reaction and a return to aerobic conditions (Williams, 1998).

The quantities of gas produced from the waste depend on the biodegradable fraction of the waste, the presence of microorganisms, suitable aerobic and anaerobic conditions and moisture (Williams, 1998).

2.3.4 FACTORS AFFECTING LANDFILL GAS PRODUCTION RATE

The production rate of landfill gas is influenced by several factors. These factors include; temperature, oxygen, pH and alkalinity, hydrogen, sulphate, water content, nutrients, and inhibitors (Christensen et al, 1996).

Temperature

Temperature has a great influence on microbial degradation activity. Couth (2000), states that optimum methane production is observed at high temperature, typically 38^oC. In laboratory landfill simulators, methane production rate has been shown to increase significantly (by up to 100 times) when temperature is raised from 20-30°C and 40°C (Buivid, 1980; Ehrig, 1984).

Anaerobic degradation of wastes produces much less heat when compared to aerobic processes, however elevated temperatures between 30-45°C in landfills have been reported (Rees, 1980b). These elevated temperatures can only be observed in landfills with high methane production rates, a moderate water flux and substantial waste thickness. At high temperatures, the rate at which methane is been produced is more vigorous and as such results in production of more heat.

Oxygen

An absence of free oxygen is required for anaerobic microbial activity and growth. The methanogenic microbes which are sensitive require very low redox potential for their activity. Oxygen may enter the landfill by diffusion from the atmosphere or through advection. The methanogenic community is not completely depleted by the introduction of oxygen, and will recover by adapting to facultative microbes.

pH and Alkalinity

Based on an analogy to anaerobic processes, alkalinity should be greater than 2000mg/l and the optimal process pH is between 6.7 and 7.2 (Farquar, 1973). According to Zender et al, (1982), the methanogenic bacteria operate efficiently only within a narrow pH range of 6-8. If the methanogenic microbes are affected by other factors, their ability to covert hydrogen and acetic acids will reduce leading to an accumulation of volatile organic acids and the pH will decrease which may inhibit the production of methane and eventually stop the generation of methane.

Hydrogen

According to Couth (2000) greater hydrogen partial pressure results in a reduction of methane production rate. In landfills, both the fermentative and acetogenic microbes produce hydrogen. At low hydrogen partial pressure, fermentative microbes produce hydrogen, carbodioxide and acetic acid while at high hydrogen partial pressures they produce hydrogen, carbodioxide, ethanol, butyric acid and propionic acid (McLnerney and Bryant, 1983). This organic acid may be further converted by the acetogenic bacteria at low hydrogen partial pressure, meaning that when the hydrogen partial pressure increases, propionic acid, and also to some extent butyric acids, will be generated without further conversion which potentially leads to an accumulation of volatile organic acids, a decrease in pH and possibly inhibition of the production of methane.

Sulphate

The conversion of acetic acid and hydrogen is carried out by both the sulphate reducing microorganisms and the methanogenic microorganisms. Investigations involving both batch experiments and landfill simulators have shown that the presence of sulphate in high concentrations significantly reduces methane production (Stegmann et al, 1985). The inhibition of methane production by sulphate is not associated with any toxic effects of sulphate on the methanogenic microbes, but is due to substrate competition.

Water content

The production of methane increases with increasing moisture content (Couth, 2000; Buivid, 1980; Rees, 1980). Active methane generation requires a refuse moisture content of 50 to 100% of the dry weight of wastes (30 to 50%, wet weight basis) (Ham, 1979). The main effect of increased water content, besides limiting the oxygen transport from the atmosphere, is probably the facilitated exchange of substrate nutrients, buffer, and possibly dilution of the inhibitors and spreading of microorganisms in niche areas (Christensen et al, 1989).

Nutrients

The anaerobic ecosystem must, apart from organic matter, have access to all required nutrients in particular nitrogen and phosphorus. All the necessary micro nutrients e.g. sulphur, calcium, magnesium, potassium, iron, zinc, copper, cobalt, molybdenite and

selenium are considered to be available in most landfills (Christensen *et al*, 1996). In anaerobic degradation, nitrogen and phosphorus are required in much less quantity compared to the aerobic system. Optimal ratios between organic matter expressed as COD, nitrogen and phosphorus is 100:16:1 (McCarty, 1964). In most landfills the presence of nitrogen and phosphorus will not be limiting but insufficient homogenization of the waste may lead to areas in the landfill that are nutrient limited.

Inhibitors

The methane forming environments is considered sensitive to inhibitors (Christensen *et al,* 1996). High carbondioxide pressure, high levels of sodium, potassium, and calcium may have inhibitory effects on the production of methane (Couth, 2000). Johnson (1981) summarized the data on inhibition by specific organic compounds and these indicated that most investigated compounds should be present in concentrations above 10mg/l and many above 100mg/l to cause substantial inhibition of methane production. Such high concentrations are only expected rarely and only in landfills receiving substantial amounts of industrial wastes. In most landfill environments, these inhibitors are present but in concentrations too low to have any significant effect on the production of methane, although they may cause a reduction in the methane production rate.

CHAPTER 3

WASTE TREATMENT AND ITS EFFECT ON

LANDFILL EMISSIONS

3.1 INTRODUCTION

The long term environmental impacts associated with the disposal of solid waste in landfills in terms of gaseous emissions (mainly methane and carbondioxide) and the high polluting leachate generated have led to various options of handling solid waste before its disposal.

Among others, the pretreatment of solid waste either by mechanical biological processes or by thermal treatment process (incineration) used for the treatment purposes before the landfilling of solid waste is generally aimed at reducing the environmental impacts related to the emissions from landfills by accelerating the stabilization of the degradable components of the solid waste.

The study of the effects of solid waste pretreatment on landfill emissions has been widely documented (Leikam *et al*, 1997; Scarff *et al*, 1995; Pichler *et al*, 1999; Robinson *et al*, 2005 and others). These studies show that when solid waste is pretreated before its disposal in landfill sites, the polluting potential of the emissions generated are reduced to a large extent. In addition to this reduction the degradation processes that generally takes many years or even decades as shown to be shortened to a few years.

3.2 WASTE PRETREATMENT PROCESSES

The most common methods in use for the pretreatment of municipal solid waste (MSW) are thermal pretreatment (incineration) and mechanical biological pretreatment. The mechanical biological pretreatment can be applied as a single treatment process or in combination with thermal pretreatment (Soyez, *et al*, 1997). The residues from the pretreated municipal solid waste may be landfilled directly or applied to soil as a soil conditioner once the waste as been processed.

3.2.1 THERMAL PRETREATMENT (WASTE INCINERATION)

Over the past few years, the use of incineration as a waste pretreatment technique has increased rapidly mainly to reduce the amount of waste and to decrease their biological activity (Bramryd, *et al*, 2001). Incineration of waste involves the controlled thermal treatment of waste by burning, with or without energy recovery.

Williams (1998), states a number of advantages of waste incineration as follows:

- Incineration of waste reduces the waste into a biologically sterile ash product and for municipal solid waste; it reduces the waste to approximately one tenth of its original volume and one third of its original weight.
- Incineration of waste produces no methane which is a green house gas and a significant contributor to global warming.
- Waste incineration can be used as a low cost source of energy to produce steam for electric power generation, industrial process heating or hot water for district heating thereby conserving valuable primary fuel resources.
- The bottom ash residues can be used for materials recovery or as a secondary aggregate in construction.
- Incineration is also the best practical environmental options for the treatment of many hazardous wastes such as highly flammable, volatile, toxic and infectious waste.

And also a number of disadvantages as follow:

- Incinerations entail much higher costs and longer pay back periods due to high capital investment.
- Because of the high capital cost of incinerator plants, the plant design must be tied to long term waste disposal contracts with little flexibility in the choice of waste disposal options once the incineration route is choosen.
- The incinerator is designed on the basis of a certain calorific value for the waste and a removal of materials such as papers and plastics for recycling may reduce the overall calorific value of the waste and consequently may affect the incinerator performance.

- Although modern incinerators do comply with existing emission regulations, the public are still concerned with the adverse effects associated with the emissions from incinerators on health.

3.2.2 MECHANICAL BIOLOGICAL PRETREATMENT OF SOLID WASTE

Mechanical biological pretreatment of municipal solid waste involves mechanical preparation of the waste and biological degradation. The mechanical process involves separation of materials such as glass, plastics, stones etc from the waste as well as optimizing the biological degradation of the remaining wastes by increasing homogeneity while the biological process involves the degradation of the remaining organic materials such as kitchen and green waste, paper etc to the greatest possible extent by the application of anaerobic or aerobic processing technologies (Raninger, *et al*, 1997).

The major benefits of mechanical biological treatment of municipal solid waste are reduction in waste volumes usually by 20-30% (Leikam, *et al*, 1997), reduction in biogas production and reduction in the organic strength of leachates. Bone, *et al* (2003) state that the degrees of these benefits are dependant on certain site specific factors which are:
- The extent of source separation
- Waste input
- The type of mechanical pretreatment
- The type and duration of the biological pretreatment.

These factors will also have an influence on the nature of the material that is finally placed in landfills and influences the emission potential of the landfill.

When compared with thermal pretreatment (incineration), mechanical biological treatment processes have the advantage of reduced gaseous emissions and low operational costs (Soyez *et al*,1997), and a disadvantage of higher emission potential when the pretreated residue is been landfilled compared to the emissions from landfilling the slag produced from incinerators (Leikam *et al*, 1997).

Mechanical treatment Processes

The mechanical treatment process involves shredding/homogenization, sorting and regulation of certain physical and chemical properties of the waste in order to optimize the biological degradation of the waste during the biological treatment processes. These properties are moisture content of the waste, particle size and carbon /nitrogen ratio.

Shredding/Homogenization

By shredding, a reduction in volume and an increase in the specific surface area of the wastes is attained. Due to this enlargement, the biological degradation taking place in the subsequent biological pretreatment step is enhanced (Leikam *et al*, 1997). The landfill properties of the waste are also improved by homogenization of the waste (Heerenklage, *et al*, 1995). Shredding of the waste can be carried out by the following ways:

- High speed hammer/impact mills
- Low speed knife shredders
- Screw, worm and cascade mills.

Sorting

Sorting of wastes as a mechanical treatment for waste can be done before and after the biological treatment process (Soyez *et al*, 2003). The use of screen sizes between 60 and 100mm has proven to be effective in separating the waste that is highly biodegradable from those that are of high calorific value. A grain size distribution of unshredded residual municipal solid waste shows that using a mesh size of 80mm, over 90% of the vegetable residues are in the sieve underflow and nearly 70% of the materials with high calorific value, like plastics and paper, are in the sieve overflow (Leikam *et al*, 1997). Sorting operations can be done by using:

- Rotating sieving drums
- Hand sorting
- Magnetic separators (for the separation of ferrous materials in the waste).
- Ballistic separation for light fractions.

Biological treatment Processes

The application of biological treatment processes in mechanical biological pretreatment of municipal solid waste can be carried out either by anaerobic process or aerobic processes.

The anaerobic pretreatment involves the conversion of the organic waste residues to produce biogas and digestion residue in the absence of oxygen. It has several advantages when compared to aerobic pretreatment which includes small space requirements, modular construction, a net gain in energy from biogas production as well as minimal odour problems due to closed construction. Anaerobic process for municipal solid waste pretreatment has to be run in combination with aerobic process since not all organic substances e.g. ammonia can be degraded in an anaerobic process within acceptable treatment times. (Heerenklage *et al*, 1995).

The aerobic process for biological waste treatment is most commonly used (Krogmann, 1995). During the aerobic process of waste pretreatment, carbodioxide, water, and salts are released; the biomass of degrading microorganism increases and carbon becomes fixed in humic substances (Krogmann, 1995). The aerobic pretreatment process requires a constant supply of oxygen for the microbial activity. The three major aeration principles applied for constant supply of oxygen during aerobic degradation processes are waste agitation (turning), forced aeration and natural (convective/diffusive) aeration (Gray *et al*, 1971).

During the aerobic degradation process, a large amount of heat is produced which enhances the degradation process (Krogmann, 1995). Because of the wide utilization of aerobic pretreatment of municipal solid waste, more focus on the aerobic treatment processes will be considered in the next section.

3.3 COMPOSTING

The fundamentals behind aerobic waste pretreatment can be based on the principles of waste composting operations. Composting involves the biochemical breakdown of the degradable organic fraction present in the waste material by microorganisms in the presence of sufficient supply of oxygen resulting in an increase in temperature and production of carbon dioxide, water and cellular protoplasm (Gray *et al*, 1971).

Composting process consists of four phases as described by Gray *et al,* (1971) which are the mesophillic phase, thermophillic phase, cooling phase and maturation phase.

Mesophillic phase

The mesophillic phase is the first phase that occurs during composting. Initially the waste mass is usually at room temperature, the temperature within the waste pile increases rapidly as soon as the mesophillic microbes are established and begin to multiply. The mesophillic microbial activities results in the production of simple organic acids which reduces the pH to an acidic pH range. The activity of the mesophillic microbes is reduced at a temperature greater than $40^{o}C$ and as soon as the temperature exceeds $40^{o}C$, the thermophillic microbes become dominant which marks the beginning of the thermophillic phase.

Thermophillic phase

Thermophillic phase is the second phase occurring during composting. During this phase, there is usually an increase in the pH value and the nitrogen content of the waste is liberated as ammonia. At temperatures above $60^{o}c$, the thermophillic microbial activity is been inhibited and this results in a reduction in their multiplication and their death. The spore forming bacteria and actinomycetes continue the degradation process within the waste pile. Proteins and hemicelluloses are readily degraded at these high temperatures while cellulose and lignin are rarely affected. The reaction rate decreases as a result of the consumption of the readily degradable fractions in the waste and the thermophillic phase comes to an end. As a result of the decrease in the reaction rate, the rate at which heat energy is generated reduces within the waste pile, leading to the cooling off of the waste mass thereby marking the beginning of the cooling phase.

Cooling phase

At this phase, the temperature continues to decrease towards the ambient temperature and once the temperature falls below $60^{o}c$, the thermophillic microbes become re-established and the degradation of the cellulose fraction continues. As soon as the temperature reduces to less than $40^{o}c$ the mesophillic microbes becomes active and the maturation phase sets in.

Maturation phase

This the final stage in the composting process and a stable end product, 'humus' is produced. The first three phases of the composting process takes place relatively quickly and are over within a matter of days to weeks while the maturation stage usually requires a period of a month (Gray *et al*, 1971).

3.3.1 FACTORS INFLUENCING COMPOSTING

Composting processes are influenced by several factors. These factors in one way or another influences the efficiency of the composting process. The factors influencing composting processes are briefly described below.

Oxygen

Composting requires an adequate supply of oxygen in order to maintain an efficient aerobic microbial activity. The oxygen requirements are dependant on the type of material (e.g. nutrients, particle size), the process temperature, the stage of the process (e.g. higher oxygen demand in the early stages), and the process conditions (e.g. moisture content, pore structure) (Stentiford, 1996). A lack of oxygen supply in the course of the composting periods can result in an anaerobic condition and the rate of degradation will decrease which will also lead to the generation of offensive odours and methane (EPA, 1995). A Minimum oxygen content in the compost of 18% is recommended (Williams, 1998).

pH

Optimal composting is achieved in the pH range of 5.5-8. Bacteria prefer a near neutral pH while fungi develop better in acidic environments (Williams, 1998).

Carbon: Nitrogen ratio

Carbon and nitrogen are the two key elements in composting; the carbon acts as food to the microorganism while the nitrogen acts as digestive enzymes to these organisms (Barnard, 2006). The presence of carbon is usually not a limiting factor in composting because of its abundance in biodegradable municipal organics although the presence of nitrogen may raise concern. The Carbon: Nitrogen ratio in the starting material is about 25, higher ratios resulting in a slow rate of degradation and lower ratios resulting in

nitrogen loss (Williams, 1998). A ratio of available carbon to nitrogen of 30-50:1 is considered ideal (EPA, 1995). Typical carbon to nitrogen ratios are given in table 3.1

Table 3.1 Typical carbon: nitrogen ratios for various materials.

MATERIALS	CARBON: NITOGEN RATIOS	SOURCES
Yard trimmings	20-80 : 1[*]	EPA, (1995)
Wood chips	400-700 :1[*]	EPA,(1995)
Saw dust	100 :1[***]	Cillie, (1971)
Manure	15-20 : 1[*]	EPA, (1995)
Finished compost	15-20 :1[*] <30: 1[***]	EPA, (1995) Cillie, (1971)
Raw sewage sludge	7-12 : 1[***]	Williams, (1998)
Municipal waste	40-100:1[*] 26-45:1[**] 30-60:1[***]	EPA, (1995) Williams, (1998) Cillie, (1971)

Moisture

The presence of moisture within the waste material influences microbial activity. Moisture content below a minimum of 40% reduces biodegradation activity significantly and high moisture content should also be avoided because the moisture occupies intraparticle spaces and thereby produces anaerobic conditions (Williams, 1998). Moisture content within 50-60% of the total weight is considered to be ideal (Peavy *et al*, 1985; EPA, 1995).

Temperature

During composting, high metabolic activity and exothermic processes produce an increased temperature in the compost heap which is because of the low thermal conductivity of the waste material and therefore the dissipation of these thermal energy is limited which consequently results in temperature rise (William,1998). The maximum microbial activity is observed in the temperature range of 30-35°c (Williams, 1998). Microbial activities are greatly influenced by temperature and all microorganisms have

an optimal temperature in which they are active. Table 3.2 shows the effects of different temperature range.

Table 3.2 Effects of Temperature Range on Composting (Stentiford, 1993).

TEMPERATURE RANGE (°c)	RESULTS
>55	Max sanitation
45-55	Max biodegradation rate
35-40	Max biological diversity

As a result of the competition between different microbial species, pathogen destruction or sanitation occurring within the compost heap is greater than that reached by thermal destruction (Gray *et al*, 1971). Table 3.3 shows the requirements for sanitation for various countries in Europe.

Table 3.3 Sanitation Requirements for composting in Europe (Stentiford, 1996).

COUNTRY	TEMPERATURE (oc)	EXPOSURE (DAYS)
Austria	65	6 (2×3)
Belgium	60	4
Denmark	55	14
France	60	4
Italy	55	3
Netherlands	55	2

Material size

The material size is an important factor that influences the composting process. Shredding of the starting waste material increases the surface area and results in enhanced rates of biodegradation (Williams, 1998).

According to Elias (2006), material size with very fine structures can create the following problems during composting:

- The windrows settle too quickly
- Air circulation is restricted

- More frequent turning will be required creating a vicious circle thereby resulting in an increased operating cost

Therefore it is necessary to make approximately 30% of the material to be coarse so as to allow for adequate aeration and fraction size should be 30-60cm for the 30% coarse material (Elias, 2006).

3.3.2 COMPOSTING SYSTEM

Composting systems use for aerobic waste treatment or degradation are classified based on the type of process, the material flow and means of aeration. A brief outline of this classification is given below.

Process Type

Based on the type of process used, composting systems can be classified into reactor processes and non-reactor processes. The reactor process used in carrying out composting operations involves an enclosed vessel while the non-reactor process is an open pile or windrow use in carrying out the composting operation. Drums, silos, tunnels and digester bins are commonly used as reactor composting system. The aeration, moisture input and mixing are carried out in these systems. The environmental conditions associated with composting processes can be controlled in a reactor system which allows for rapid degradation of the waste material. The emissions of odour and leachate to the environment can be reduced to a minimal value if operated in a building. The disadvantages of reactor systems are their complexity and high construction, operation and maintenance costs (Tardy et al, 1996).

Materials Flow

Materials flow during the composting process or operation can either be carried out as a continuous, semi continuous, or batchwise process. Although some operate as batchwise, reactor composting operations are mostly continuous feed systems, with retention times ranging from one to four weeks (EPA, 1995). The open windrow operations are done in batches because of the relatively long rotting period.

Aeration Supply

Adequate supply of oxygen is required to maintain optimal oxygen levels during aerobic composting operations. This can be achieved by several methods which may include mechanical turning for aeration using machinery equipped with auguers,

paddles or tines (EPA, 1995). Oxygen can also be supply to the waste pile by forced aeration systems which involves air blown or sucked through the pile of composting waste by a fan (Williams, 1998).

The use of airflow systems creates a diffusion of atmospheric air through the waste pile thereby supplying oxygen and removing compost gas. The airflow is maintained by forced aeration or by exploiting the naturally occurring thermal convection and diffusion mechanisms (Mollekopf et al, 2002).

3.4 DOME AERATION TECHNOLOGY

The use of Dome Aeration Technology for waste pretreatment through passive aeration in windrows was conducted at the landfill site of Plauen in Germany by the University of Dresden (Paar, 2000). It utilizes convection of heat energy as a means to drive the aeration process during the composting process. Figure 3.1 below shows the thermal flow of the Dome Aeration windrow (Griffith, 2005). Although the length of the windrow depends on the availability of space, typical windrow constructed for the application of Dome Aeration Technology is usually approximately 10m wide at the bottom, approximately 4m high and 60m long, the shredded waste is covered by a blanket of soil or treated waste to protect the waste from desiccation and temperature extremes and air passes through simple and inexpensive grids spaced at 5m intervals along the foot of the windrow and then leaves the windrow through a similar simple and inexpensive grid into plastic chimneys which protrude about 3m above the windrow (Magongwa et al, 2004).
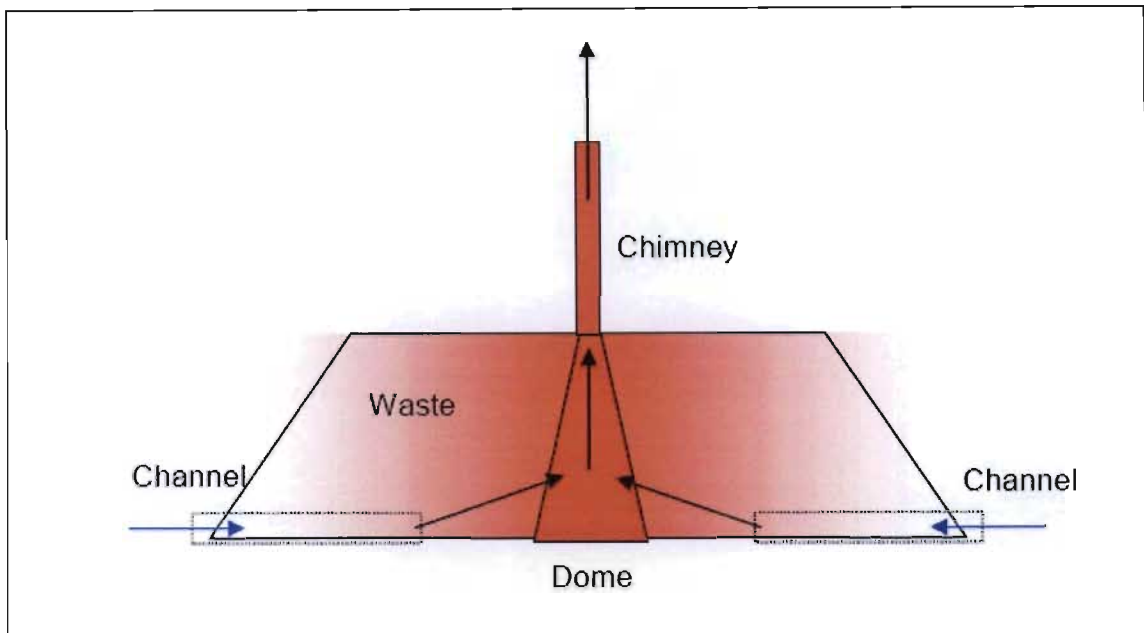
Fig 3.1: Thermal flow of the Dome Aeration Windrow (Griffith, 2005)

According to Mollekopf, *et al* (2002) the principle behind the use of Dome Aeration Technology is to convert open rotting windrows into real self aerated systems by installing specially developed devices (vertical domes and channels) in the windrow during construction in order to generate a defined airflow through the waste pile. The design and arrangement of the domes and channels allow for the maximum use of the resultant thermal buoyancy for driving the airflow through the windrow, thereby ensuring that the core of the windrow is reliably supplied with oxygen throughout the aerobic treatment. Figure 3.2 shows the structure of a windrow using the Dome Aeration Technology.
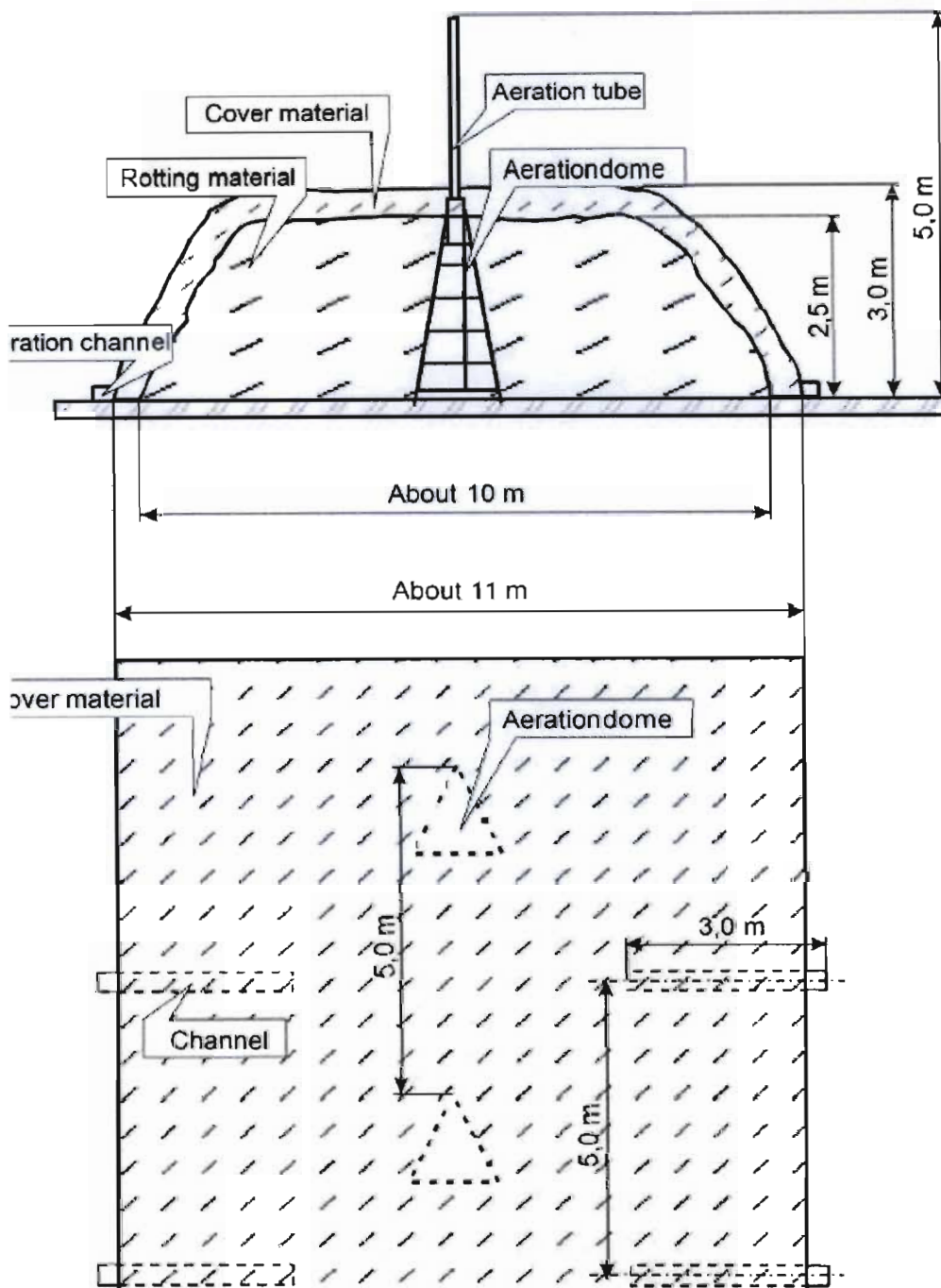
Fig 3.2 Cross section and plan of atypical windrow (Mollekopf, *et al* 2002)

The Dome Aeration Technology follows staged mechanical pretreatment of mixing, shredding, and adjustment of the moisture content of the waste material before the commencement of the biological treatment stage (Mollekopf, *et al*, 2002). Figure 3.3 presents the operational steps involve in the utilization of the Dome Aeration Technology.
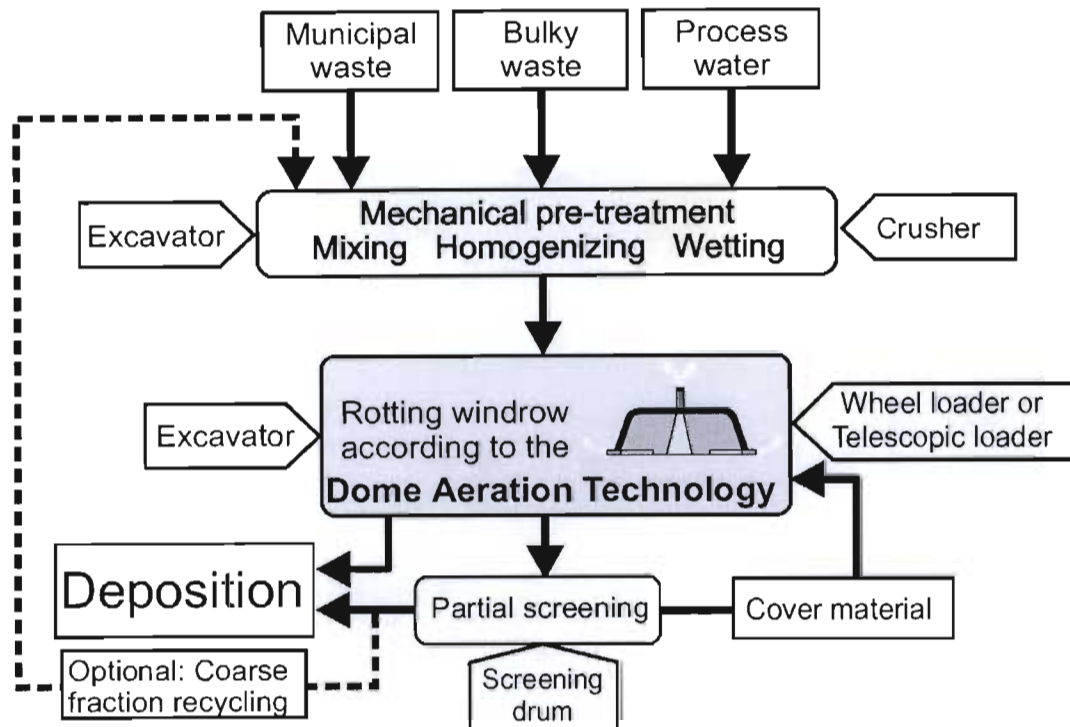
Fig 3.3 The MBP operations utilizing Dome Aeration Technology (Mollekopf, *et al* 2002)

According to Mollekopf *et al*, (2002), the three mechanical pretreatment operations of mixing the waste to be treated with bulky waste, shredding and adjustment of the moisture content of the waste material are performed simultaneously in the shredder with a water spraying device. The bulky waste functions to bring structure into the waste material which is important for the later aeration stage. The moisture content of the waste is increased to about 55% by mass on average, and this is an important factor of the technology, because it is not possible to increase the moisture content of the waste material once the windrow has been constructed. Therefore it is necessary to adjust the moisture content of the waste material to the required value before the windrows are constructed. Once the windrow has been constructed they are not turned or moistened and are left undisturbed throughout the whole composting period. Hence, depending on the desired results, the duration of the composting process may take 3-6 months. After the required composting period is reached, the windrows are dismantled and a portion of the pretreated waste is screened and the fine fraction can be used for covering new windrows (Mollekopf *et al*, 2002). The fine fraction used as a cover material for the new windrow provides for heat insulation, reduction of moisture losses

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and also acts as a biofilter for the reduction of odours (Paar *et al,* 1999). The remaining residues of the composted waste can then be landfilled.

Paar *et al,* (1999) states some advantages of using the Dome Aeration Technology as follows:

- The construction materials for the domes are very inexpensive easy to install and are reusable and the process can be performed with the available machinery on the landfill requiring no additional means for aeration.
- Dome Aeration Technology is a cost effective method for the application in transition periods or for smaller waste treatment enterprises.
- The amount as well as the environmental problems associated with waste disposal in landfills is significantly reduced.

3.5 ENVIRONMENTAL PROBLEMS ASSOCIATED WITH COMPOSTING OPERATIONS

The principal environmental issues at composting plants arises as a result of the leachate generated from the composting waste pile, odour emitted from the waste pile and the pathogenic microorganisms within the waste pile. Adequate precautions should be in place to reduce these environmental problems related to composting operation.

Leachate

Moisture that has been in contact with the rotting waste materials is been released during the degradation process and can results to environmental problems such as contamination of ground water, generation of odours and breeding area for flies and mosquitoes (EPA, 1995). Provision for adequate leachate collection system should be made in the case of open windrow systems which are exposed to rainfall.

Odour

Odour generated during composting operations depends on whether the process is well managed or not. The odour from the composting waste pile is more offensive during the initial stage of the composting process. Hence in order to reduce the environmental problems associated with odours during composting a means of controlling the odour should be in place and this may include the use of deodorizers or scrubbers, or routing exhaust air through filters.

Pathogens

The spores of Aspergillus fumigatus, a fungus that occurs naturally in decaying organic matter can cause health problems for some workers, particularly if the conditions are dry and dusty (EPA,1995).

3.6 BEHAVIOUR OF PRETREATED WASTE IN LYSIMETERS

The long term behaviour of pretreated waste in lysimeters has been widely documented (Brinkmann *et al*, 1995; Rieger *et al*, 1995; Leikam *et al*, 1997 and others). All these studies have shown that the polluting potential of leachate and biogas can be reduced significantly by pretreatment processes.

Leachate Quality

Various lysimeter studies on the behaviour of pretreated waste have shown that the pretreatment of waste significantly reduces the organic strength of leachates. Also the acid phase during which highly loaded leachate is produced in the landfill body is omitted and organic content (COD) and total nitrogen in the leachate are about 90% lower than that of the untreated waste (Leikam *et al*, 1997).

Biogas Production

Studies have shown that the biogas production rate from adequately pretreated waste is significantly lower compared to the biogas production rate of untreated waste. Also various investigations has indicated that the volume of gas produced from untreated waste can be significantly reduced by about 90% when after the pretreatment (Leikam *et al* 1997 and others)

3.7 SUMMARY OF LITERATURES REVIEWED

A critical summary of the literatures reviewed indicates that mechanical biological pretreatment of waste significantly reduces the biodegradability of the waste body and thus reduces the long term management of a landfill when compared to untreated waste. The moisture content of the waste body which is a major factor that influences waste degradation process is one of the main factors among others that enhance the efficiency of the MBP Technology. The other factors include Air supply (Aeration), waste composition in terms of percentage putrescibles and material size. At present in South Africa, MBP methods are not adopted and wastes are generally disposed without any

form of treatment process. This research is driven by the need to introduce MBP methods as a means of waste treatment prior to the disposal of waste in landfill and does entails the simulation of the long term polluting potential of pretreated waste in relation to the factors that affect the efficiency of the treatment process (in particular grain size and waste composition). From the literatures reviewed the use of anaerobic bioreactors (Lysimeter) was found to be an appropriate method to conduct the experimental work. A detailed description of the experimental process is given in the following chapter.

CHAPTER 4
MATERIALS AND METHODS

4.1 INTROUCTION

The experimental process involved preparing the waste samples which were collected from the Dome Aeration Technology windrows and setting up the lysimeters, after which representative samples were taken for a full characterization according to EU standards. The lysimeters were operated by irrigating the waste body and monitored on a weekly basis which involved biogas analysis to determine the gas quality, temperature readings and collection of leachate samples for analysis.

The analytical work was carried out at the School Of Civil/ Environmental Engineering University of Kwa-Zulu Natal according to standard methods for examination of water and waste water (Clesceri *et al*, 1989). A detailed description of the experimental procedures is given this chapter. Figure 4.1 summaries the overall approach of the experimental work of this research.

Activities   **Output**

```
┌─────────────────┐                    ┌──────────────────────────────┐
│ Waste sample    │───────────────────▶│ -16wks pretreated waste-fines│
│ preparation     │                    │ -16wks pretreated waste-coarse│
└─────────────────┘                    │ - Untreated fresh waste      │
         │                             └──────────────────────────────┘
         ▼
┌─────────────────┐                    ┌──────────────────────────────┐
│ Lysimeter set up│───────────────────▶│  - Lysimeter A               │
└─────────────────┘                    │  - Lysimeter B               │
         │                             │  -Lysimeter C                │
         │                             └──────────────────────────────┘
         ▼
┌─────────────────┐                    ┌──────────────────────────────┐
│ Waste           │                    │ -Analysis on solid waste     │
│ Characterization│───────────────────▶│  sample                      │
└─────────────────┘                    │ - Eluates tests              │
         │                             └──────────────────────────────┘
         ▼
┌─────────────────┐                    ┌──────────────────────────────┐
│ Process         │                    │ -Biogas Analysis             │
│ monitoring      │───────────────────▶│ - Temperature readings       │
└─────────────────┘                    │ -Leachate collection         │
         │                             │ -Irrigation of waste body    │
         │                             └──────────────────────────────┘
         ▼
┌─────────────────┐                    ┌──────────────────────────────┐
│ Leachate        │                    │ - pH                         │
│ characterization│───────────────────▶│  -conductivity               │
└─────────────────┘                    │  - COD                       │
         │                             │ -Total & Volatile solids     │
         │                             │ -NH3& NOx                    │
         ▼                             └──────────────────────────────┘
┌─────────────────┐
│ Results         │
└─────────────────┘
         │
         ▼
┌─────────────────┐
│ Conclusion      │
└─────────────────┘
```

Fig 4.1 Flow chart showing the methodology of the study.

4.2 WASTE SAMPLES PREPARATION

Heavily pretreated waste samples collected from the Mechanical Biological Pretreatment pilot project at the Bisasar Road landfill site were sieved into two fractions; fine and coarse fraction using a screen size of 50mm. Untreated fresh waste samples was also collected to serve as a control for the experimental work. The waste samples were grouped into four categories as follows:

- 16 weeks pretreated global waste sample; which is the mechanical biological pretreated waste collected directly from the windrows without any screening operation.

- 16 weeks pretreated fine fraction waste sample; which is the waste mass that passed through the 50mm screen size also referred to as the undersize waste sample.

- 16 weeks pretreated coarse fraction waste sample; which is the waste mass retained on the 50mm screen size also referred to as the oversize waste sample.

- Untreated fresh waste sample.

Plate 1 shows the sieving process used for the separation of the pretreated waste into fine and coarse fractions.

Plate 1 Waste sample sieving process at the Bisasar road landfill site.

4.3 LYSIMETER SET-UP

Three lysimeters were set up at the School of Civil Engineering/Environmental Engineering laboratory in order to investigate the degradation processes and the effect of grain size on leachate contamination of heavily pretreated waste in an anaerobic environment. Table 4.1 below shows the waste input in each lysimeter.

Table 4.1 Lysimeter waste input.

	Waste constituents	Composting periods
Lysimeter A	Undersize of heavily pretreated waste Φ <50mm	16 weeks
Lysimeter B	Oversize of heavily pretreated waste Φ >50mm	16 weeks
Lysimeter C	General waste	Unsorted.

The lysimeters consisted of sealed 1000litre PDE tanks each with a gas sampling point through which the amount of biogas generated was measured, a probe for temperature measurement and an opening in which moisture was added, all of which were located on top of the lysimeters. The edges of the tanks were supported in such a way to allow for the drainage of leachates to a central collection point at the base of the tank.

Washed crushed stones were used to fill the base of the tanks to allow for proper leachate drainage and act as a separation layer between the leachate and the waste materials in the lysimeters. The leachate is drawn from a central collection point by means of an extraction pipe fitted to the base of each tank. The waste materials for each lysimeter were then placed into the lysimeters and another layer of washed crushed stones was used to cover the top of the waste. A water sprinkle device was then installed in the head space of each lysimeters to effectively distribute the water added for irrigation onto the waste body. The stones used to cover the top of the waste material reduce preferential flow paths and prevent erosion of the waste that might result from the water from the sprinkler. All piping and fittings used were made of PVC materials.

Plate 2: Lysimeter view.

Table 4.2 Lysimeter input parameters.

Parameters	Lysimeter A: Undersieve of the pretreated waste.	Lysimeter B: Oversieve of the pretreated waste.	Lysimeter C: Fresh waste sample.
Total mass (Kg)	330.06	70.26	269.00
Moisture content(L)	47.00	7.00	156.00
Dry mass (Kg)	283.05	63.47	112.85
Total mass at field capacity	707.63	158.68	-
Waste particle size	<50mm	>50mm	Unsorted

The variation in the mass of the input waste in each lysimeter depends on the degree of compaction of each waste material that was placed in the lysimeters. Waste materials

for lysimeter A which is the pretreated fine fraction demonstrated a high degree of compaction compared to the waste in the other two lysimeter.

4.4 WASTE CHARACTERIZATION

Characterization of the waste samples in each lysimeters involved a series of analyses performed on both the solid waste material and the eluates prepared from the leaching tests. The section below gives a detailed description of all the analyses performed.

4.4.1 Analysis on Solid Matter

The analysis carried out on the solid waste samples involves: waste composition analysis, moisture content, field capacity test, respiratory index test (RI$_4$), and biogas production. Below is a description of the procedure used in carrying out each analysis.

Waste Composition

The waste composition analysis was performed to determine the constituent materials present in each lysimeter in terms of paper, plastics, fabrics etc. The process used involved quartering a representative sample of each waste material and sorting it into the various constituent fractions. A moisture content test was also carried out on each constituent waste fraction. The composition of each constituent waste fraction was expressed in percentage of dry mass of the total mass of the representative sample from each lysimeter.

Moisture Content

This analysis was performed by taking a known mass of the representative sample of each waste material in the lysimeter. This representative sample was then place in a beaker and oven dried at a temperature of 105°c for 24hrs, thereafter the mass of the dried waste sample was measured and recorded. The moisture content was then calculated from the equation given below.

$$W\ (\%) = \frac{M_W - M_D}{M_W} \times 100$$

where

W (%) is the moisture content

MW is the mass of wet sample

MD is the mass of oven dried sample.

Field Capacity Test

The field capacity is defined as the maximum moisture content held in compacted waste in a landfill by capillary action (Novella, 1995). The experimental set up used in determining the field capacity of each representative waste sample consisted of conical flask, funnel and filter cloth. The flask together with the funnel and the filter cloth were first weighed and then a representative waste sample was placed in the funnel and the whole set up weighed again. Distilled water was then added slowly to the sample in the funnel until water started seeping out through the filter cloth into the conical flask. The experimental set was then left to stand until the water stops dripping out into the conical flask and the apparatus was then reweighed. The amount of water retained at field capacity is calculated as the difference in the mass of the wet sample and the dry sample.

Respiratory Index Test (RI₄)

The respiratory index test is a measure of the amount of oxygen consumed by biological activity taking place per unit time at $20^{o}C$ in an incubator. The test involves taking representative samples of the waste material, carrying out a field capacity test on them, and then placing them in a 1500ml vessel in an incubator for four days. The microbial break down of the waste in the vessel results in the consumption of available oxygen in the vessel thereby producing carbon dioxide as a by product which was removed by potassium hydroxide added. The negative pressure that develops in the airtight vessel is measured by a pressure sensor placed in the lid of the vessel. These pressures are related to the amount of carbodioxide absorbed and therefore the amount of oxygen consumed, indirectly represents the organic substances present in the sample. After four days of incubation the pressure difference due to oxygen consumption by the degradation process taking place was recorded and determined by equation 5.1 below.

$$\Delta P = \frac{BOD_4}{\left[\dfrac{M}{RT_m}\right]\left[\dfrac{V_t - V_l}{V_l} + \alpha \dfrac{T_m}{T_o}\right]} \qquad (5.1)$$

Where: BOD_4 = results from the tests

M = 3200mg/mol

T_0 = Reference temperature = 273.15K (STP)

Tm = 20°C = 293.15K (STP) –Testing Temperature

Vt = Volume of the vessel

Vl = Volume of the sample

R = 83.144 mbar/mol.k- Gas constant

α = 0.03103

Based on the pressure change the number of oxygen molecules can be estimated using the ideal gas law given below.

PV = nRT   (Ideal gas law equation)   (5.2)

Assumptions: starting condition: Concentration of O_2 = 20% and N_2 = 80%

The respiration index after four days (RI_4) is then obtained by dividing the amount of oxygen consumed by the amount of dry mass.

This aspect of the analytical work was carried out by Xulu (2005).
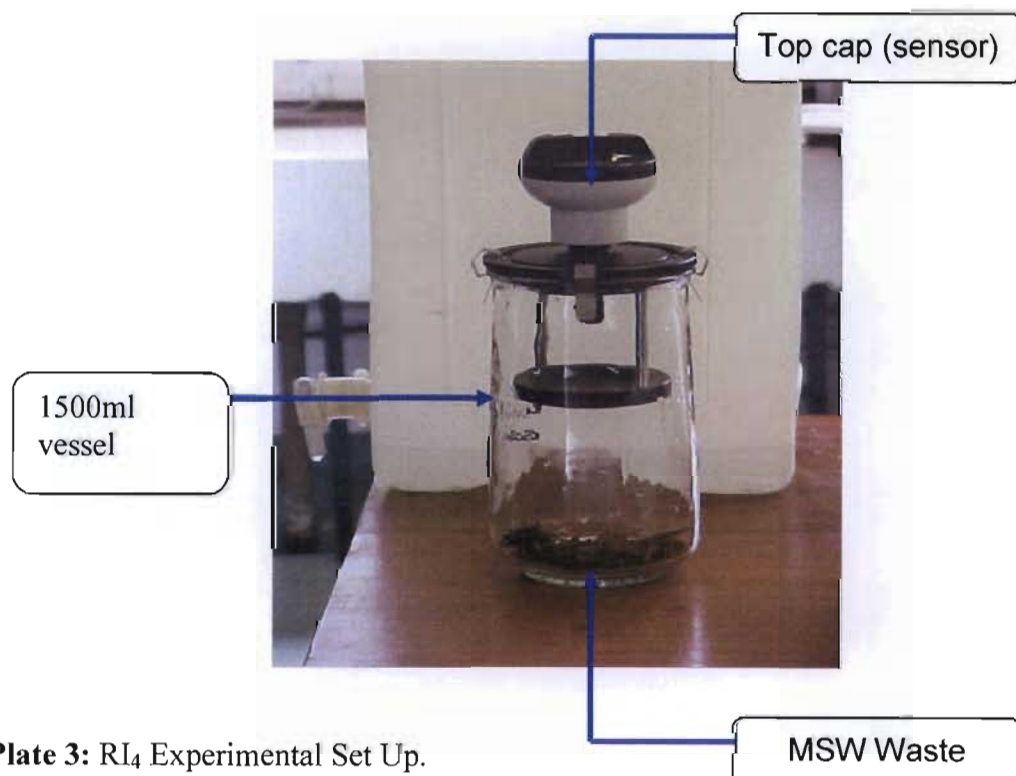
Plate 3: RI_4 Experimental Set Up.

Top cap (sensor)

1500ml vessel

MSW Waste

Biogas Production

The Biogas production test for each representative sample was performed using the liquid displacement method. A representative sample at field capacity was placed into a 500ml amber bottle which was then connected to a 1litre glass burette by a gas tube. The glass burette was then connected to the liquid displacement reservoir. The glass burette was filled with a solution of sodium chloride and sulphuric acid in order to ensure that the biogas components were not absorbed during the analysis. A proper sealing of all connections must be done to avoid any form of leakage. Plate 4 shows the experimental set up for the biogas production analysis. The production of biogas from the waste in the 500ml amber bottle results in the displacement of the liquid solutions in the calibrated glass burette and the amount of liquid displaced gives the amount of biogas produced at any point in time. The quality of the biogas was determined by drawing a sample through an infrared gas analyzer (GA 2000). The parameters analyzed for were mainly carbodioxide, methane and oxygen and this was carried out on a weekly basis with the temperature at 30°C throughout the period of the analysis. The biogas production analysis was carried out using the global sample and the fine sample of the 16weeks pretreated waste samples. The global sample is the mechanical biological pretreated waste collected directly from the windrows without the screening operation. This aspect of the analytical work was carried out by Thato (2006).
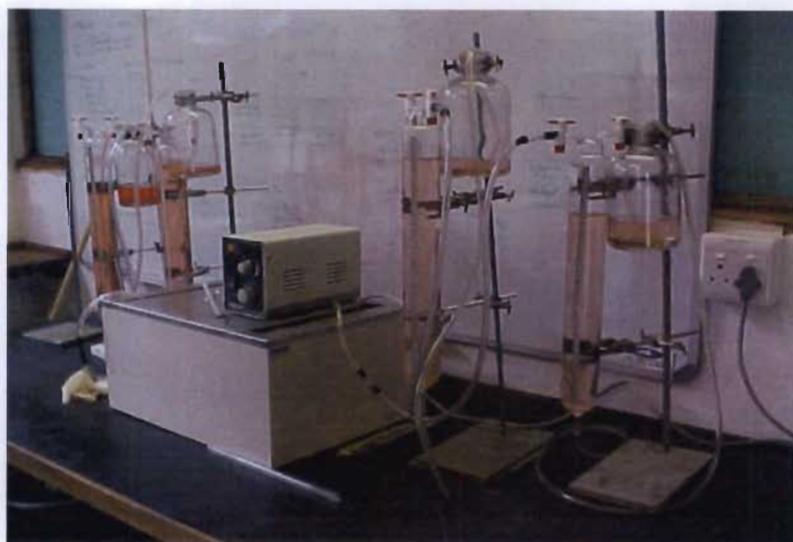
Plate 4: Experimental set up for the Biogas Production analysis

4.4.2 Eluates Test

An eluate test was performed on the input material to the reactors. The eluate test is a leaching test which determines the amount of soluble organic and inorganic components leached out from a waste sample in 24hrs. Eluates were prepared by mixing the waste sample with distilled water for 24hrs using a liquid/solid of10 corrected for the moisture content of each solid sample. The eluates were filtered and the filtrate collected was analyzed for pH, conductivity, COD, NH_3, NO_x, TS and VS. The description of these parameters is given in a latter part of this chapter. The analyses were conducted according to the American Standard Methods for Waste Water Analysis (Clesceri *et al*, 1989).

4.5 PROCESS MONITORING.

The operation of the lysimeters involved irrigation of the waste body, leachate collection and characterization, biogas quality monitoring and temperature measurement. Table 4.3 below shows the process monitoring.

Table 4.3 Lysimeter process monitoring parameters and sampling points

PROCESSES.	SAMPLING POINT	PARAMETERS TESTED.	FREQUENCY.
Leachate collection	Extraction pipe at the base of the lysimeter	PH Conductivity COD $N-NH_4$ $N-NO_x(NO_2$ &$NO_3)$ Total and volatile solids(TS & VS) TKN TOC	Weekly.
Biogas Analysis	Pipe leading into lysimeter head space.	Methane (CH_4) Carbon(IV)Oxide (CO_2) Oxygen (O_2)	Weekly.

Temperature	Probe leading into the lysimeter waste body.	Lysimeter waste body temperature.	Weekly.

IRRIGATION OF THE WASTE BODY

The process of irrigating the lysimeter was carried out on a weekly basis after taking the readings for the amount of biogas generated, temperature readings, and extraction of the leachates. Water was initially added to the lysimeter at the commencement of the operation in order for the waste body to attain field capacity. The irrigation process was carried out by adding water through an opening on the lysimeter head space, 14.5 litres of water was added to lysimeter A, 3.5 litres of water to lysimeter B and 5.6 litres to lysimeter C, based on the waste hydraulic properties i.e. the field capacity of the waste material in each lysimeters. The initial water added to all the lysimeters at the commencement of their operation was done so as to accelerate the attainment of field capacity for the waste body in the lysimeters. The result of all the water addition and removal from the lysimeters is given in the appendix. This process of water addition to the waste material increases the rate of degradation of the waste material by flushing out degradation products and replenishing nutrients for the micro-organisms (Williams, 1998). The essence of these irrigations was to enhance biogas generation and rate of degradation of the waste material hence promoting the anaerobic bioactivity in the lysimeter.

BIOGAS ANALYSIS

This analysis was carried out on a weekly basis using an infrared gas analyzer (GA2000) to determine the composition of biogas generated through the gas vent connected to the lysimeter head space. The major constituent of the biogas generated is methane and carbon dioxide with traces of oxygen. The amount of methane and carbon dioxide generated varies according to the type and phase of degradation taking place in the lysimeters. The presence of oxygen is undesirable since the lysimeter is expected to be operating in anaerobic conditions.

TEMPERATURE

The lysimeter temperature readings were taken on a weekly basis by means of a thermocouple from a probe connected to the lysimeters head space. The ambient temperature which was taken as the surrounding temperature were the lysimeters was set up was also taken using the thermocouple. Temperature governs, to a large extent, the microbial activity. The active temperature phase for the methanogenic bacteria fall into two ranges; 30 - 35°C for the mesophillics and 45 - 65 °C for the thermophillics and at lower temperatures, less gas is been produced than at higher temperatures (Williams, 1998).

4.6 LEACHATE ANALYSIS

The leachates from each lysimeters were extracted on a weekly basis from the extraction pipe located at the bottom of each lysimeter. A brief description of the parameters analyzed in the leachates extracted is reported below.

pH

The pH values were taken weekly using an electronic meter (Orion LABTECH model 410A). The pH of the leachates indicates the state of biological activity taking place in the lysimeters. In the early stages of degradation, the waste forms leachates characterized by an acidic pH values due to the formation of acetic acid and other organic acids by the acetogenic microbes under anaerobic conditions. At subsequent stages of degradation, the pH ranges between a neutral value and a slightly basic value, indicating the degradation of the organic acids formed from the earlier stage producing methane and carbon dioxide by the methanogenic microbes (Williams, 1998). A neutral pH value for leachates indicates existence of a dynamic equilibrium between the acetogenic and methanogenic micro-organisms (Griffith, 2005).

CONDUCTIVITY

A conductivity test was also carried out immediately after the collection of the leachate sample weekly using a conductivity meter (Corning Checkmate II sensor). The conductivity of the leachates sample is an indication of the quantities of the soluble salts present in the leachate. Leachate with high conductivity indicates the presence of high quantity of soluble salts in the waste material in the lysimeter.

CHEMICAL OXYGEN DEMAND (COD) (ASTM methods 5220B)

Chemical oxygen demand is the amount of oxygen required to oxidize the organic matter in the leachate sample by use of dichromate in an acid solution and to convert it to carbon dioxide and water. The value of chemical oxygen demand is always higher than that of biochemical oxygen demand because many organic substances can be oxidized chemically rather than biologically. The chemical oxygen demand is an indication of the polluting potential of the leachate samples. In this experiment a sample was oxidized with a known excess amount of potassium dichromate ($K_2Cr_2O_7$). After oxidation the sample was then titrated with ferrous ammonium sulphate (FAS) to determine the amount of $K_2Cr_2O_7$ consumed which was then expressed in terms of its oxygen equivalence. A blank sample of the reagent was also tested and this was considered as a control for the entire experiment. The American Standard Method 5220 B and the open reflux procedure were followed, to determine the COD.

AMMONICAL-NITROGEN AND NITRATES (SABS method 217:1990)

The SABS method 217: 1990 was followed to carry out the analysis on ammonical nitrogen and nitrates. This test indicates the amount of nitrogen in the form of ammonia and nitrates/ nitrites present in the leachate sample. Leachate samples were distilled under milky alkaline conditions and the distillate was collected in boric acid solution. Under alkaline conditions and continuous removal of ammonia by distillation, the ammonia is converted to ammonium. The distillate collected in boric acid was titrated with a standard acid (HCl) solution to determine the amount of ammonical nitrogen in the solution. Once ammonical –N is removed by the distillation process under alkaline conditions, the nitrate is determined by adding Devardas Alloy to the remaining sample and then distilled again, and the nitrates is collected in boric acid solution and also titrated with HCl to determine the nitrates content

TOTAL SOLIDS AND VOLATILE SOLIDS (ASTM methods 2540B)

Total solids was measured by evaporating the leachate sample to dryness in crucibles in an oven at 103-105°c and weighing the residue. The weight of the residue is the total solids present in the leachate sample. On ignition of the residue in the crucible in a muffle furnace at 550°c and allowing to cool in a dessicator, the weight loss on ignition is the volatile solids. These two parameters indicate approximately the amount of organic matter present in the solid fraction of the leachate samples collected.

4.7 REPEATABILTY CHECKS.

On every analysis that was carried out, the necessary precautions were followed. The standard methods for examination of water and wastewater (Clesceri *et al*, 1989) and in some cases SABS methods were used for the analyses. Each leachate analysis was carried out in triplicate and in some cases duplicate and the averages of each analysis were computed for the final results. For each set of leachate tests, the standard deviation and variance were computed as a repeatability checks for the analysis. The equations below were used to compute the average, standard deviation and the variance for each set of leachate analysis.

$$Average = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad\qquad 4.1$$

$$variance = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - x)^2 \qquad\qquad 4.2$$

$$standard\ deviation = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - x)^2} \qquad\qquad 4.3$$

where

x_i is values of the analysis data

n is number of observation or data (n =3)

x is average of the analysis data

Below is an example on how the accuracy checks were carried out.

Table 4.4 Accuracy Check carried out on the Total and Volatile Solids Results.

DATE		RAW DATA			AVE	STDEV	VAR
		Lysimeter A					
31-May-06	TS	2.35	2.29	2.29	2.31	0.04	0.001
"	VS	1.68	1.67	1.60	1.65	0.05	0.002
27-Jun-06	TS	1.90	1.79	1.92	1.87	0.07	0.005
"	VS	1.36	1.27	1.33	1.32	0.05	0.002
11-Jul-06	TS	1.67	1.57	1.51	1.58	0.08	0.007
"	VS	1.23	1.31	1.31	1.28	0.05	0.002
		Lysimeter B					
31-May-06	TS	2.39	2.46	2.46	2.44	0.04	0.002
"	VS	1.57	1.61	1.66	1.61	0.05	0.002
27-Jun-06	TS	2.65	2.64	2.62	2.64	0.01	0.000
"	VS	1.76	1.79	1.70	1.75	0.04	0.001
11-Jul-06	TS	2.20	2.08	2.20	2.16	0.07	0.004
"	VS	1.63	1.56	1.60	1.59	0.04	0.001
		Lysimeter C					
11-Jul-06	TS	12.14	11.73	11.72	11.86	0.24	0.056
"	VS	6.20	6.31	6.24	6.25	0.05	0.005
08-Aug-06	TS	15.66	16.20	16.29	16.05	0.34	0.117
"	VS	7.80	7.78	7.74	7.77	0.03	0.000
15-Aug-06	TS	17.04	16.89	16.53	16.82	0.26	0.067
"	VS	8.33	8.28	8.24	8.28	0.05	0.002

Table 4.5 Accuracy Check carried out on the COD results.

DATE	RAW DATA			AVE	STDEV	VAR	RESULT
	Lysimeter A						COD
16-Feb-06	0.17	0.17	0.16	0.16	0.005	0.000	1125.48
06-Mar-06	0.15	0.15	0.15	0.15	0.001	0.000	1052.13
23-Mar-06	0.16	0.16	0.15	0.16	0.002	0.000	964.45
	Lysimeter B						
16-Feb-06	0.137	0.139	0.138	0.138	0.001	0.000	849.96
06-Mar-06	0.173	0.176	0.172	0.173	0.002	0.000	895.69
23-Mar-06	0.167	0.167	0.167	0.167	0	0.000	863.88
	Lysimeter C						
23-May-06	0.034	0.038	0.039	0.037	0.003	0.000	4487.03
06-Jun-06	0.165	0.184	0.183	0.18	0.011	0.000	21888.43
13-Jun-06	0.145	0.138	0.141	0.14	0.003	0.000	17401.41

Table 4.6 Accuracy Check carried out on the Nitrogenous Compound Results.

DATE		RAW DATA			AVE	STDEV	VAR	RESULTS
		Lysimeter A						
16-Feb-06	NH_3	4.04	3.96	3.95	3.98	0.049	0.002	111.53
"	NO_x	0.5	0.39	0.35	0.41	0.078	0.006	11.57
03-Mar-06	NH_3	3.96	3.92	3.89	3.92	0.035	0.001	109.85
"	NO_x	0.42	0.33	0.33	0.36	0.052	0.003	10.08
09-Mar-06	NH_3	3.53	3.54	3.49	3.52	0.026	0.001	98.56
"	NO_x	0.49	0.31	0.36	0.39	0.093	0.009	10.83
		Lysimeter B						
16-Feb-06	NH_3	1.37	1.35	1.32	1.35	0.025	0.001	37.71
"	NO_x	0.29	0.32	0.29	0.30	0.017	0.000	8.40
03-Mar-06	NH_3	1.58	1.57	1.59	1.58	0.01	0.000	44.24
"	NO_x	0.33	0.43	0.44	0.40	0.061	0.004	11.20
16-Mar-06	NH_3	1.67	1.69	1.68	1.68	0.01	0.000	47.04
"	NO_x	0.47	0.48	0.475	0.48	0.005	0.000	13.30
		Lysimeter C						
13-Jun-06	NH_3	5.69	5.72		5.71	0.021	0.000	159.74
"	NO_x	0.64	0.67		0.66	0.021	0.000	18.34
27-Jun-06	NH_3	3.4	2.93		3.17	0.332	0.110	88.90
"	NO_x	5.54	5.57		5.56	0.021	0.000	155.54
25-Jul-06	NH_3	15.26	15.22		15.24	0.028	0.000	426.72
"	NO_x	0.65	0.62		0.64	0.021	0.000	17.78

CHAPTER 5

RESULTS AND DISCUSSION

5.1 INTRODUCTION

This chapter presents the analytical results of the waste characterization and the lysimeters process monitoring that was carried out with discussion on relevant findings.

5.2 WASTE CHARACTERISATION RESULTS

This section presents the results of the analysis carried out on the solid waste material and the eluates prepared from representative samples of the input material to the lysimeters.

5.2.1 Waste Composition

The composition of the input material in lysimeter A (16wks pretreated fines) and lysimeter B (16wks pretreated coarse) is presented in Table 5.1. Table 5.2 presents the waste stream analysis for general waste from Bisasar Road Landfill which provides information on the composition of the input material in Lysimeter C.

Table 5.1 Waste composition of lysimeters input materials.

Component Material (% mass)	LYSIMETER A	LYSIMETER B
Plastic	2.5	26.7
Glass	7.7	0.7
Wood	0.3	7.4
Metal	0.8	4.7
Paper	6.3	19.8
Rubber	-	3.5
Fabrics	1.2	25.9
Plant	15.1	-
Stone	11.5	3.9
Fines	54.5	7.5
Total	100	100

The results of the waste composition analysis presented in Table 5.1 shows that lysimeter A comprises of the biodegradable fractions of the pretreated waste with higher percentage in materials such as plants, fines compared to lysimeter B. The table also shows that the composition of waste materials placed in lysimeter B comprises, high percentage of non/slowly biodegradable materials which is indicated by the percentage of materials such as paper, plastics, and fabrics as shown by the results in the table. This results is not surprising and it is expected as the pretreated waste were separated using a rotatory drum screen in other to gain an insight on the effect of grain size on leachate contamination which is a major aim of the this study.

Table 5.2 Waste composition of MSW (Bowers, 2002)

Component Material	Percentage (mass)
Hard Plastic	6.4
Soft Plastics	11.0
Glass	7.1
Tin /Aluminum	6.9
Cardboard	9.0
Paper	10.3
Putrescible	42.5
Other	6.8
Total	100

A representative sample of the input material to each lysimeter was analyzed to determine the moisture content, total solids, volatile solids and was used to prepare eluates, respiration and biogas generation tests. The results of this analysis are presented in the Tables 5.3.

Table 5.3 Results of the solid input materials

PARAMETERS	LYSIMETER A: Undersieve of the Pretreated waste	LYSIMETER B: Oversieve of the Pretreated waste	LYSIMETER C: Untreated fresh waste Sample.
Moisture content (%)	13.50	8.75	41.92
Total solids (g/l)	387.1	68.4	58.08
Volatile solids (g/l)	105.50	58.20	-

5.2.2 Respiration Index Test Results

Table 5.4 presents the results of the amount of oxygen consumed during the biodegradation of treated waste in aerobic conditions. The Respiration Index was computed as the amount of oxygen consumed in four days of incubation divided by the total dry mass of the waste. The result of the respiration index presented in Table 5.4 shows a higher value for the undersieve waste sample compared with the oversieve waste sample of the pretreated waste fractions, this result prove the fact that the undersieve waste sample comprises mainly the biodegradable fractions of the pretreated waste. An unexpected results of a higher respiration index value for the global waste compared to both the undersieve and oversieve waste samples was recorded, this suggest that the global waste sample comprises of high proportion of the biodegradable component, however, the effect and benefit of MBP on respiration index is observed when comparing the values of the respiration index of the global, undersieve, oversieve waste samples with the untreated fresh waste sample which are significantly lower.

Table 5.4 Respiration Index values for waste samples (Xulu, 2005).

Waste Sample	RI_4(mgO$_2$/gDry mass)
Global Waste Sample	9.34
Undersieve Waste Sample	8.14
Oversieve Waste Sample	4.6
Untreated Fresh Waste Sample	16.7

5.2.3 Biogas Production Results

The results of the biogas production carried out on the waste sample at varying moisture contents are presented in this section. Table 5.5 presents the results for natural moisture content and the field capacity for the waste samples. The moisture content test was done inorder to determine the moisture content of each representative waste samples before the biogas production test, while the field capacity test was done so as to raise the moisture content of each representative waste samples to the acceptable value that will enhances bioactivity during the biogas production analysis.

Table 5.5 Results of the waste sample moisture content and moisture at field capacity of the waste sample prior to Biogas Tests (Thato, 2006).

Parameters	Units	16 Weeks Global Sample	16 Weeks Undersieve Sample
Sample Mass	g	103.03	256.96
Moisture Content	%	4.92	12.63
Field Capacity (practical)	ml	60	150

Tables 5.6 and 5.7 below present the results of the biogas production analysis of the waste samples.

Table 5.6 Results of the biogas production test for 16 weeks pretreated fines (Thato, 2006)

Biogas Production		0.22451	kilograms (dry mass)				
Time (wks)	%CH$_4$	%C0$_2$	%O$_2$	Volume (ml)	CH4 Volume (L/kgDM)	CH4 Volume (NL/KgDM)	Cum. CH4 Volume (NL/kgDM)
1	0	0	0	0	0	0	0
2	43.7	23	1.2	227.6	0.44	0.21	0.21
3	50.45	22.7	1.8	371	0.83	0.39	0.60
4	57.2	22.4	2.4	182.7	0.47	0.22	0.82
5	58.2	19.8	2.1	61.9	0.16	0.08	0.90
6	59.2	17.2	1.8	38.4	0.10	0.05	0.95
7	59.1	17.2	1.9	69.3	0.18	0.09	1.04
8	45.4	14.3	3.6	38.5	0.08	0.04	1.08
9	45.8	14.3	2.95	51.1	0.10	0.05	1.13
10	46.2	14.3	2.3				

Table 5.7 Results of the biogas production test for 16 weeks pretreated global sample (Thato, 2006).

Biogas Production		0.098	Kilograms (dry mass)				
Time (wks)	%CH$_4$	%C0$_2$	%O$_2$	Volume (ml)	CH$_4$ Volume (L/kgDM)	CH4 Volume (Nl/kgDM)	Cum. CH$_4$ Volume (Nl/kgDM)
1	0	0	0	0	0	0	0
2	0	0	0	178.40	0	0	0
3	15.3	10.35	0.8	196.50	0.31	0.15	0.15
4	30.6	20.7	1.6	98.30	0.31	0.15	0.30
5	41.25	22.45	1.6	76.00	0.32	0.15	0.45
6	51.9	24.2	1.6	76.40	0.40	0.19	0.64
7	56.3	25.5	1.7	48.10	0.28	0.13	0.77
8	56.9	23.9	2.4	29.10	0.17	0.08	0.85
9	56.55	22.65	2.55	38.90	0.22	0.10	0.95
10	56.2	21.4	2.7				
11	58.3	21.4	2.4				
12	59.9	20.5	2.5				
13	57.2	20.1	2.7				

From Tables 5.6 and 5.7 above which presents the biogas production test results, the cumulative production of methane for the 16weeks pretreated undersieve waste sample was 1.13NL/Kgdrymass while that of the 16weeks pretreated global waste sample was 0.95NL/Kgdrymass. Although, this analysis was not carried out for the 16weeks pretreated oversieve waste sample, this results shows that waste materials which comprises of mainly biodegradable materials such as that of the 16weeks pretreated undersieve waste sample has a higher rate of methane production compared to waste materials comprising of non/slowly biodegradable materials.

5.2.4 Eluate Tests Results

The results of the eluate tests performed on the waste samples in each of the lysimeters are presented in Table 5.8.

Table 5.8 Characterization of waste samples using eluate tests.

PARAMETER	LYSIMETER A: 16 weeks fines	LYSIMETER B: 16 weeks coarse	LYSIMETER C: untreated
pH	7.32	7.04	5.29
Conductivity (μS/cm)	1408	1839	6195
COD (mg/l)	3423	3457.5	7598.72
Ammonical-N (mg/l)	1.11	0.95	48.49
Nitrites & Nitrates (mg/l)	0.20	0.24	18.15

The effect of waste pretreatment is clearly seen from the eluate test results presented in Table 5.8 above. The pretreated waste samples (undersieve and oversieve) demonstrated a drastic reduction of all pollutants. The eluate pH results for the pretreated waste samples also indicated that the acidic inhibition stage of waste degradation which is encountered during the degradation process of untreated waste as been eliminated by the pretreatment process.

5.3 LYSIMETERS RESULTS

This section presents the results of the process monitoring which involve temperature readings, biogas quality and leachate analyses carried out on the lysimeters. At the presentation of this work, the data collected for lysimeter C is just for the first 4months of the analysis as it is still in operation. In analyzing the lysimeter results, two independent variables are important. These two independent variables are time and liquid/solid ratio. The biological process occurring in the lysimeters are time dependant while the leaching process occurring are dependant on the moisture flux. For continuity, the presentation of the lysimeters results will be made using the liquid/solid ratio as the independent variable. However, as the sampling frequency is consistent, there is a uniform relation between liquid/solid ratio and time. Figures 5.1 to 5.3 below presents a plot of liquid/solid ratio versus time in weeks for each lysimeter showing the relationship between the two.
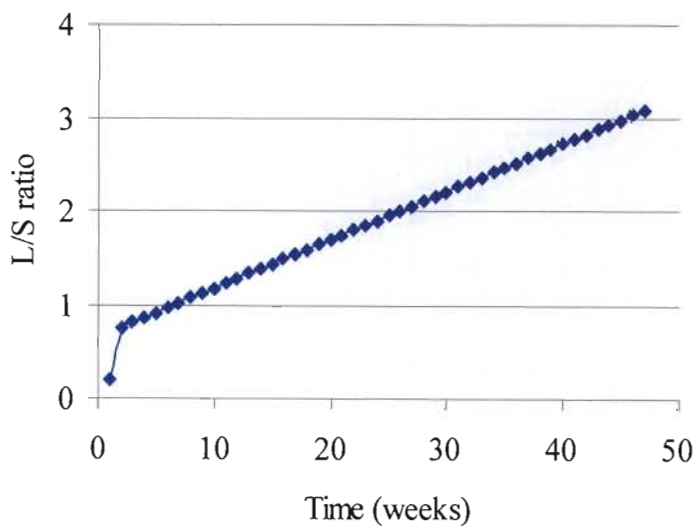
Figure 5.1 Plot of L/S ratio versus Time (lysimeter A).
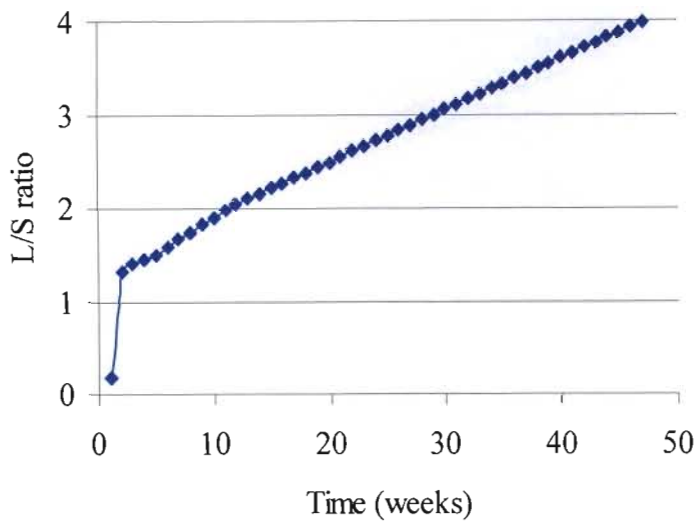
Figure 5.2 Plot of L/S ratio versus Time (lysimeter B).
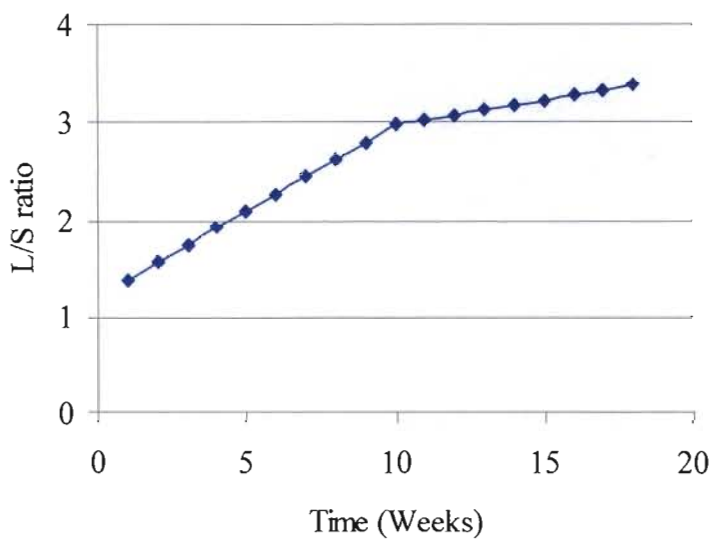
Figure 5.3 Plot of L/S ratio versus Time (lysimeter C).

The initial sharp increase in the both plot as shown in figure 5.1 and 5.2 for lysimeter A and B respectively was as a result of large volume of water added to raise the waste moisture content in both lysimeter to their respective field capacity.

5.3.1 LYSIMETERS TEMPERATURE RESULTS

Figures 5.4 to 5.6 below presents the results of the lysimeters and ambient temperatures recorded over the period of analysis. As can be seen in the figures presented, there is a significant correlation between the lysimeters temperature and the ambient temperature. It confirms that no significant exothermic biochemical process has occurred. The temperature recorded for the three lysimeters over the analytical period is far from the optimum temperature requiring for significant microbial activity. These low temperatures recorded could be a strong inhibitor for the anaerobic bioreactions taking place in the three lysimeters even if the leaching process promotes good conditions for anaerobic bioactivity.
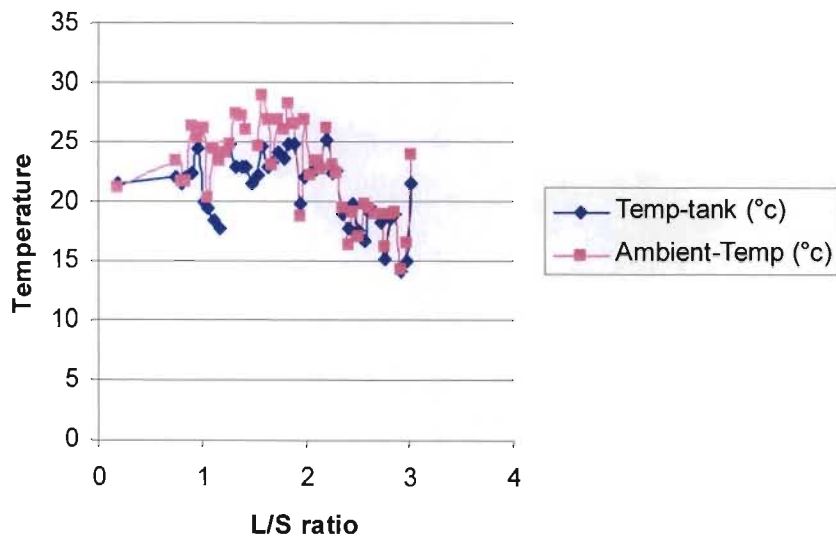
Figure 5.4 Lysimeter A: Temperature Results
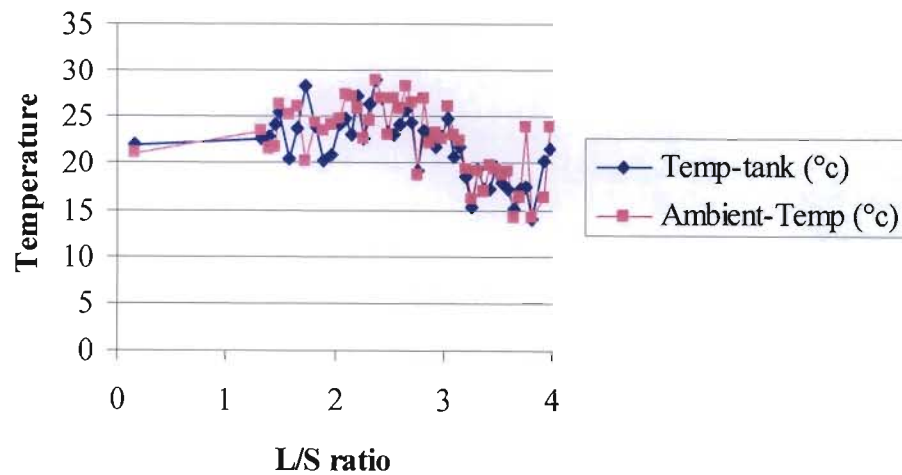
Figure 5.5 Lysimeter B: Temperature Results
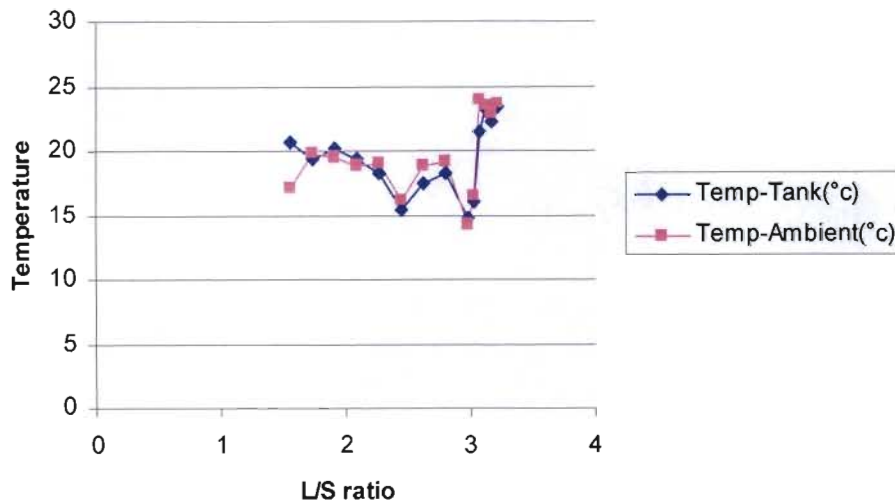
Figure 5.5 Lysimeter B: Temperature Results

5.3.2 LYSIMETERS BIOGAS QUALITY RESULTS

Figures 5.7 to 5.9 below presents the results of the lysimeters biogas quality recorded over the period of analysis. It illustrates the evolution of the gas compositions (methane, carbon dioxide and oxygen) from the lysimeters. As shown in figure 5.7, methane production from lysimeter A commences immediately, indicating that the acidic inhibition stage which is normally encountered during the degradation of untreated waste as been eliminated by the pretreatment process (MBP) which was carried out on waste samples in lysimeter A. The methane concentrations increases to the maximum value of 33.1% recorded for the entire period of analysis. It was observed that there was a drop from this maximum value to a value of 5.3% which might be as a result of atmospheric air entering the lysimeter through the gas vent due to moderate leakage at the seal thereby affecting the activity of the methanogenic microbes which were already established. The concentration of methane then rose back to 32.2% after resealing and then remains in the range of 25-30% before gradually dropping to the final recorded value of 0.1% at the end of the analysis. There was a sharp increase in the concentration of carbon dioxide at the initial commencement of the analysis to the maximum value of 42.5%, however this was also affected by the ingress of atmospheric air into the lysimeter as this maximum recorded value drops. After resealing the gas vent, the concentration picked up as observed for the methane production before reducing gradually to the final recorded value of 21.1% at the end of the analysis. Oxygen

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concentration remains negligible throughout the analysis except for the instance when there was a moderate leakage.

As shown in figure 5.8, a slow production of methane was observed from lysimeter B at the initial commencement of the analysis. This might be as a result of the initial concentration of oxygen present in the lysimeter thereby retarding the establishment of methanogenic microbes. As soon as the oxygen was depleted, there was a gradual increase in the concentration of methane which then reached the maximum value of 15.7% recorded for the entire duration of the analysis. The maximum value of methane recorded for lysimeter B was significantly lower than that of lysimeter A. This is one of the important results of this study as it shows a clear comparison between the two lysimeters proving the effect in which the composition of waste materials in lysimeter B which comprises of higher proportion of non/slowly biodegradable materials as shown in Table 5.1 compared to lysimeter A as on the production rate of methane. The concentration of carbon dioxide increased from the initial value of 20% and reached the maximum recorded value of 29.2% at the same time as the methane peak. The final recorded value at the end of the analysis indicates a reduction in the concentration of carbon dioxide.

Although, the data presented for lysimeter C are for the first 4months of the analysis, the effect of mechanical biological pretreatment of waste samples in lysimeter A and B when comparing with the untreated waste samples in lysimeter C is clearly evident. As shown in figure 5.9, the concentration of methane over this initial period of analysis is negligible. This confirms the acidic inhibition stage which is normally observed in the degradation of untreated waste in landfills in which the production of methane is not expected. The concentration of carbon dioxide fluctuates in a decreasing mode which might be as a result of certain microorganisms using up carbon dioxide produced from the degradation process in converting carbonhydrates present in the waste body directly into acetic acid which is a typical characteristic of acetogenic phase of waste degradation processes (Williams, 1998). The high level of oxygen detected was due to atmospheric air entering through the lysimeter head space and was immediately resealed.
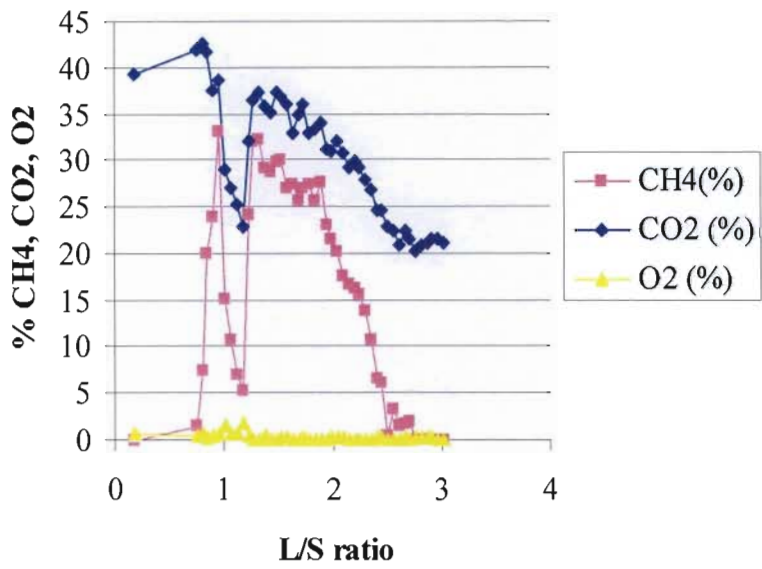
Figure 5.7 Lysimeter A: Biogas Quality
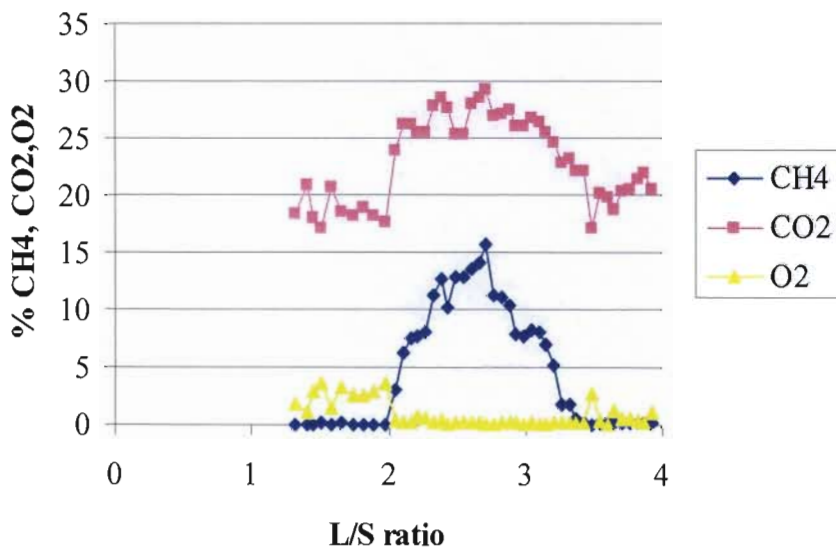
Figure 5.8 Lysimeter B: Biogas Quality
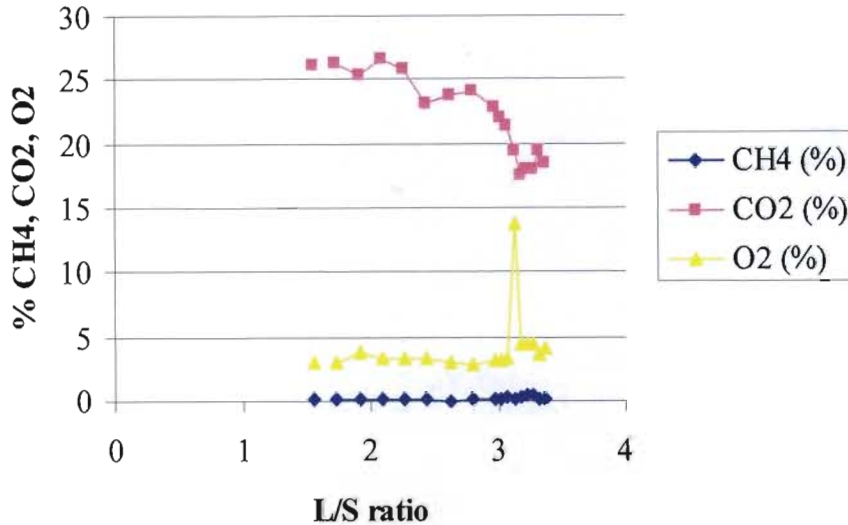
Figure 5.9 Lysimeter C: Biogas Quality

5.3.3 LYSIMETERS LEACHATE ANALYSIS RESULTS

From the analysis carried out to determine the various parameters described below in the leachate samples collected from the lysimeters on a weekly basis, it is observed that two processes serves to stabilize the waste material in this lysimeters. These processes are the physical removal and biological conversion. The physical removal is facilitated by the leaching of water through the waste body in the lysimeters, which results in the removal or washing out of contaminants. The biological conversion involves the metabolism of the organic material present in the waste material in each lysimeters by microorganisms. The parameters analyzed for in the leachate samples from each lysimeters are pH, conductivity, chemical oxygen demand, nitrogenous compounds, and solids (total and volatile solids).

pH and Conductivity

Figures 5.10 to 5.12 below present the lysimeters leachate pH and conductivity results. The pH values for both lysimeter A and B as shown in figures 5.10 and 5.11 remain consistent between a slightly acidic pH and neutral pH for the entire period of the analysis. This recorded pH values are consistent with other studies of pretreated waste (Cossu, 2003). The acidic pH values observed in this initial period of analysis for lysimeter C as shown in figure 5.12 are consistent with other studies of untreated fresh waste (Robinson, 1989). The early peak conductivity value observed at the onset of the

analysis for lysimeter A as shown in figure 5.10 can be attributed to the establishment anaerobic activity in the lysimeter, this then gradually decreases as soon as methanogenic microbes becomes established. Due to the slowly establishment of methanogenic microbes observed in lysimeter B, there was a gradual increase in the conductivity values as shown in figure 5.11, which also decreased gradually as observed in lysimeter A as methanogenic microbes are established. The increasing trend observed in the conductivity results of lysimeter C as shown in figure 5.12 compared to lysimeter A and B is a typical behaviour observed during the anaerobic degradation of untreated waste. This is due to hydrolysis reaction taking place in the lysimeter resulting into the production of dissolved ions which is leached out by the water percolating through the waste body in the lysimeter.
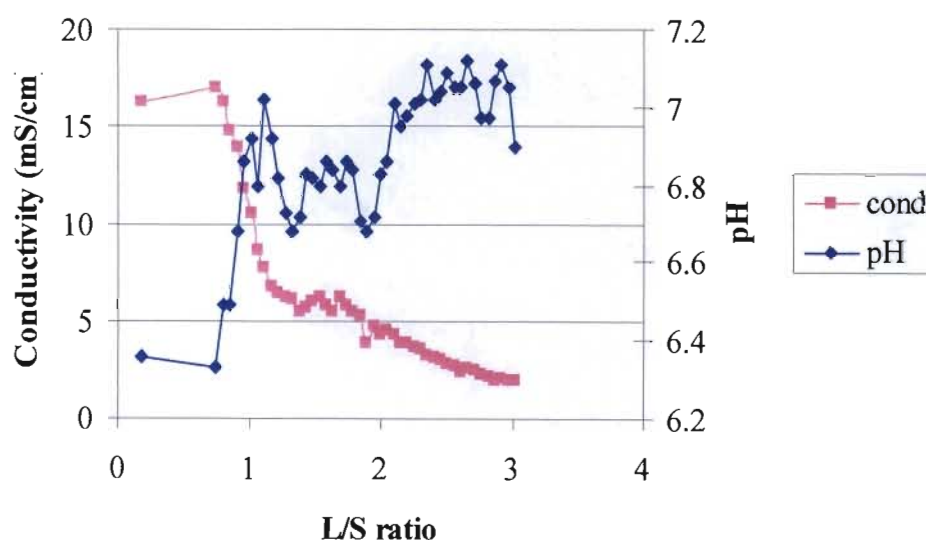
Figure 5.10 Lysimeter A: pH and conductivity
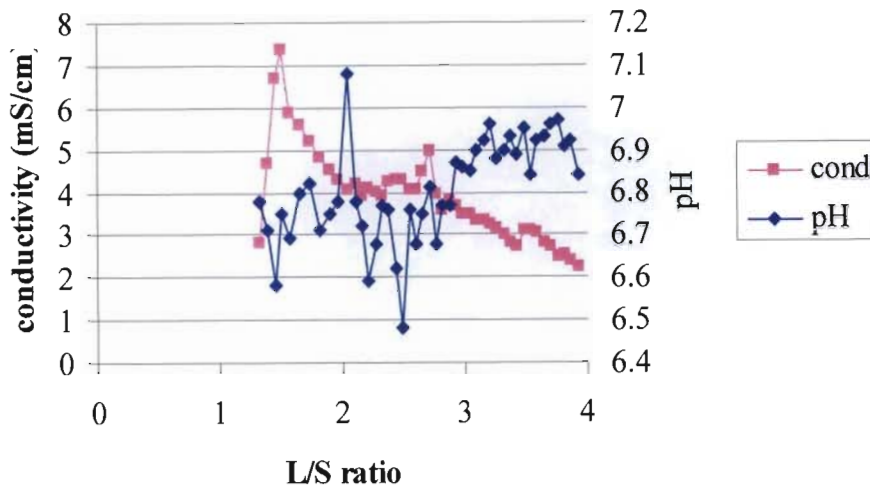
Figure 5.11 Lysimeter B: pH and conductivity
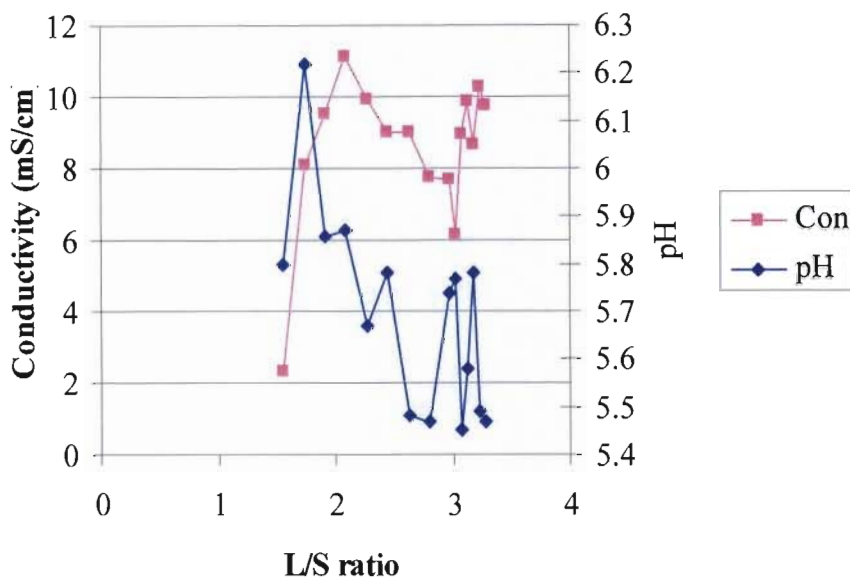
Figure 5.12 Lysimeter C: pH and conductivity

Chemical Oxygen Demand (COD)

Figures 5.13 to 5.15 present the results of COD evolution from the lysimeters for the entire analytical periods. The rapid increase in the leachate COD observed for both lysimeter A and B as shown in figures 5.13 and 5.14 respectively, reflects activity of early anaerobic microbial development which then decreases as the methanogenic microbes becomes established. The maximum recorded COD values for both lysimeter A and B was approximately 14,263mg/l and 4547mg/l respectively. When comparing

the final recorded COD values for both lysimeter A and B which was approximately 450mg/l and 676mg/l respectively, this indicates that the rate of COD removal for lysimeter A is higher than that of lysimeter B. This confirms the fact that the material composition in lysimeter B which comprises of non/slowly biodegradable material results to the long term polluting effect. As shown in figure 5.15, lysimeter C, COD increases from the initial value of 4487mg/l and remains above 10,000mg/l. This is generally common to leachate produced during the acidic stage of landfill emission stages as described in chapter 2.
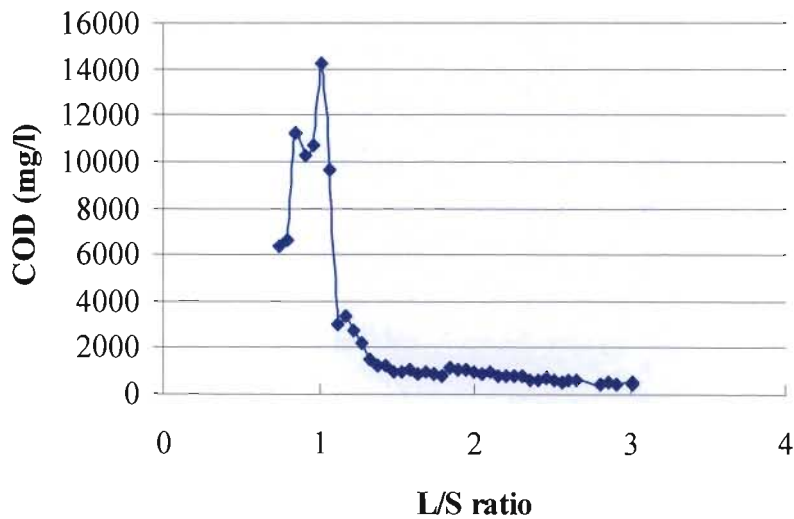
Figure 5.13 Lysimeter A: COD Evolution
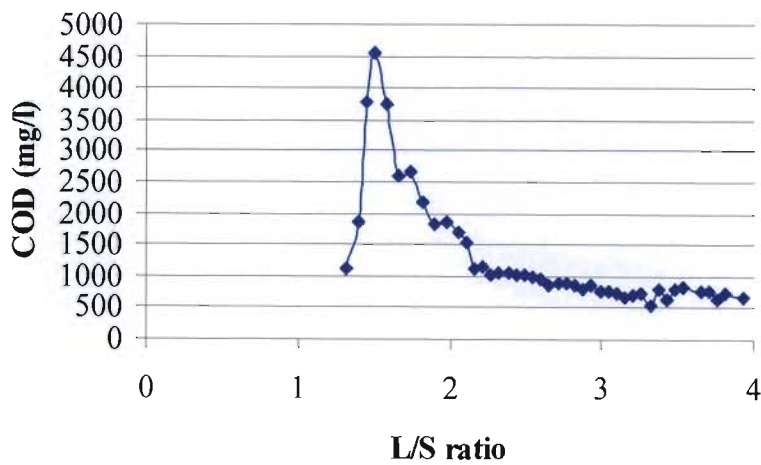
Figure 5.14 Lysimeter B: COD Evolution
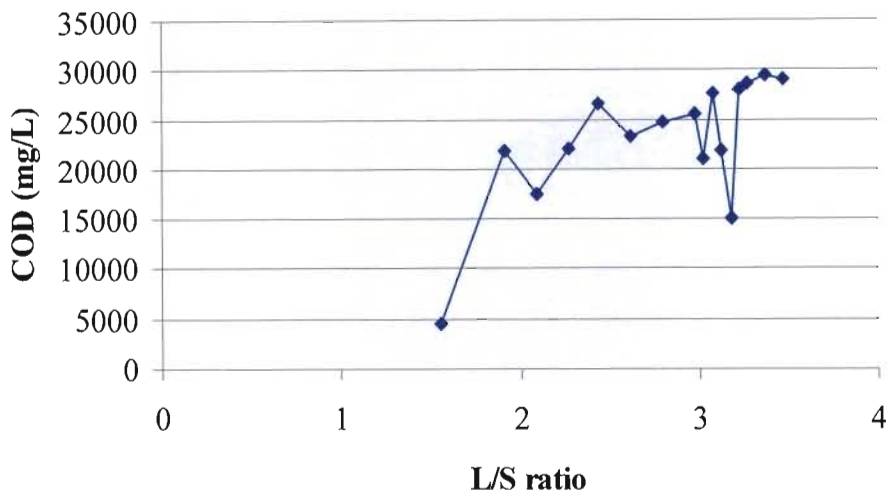
Figure 5.15 Lysimeter C: COD Evolution

Nitrogenous Compounds

Figures 5.16 to 5.18 below presents the lysimeters results for nitrogenous compounds recorded for the entire period of the analysis. The rapid increase in the ammonical-nitrogen concentration observed in both lysimeter A and B as shown in figures 5.16 and 5.17 respectively suggests the breaking down of organic compounds in the waste body. An unexpected decreasing trend in the concentration of ammonical-nitrogen in both lysimeter A and B was observed as this is not expected to occur. Although the reason is not clearly understood, however, it may be attributed to physical flushing resulting from the water percolating the waste body in both lysimeter. Hence, these suggest that the leaching process supersedes the biological conversion process taking place in both lysimeter. As it is shown in figures 5.18 the concentration of ammonical-nitrogen in lysimeter C is very high and it is increasing rapidly, this is a typical characteristics of the leachate produced during the acidic stage of landfill emissions as discussed in chapter 2. The presence of nitrates/nitrites, observed in the three lysimeters is an indication of the presence aerobic niches within the waste body.
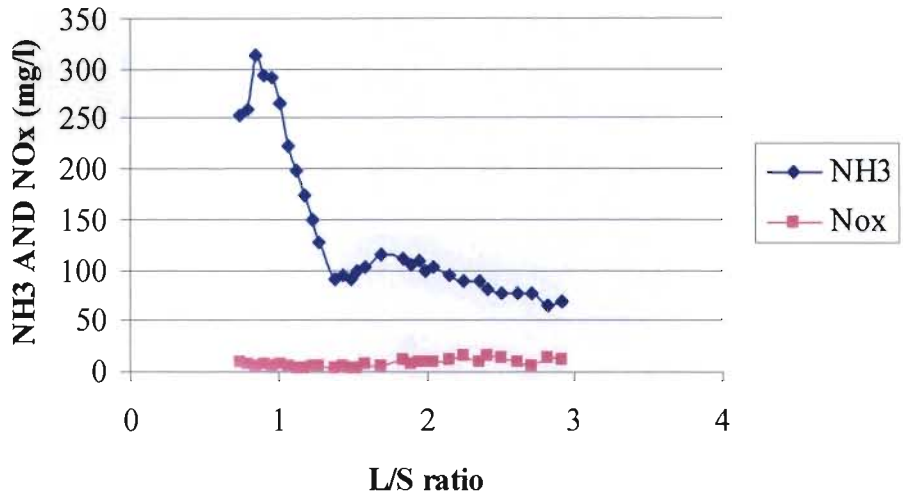
Figure 5.16 Lysimeter A: Leachate Nitrogenous compound concentrations
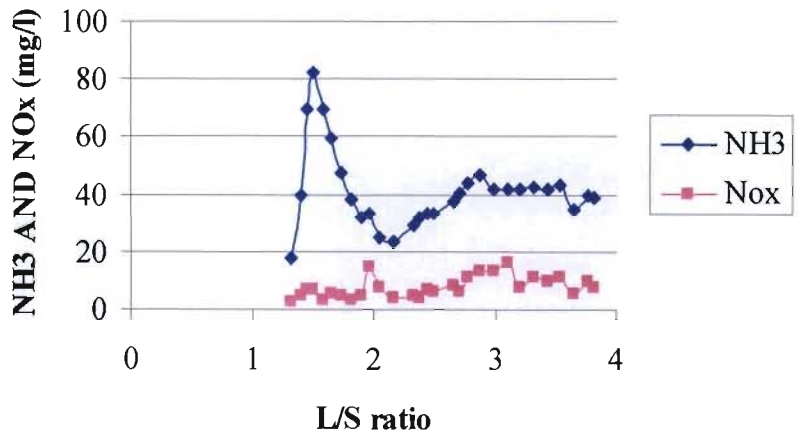
Figure 5.17 Lysimeter B: Leachate Nitrogenous compound concentrations
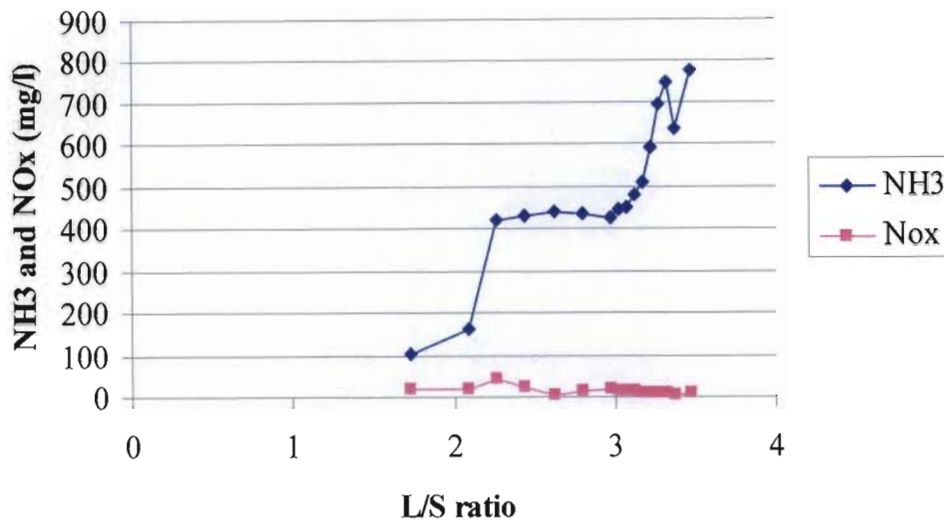
Figure 5.18 Lysimeter C: Leachate Nitrogenous compound concentrations

Solids (Total and Volatile Solids)

The results of the lysimeters total and volatile solids are presented in figures 5.19 to 5.21 below. The initial high concentrations of total and volatile solids observed in lysimeter A as shown in figure 5.19 can be attributed to the fact that the microorganisms in the lysimeter are still adjusting to the environment within the lysimeter. However, as soon as the microorganisms becomes adjusted to the environment, the microbes proceed to degrade the waste material and the amount of solids leached out becomes reduced thereby resulting in declining trend in both the total and volatile solids. The rapid increase in the concentration of total and volatile solids observed in the initial period of analysis for lysimeter B s shown figure 5.20, this suggest that the microorganisms within the lysimeter are not yet well established. A decreasing trend was also observed as soon as the microorganisms become established. The increasing trend observed in lysimeter C as shown in figure 5.21 suggests that the microorganisms within the lysimeter are not actively degrading the waste material.
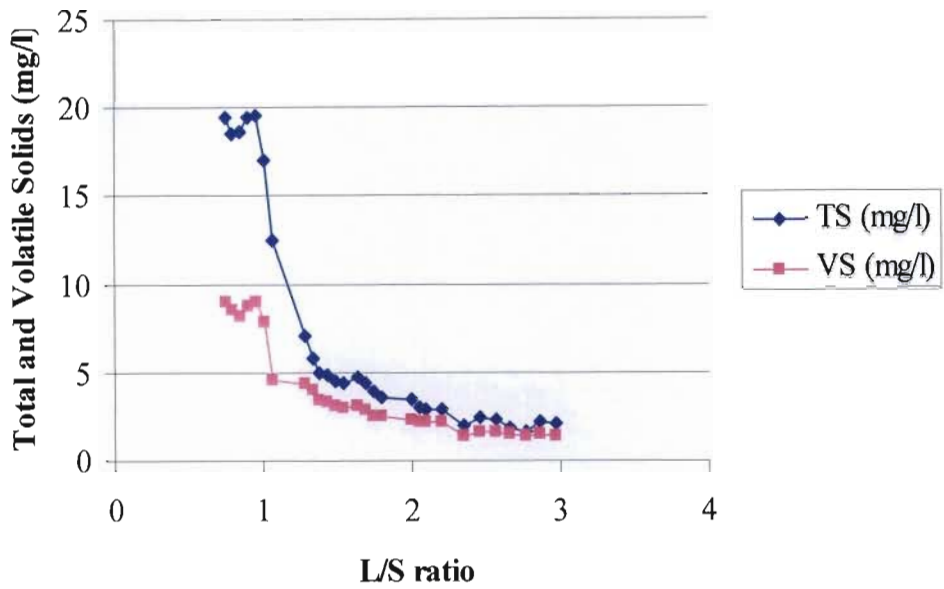
Figure 5.19 Lysimeter A: Total and Volatile Solid concentrations
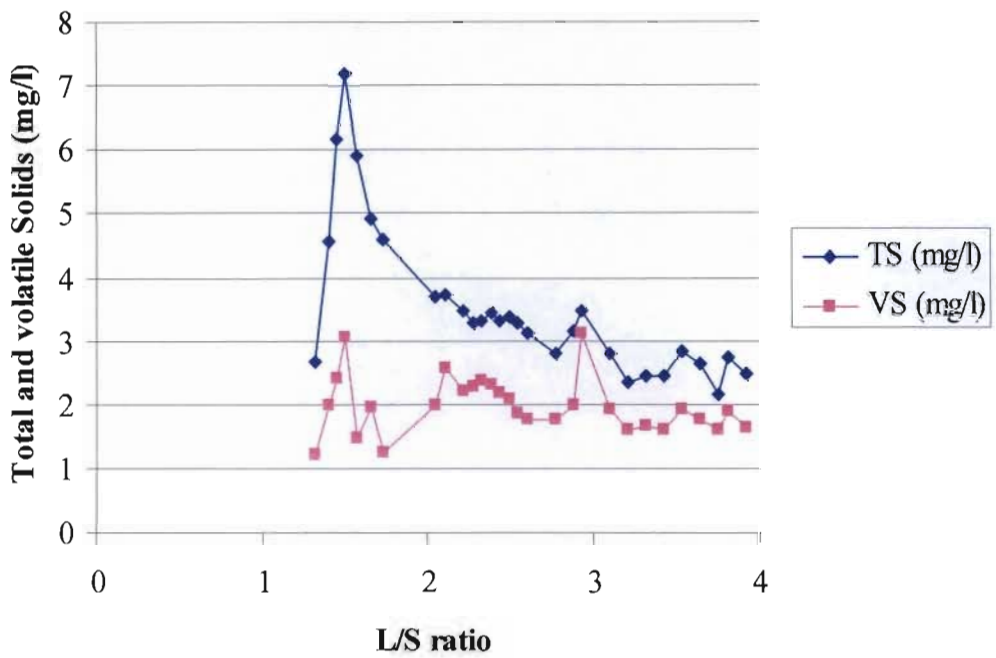
Figure 5.20 Lysimeter B: Total and Volatile Solid concentrations
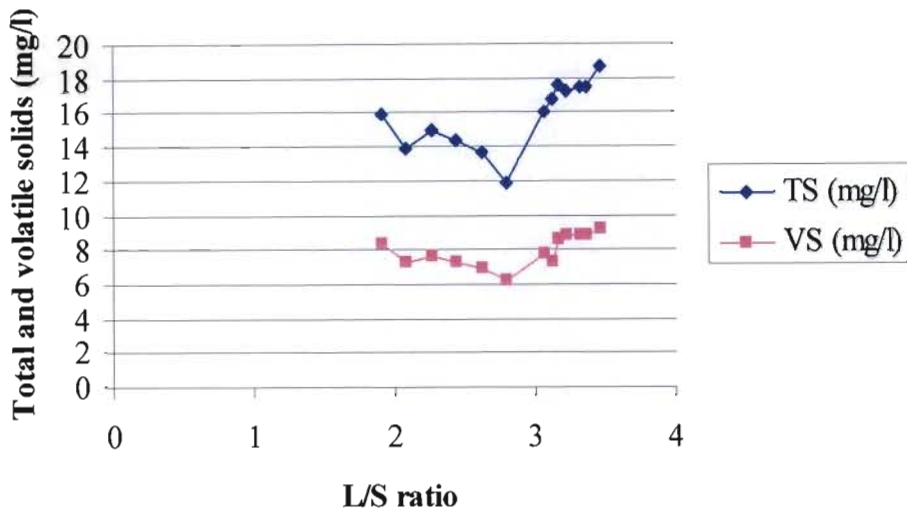
Figure 5.21 Lysimeter C: Total and Volatile Solid concentrations

5.3.4 CUMULATIVE RELEASE OF ORGANICS (COD).

Figures 5.22 to 5.24 present the lysimeters cumulative or total release of the organics (COD) from the waste fractions in each lysimeter. It is an indication of the release of contaminants into the leachate sample. The effect of mechanical biological pretreatment on waste samples in lysimeter A and B is clearly confirmed, as it can be seen from figures 5.22 and 5.23, the cumulative amount of organics release from both lysimeters is significantly lower than that which is released from lysimeter C as shown in figure 5.24. Also the effect of grain size on leachate contamination becomes evident when comparing figures 5.22 with 5.23. Although the cumulative release of organics from lysimeter A is greater than that of lysimeter B, these only confirms the presence of readily biodegradable materials in lysimeter A. However, as it could be seen from the trend of increase in figure 5.22 which is now becoming relatively constant compared to figure 5.23 which is still in an increasing trend, this suggest that, as the trend line becomes flattened out for figure 5.22, the trend line for figure 5.23 will continue to increase gradually. Hence, this confirms the fact that the long term polluting effect is caused by the coarse materials of lysimeter B, as contaminants will slowly continue be leached from the waste body for a long period.
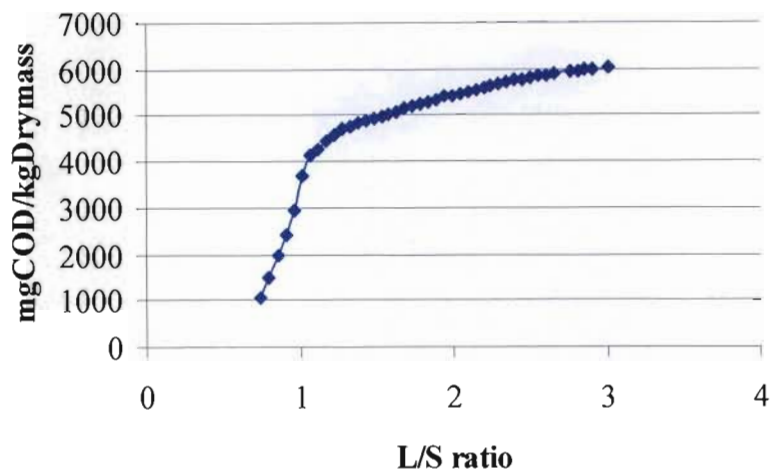
Fig 5.22 Lysimeter A: COD cumulative Release
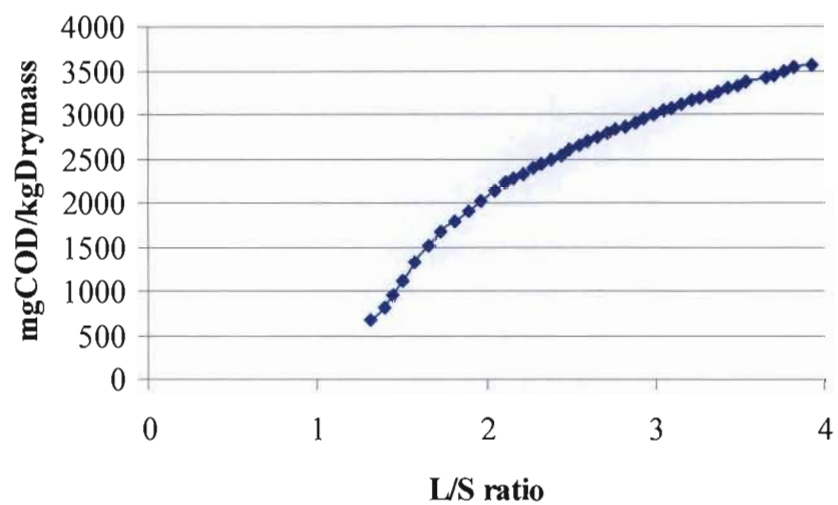
Fig 5.23 Lysimeter B: COD Cumulative Release.
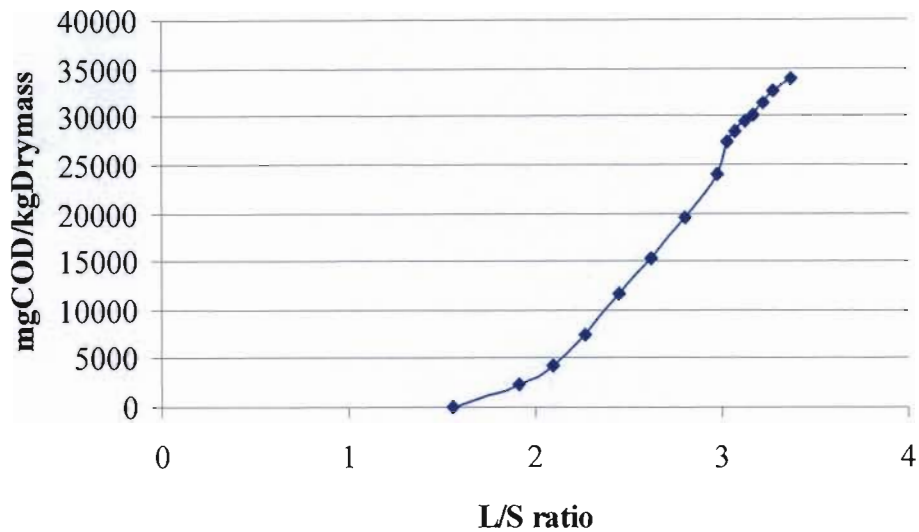
Fig 5.24 Lysimeter C: COD Cumulative Release

5.3.5 CUMULATIVE RELEASE OF NITROGENOUS COMPOUND

Figures 5.25 to 5.27 below presents the cumulative release of nitrogenous compounds from the waste body in lysimeters. The explanation is similar to that discussed for the cumulative release of organics (COD).
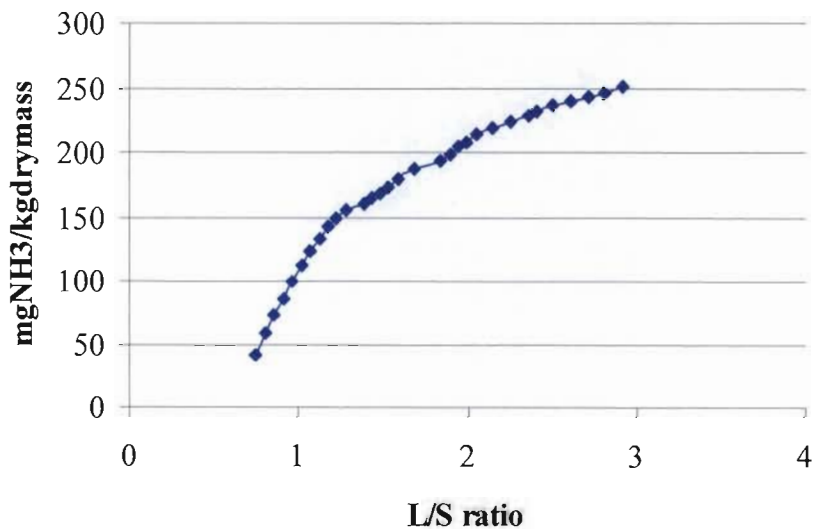
Fig 5.25 Lysimeter A: Ammonical Nitrogen Cumulative Release.
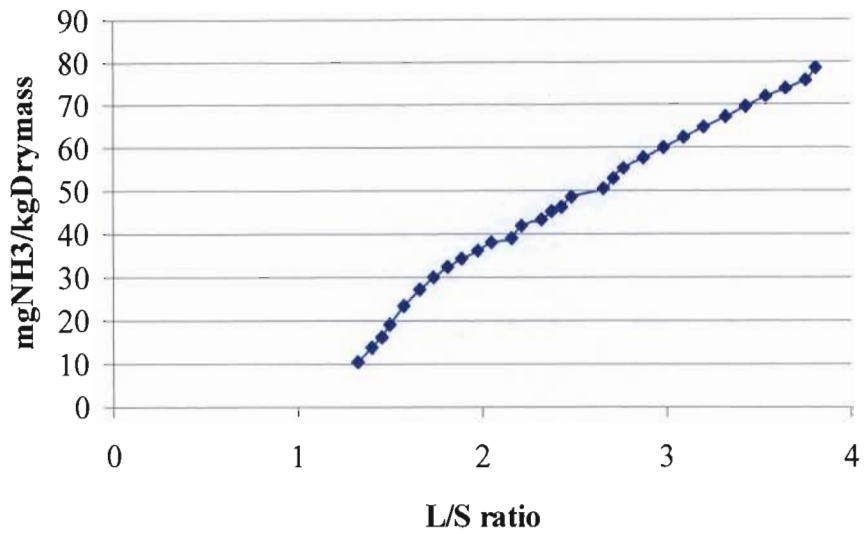
Fig 5.26 Lysimeter B: Ammonical Nitrogen Cumulative Release
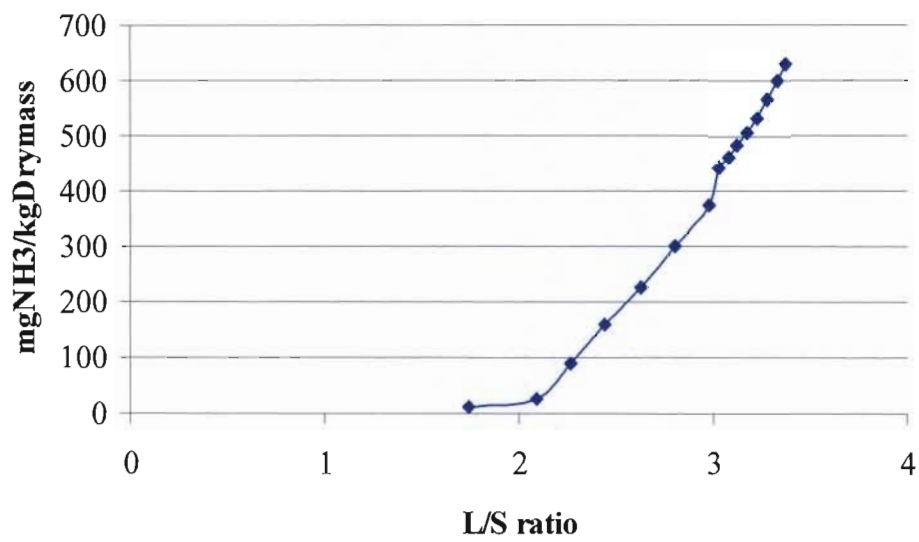
Fig 5.27 Lysimeter C: Ammonical Nitrogen Cumulative Release.

5.4 PREDICTIONS OF LONG TERM POLLUTING POTENTALS.

In order to assess the long term emissions from the lysimeter, the establishment of an acceptable discharge standard is required. The current DWAF Discharge Standards were used as criterion for assessing whether the leachate was suitable for discharge into a natural receptor. The discharge standards for the significant parameters COD and NH_3 are presented in Table 5.8 below.

Table 5.9 DWAF Discharge Standards for Significant Leachate Parameters (1998b)

Parameter	Unit	DWAF Discharge Limit
COD	mg/l	75
NH_3	mg/l	15

The prediction of the long term polluting potentials of these significant leachate parameters is based on modeling them using a 1st order kinetic equation. This equation describes the long term evolution of these parameters in the lysimeters. Figures 5.25 to 5.28 below shows the prediction model which was used for lysimeter A and lysimeter B, the model could not be applied to lysimeter C since it is still in the early phases of waste degradation, making it difficult to draw significant predictions.

Scatter plot with y-axis labelled "mg/l COD" ranging from 0 to 16000, x-axis labelled "Cum L/S" ranging from 0 to 4, with fitted equation $y = 4451.2e^{-0.7712x}$
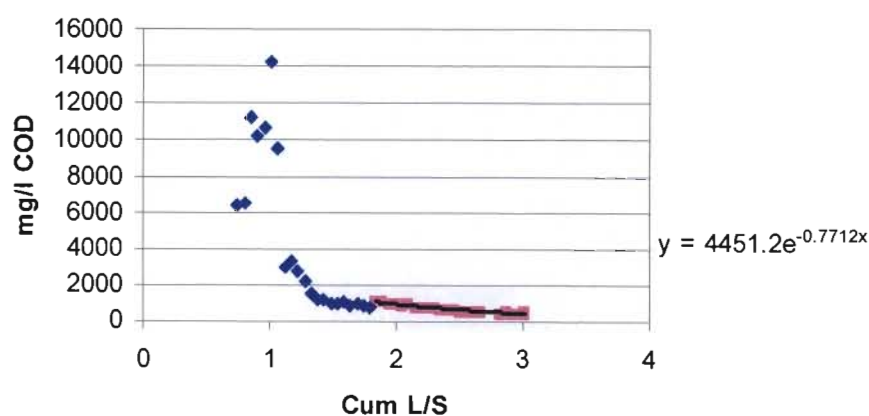
Fig 5.28: Lysimeter A COD Long Term Prediction Model
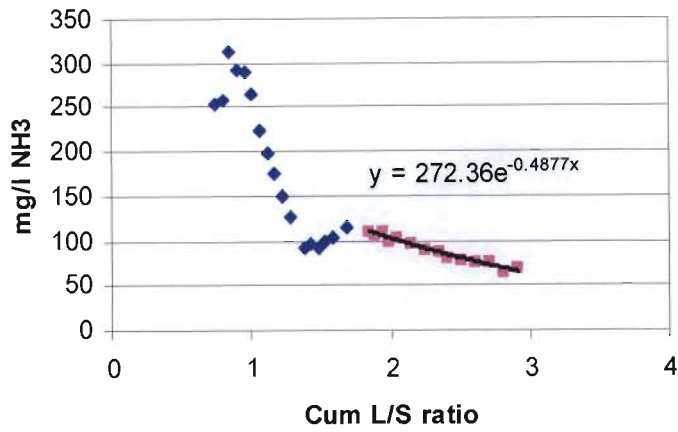
Fig 5.29: Lysimeter A Ammonical- N Long Term Prediction Model
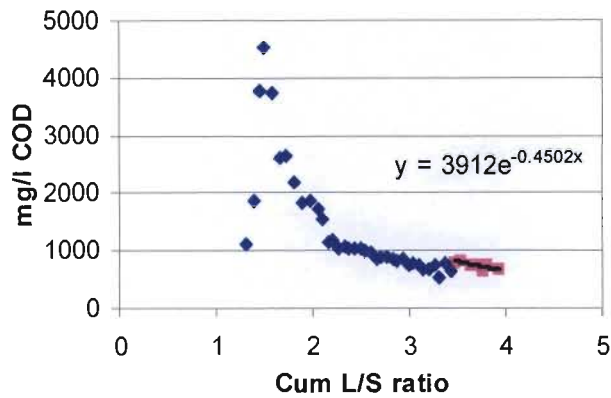
Fig 5.30: Lysimeter B COD Long Term Prediction Model
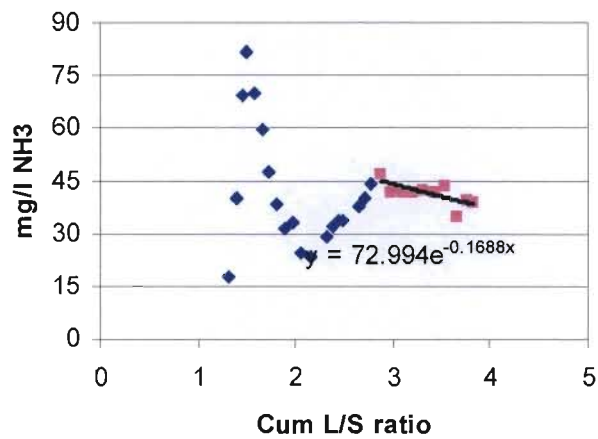
Fig 5.31: Lysimeter B Ammonical-N Long Term Prediction Model.

Applying the exponential function on each model in the figures above to the DWAF discharge standards, the cumulative Liquid/Solid ratio required to meet the discharge standards can be determined. The exponential function on each model used can be described mathematically by equation 5.1 below.

$$y = ae^{-bx} \hspace{6cm} 5.1$$

Where:

y is the DWAF discharge limits of a particular significant parameter

a and b are constant value as shown in the figures above.

x is the cumulative L/S ratio required to reach the discharge limits.

The extrapolation of the liquid/solid ratio gives an idea of the time frames that may be expected to reach the discharge standards. The full scale predictions of the long term polluting potentials of each significant leachate parameters from the lysimeters were based on a 20m deep landfill with an infiltration rate of $250l/m^2.a$ and a dry density of $600kg/m^3$ (Leikam et al, 1997). Table 5.9 presents the time frame required in order to meet the DWAF discharge standards.

Table 5.10 Projected Time for the Long Term Polluting Potentials to reach DWAF standards.

Parameter	Unit	Lysimeter A	Lysimeter B
COD			
Value at the end of trials	mg/l	450	676.
DWAF discharge Standard	mg/l	75	75
Long Term L/S ratio		5.29	8.78
Time required to reach DWAF discharge standard	years	264	439
NH4-N			
Value at the end of trials	mg/l	68.74	38.78
DWAF discharge Standard	mg/l	15	15
Long Term L/S ratio		5.94	9.37
Time required to reach DWAF discharge standard	years	297	468

An unexpected result for the projected time for the long term polluting potential to reach the DWAF standard was observed. As can be seen from Table 5.10, the projected time for COD and NH4-N for both lysimeter A and B is significantly longer than the typical time of activity for a classical landfill which is usually less than 50years. The reason for this surprising result is not clearly understood, however it could be attributed to the operating conditions of the lysimeter during the analysis. One of such operating condition could be temperature which was far from the optimum temperature in which significant biological conversion could occur. Another reason might be that the leaching process was predominant over biochemical reaction taking place in the lysimeter.

CHAPTER 6

CONCLUSIONS

The outcome of this research has provided information on the behaviour of the long term emissions from waste which has been pretreated for 16 weeks and separated into fine waste fractions characterized by particle size less than 50mm and coarse waste fractions characterized by particle size greater than 50mm.

The Lysimeter investigation demonstrated that the elimination of the acidic inhibition that is a characteristic of waste with high organic content is possible through Mechanical Biological Pretreatment of waste. The elimination of the characteristic acid stage was achieved in both lysimeters A and B but not in lysimeter C which comprises of fresh waste without pretreatment. This confirms the benefits of the Mechanical Biological Pretreatment. Despite the short period of analysis carried out on lysimeter C, the lysimeter still exhibits the highest cumulative amounts of organics leached out from the waste body into the leachate when compared to both lysimeter A and B. This confirms that lysimeter C, which comprises untreated waste, is still in the acidic phase of landfill emissions. The cumulative release of organics into the leachate also exhibited a higher concentration for lysimeter A compared to lysimeter B as shown in fig 5.22 and 5.23 respectively. This confirms the presence of high organic content in the waste body in lysimeter A which is composed of the 16week pretreated fine waste fractions. Thus, separating waste into fine and coarse waste fraction prior to pretreatment is beneficial to the efficiency of the treatment process, and leads to significant reduction in organic content in the coarse waste fraction which was placed lysimeter B. From the projected results in Table 5.10, lysimeter A reaches the required discharge standards for both COD and NH_3 earlier than that of lysimeter B. This confirms that the fine fractions contain not only more organic compounds but that there are also far more readily biodegradable compounds present in the fine fraction of the waste than the coarse material which is constituted primarily of organics of refractory nature.

Thus, the mechanical separation of waste into fine and coarse fraction does assist in reducing the polluting potential of the waste as this process allows for significant separation of biodegradable organic materials present in the waste from slowly or

after the separation, waste fractions with high calorific values can be recycled or reused as Refuse Derived Fuel while waste fractions containing the biodegradable components can then be landfilled. Thus, the landfill aftercare period would be reduced as leachate and biogas production occurs for a shorter time frame.

Therefore Mechanical Biological Pretreatment has a significant positive effect on the operation and maintenance of landfills. The separation of pretreated waste into fine and coarse waste fractions thus has the potential to significantly reduce the overall negative impacts of landfill emissions.

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APPENDIX A

LYSIMETER A
(16 WEEKS PRETREATED UNDERSIEVE WASTE SAMPLES)

BIOGAS AND LEACHATE ANALYSIS DATA

CUMMULATIVE LIQUID/ SOLID RATIO

Dates	Water Input (L)	Extracted	Retained	Tot Moist	cuml added	Cuml L/S
06-Sep-05	54.01	0.00	54.01	54.01	54.01	0.19
13-Sep-05	158.50	46.08	112.42	166.43	212.51	0.75
20-Sep-05	15.00	18.93	-3.93	162.50	227.51	0.80
27-Sep-05	15.00	12.82	2.18	164.68	242.51	0.86
04-Oct-05	15.00	12.28	2.72	167.40	257.51	0.91
11-Oct-05	15.00	13.78	1.22	168.62	272.51	0.96
19-Oct-05	15.00	14.63	0.37	168.99	287.51	1.02
25-Oct-05	15.00	13.03	1.97	170.96	302.51	1.07
01-Nov-05	15.00	13.98	1.02	171.97	317.51	1.12
09-Nov-05	15.00	14.88	0.12	172.09	332.51	1.17
15-Nov-06	15.00	11.84	3.16	175.25	347.51	1.23
21-Nov-06	15.00	14.63	0.37	175.62	362.51	1.28
29-Nov-06	14.50	13.81	0.69	176.31	377.01	1.33
06-Dec-06	14.50	13.53	0.97	177.28	391.51	1.38
15-Dec-06	14.50	14.25	0.25	177.53	406.01	1.43
22-Dec-06	14.50	13.35	1.15	178.69	420.51	1.49
28-Dec-06	14.50	12.91	1.59	180.28	435.01	1.54
05-Jan-06	14.50	15.69	-1.19	179.09	449.51	1.59
12-Jan-06	14.50	8.93	5.57	184.66	464.01	1.64
24-Jan-06	14.50	21.43	-6.93	177.74	478.51	1.69
02-Feb-06	14.50	10.65	3.85	181.59	493.01	1.74
10-Feb-06	14.50	16.71	-2.21	179.38	507.51	1.79
16-Feb-06	14.50	14.03	0.47	179.85	522.01	1.84
23-Feb-06	14.50	14.71	-0.21	179.64	536.51	1.90
06-Mar-06	14.50	16.26	-1.76	177.88	551.01	1.95
09-Mar-06	14.50	10.21	4.29	182.17	565.51	2.00
16-Mar-06	14.50	14.21	0.29	182.46	580.01	2.05

23-Mar-06	14.50	14.35	0.15	182.61	594.51	2.10
30-Mar-06	14.50	14.36	0.14	182.75	609.01	2.15
06-Apr-06	14.50	14.36	0.14	182.90	623.51	2.20
13-Apr-06	14.50	14.67	-0.17	182.73	638.01	2.25
20-Apr-06	14.50	14.03	0.47	183.20	652.51	2.30
02-May-06	14.50	16.43	-1.93	181.27	667.01	2.36
09-May-06	14.50	12.64	1.86	183.12	681.51	2.41
16-May-06	14.50	14.07	0.43	183.55	696.01	2.46
23-May-06	14.50	14.86	-0.36	183.19	710.51	2.51
31-May-06	14.50	14.30	0.20	183.39	725.01	2.56
06-Jun-06	14.50	13.72	0.78	184.17	739.51	2.61
14-Jun-06	14.50	13.68	0.82	184.98	754.01	2.66
20-Jun-06	14.50	13.54	0.96	185.94	768.51	2.72
27-Jun-06	14.50	14.80	-0.30	185.64	783.01	2.77
04-Jul-06	14.50	14.45	0.05	185.69	797.51	2.82
11-Jul-06	14.50	14.74	-0.24	185.45	812.01	2.87
25-Jul-06	14.50	17.53	-3.03	182.42	826.51	2.92
02-Aug-06	14.50	12.93	1.57	183.99	841.01	2.97
08-Aug-06	14.50	14.13	0.37	184.36	855.51	3.02
15-Aug-06	14.50	15.14	-0.64	183.73	870.01	3.07

BIOGAS QUALIY

Dates	CUM L/S	CH4(%)	CO2(%)	O2 (%)	Temp-tank (°c)	Ambient-Temp (°c)
06-Sep-05	0.19	0.10	39.40	0.70	21.50	21.20
13-Sep-05	0.75	1.50	41.90	0.40	22.00	23.50
21-Sep-05	0.80	7.50	42.50	0.60	21.50	21.70
27-Sep-05	0.86	19.90	41.60	0.30	22.00	21.80
04-Oct-05	0.91	24.00	37.50	0.40	22.50	26.40
11-Oct-05	0.96	33.10	38.70	0.70	24.50	25.30
19-Oct-05	1.02	15.20	29.00	1.50	20.00	26.20
25-Oct-05	1.07	10.80	27.10	0.70	19.50	20.40
01-Nov-05	1.12	7.10	25.30	0.70	18.50	24.40
09-Nov-05	1.17	5.30	22.80	1.70	17.70	23.50
15-Nov-05	1.23	24.10	32.10	0.40	22.90	24.20
21-Nov-05	1.28	32.00	36.40	0.00	24.90	24.80
29-Nov-05	1.33	32.20	37.30	0.00	22.90	27.50
06-Dec-05	1.38	29.30	35.70	0.40	23.00	27.30
15-Dec-05	1.43	28.70	35.10	0.00	23.00	26.00
22-Dec-05	1.49	29.90	37.30	0.10	21.60	22.60
28-Dec-05	1.54	30.00	36.90	0.30	22.30	24.70
05-Jan-06	1.59	27.00	36.10	0.30	24.60	29.00
11-Jan-06	1.64	27.50	32.90	0.00	23.00	26.90
24-Jan-06	1.69	25.70	34.80	0.00	23.20	23.10
02-Feb-06	1.74	27.00	36.10	0.30	24.20	26.90
10-Feb-06	1.79	27.50	32.90	0.00	23.70	26.00
16-Feb-06	1.84	25.60	33.30	0.10	24.90	28.20
23-Feb-06	1.90	27.60	34.10	0.10	24.80	26.60
06-Mar-06	1.95	23.00	31.20	0.10	19.80	18.80
09-Mar-06	2.00	21.60	31.00	0.30	22.00	26.90
16-Mar-06	2.05	20.30	32.00	0.30	22.40	22.30
23-Mar-	2.10	17.60	30.70	0.20	22.70	23.40

06						
30-Mar-06	2.15	16.60	29.20	0.10	23.00	22.70
06-Apr-06	2.20	16.30	29.90	0.10	25.20	26.20
13-Apr-06	2.25	15.50	29.10	0.00	22.50	23.10
20-Apr-06	2.31	13.80	27.90	0.00	22.60	22.40
02-May-06	2.36	10.80	26.70	0.10	18.90	19.50
09-May-06	2.41	6.60	24.50	0.20	17.80	16.30
16-May-06	2.46	6.20	24.60	0.20	19.80	19.20
23-May-06	2.51	0.40	22.90	0.00	17.60	17.10
31-May-06	2.56	3.20	22.40	0.10	16.70	19.80
06-Jun-06	2.61	1.60	20.80	0.10	19.20	19.50
14-Jun-06	2.66	1.80	22.30	0.20	19.20	18.90
20-Jun-06	2.72	2.00	21.50	0.00	18.20	19.00
27-Jun-06	2.77	0.00	20.10	0.20	15.20	16.20
04-Jul-06	2.82	0.10	20.90	0.20	18.60	18.90
11-Jul-06	2.87	0.10	21.00	0.20	18.90	19.20
25-Jul-06	2.92	0.10	21.50	0.20	14.20	14.30
02-Aug-06	2.97	0.10	21.60	0.10	15.00	16.50
08-Aug-06	3.02	0.10	21.10	0.10	21.60	24.00
15-Aug-06	3.07	-	-	-	-	-

pH AND CONDUCTIVITY

Dates	CUM L/S	pH	Conductivity (mS/cm)
06-Sep-05	0.19	6.36	16.34
13-Sep-05	0.75	6.33	17.01
21-Sep-05	0.80	6.49	16.28
27-Sep-05	0.86	6.49	14.86
04-Oct-05	0.91	6.68	13.99
11-Oct-05	0.96	6.86	11.86
19-Oct-05	1.02	6.92	10.53
25-Oct-05	1.07	6.797	8.66
01-Nov-05	1.12	7.02	7.75
09-Nov-05	1.17	6.92	6.74
15-Nov-05	1.23	6.82	6.45
21-Nov-05	1.28	6.73	6.24
29-Nov-05	1.33	6.68	6.13
06-Dec-05	1.38	6.72	5.48
15-Dec-05	1.43	6.83	5.72
22-Dec-05	1.49	6.82	6.01
28-Dec-05	1.54	6.80	6.29
05-Jan-06	1.59	6.86	5.86
11-Jan-06	1.64	6.84	5.48
24-Jan-06	1.69	6.8	6.29
02-Feb-06	1.74	6.86	5.86
10-Feb-06	1.79	6.84	5.48
16-Feb-06	1.84	6.71	5.27
23-Feb-06	1.90	6.68	3.90
06-Mar-06	1.95	6.72	4.75
09-Mar-06	2.00	6.83	4.36
16-Mar-06	2.05	6.86	4.54

23-Mar-06	2.10	7.01	4.38
30-Mar-06	2.15	6.95	3.92
06-Apr-06	2.20	6.98	3.94
13-Apr-06	2.25	7.01	3.71
20-Apr-06	2.31	7.02	3.56
02-May-06	2.36	7.11	3.31
09-May-06	2.41	7.02	3.20
16-May-06	2.46	7.04	3.10
23-May-06	2.51	7.09	2.87
31-May-06	2.56	7.05	2.72
06-Jun-06	2.61	7.05	2.48
14-Jun-06	2.66	7.12	2.67
20-Jun-06	2.72	7.06	2.53
27-Jun-06	2.77	6.97	2.34
04-Jul-06	2.82	6.97	2.23
11-Jul-06	2.87	7.07	2.01
25-Jul-06	2.92	7.11	2.09
02-Aug-06	2.97	7.05	2.01
08-Aug-06	3.02	6.90	2.00
15-Aug-06	-	-	-

CHEMICAL OXYGEN DEMAND

Dates	CUM L/S	COD (mg/l)
06-Sep-05	0.19	-
13-Sep-05	0.75	6408.84
21-Sep-05	0.80	6605.42
27-Sep-05	0.86	11263.26
04-Oct-05	0.91	10239.80
11-Oct-05	0.96	10695.93
19-Oct-05	1.02	14262.50
25-Oct-05	1.07	9600.64
01-Nov-05	1.12	3017.08
09-Nov-05	1.17	3321.25
15-Nov-05	1.23	2766.59
21-Nov-05	1.28	2183.24
29-Nov-05	1.33	1517.79
06-Dec-05	1.38	1239.13
15-Dec-05	1.43	1255.48
22-Dec-05	1.49	1002.51
28-Dec-05	1.54	982.49
05-Jan-06	1.59	1081.27
11-Jan-06	1.64	871.06
24-Jan-06	1.69	983.16
02-Feb-06	1.74	894.39
10-Feb-06	1.79	821.97
16-Feb-06	1.84	1125.48
23-Feb-06	1.90	1102.56
06-Mar-06	1.95	1052.13
09-Mar-06	2.00	961.87
16-Mar-06	2.05	868.52

23-Mar-06	2.10	964.45
30-Mar-06	2.15	791.16
06-Apr-06	2.20	773.63
13-Apr-06	2.25	787.11
20-Apr-06	2.31	790.29
02-May-06	2.36	649.16
09-May-06	2.41	646.84
16-May-06	2.46	708.73
23-May-06	2.51	601.71
31-May-06	2.56	570.76
06-Jun-06	2.61	575.28
14-Jun-06	2.66	579.79
20-Jun-06	2.72	-
27-Jun-06	2.77	482.66
04-Jul-06	2.82	502.43
11-Jul-06	2.87	438.39
25-Jul-06	2.92	513.60
02-Aug-06	2.97	-
08-Aug-06	3.02	450.29
15-Aug-06	3.07	-

NITROGENOUS COMPOUNDS

Dates	CUM L/S	Ammonical-N (mg/l)	Nitrates& Nitrites (mg/l)
06-Sep-05	0.19	-	-
13-Sep-05	0.75	252.95	9.24
21-Sep-05	0.80	258.00	8.50
27-Sep-05	0.86	314.15	6.65
04-Oct-05	0.91	292.85	8.25
11-Oct-05	0.96	290.75	6.41
19-Oct-05	1.02	264.02	8.62
25-Oct-05	1.07	222.62	5.30
01-Nov-05	1.12	197.35	3.90
09-Nov-05	1.17	173.96	4.80
15-Nov-05	1.23	150.14	6.90
21-Nov-05	1.28	127.76	6.53
29-Nov-05	1.33	-	-
06-Dec-05	1.38	91.74	4.93
15-Dec-05	1.43	95.93	6.90
22-Dec-05	1.49	91.29	4.40
28-Dec-05	1.54	99.40	5.04
05-Jan-06	1.59	102.76	8.12
11-Jan-06	1.64	-	-
24-Jan-06	1.69	115.64	5.60
02-Feb-06	1.74	-	-
10-Feb-06	1.79	-	-
16-Feb-06	1.84	111.53	11.57
23-Feb-06	1.90	106.12	8.21
06-Mar-06	1.95	109.85	10.08
09-Mar-06	2.00	98.56	10.83
16-Mar-06	2.05	103.46	10.92

Date			
23-Mar-06	2.10	-	-
30-Mar-06	2.15	95.90	11.34
06-Apr-06	2.20	-	-
13-Apr-06	2.25	90.02	16.24
20-Apr-06	2.31	-	-
02-May-06	2.36	88.62	9.80
09-May-06	2.41	80.50	15.40
16-May-06	2.46	-	-
23-May-06	2.51	77.42	14.70
31-May-06	2.56	-	-
06-Jun-06	2.61	77.00	10.22
14-Jun-06	2.66	-	-
20-Jun-06	2.72	76.02	6.16
27-Jun-06	2.77	-	-
04-Jul-06	2.82	64.26	13.58
11-Jul-06	2.87	-	-
25-Jul-06	2.92	68.74	12.46
02-Aug-06	2.97	-	-
08-Aug-06	3.02	-	-
15-Aug-06	3.07	-	-

TOTAL SOLIDS AND VOLATILE SOLIDS

Dates	CUM L/S	Total solids (g/l)	Volatile solids (g/l)
06-Sep-05	0.19	-	-
13-Sep-05	0.75	19.50	9.00
21-Sep-05	0.80	18.56	8.56
27-Sep-05	0.86	18.63	8.17
04-Oct-05	0.91	19.45	8.76
11-Oct-05	0.96	19.56	9.00
19-Oct-05	1.02	17.01	7.85
25-Oct-05	1.07	12.50	4.68
01-Nov-05	1.12	-	-
09-Nov-05	1.17	-	-
15-Nov-05	1.23	-	-
21-Nov-05	1.28	7.02	4.38
29-Nov-05	1.33	5.80	4.00
06-Dec-05	1.38	-	-
15-Dec-05	1.43	5.02	3.52
22-Dec-05	1.49	4.84	3.35
28-Dec-05	1.54	4.52	3.18
05-Jan-06	1.59	4.37	3.03

11-Jan-06	1.64	-	-
24-Jan-06	1.69	4.75	3.15
02-Feb-06	1.74	4.35	2.90
10-Feb-06	1.79	3.99	2.57
16-Feb-06	1.84	-	-
23-Feb-06	1.90	-	-
06-Mar-06	1.95	3.62	2.59
09-Mar-06	2.00	-	-
16-Mar-06	2.05	3.51	2.34
23-Mar-06	2.10	2.98	2.19
30-Mar-06	2.15	2.93	2.18
06-Apr-06	2.20	-	-
13-Apr-06	2.25	2.87	2.18
20-Apr-06	2.31	-	-
02-May-06	2.36	-	-
09-May-06	2.41	2.00	1.41
16-May-06	2.46	-	-
23-May-06	2.51	2.39	1.65
31-May-06	2.56	-	-
06-Jun-	2.61	2.33	1.65

06			
14-Jun-06	2.66	-	-
20-Jun-06	2.72	1.88	1.56
27-Jun-06	2.77	-	-
04-Jul-06	2.82	1.59	1.33
11-Jul-06	2.87	-	-
25-Jul-06	2.92	2.16	1.49
02-Aug-06	2.97	-	-
08-Aug-06	3.02	2.07	1.34
15-Aug-06	3.07	-	-

CUMMULATIVE COD RELEASE.

Dates	CUM L/S	COD (mg/l)	Extracted	COD (mg)	COD/DM	cum COD/DM
13-Sep-05	0.75	6408.84	46.08	295312.90	1043.32	1043.32
21-Sep-05	0.80	6605.42	18.93	125047.20	441.78	1485.11
27-Sep-05	0.86	11263.26	12.82	144395.00	510.14	1995.25
04-Oct-05	0.91	10239.80	12.28	125714.00	444.14	2439.39
11-Oct-05	0.96	10695.93	13.78	147422.00	520.83	2960.22
19-Oct-05	1.02	14262.50	14.63	208688.90	737.29	3697.51
25-Oct-05	1.07	9600.64	13.03	125125.10	442.06	4139.57
01-Nov-05	1.12	3017.08	13.98	42187.83	149.05	4288.62
09-Nov-05	1.17	3321.25	14.88	49413.56	174.58	4463.19
15-Nov-05	1.23	2766.59	11.84	32761.96	115.75	4578.94
21-Nov-05	1.28	2183.24	14.63	31945.17	112.86	4691.80
29-Nov-05	1.33	1517.79	13.81	20963.72	74.06	4765.86
06-Dec-05	1.38	1239.13	13.53	16760.47	59.21	4825.08
15-Dec-05	1.43	1255.48	14.25	17888.08	63.20	4888.27
22-Dec-05	1.49	1002.51	13.35	13379.50	47.27	4935.54
28-Dec-05	1.54	982.49	12.91	12680.02	44.80	4980.34
05-Jan-06	1.59	1081.27	15.69	16965.13	59.94	5040.28
11-Jan-06	1.64	871.06	8.93	7776.82	27.48	5067.75
24-Jan-06	1.69	983.16	21.47	21066.17	74.43	5142.18
02-Feb-06	1.74	894.39	10.65	9523.47	33.65	5175.82
10-Feb-06	1.79	821.97	16.71	13738.41	48.54	5224.36
16-Feb-06	1.84	1125.48	14.03	15785.98	55.77	5280.13
23-Feb-06	1.90	1102.56	14.71	16214.25	57.28	5337.42
06-Mar-06	1.95	1052.13	16.26	17109.74	60.45	5397.86
09-Mar-06	2.00	961.87	10.21	9824.54	34.71	5432.57
16-Mar-06	2.05	868.52	14.21	12339.93	43.60	5476.17
23-Mar-06	2.10	964.45	14.35	13839.86	48.90	5525.07

30-Mar-06	2.15	791.16	14.36	11359.48	40.13	5565.20
06-Apr-06	2.20	773.63	14.36	11106.23	39.24	5604.44
13-Apr-06	2.25	787.11	14.67	11543.76	40.78	5645.22
20-Apr-06	2.31	790.29	14.03	11090.93	39.18	5684.40
02-May-06	2.36	649.16	16.43	10665.70	37.68	5722.08
09-May-06	2.41	646.84	12.64	8178.65	28.89	5750.98
16-May-06	2.46	708.73	14.07	9971.83	35.23	5786.21
23-May-06	2.51	601.71	14.86	8943.82	31.60	5817.81
31-May-06	2.56	570.76	14.30	8159.59	28.83	5846.63
06-Jun-06	2.61	575.28	13.72	7895.14	27.89	5874.53
14-Jun-06	2.66	579.79	13.68	7933.85	28.03	5902.56
27-Jun-06	2.77	482.66	14.80	7144.33	25.24	5927.80
04-Jul-06	2.82	502.43	14.45	7262.12	25.66	5953.45
11-Jul-06	2.87	438.39	14.74	6461.87	22.83	5976.28
25-Jul-06	2.92	513.60	17.53	9003.41	31.81	6008.09
08-Aug-06	3.02	450.29	14.13	6361.70	22.48	6030.57

CUMMULATIVE RELEASE OF NITROGENOUS COMPOUND

Dates	CUM L/S	NH3 mg/l	Extracted	NH3 mg	NH3/Dm	cum NH3/Dm
13-Sep-05	0.75	252.95	46.08	11655.68	41.18	41.18
21-Sep-05	0.80	258.00	18.93	4884.20	17.26	58.43
27-Sep-05	0.86	314.15	12.82	4027.40	14.23	72.66
04-Oct-05	0.91	292.85	12.28	3595.32	12.70	85.37
11-Oct-05	0.96	290.75	13.78	4007.41	14.16	99.52
19-Oct-05	1.02	264.02	14.63	3863.14	13.65	113.17
25-Oct-05	1.07	222.62	13.03	2901.41	10.25	123.42
01-Nov-05	1.12	197.35	13.98	2759.55	9.75	133.17
09-Nov-05	1.17	173.96	14.88	2588.18	9.14	142.32
15-Nov-05	1.23	150.14	11.84	1777.96	6.28	148.60
21-Nov-05	1.28	127.76	14.63	1869.38	6.60	155.20
06-Dec-05	1.38	91.74	13.53	1240.88	4.38	159.58
15-Dec-05	1.43	95.93	14.25	1366.81	4.83	164.41
22-Dec-05	1.49	91.29	13.35	1218.36	4.30	168.72
28-Dec-05	1.54	99.40	12.91	1282.86	4.53	173.25
05-Jan-06	1.59	102.76	15.69	1612.30	5.70	178.95
24-Jan-06	1.69	115.64	21.43	2477.82	8.75	187.70
16-Feb-06	1.84	111.53	14.03	1564.32	5.53	193.23
23-Feb-06	1.90	106.12	14.71	1560.60	5.51	198.74
06-Mar-06	1.95	109.85	16.26	1786.38	6.31	205.05
09-Mar-06	2.00	98.56	10.21	1006.69	3.56	208.61
16-Mar-06	2.05	103.46	14.21	1469.96	5.19	213.80
30-Mar-06	2.15	95.90	14.36	1376.93	4.86	218.67
13-Apr-06	2.25	90.02	14.67	1320.23	4.66	223.33
02-May-06	2.36	88.62	16.43	1456.03	5.14	228.47
09-May-06	2.41	80.50	12.64	1017.84	3.60	232.07
23-May-06	2.51	77.42	14.86	1150.77	4.07	236.14

06-Jun-06	2.61	77.00	13.72	1056.75	3.73	239.87
20-Jun-06	2.72	76.02	13.54	1029.31	3.64	243.51
04-Jul-06	2.82	64.26	14.45	928.81	3.28	246.79
25-Jul-06	2.92	68.74	17.53	1205.01	4.26	251.04

APPENDIX B

LYSIMETER B

(16 WEEKS PRETREATED OVERSIEVE WASTE SAMPLES)

BIOGAS AND LEACHATE ANALYSIS DATA

CUMMULATIVE LIQUID/SOLID RATIO

DATES	Water Input(L)	Extracted	Retained	Tot Moist	cuml added	Cuml L/S
06-Sep-05	10.78	0.00	10.78	10.78	10.78	0.17
13-Sep-05	73.14	37.76	35.38	46.17	83.93	1.32
21-Sep-05	5.00	5.11	-0.11	46.06	88.93	1.40
27-Sep-05	3.20	2.32	0.88	46.94	92.13	1.45
04-Oct-05	3.20	2.29	0.91	47.85	95.33	1.50
11-Oct-05	5.00	3.69	1.31	49.15	100.33	1.58
19-Oct-05	5.00	4.09	0.91	50.07	105.33	1.66
25-Oct-05	5.00	3.91	1.09	51.16	110.33	1.74
01-Nov-05	5.00	3.71	1.29	52.45	115.33	1.82
09-Nov-05	5.00	4.22	0.78	53.23	120.33	1.90
15-Nov-05	5.00	3.95	1.05	54.28	125.33	1.97
21-Nov-05	5.00	4.36	0.64	54.92	130.33	2.05
29-Nov-05	3.50	3.12	0.38	55.30	133.83	2.11
06-Dec-05	3.50	3.15	0.35	55.65	137.33	2.16
15-Dec-05	3.50	3.05	0.45	56.10	140.83	2.22
22-Dec-05	3.50	3.07	0.43	56.53	144.33	2.27
28-Dec-05	3.50	2.88	0.62	57.15	147.83	2.33
05-Jan-06	3.50	3.32	0.18	57.32	151.33	2.38
11-Jan-06	3.50	2.39	1.11	58.43	154.83	2.44
24-Jan-06	3.50	3.28	-0.28	60.09	158.33	2.99
00-Feb-06	3.50	3.02	0.08	60.98	169.83	2.99
06-Feb-06	3.50	3.99	0.58	60.90	165.33	2.60
16-Feb-06	3.50	3.25	0.09	60.36	166.83	2.60
20-Feb-06	3.50	3.02	0.09	60.86	200.33	2.76
05-May-06	3.50	3.63	-0.18	60.68	205.83	2.77
09-May-06	3.50	2.60	0.90	69.68	209.33	2.83
16-May-06	3.50	3.43	0.07	61.25	210.83	3.32
06	3.50	3.29	0.21	59.84	182.83	2.88

06						
23-May-06	3.50	3.41	0.09	61.35	214.33	3.38
31-May-06	3.50	3.45	0.05	61.40	217.83	3.43
06-Jun-06	3.50	2.19	1.31	62.70	221.33	3.49
14-Jun-06	3.50	3.68	-0.18	62.52	224.83	3.54
20-Jun-06	3.50	3.34	0.16	62.68	228.33	3.60
27-Jun-06	3.50	3.24	0.26	62.94	231.83	3.65
04-Jul-06	3.50	3.59	-0.09	62.85	235.33	3.71
11-Jul-06	3.50	3.51	-0.01	62.83	238.83	3.76
25-Jul-06	3.50	4.17	-0.67	62.17	242.33	3.82
02-Aug-06	3.50	3.14	0.36	62.53	245.83	3.87
08-Aug-06	3.50	3.00	0.50	63.03	249.33	3.93
15-Aug-06	3.50	3.64	-0.14	62.90	252.83	3.98

BIOGAS QUALITY

DATE	CUM L/S	CH4	CO2	O2
13-Sep	1.32	0.00	18.40	1.70
21-Sep	1.40	0.00	20.90	1.10
27-Sep	1.45	0.00	18.00	2.90
04-Oct	1.50	0.20	17.10	3.50
11-Oct	1.58	0.00	20.70	1.50
19-Oct	1.66	0.10	18.50	3.20
25-Oct	1.74	0.00	18.20	2.50
01-Nov	1.82	0.00	19.00	2.50
09-Nov	1.90	0.00	18.20	2.90
15-Nov	1.97	0.00	17.60	3.50
22-Nov	2.05	3.10	23.90	0.30
29-Nov	2.11	6.20	26.30	0.20
06-Dec	2.16	7.50	26.30	0.10
15-Dec	2.22	7.60	25.50	0.70
22-Dec	2.27	8.10	25.50	0.60
28-Dec	2.33	11.20	27.80	0.10
05-Jan	2.38	12.60	28.60	0.30
12-Jan	2.44	10.20	27.70	0.00
24-Jan	2.49	12.90	25.40	0.10
02-Feb	2.55	12.90	25.40	0.10
10-Feb	2.60	13.50	28.10	0.10
16-Feb	2.66	14.10	28.60	0.10
23-Feb	2.71	15.70	29.20	0.00
06-Mar	2.77	11.20	26.90	0.00
09-Mar	2.83	11.10	27.10	0.10
16-Mar	2.88	10.40	27.50	0.10
23-Mar	2.94	7.90	26.10	0.10
30-Mar	2.99	7.70	26.10	0.00
06-Apr	3.05	8.30	26.70	0.10
13-Apr	3.10	8.00	26.50	0.00
20-Apr	3.16	7.00	25.60	0.00
02-May	3.21	5.20	24.60	0.20
09-May	3.27	1.70	22.90	0.10
16-May	3.32	1.80	23.20	0.10
23-May	3.38	0.60	22.20	0.10
31-May	3.43	0.10	22.10	0.10
06-Jun	3.49	0.00	17.10	2.60
14-Jun	3.54	0.10	20.10	0.40
20-Jun	3.60	0.10	19.90	0.00
27-Jun	3.65	0.10	18.80	1.30
04-Jul	3.71	0.10	20.40	0.50
11-Jul	3.76	0.10	20.50	0.50
25-Jul	3.82	0.10	21.40	0.40
02-Aug	3.87	0.10	21.90	0.10
08-Aug	3.93	0.10	20.60	1.00

pH AND CONDUCTIVITY

Dates	CUM L/S	pH	Conductivity(mS/cm)
06-Sep-05	0.17		
13-Sep-05	1.32	6.78	2.81
21-Sep-05	1.40	6.71	4.71
27-Sep-05	1.45	6.58	6.70
04-Oct-05	1.50	6.75	7.38
11-Oct-05	1.58	6.69	5.91
19-Oct-05	1.66	6.80	5.61
25-Oct-05	1.74	6.82	5.22
01-Nov-05	1.82	6.71	4.82
09-Nov-05	1.90	6.75	4.56
15-Nov-05	1.97	6.78	4.29
21-Nov-05	2.05	7.08	4.09
29-Nov-05	2.11	6.78	4.22
06-Dec-05	2.16	6.72	3.93
15-Dec-05	2.22	6.59	4.11
22-Dec-05	2.27	6.68	4.03
28-Dec-05	2.33	6.77	3.95
05-Jan-06	2.38	6.76	4.28
11-Jan-06	2.44	6.62	4.29
24-Jan-06	2.49	6.48	4.29
02-Feb-06	2.55	6.76	4.08
10-Feb-06	2.60	6.68	4.05
16-Feb-06	2.66	6.75	4.52
23-Feb-06	2.71	6.81	4.99
06-Mar-06	2.77	6.68	3.97
09-Mar-06	2.83	6.77	3.61
16-Mar-06	2.88	6.77	3.82

Date			
23-Mar-06	2.94	6.87	3.69
30-Mar-06	2.99	6.86	3.52
06-Apr-06	3.05	6.85	3.52
13-Apr-06	3.10	6.90	3.36
20-Apr-06	3.16	6.92	3.36
02-May-06	3.21	6.96	3.27
09-May-06	3.27	6.88	3.15
16-May-06	3.32	6.90	3.04
23-May-06	3.38	6.93	2.82
31-May-06	3.43	6.89	2.74
06-Jun-06	3.49	6.95	3.11
14-Jun-06	3.54	6.84	3.10
20-Jun-06	3.60	6.92	3.06
27-Jun-06	3.65	6.93	2.85
04-Jul-06	3.71	6.96	2.72
11-Jul-06	3.76	6.97	2.48
25-Jul-06	3.82	6.91	2.53
02-Aug-06	3.87	6.92	2.41
08-Aug-06	3.93	6.84	2.24
15-Aug-06	3.98		

CHEMICAL OXYGEN DEMAND

Dates	CUM L/S	COD (mg/l)
06-Sep-05	0.17	
13-Sep-05	1.32	1117.99
21-Sep-05	1.40	1863.50
27-Sep-05	1.45	3778.85
04-Oct-05	1.50	4546.50
11-Oct-05	1.58	3744.00
19-Oct-05	1.66	2608.00
25-Oct-05	1.74	2655.00
01-Nov-05	1.82	2184.00
09-Nov-05	1.90	1823.50
15-Nov-05	1.97	1859.00
21-Nov-05	2.05	1710.50
29-Nov-05	2.11	1526.00
06-Dec-05	2.16	1128.50
15-Dec-05	2.22	1163.50
22-Dec-05	2.27	1024.00
28-Dec-05	2.33	1061.50
05-Jan-06	2.38	1042.50
11-Jan-06	2.44	1038.00
24-Jan-06	2.49	1033.50
02-Feb-06	2.55	1009.50
10-Feb-06	2.60	962.50
16-Feb-06	2.66	849.96
23-Feb-06	2.71	895.69
06-Mar-06	2.77	895.69
09-Mar-06	2.83	851.42
16-Mar-06	2.88	811.45
23-Mar-	2.94	863.88

06		
30-Mar-06	2.99	764.17
06-Apr-06	3.05	783.94
13-Apr-06	3.10	735.00
20-Apr-06	3.16	684.92
02-May-06	3.21	691.96
09-May-06	3.27	737.95
16-May-06	3.32	548.84
23-May-06	3.38	795.97
31-May-06	3.43	656.72
06-Jun-06	3.49	797.69
14-Jun-06	3.54	823.91
20-Jun-06	3.60	
27-Jun-06	3.65	757.72
04-Jul-06	3.71	760.30
11-Jul-06	3.76	644.69
25-Jul-06	3.82	733.65
02-Aug-06	3.87	
08-Aug-06	3.93	676.06
15-Aug-06	3.98	

NITROGENOUS COMPOUNDS

Dates	CUM L/S	Ammonical-N (mg/l)	Nitrates&Nitrites (mg/l)
06-Sep-05	0.17		
13-Sep-05	1.32	17.62	2.59
21-Sep-05	1.40	40.04	5.05
27-Sep-05	1.45	69.48	7.02
04-Oct-05	1.50	82.17	7.27
11-Oct-05	1.58	69.85	3.82
19-Oct-05	1.66	59.38	5.79
25-Oct-05	1.74	47.31	5.17
01-Nov-05	1.82	38.30	3.70
09-Nov-05	1.90	31.79	4.93
15-Nov-05	1.97	33.02	14.78
21-Nov-05	2.05	24.89	7.88
29-Nov-05	2.11		
06-Dec-05	2.16	23.28	4.31
15-Dec-05	2.22	58.31	3.70
22-Dec-05	2.27		
28-Dec-05	2.33	29.40	5.04
05-Jan-06	2.38	32.20	4.48
11-Jan-06	2.44	33.60	7.00
24-Jan-06	2.49	33.60	6.16
02-Feb-06	2.55		
10-Feb-06	2.60		
16-Feb-06	2.66	37.71	8.40
23-Feb-06	2.71	40.32	6.44
06-Mar-06	2.77	44.24	11.20
09-Mar-06	2.83		
16-Mar-06	2.88	47.04	13.30

Date			
23-Mar-06	2.94		
30-Mar-06	2.99	42.00	13.72
06-Apr-06	3.05		
13-Apr-06	3.10	42.00	16.38
20-Apr-06	3.16		
02-May-06	3.21	42.00	7.56
09-May-06	3.27		
16-May-06	3.32	42.70	11.48
23-May-06	3.38		
31-May-06	3.43	41.58	10.08
06-Jun-06	3.49		
14-Jun-06	3.54	43.54	11.48
20-Jun-06	3.60		
27-Jun-06	3.65	35.00	5.32
04-Jul-06	3.71		
11-Jul-06	3.76	39.62	9.94
25-Jul-06	3.82	38.78	7.56
02-Aug-06	3.87		
08-Aug-06	3.93		
15-Aug-06	3.98		

TOTAL AND VOLATILE SOLIDS

Dates	CUM L/S	Total solids(g/l)	Volatile solids(g/l)
06-Sep-05	0.17		
13-Sep-05	1.32	2.67	1.23
21-Sep-05	1.40	4.58	1.99
27-Sep-05	1.45	6.18	2.41
04-Oct-05	1.50	7.19	3.04
11-Oct-05	1.58	5.92	1.47
19-Oct-05	1.66	4.93	1.96
25-Oct-05	1.74	4.59	1.25
01-Nov-05	1.82		
09-Nov-05	1.90		
15-Nov-05	1.97		
21-Nov-05	2.05	3.68	1.98
29-Nov-05	2.11	3.73	2.58
06-Dec-05	2.16		
15-Dec-05	2.22	3.47	2.22
22-Dec-05	2.27	3.26	2.27
28-Dec-05	2.33	3.32	2.38
05-Jan-06	2.38	3.44	2.30
11-Jan-06	2.44	3.30	2.18
24-Jan-06	2.49	3.38	2.09
02-Feb-06	2.55	3.27	1.88
10-Feb-06	2.60	3.12	1.76
16-Feb-06	2.66		
23-Feb-06	2.71		
06-Mar-06	2.77	2.78	1.76
09-Mar-06	2.83		
16-Mar-06	2.88	3.16	2.00
23-Mar-06	2.94	3.48	3.10

30-Mar-06	2.99		
06-Apr-06	3.05		
13-Apr-06	3.10	2.81	1.92
20-Apr-06	3.16		
02-May-06	3.21	2.36	1.61
09-May-06	3.27		
16-May-06	3.32	2.46	1.67
23-May-06	3.38		
31-May-06	3.43	2.44	1.61
06-Jun-06	3.49		
14-Jun-06	3.54	2.83	1.94
20-Jun-06	3.60		
27-Jun-06	3.65	2.64	1.75
04-Jul-06	3.71		
11-Jul-06	3.76	2.16	1.59
25-Jul-06	3.82	2.73	1.89
02-Aug-06	3.87		
08-Aug-06	3.93	2.47	1.62
15-Aug-06	3.98		

CUMMULATIVE COD RELEASE

Dates	CUM L/S	COD (mg/l)	Extracted	COD mg	COD/Dm	Cum COD/Dm
13-Sep-05	1.32	1117.99	37.76	42214.18	665.10	665.10
21-Sep-05	1.40	1863.50	5.11	9518.76	149.97	815.08
27-Sep-05	1.45	3778.85	2.32	8759.37	138.01	953.09
04-Oct-05	1.50	4546.50	2.29	10429.67	164.32	1117.41
11-Oct-05	1.58	3744.00	3.69	13830.34	217.90	1335.31
19-Oct-05	1.66	2608.00	4.09	10658.90	167.94	1503.25
25-Oct-05	1.74	2655.00	3.91	10370.43	163.39	1666.64
01-Nov-05	1.82	2184.00	3.71	8107.01	127.730	1794.37
09-Nov-05	1.90	1823.50	4.22	7691.52	121.19	1915.55
15-Nov-05	1.97	1859.00	3.95	7346.77	115.75	2031.31
21-Nov-05	2.05	1710.50	4.36	7450.94	117.39	2148.70
29-Nov-05	2.11	1526.00	3.12	4764.17	75.06	2223.76
06-Dec-05	2.16	1128.50	3.15	3554.78	56.01	2279.77
15-Dec-05	2.22	1163.50	3.05	3548.68	55.911	2335.68
22-Dec-05	2.27	1024.00	3.07	3143.68	49.53	2385.21
28-Dec-05	2.33	1061.50	2.88	3061.37	48.23	2433.44
05-Jan-06	2.38	1042.50	3.32	3463.19	54.56	2488.01
11-Jan-06	2.44	1038.00	2.39	2484.97	39.15	2527.16
24-Jan-06	2.49	1033.50	4.48	4630.08	72.95	2600.11
02-Feb-06	2.55	1009.50	3.03	3058.79	48.19	2648.30
10-Feb-06	2.60	962.50	2.92	2810.50	44.28	2692.58
16-Feb-06	2.66	849.96	3.25	2763.22	43.54	2736.12
23-Feb-06	2.71	895.69	3.41	3056.09	48.15	2784.27
06-Mar-06	2.77	895.69	3.63	3253.15	51.25	2835.52
09-Mar-06	2.83	851.42	2.58	2193.26	34.56	2870.08
16-Mar-06	2.88	811.45	3.29	2668.05	42.04	2912.11
23-Mar-06	2.94	863.88	3.25	2805.88	44.21	2956.32

30-Mar-06	2.99	764.17	3.42	2610.41	41.13	2997.45
06-Apr-06	3.05	783.94	3.39	2657.56	41.87	3039.32
13-Apr-06	3.10	735.00	3.41	2506.35	39.49	3078.81
20-Apr-06	3.16	684.92	3.02	2068.46	32.59	3111.40
02-May-06	3.21	691.96	3.68	2543.65	40.08	3151.48
09-May-06	3.27	737.95	2.99	2212.37	34.86	3186.33
16-May-06	3.32	548.84	3.43	1883.62	29.68	3216.01
23-May-06	3.38	795.97	3.41	2711.07	42.71	3258.72
31-May-06	3.43	656.72	3.45	2265.68	35.70	3294.42
06-Jun-06	3.49	797.69	2.19	1748.54	27.55	3321.97
14-Jun-06	3.54	823.91	3.68	3031.99	47.77	3369.74
27-Jun-06	3.65	757.72	3.24	2456.53	38.70	3408.44
04-Jul-06	3.71	760.30	3.59	2731.00	43.03	3451.47
11-Jul-06	3.76	644.69	3.51	2265.44	35.69	3487.17
25-Jul-06	3.82	733.65	4.17	3056.39	48.15	3535.32
08-Aug-06	3.93	676.06	2.99	2025.48	31.91	3567.23

APPENDIX C

LYSIMETER C

(UNTREATED FRESH WASTE SAMPLES)

BIOGAS AND LEACHATE ANALYSIS DATA

CUMMULATIVE LIQUID/SOLID RATIO

Dates	Water Input(L)	Extracted	Retained	Tot Moist	Cuml added	cuml L/S
21-May-06	156.15	0.00	156.15	156.15	156.15	1.38
23-May-06	20.00	1.24	18.76	174.92	176.15	1.56
31-May-06	20.00	6.63	13.37	188.28	196.15	1.74
06-Jun-06	20.00	11.77	8.23	196.52	216.15	1.92
14-Jun-06	20.00	11.81	8.19	204.70	236.15	2.09
20-Jun-06	20.00	16.32	3.68	208.39	256.15	2.27
27-Jun-06	20.00	18.24	1.76	210.15	276.15	2.45
04-Jul-06	20.00	17.86	2.14	212.29	296.15	2.62
11-Jul-06	20.00	18.86	1.14	213.43	316.15	2.80
25-Jul-06	20.00	20.00	0.00	213.43	336.15	2.98
02-Aug-06	5.60	17.67	-12.07	201.36	341.75	3.03
08-Aug-06	5.60	4.59	1.01	202.37	347.35	3.08
15-Aug-06	5.60	5.17	0.43	202.80	352.95	3.13
22-Aug-06	5.60	4.78	0.82	203.63	358.55	3.18
29-Aug-06	5.60	5.10	0.50	204.13	364.15	3.23
05-Sep-06	5.60	5.11	0.49	204.62	369.75	3.28

BIOGAS QUALITY

Dates	CUM L/S	CH4 (%)	CO2 (%)	O2 (%)	Temp-Tank(°c)	Temp-Ambient(°c)	
23-May-6	1.56	0.20	26.20	3.10	20.60	17.10	
31-May	1.74	0.10	26.30	3.10	19.30	19.80	
6-Jun	1.92	0.10	25.30	3.90	20.20	19.50	
14-Jun	2.09	0.10	26.70	3.40	19.40	18.90	
20-Jun	2.27	0.10	25.80	3.30	18.30	19.00	
27-Jun	2.45	0.10	23.10	3.40	15.40	16.20	
4-Jul	2.62	0.00	23.70	3.00	17.50	18.90	
11-Jul	2.80	0.10	24.10	2.90	18.20	19.20	
25-Jul	2.98	0.10	22.80	3.20	14.80	14.30	
2-Aug	3.03	0.20	22.10	3.20	16.00	16.50	
8-Aug	3.08	0.30	21.40	3.30	21.50	24.00	
15-Aug	3.13	0.10	19.45	13.80	23.20	23.50	
22-Aug	3.18	0.30	17.50	4.50	22.30	22.90	
29-Aug	3.23	0.50	18.10	4.50	23.40	23.70	
5-Sep	3.28	0.40	18.10	4.40			
12-Sep	3.33	0.20	19.40	3.70			
19-Sep	3.38	0.20	18.50	4.10			

pH AND CONDUCTIVITY

Dates	CUM L/S	pH	Conductivity (mS/cm)
23-May	1.56	5.80	2.35
31-May	1.74	6.22	8.10
06-Jun	1.92	5.86	9.57
14-Jun	2.09	5.87	11.16
20-Jun	2.27	5.67	9.97
27-Jun	2.45	5.78	9.05
04-Jul	2.62	5.48	9.04
11-Jul	2.80	5.47	7.79
25-Jul	2.98	5.74	7.69
02-Aug	3.03	5.77	6.19
08-Aug	3.08	5.45	8.95
15-Aug	3.13	5.58	9.90
22-Aug	3.18	5.78	8.68
29-Aug	3.23	5.49	10.29
05-Sep	3.28	5.47	9.78

CHEMICAL OXYGEN DEMAND

Dates	cuml L/S	COD (mg/l)
21-May-06	1.38	-
23-May-06	1.56	4487.00
31-May-06	1.74	
06-Jun-06	1.92	21888.40
14-Jun-06	2.09	17401.40
20-Jun-06	2.27	22074.10
27-Jun-06	2.45	26548.20
04-Jul-06	2.62	23239.70
11-Jul-06	2.80	24756.00
25-Jul-06	2.99	25465.20
02-Aug-06	3.03	21083.900
08-Aug-06	3.08	27618.40
15-Aug-06	3.13	21723.40
22-Aug-06	3.18	15085.70
29-Aug-06	3.23	27927.90
05-Sep-06	3.28	28662.80
12-Sep-06	3.33	
19-Sep-06	3.38	29366.80

TOTAL AND VOLATILE SOLIDS

Dates	CUM L/S	Total solids (g/l)	Volatile solids (g/l)
23-May	1.56		
31-May	1.74		
06-Jun	1.92	15.94	8.34
14-Jun	2.09	13.90	7.27
20-Jun	2.27	14.94	7.71
27-Jun	2.45	14.35	7.35
04-Jul	2.62	13.61	6.92
11-Jul	2.80	11.86	6.25
25-Jul	2.98	12.45	19.58
02-Aug	3.03	0.00	0.00
08-Aug	3.08	16.05	7.77
15-Aug	3.13	16.82	7.35
22-Aug	3.18	17.60	8.68
29-Aug	3.23	17.30	8.84
05-Sep	3.28	2.13	1.32
12-Sep	3.33	17.54	8.85
19-Sep	3.38	17.50	8.86
26-Sep	3.43	0.00	0.00
03-Oct	3.48	18.68	9.23

NITROGENOUS COMPOUNDS

Dates	CUM L/S	NH3 (mg/l)	Nox (mg/l)
06-Jun	1.74	102.00	18.40
14-Jun	2.09	159.74	18.34
20-Jun	2.27	420.00	44.52
27-Jun	2.45	430.29	24.99
04-Jul	2.62	440.58	5.46
11-Jul	2.80	436.38	12.32
25-Jul	2.98	426.72	17.78
02-Aug	3.03	446.20	14.60
08-Aug	3.08	451.50	13.00
15-Aug	3.13	478.90	12.60
22-Aug	3.18	508.60	11.84
29-Aug	3.23	592.90	11.50
05-Sep	3.28	696.22	11.48
12-Sep	3.33	746.48	11.34
19-Sep	3.38	634.48	6.72
03-Oct	3.48	777.56	7.70

CUMMULATIVE COD RELEASE

Dates	cuml L/S	COD (mg/l)	Extracted	mgCOD	COD/Dm	cum COD/Dm
23-May-06	1.56	4487.00	1.24	5554.91	49.22	49.22
06-Jun-06	1.92	21888.40	11.77	257582.70	2282.52	2331.75
14-Jun-06	2.09	17401.40	11.81	205580.10	1821.71	4153.46
20-Jun-06	2.27	22074.10	16.32	360161.00	3191.50	7344.96
27-Jun-06	2.45	26548.20	18.24	484186.10	4290.53	11635.49
04-Jul-06	2.62	23239.70	17.86	415014.60	3677.58	15313.07
11-Jul-06	2.80	24756.00	18.86	466848.60	4136.90	19449.96
25-Jul-06	2.98	25465.20	20.00	509304.00	4513.11	23963.07
02-Aug-06	3.03	21083.90	17.67	372552.50	3301.31	27264.37
08-Aug-06	3.08	27618.40	4.59	126823.70	1123.83	28388.20
15-Aug-06	3.13	21723.40	5.17	112223.10	994.44	29382.64
22-Aug-06	3.18	15085.70	4.78	72049.30	638.45	30021.10
29-Aug-06	3.23	27927.90	5.10	142320.60	1261.15	31282.24
05-Sep-06	3.28	28662.80	5.11	146581.60	1298.91	32581.15
19-Sep-06	3.38	29366.80	5.29	155467.80	1377.65	33958.80

CUMMULATIVE RELEASE OF NITROGENOUS COMPOUNDS

Dates	CUM L/S	NH3 (mg/l)	Extracted	mgNH3	NH3/Dm	cumCOD/Dm
06-Jun	1.74	102.00	11.77	1200.34	10.64	10.64
14-Jun	2.09	159.74	11.81	1887.17	16.72	27.36
20-Jun	2.27	420.00	16.32	6852.72	60.72	88.08
27-Jun	2.45	430.29	18.24	7847.63	69.54	157.62
04-Jul	2.62	440.58	17.86	7867.88	69.72	227.34
11-Jul	2.80	436.38	18.86	8229.254	72.92	300.27
25-Jul	2.98	426.72	20.00	8534.40	75.63	375.89
02-Aug	3.03	446.20	17.67	7884.35	69.87	445.76
08-Aug	3.08	451.50	4.59	2073.29	18.37	464.13
15-Aug	3.13	478.90	5.17	2474.00	21.92	486.05
22-Aug	3.18	508.60	4.78	2429.07	21.52	507.58
29-Aug	3.23	592.90	5.10	3021.42	26.77	534.35
05-Sep	3.28	696.22	5.11	3560.47	31.55	565.90
12-Sep	3.33	746.48	5.21	3887.67	34.45	600.35
19-Sep	3.38	634.48	5.29	3358.94	29.76	630.12