THE STUDY OF THE KINETICS OF DEGRADATION OF MECHANICAL-BIOLOGICAL PRETREATED WASTE USING TEST CELLS

By

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ABSTRACT

This research was carried out at the Bisasar Road Landfill site, Durban, South Africa, with the objective of investigating the nature of the emissions from mechanically and biologically pretreated waste and the efficiency of prolonged treatment of waste in passively aerated shallow landfills. Waste treatment was performed with the use of passive aerated windrows, so to achieve low energy and low cost operations. Waste decomposition temperature, gas composition (CO_2, O_2 and CH_4) and gas velocity were monitored for 8 and 16 weeks. The municipal solid waste was characterized before and after the pretreatment stages. Five test cells were constructed to simulate large-scale shallow landfills. The cells were filled with unsorted untreated waste, with unsorted pretreated waste from the windrows and with the fine fractions of the latter sieved with a 50 mm (diameter) sieve. The untreated municipal solid waste formed the basis of comparing the benefits of landfilling mechanical biological pretreated waste over untreated waste. Leachate and gas composition were monitored in test cells. The test cells were passively aerated and flushed. The pretreatment in the open windrows was efficient in reducing the organic content of waste by 22 to 35 percent. Longer periods of aerobic treatment, however, did not increase the efficiency, but were affected by desiccation. In the cells, after flushing, the fine material showed rapid decline in the organic load compared to the global sample. Untreated municipal solid waste had the highest organic load, suggesting that both forms of pretreatment (in windrows and in cells) could be applied successfully in the South African context.

PREFACE

I, Oscar T Simelane, herby declare that the whole of this dissertation is my work and has not been submitted in part, or whole to any other university. Where use has been made of the work of others it is duly acknowledged in the text. This work was carried out at the University of KwaZulu Natal, Department of Civil Engineering under the supervision of Dr Cristina Trois. The style guide for dissertations in the Civil Engineering Department has been used in the preparation of this document.

07TH AUGUST 2007
Date

OT Simelane.
Signature

As the candidate' supervisor I have approved this dissertation fro submission

Signed C. Trois Name DR C. TROIS Date 13/02/08

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LIST OF ABBREVIATIONS

AAT	Advanced Thermal Treatment
AT*	Respiration Index (*as used in Germany*)
BMW	Biodegradable Municipal Waste
BOD	Biological Oxygen Demand
BPT	Biological Pretreatment
COD	Chemical Oxygen Demand
DEFRA	Department for Environment Food and Rural Affairs
DM	Dry Matter
DS	Dry solids
DSW	Durban Solid Waste
DWAF	Department of Water Affairs & Forestry
EU	European Union
FMC	Field Moisture Capacity
GB	Biogas Production Potential
GS	Biogas Production Potential
HDPE	High Density Polyethylene
IR*	Respiration Index (*as used in Italy*)
LATS	Landfill Allowance Trading Scheme
MBP	Mechanical Biological Pretreatment
MBT	Mechanical Biological Treatment
MPT	Mechanical Pretreatment
MSW	Municipal Solid Waste
Nm^3	Normal meter cubic
PAF	Pretreatment Aeration Flushing
PET	Polyethylene Terephtalate
PET	Potential Evapo-Transpiration
RCRA	Resource Conservation and Recovery Act
RDF	Refuse Derived Fuel
RI*	Respiration Index (*as used in England*)
RMSW	Residual Municipal Solid Waste
S/L	Solid to Liquid ratioSOUR Specific Oxygen Uptake Rate
TASi	Technische Anleitung Siedlunsabfall *Technical Instructions on Waste from Human Settlement*
TKN	Total Kjeldahl Nitrogen

TOC	Total Organic Carbon
TS	Total Solids
UK	United Kingdom
VS	Volatile Solids
*	*IR, RI and AT are all initials for the respiration index as used in Italy, England and Germany.*

CHAPTER 1

INTRODUCTION

An accompanying transformation to all the alterations brought about by evolution is the increase in volume and nature of waste produced by man. As the world's population exponentially grows and people becoming more affluent there is a production of more waste volumes with higher toxicity. Handling and storage of waste has changed from disposal on land to engineered 'impermeable' surfaces. Science and method of waste disposal are changing from long-term environment effects towards a sustainable way.

Scope of the study

The disposal of domestic solid waste became a problem when humans started living in cities, which generated large quantities of this waste over an area too small to rely on natural decomposition of waste. The first engineering effort of solving this problem was to encapsulate the waste in what has become known as a landfill. This is still the way in which more than 90 percent of this type of waste is being disposed in South Africa. The large quantity of waste that needs to be disposed of, and realization that landfilling was, for a number of reasons, not a sustainable solution, has led to research towards more appropriate solutions.

Efforts directed towards containing environmental effects of landfills within a generation have been explored in recent scientific research (Leikam and Stegmann, 1997; and Zach *et al*, 1999). The ultimate goal is to accelerate waste degradation in the landfills and reduce space requirement by waste, both can be achieved by treatment of waste using biological stabilization before landfilling. Waste treatment processes are successful in connection with sound waste collection systems such as: separate collection of municipal solid waste that has proven to be a catalyst for waste treatment before landfilling (Sabbas *et al*, 1999).

The basis of separate waste collection could be biological degradability, composition (dry or wet waste), the possibility of re-using material as glass, wood, metal, plastic, paper, stone, sand etc. Amongst others, the two strategies which have been employed significantly for waste treatment prior to landfilling are thermal and mechanical biological treatment (MBP). Developing and 'emerging' nations have not as much explored waste pretreatment compared to developed nations like in the European Union (Trois *et al*, 2005).

MBP is a combination of mechanical and biological processes used in the pretreatment of waste as defined by Raninger and Nelles (1997). The mechanical operations comprise of sorting, size reduction, homogenizing, wetting and moving of waste. Normally the mechanical process is a preparatory stage for the optimization of the biological processes, which entails the harnessing of natural aerobic processes to degrade waste in order to reduce its organic load. The organic load in waste is related to natural organic compounds such as proteins, carbohydrates, fats and other polysaccharides. MBP can be achieved by the use of machinery which is locally available in landfills.

Laboratory and full scale MBP projects have been very successful in reducing the long-term impacts of waste (Scheelhaase and Bidlingmaier, 1997; Leikam and Stegmann, 1997; Raninger and Nelles, 1997). Another management strategy that allows for a sustainable landfill is the operation of a flushing bioreactor. According to Augestein *et al*, (1999), a bioreactor landfill allows rapid waste stabilization and it reduces landfill volumes compared to conventional 'dry' landfill.

This dissertation investigates the applicability, in the South African context of mechanical biological pretreatment of waste in open windrows and shallow landfills; with particular focus to process dynamics and emissions. The results of the first part of the investigation (MBP using passively aerated windrows) are then analyzed in relation to the efficiency of an alternative treatment technology: prolonged treatment in passively aerated shallow landfills that is gaining momentum and interest in several emerging subtropical or tropical countries, where high ambient temperatures, large content of putrescible waste and ambient heavy rainfall are conducive of high aerobic stabilization rates of waste (Trankler *et al*, 2005).

MBP were introduced in South Africa in a pilot project at the Bisasar Road Landfill since 2002 (Griffith and Trois, 2005). This work aims at studying the possibility of coupling MBP with prolonged treatment in shallow landfills using the Pretreatment Aeration and Flushing (PAF) as suggested by Cossu *et al* (2001).

Objectives

The purpose of this research was to investigate the kinetics of aerobic degradation of waste in passively aerated windrows followed by prolonged stabilisation in semi-aerobic shallow landfills (test cells) operated as flushing bioreactors. The influence of separated collection on the efficiency of the process was also investigated.

The specific objectives were:

- To asses the efficiency of passively aerated windrows in stabilising waste for different pre-treatment periods, i.e 16 and 8 weeks.
- To assess the influence of sorting (simulating separated collection and waste sieving prior to pre-treatment) the waste into fine and coarse fractions on the treatment efficiency.
- To study the efficiency of the pretreatment, aeration and flushing (PAF) model in the reduction of long-term emissions from MBP waste.

Materials and methodology

Domestic refuse disposed at the Bisasar Road Landfill site was aerobically treated for 8 and 16 weeks using open self-aerated windrows. Three windrows were constructed under different prevailing climatic conditions at the Bisasar road landfill site. Windrow 1 and windrow 2 were operated for 16 weeks during winter months (April to July). Windrow 3 was operated for 8 weeks during the summer months (from the end of September to the end of November).

To monitor waste degradation in the windrows, percent of the volumetric composition of gases (carbon dioxide, oxygen and methane) and exhaust gas's temperature and exhaust gas velocity were measured. Input and output materials of the windrows were characterized at the Environmental Engineering Laboratory at the University of KwaZulu Natal, Durban, according to standard methods. The tests were performed for volatile solids, total solids, BOD_5, COD, TOC, TKN, NH_3-N, NOx, pH and conductivity were performed. The biological stability and potential long-term methane production of waste were also determined.

After pretreatment, waste was disposed into five miniature landfills, i.e test cells. The test cells were filled with unsorted non-pretreated waste, unsorted global samples of pretreated waste, and the under-sieved fines of respective fractions. The under-sieved material was obtained by sieving waste on 50 mm sieve. The rationale for separating the fines from the global sample was the assumption that fines were more easily biodegradable than the latter, and therefore they play an important role in the kinetics of waste stabilization. Operation of the test cells followed the sequence of self-aeration, flushing, self-aeration and flushing as suggested by the PAF model (Cossu *et al*, 2001). The degradation of the waste was monitored by determining properties of gaseous and liquid emissions.

General overview of the study

Chapter 2 presents a literature review on landfill emissions, legislations on waste management, waste pretreatment and MBP in particular (Dome Aeration Technology), laboratory tests methods for characterizing MBP waste, long-term emissions from MBP waste and the PAF model. The literature review was designed to show the evolution of landfilling methods and legislations and it explores areas of research that require further investigations.

Since MBP and separate waste collection is generally not practiced in South Africa, experience from European countries was gathered. Chapter 3 focuses on case studies of two European countries namely, Austria and England, which were visited by the researcher during a study period in Europe. The chapter gives the basis of comparison of how municipal solid waste is managed in developed and emerging countries. Understanding and adapting from these experiences were considered critical in the appropriate development and application of MBP in South Africa.

Chapter 4 presents the materials and methods used in constructing windrows together with the DAT monitoring. The laboratory standard methods used during the research are discussed in this chapter. The methods of establishing accuracy and bias of laboratory test methods are outlined. Results and discussion of the windrow processes are given in chapter 5.

The methodology of the construction of the test cells is presented in Chapter 6. The degradation of the waste in the cells was monitored by determining properties of gaseous and liquid emissions. Results and discussion of test cells are reported in chapter 7. The conclusions of the study are presented in chapter 8.

CHAPTER 2

LITERATURE REVIEW

The purpose of the research was to investigate the kinetics of degradation of waste by using miniature landfills, i.e test cells, and their potential to be used as aerobic prolonged pretreatment options. The test cells were operated according to the pretreatment aerationflushing (PAF) model as suggested by Cossu *et al* (2001). Traditionally untreated waste is disposed in landfills, which pose long-term environmental impacts such as contamination of ground water, generation of greenhouse gases and unpleasant odours. Scientific research has proven to accelerate waste degradation with the use of MBP before landfilling (Binner *et al* 1997, Cossu *et al* 1999 and Muller *et al* 2001). However, nitrogen emissions over a long period of time is still a problem (Heyer and Stegmann 1999 and Kruempelbeck and Ehrig 1999). This chapter therefore presents literature reviewed on landfill emissions, waste pretreatment using the dome aeration technology (DAT), laboratory tests methods for characterizing MBP waste, emissions from MBP waste and the observed efficiencies of the PAF model. Research challenges like application of the PAF model at full scale are also highlighted.

2.1 Landfills

Landfilling is defined as the deposition of waste on land, whether it be the filling in of excavations or the creation of a landfill above grade, where the term 'fill' is used in the engineering sense (DWAF, 2005). Landfills have been preponderantly used for the management of general MSW. However, there are still environmental challenges faced with the use of landfills. Emissions of landfills, that is biogas and leachate, and the landfill after-care period are of major concern to landfill managers. Environmental impacts that come with landfills include pollution of underground water, emission of green house gases and eutrophication.

In the recent years, European countries have enacted legislation, which are geared towards minimizing environmental impacts and emissions of landfills. Waste pretreatment before disposing in the landfill has been a useful tool for minimizing landfill emissions. The management practices of landfills have evolved from traditional landfilling to managing landfills as bioreactors. In recent times the flushing bioreactor method has evolved into the PAF model (Cossu *et al*, 2001).

European countries have limit values for waste quality before landfilling. In South Africa and other emerging and developing countries, general municipal waste is still landfilled without any kind of pretreatment. Waste can be pretreated either by thermal or mechanical biological pretreatment (MBP). This research, however, is focused on MBP and the efficiency of the use of Dome Aeration Technology (DAT) for waste pretreatment. Determining the biological activity and the long-term biogas production of waste in the laboratory normally assesses the efficiency of aerobic waste pretreatment. In a larger scale, long-term emissions of landfills have been simulated using landfill cells and lysimeters have been used at laboratory scale (Zach *et al,* 1999 and Stegmann, 2005). Modeling waste degradation according to the PAF model using test cells was explored in this research.

The technology of landfilling is gradually evolving from traditional 'dry' landfill to a bioreactor landfill. The motivation behind the evolution is the achievement of a 'sustainable' landfill. Generally, development is considered sustainable when "it meets the needs of the present generation without compromising the ability of future generations" as defined by Bond (2002). Subsequently, a 'sustainable' landfill reduces environmental impacts and reduces risks in the future. The technical definition of sustainable landfills implies final storage quality within 30 years at moderate costs. Mathlener (2001) argues that a sustainable landfill should not only focus on the technical definition but it should incorporate social, environmental and economic impacts. Generally, the concept of sustainable landfill includes three technological elements, which are how to manage incoming wastes, how to design and construct a landfill container, and how to fill the wastes and monitor the landfill (Inoue *et al*, 2005).

Augestein *et al* (1999) and Cossu *et al* (2001), outline the benefits of a bioreactor landfill over a conventional "dry" landfill as given below:

- Reduction of green house gas, i.e methane
- Elimination of organic air pollutants
- Reduction of long-term risks, i.e long-term gas and management costs
- Reduction of costs of post closure
- Maximizing the rate and yield of methane recovery hence improving the capture renewable energy.

Other remarkable benefits that can be derived from a bioreactor landfill are better settlement allowing additional placement of waste, rapid stabilization of the waste, high landfill density, low hydraulic permeability, reduced demand for air space volume and landfill stability (Zach *et al*, 1999).

Different authors have suggested various strategies of attaining a "sustainable landfill". The approaches comprise MBP (Leikam and Stegmann, 1997, and Zach *et al*, 1999); thermal pretreatment (Cappai *et al*, 1999, Cappai *et al*, 2001, and Bramryd and Binder, 2001) and the uptake of CO_2 and the build-up of stable nitrogen and carbon compounds, i.e phyto-depuration (Zach *et al*, 1999). A schematic presentation of a typical bioreactor landfill is shown in figure 2.1.

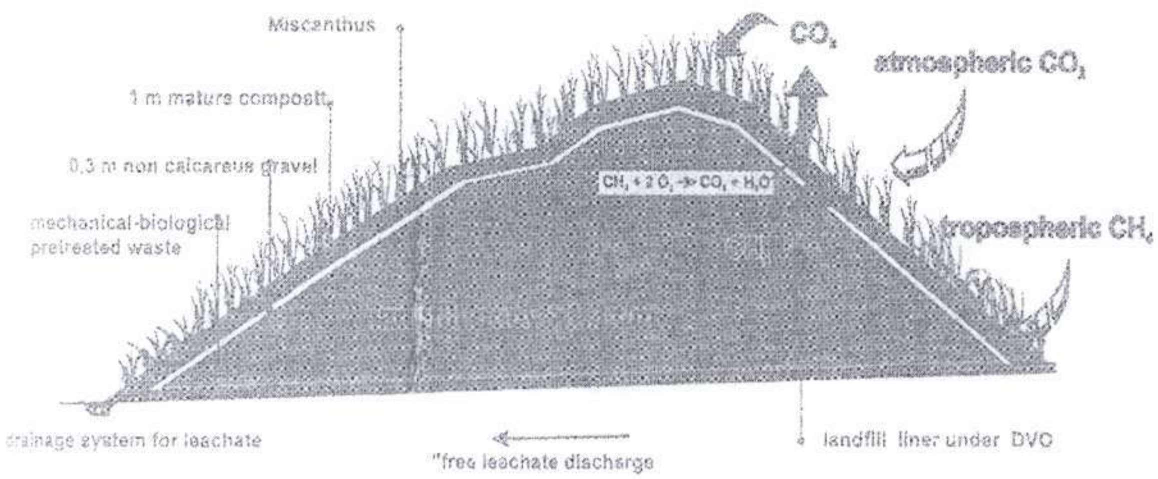

Figure 2.1 Schematic presentation of a "sustainable landfill" (Zach et al, 1999)

Intensive research has been done, since 1990, in Europe and America, on the movement from a conventional dry landfill to a bioreactor landfill. The basic principle of such landfill has been enhancing microbial activity hence transferring organic pollutants from leachate to landfill gas, by manipulating temperature and moisture content. Transferring organic pollutants to landfill gas is preferred because the latter can be actively removed by degassing. Greatest potential of landfill gas generation (LFG) is achieved in the temperature and moisture content ranges of 40 to 60^{0}C and 35 to 40 percent, respectively (Pacey, 1997). A combination of MBP and a flushing bioreactor gave a new model, i.e the PAF model (Cossu, *et al* 2001). Table 2.1 presents a summary of experimental studies carried out in Europe and America towards achieving sustainable landfill.

Table 2.1 Experiment results of the use of a bioreactor landfill

Bioreactor advantage over "dry" landfill	**Author, Location**
1. Reduces gas production to 20 ℓ /KgDM by 90%. 2. Reduces COD and N_{TOTAL} by 90% on leachate. 3. Reduces landfill volume by 60%.	Leikam K. and Stegmann R., 1997, Hamburg, Germany
1. Waste stabilization, achieved in 10 years after closure versus 40 years from a "dry" landfill. 2. High gas collection efficiency. 3. Relatively uniform moisture and temperature. 4. BOD:COD of less than 0.1	Pacey,1999. California, USA.
1. Gas recovery exceeds "dry" landfill by 5 -10 times. 2. Gas fuelled electricity potential > 3000 MWe. 3. Gas recovery can complete in less than 5 years.	Augestein *et al*, 1999, Yolo County USA
1. Fixation of up to 95% of carbon stock. 2. Reduction of leachate carbon load by 80%. 3. Reduction of degassing potential by 90%.	Scheelhaase, 2001
1. With irrigation, leachate was only 1% of input after 2 years. 2. Gas production decreased by 80%	Lorber K.E *et al*, 1999. Austria

In Europe treatment of organic solid waste has evolved from landfilling to high technology processes, like incineration (Wens, 2005). In South Africa and other developing countries, landfilling of unsorted and non pre-treated waste is still the only technique adopted (Trois *et al*, 2005 and Wagner *et al*, 2001).

2.2 Landfill emissions

Degradation of organic compounds of MSW in anaerobic environment in the landfill liberates liquid (Leachate) and biogas (biogas is composed mainly of CH_4 and CO_2). Waste decomposition can be illustrated by four main phases based on gas composition and type of microorganisms present in the waste mass. According to Farquhar and

Rovers (1997) the four phases are aerobic (I), anaerobic non-methanogenic (II), anaerobic unsteady methanogenic (III) and anaerobic steady methanogenic (IV).

Figure 2.2 below shows a schematic presentation of the four stages.

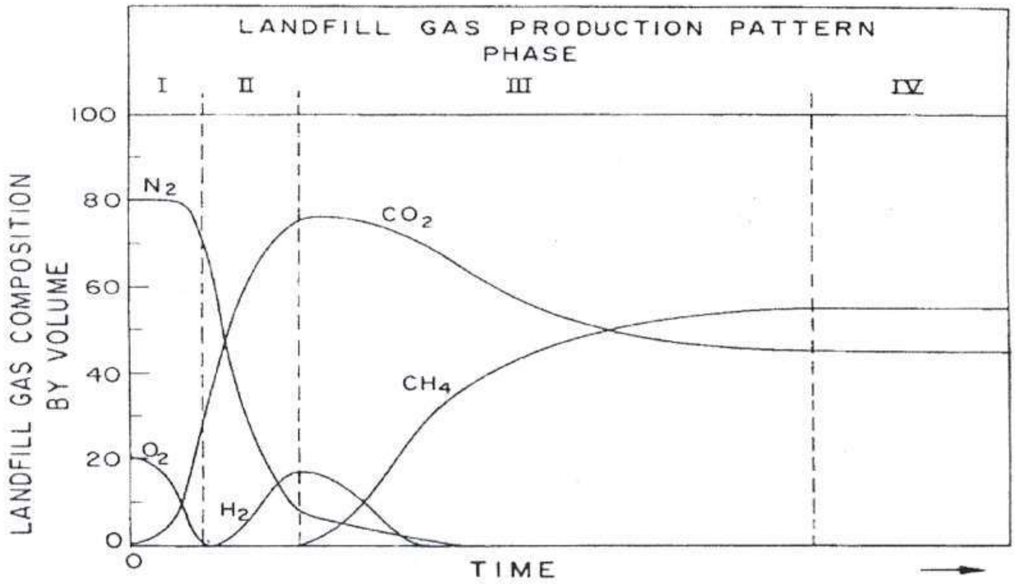

Figure 2.2 Pattern of gas production in a sanitary landfill (Farquhar and Rovers, 1997)

The length of the decomposition phases is variable. According to Kruempelbeck and Ehrig (1999) the first phase, during which organic compounds are hydrolyzed, also called the acid phase, can last for 2 to 3 years. Heyer and Stegmann (1997) report intermediate anaerobic phase of 6 to 8 years and stabilized methane phase occurs at 28 to 33 years.

Observing parameters of leachate and biogas, Knox *et al* (1999) state that the separation of acidogenesis and methanogenesis occurred after 1.5 to 2 years; methanogenesis established after 1 year; gas generation increased steadily for 6 to 7 years; and full stabilized methanogenic phase occurred 7 years after waste placement. Not only the active life of landfills is important but also the period of landfill activity after closure is a central point of study. Landfill after care period and landfill processes are discussed in depth in the paragraphs below.

The occurrence of landfill processes depends on internal factors such as initial waste composition and external condition such as climatic (Sabbas *et al*, 1999). Factors which control the rate of gas production in the landfill include moisture content, pH, waste composition and particle size. The optimum pH and temperature for gas production is neutral and 30^0C to 35^0C, respectively (Farquhar and Rovers,1997). However, Knox *et al* (1999) observed that gas production increased with a fall in temperature. Hence temperature may not be the only factor responsible for the control of microbial activity in favour of other factors that are rate controlling.

In a study carried out by Burton and Watson-Craik (1997), it was found that methane production increases with moisture content, 20 percent less methane was produced at 80 percent moisture content as compared with 90 percent moisture content. A range of moisture content around 35 to 40 percent, represents optimum conditions for methane production (Pacey, 1997). According to Jokela *et al* (1999) the highest methane yield are obtained at 40 to 50 percent moisture in the lowest at 30 to 35 percent moisture. Shredding waste increases the contact surface area and leads to rapid methane production (Ham and Bookter, 1997). Farquhar and Rover (1997) present a schematic summary of the factors which affect gas production in figure 2.3 below.

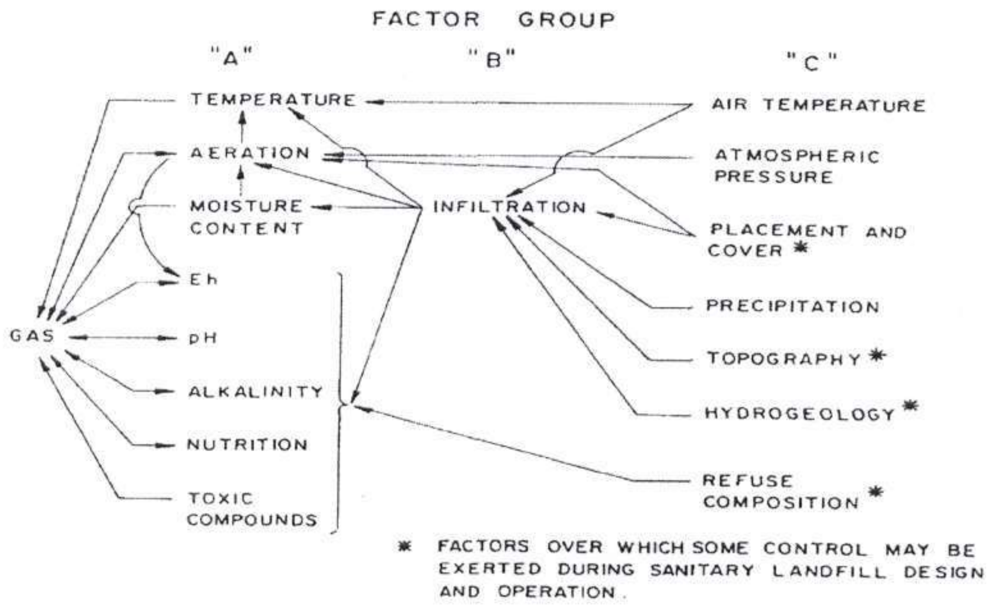

Figure 2.3 Factors affecting landfill gas production (Farquhar and Rovers,1997)

The stoichometric calculation of biodegradable material that can be converted to biogas is shown in equation 2.1 (Christensen *et al*, 1996) .

$$C_aH_bO_cN_d + \frac{4a-b-2c+3d}{4}.H_2O \rightarrow \frac{4a+b-2c-3d}{8}.CH_4 + \frac{4a-b+2c+3d}{8}.CO_2 + dNH_3 \quad (2.1)$$

Where:*a, b, c* and *d* are stoichometric composition of C (carbon), H (hydrogen), O (oxygen) and N (nitrogen), respectively. Table 2.2 below presents typical elementary composition of organic fractions in MSW (Tchobanoglous *et al*, 1993).

Table 2.2 Typical elementary composition of organic fractions in MSW expressed as percentage of dry weight (Tchobanoglous et al, 1993)

Component	*Wet weight (%)*	*Dry weight (%)*	*Elementary composition (%)*					
			C	*H*	*O*	*N*	*S*	*Ash*
Food wastes	11.4	4.6	4.7	4.7	4.4	13.0	10.0	4.0
Paper	42.8	55.0	50.8	53.0	61.3	18.5	60.0	55.2
Cardboard	7.5	9.8	9.2	9.4	11.1	3.7	10.0	8.0
Plastics	8.8	11.9	15.1	13.8	6.8	–	–	19.8
Textiles	2.5	3.1	3.6	3.3	2.4	14.8	–	1.4
Rubber	0.6	0.9	1.4	1.4	–	1.9	–	1.4
Leather	0.6	0.7	0.9	0.8	0.2	7.4	–	1.1
Yard wastes	23.3	11.2	11.4	10.8	10.8	40.7	20.0	8.3
Wood	2.5	2.8	2.9	2.8	3.0	–	–	0.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Landfill cover does not only affect gaseous emissions but also the water balance in the waste mass hence the leachate production. The concept of water balance is presented in equation 2.2 (Ghiani, 2006).

Leachate = Infiltrating rain + Infiltrating superficial water + Infiltrating ground water + Moisture content variation + Microbial water production or consumption

In which

Infiltrating rain = Precipitation + Inflow of adjacent area runoff – Runoff – Evaporation - Transpiration (2.2)

Leachate quality rather than volumes is important in determining the discharge limits into natural receptors. Legislations, degree of waste stabilization, pollution load of municipal solid waste and discharge limits are based on organic compounds (represented by TOC, COD and BOD), nutrients (expressed as ammoniacal nitrogen, total oxidized nitrogen, sulphate and chlorine), pH, conductivity, alkalinity, and other trace elements. Table 2.3 shows some of the leachate discharge limits and the number of years after landfill closure required to achieve the discharge limits in Germany, Austria and South Africa.

Table 2.3 Leachate discharge limits and required years after closure to reach discharge limits

Parameters	Discharge limit	Years After Closure	Author
COD TKN Cl	200 mg/ℓ 70 mg/ℓ 100 mg/ℓ	120 – 220 280 – 580 120 – 220	Heyer and Stegmann, 1999. Germany
COD NH_4-N	110 – 2600 mg/ℓ ---	20 <20, Not possible	Kruempelbeck and Ehrig, 1999. Germany
Cl	>8000 mg/ℓ	100	Doberl *et al*, 2001. Austria
Cl Ammonia	100 mg/ℓ 70 mg/ℓ	240 – 1090 320 - 430	Rohrs *et al*, 2001. South Africa

The leachate quality depends, among other factors, on landfill depth, cover, particle size of the waste, presence of substances that can be mobilized (degree of waste stabilization) and the level of a water table within the waste. Ham and Bookter (1997) found that the absence of soil cover resulted in a rapid decline of leachate strength (COD) during the life of a landfill; the cover prolonged the production of leachate with high contaminating concentration and doubling depth helped to double the COD levels and increase in the waste stabilization time.

According to Kruempelbeck and Ehrig (1999) the amount of leachate depends on the landfilling techniques adopted, composition of waste input, precipitation and landfill cover. The installation of impermeable surface covers for non-pretreated waste and landfilling of un-treated MSW is not advisable because the period of landfill after care is lengthened (Heyer and Stegmann, 1997). Typical landfill aftercare periods are set at 30 to 50 years, however, in many instances achieving such a period is still not practicable. Sabbas *et al* (1999) define active after care period as the time during which gas collection, leachate treatment and other after care measures are conducted. Methane treatment is not usually a problem during after-care especially after active degassing. Leachate, on the contrary, is the major source of concern.

A critical parameter is the ammonical nitrogen (Burton and Watson-Craik, 1997, Heyer and Stegmann, 1997, Kruempelbeck and Ehrig, 1999). In a study carried out to look at the composition of leachate in large landfills, including Bisasar road landfill in South Africa, Robinson (2005) found that leachates have extremely high concentrations of ammonical-N, up to 3000 mg/ℓ in concentration.

Current literature on landfill emission management and control revealed that the ultimate goal of a sustainable landfill is to reduce the after care period. Sustainable landfilling can be achieved by proper waste management practices and sound environmental legislations. Processes, which promote elevated emissions over time, should be avoided. Separate waste collection, waste pretreatment, avoiding impermeable landfill covers and flushing can help to reduce elevated emissions over a long time (Sabbas *et al*, 1999).

2.3 Legislations on waste management

In the Europe Union, there has been a gradual change of legislations governing waste disposal techniques and the quality of refuse disposed in landfills. The movement towards a "sustainable" landfill has led to new developments in waste legislations with the introduction of waste stabilization prior to disposal.

South Africa and other developing countries

In South Africa and other developing countries, waste legislations are still focused on the "concentrate and contain" approach, which entails long-term environmental impacts (Trois *et al*, 2005). The politics of developing countries ignore the side effects of waste, waste management costs are underestimated and people lack knowledge on the consequences that uncontrolled waste disposal may have on health and environment (Wagner *et al*, 2001). South African legislations are focused, amongst other goals, on planning waste management strategies and creating job opportunities to improve waste management (Blight and Mussane, 2005).

USA (Pacey, 1999)

The Resource Conservation and Recovery Act (RCRA) subtitle D in 1993 was introduced with the intention to minimize environmental impacts associated with landfill leakage and gas emissions. The law recommends the following:

- Landfill requires composite underlying system,
- Impermeable cover,
- Leachate and gas collection,
- A minimum of 30 years post-closure period is required to manage long-term environmental liabilities.

The European Union (EU) (2003/33/EC)

Member states of the EU have targets to reduce biodegradable fraction of MSW by 25%, 50% and 65% during the years 2006, 2009 and 2016, respectively (Stegmann, 2005). The first step to the acceptance of waste in to the landfill is its full characterization. Treated waste must comply with strict disposal limits before being landfilled, in relation to origin, type, composition, consistency, leachability, degradability and potential for methane production.

Italy (Bozzo *et al*, 2001)

The Italian law D.Lgs 22/97 governs the disposal of waste. The law requests to municipalities to reach minimum rates of waste recycling hence limiting landfill disposal. There are waste recovery requirements whereby the MSW collection system must have a strong control on quality and quantity of recyclable materials and effective recovery rate. Separate collection is the mechanism used to control waste quality. Italy set a goal of reaching 15, 25 and 35 percent of MSW separate collection in the years 1999, 2001 and 2003 which can be achieved by biowaste separate collection from households. Currently, separate collection is coupled with treatment prior to disposal in compliance with the EU and landfill directives.

Czech Republic (Kuras and Mikolas, 2001)

The basic objective of Czech laws is to use integrated waste management to minimize the overall impacts and hazards of waste in a cost-effective and sustainable manner. The Czech laws towards integrated waste management were established in 1991 and 1997. In 1991 the law created basis for a modern and environmentally acceptable waste management system. It monitors waste generation, movement of waste and methods of handling waste and stated closure of environmentally unfriendly landfills by 1996. Since 1997 the Czech Republic complies with EU standards.

The Netherlands (Mathlener, 2001)

A project called 'sustainable landfilling' was commissioned for 5 years (1999 to 2004) to assess technical, economic and legal or political feasibility of sustainable landfilling. The aim was to define technical parameters necessary for sustainable landfilling, evaluate economical and environmental savings that could be gained by managing landfills in an inherently safe manner. The concepts of management are:

- Recyclable landfilling,
- Biochemical processing focused on final storage,
- Inorganic processing focusing on final storage quality.

Austria and Germany

According to Zach *et al* (1999), in 1999 Austrian Landfill Ordinance, BGBI Nr. 164/96 and German Technical Regulation on Municipal Solid Waste (TASi) lacked the description of waste activity values of treated waste that goes to the landfill. By the year 2001, Austria and Germany set the waste activity parameters of MBP waste before landfilling. Table 2.4 shows the general parameters and limit values of waste in Austria and Germany landfills before 2001. Table 2.5 and Table 2.6 present the specific disposal limits of MBP waste in Austria and Germany after 2001. From Table 2.4 to 2.6, it may be observed that there is a constant implementation of strategies to reduce waste volumes and promote rapid stabilization of waste in landfills.

Table 2.4 Limit values for landfill input material in Austria and Germany

Parameter	Limit Value	Law	Author
TOC	50 000 mg/kg DM	Landfill Ordinance 164/1996 Austria	Raninger and Nelles, 1997
pH	6 – 13		
NH_4-N	100 000 mg/kg DM		
Cl	30 mg/kg DM		
Calorific value	6000 kJ/kg DS		
TOC	100 mg/ℓ	TASi, 1993 Germany	Leikam and Stegmann, 1999
pH	5.5 – 13		
NH_4-N	200 mg/ℓ		
Conductivity	50 mS/cm		

Bramryd and Binder (2001) present the specific disposal limits for Austria in Table 2.5.

Table 2.5 Waste activity values for Austria

Parameter	Limit Value
$SOUR_4$*	5 mgO_2/g DS
Gas Production (90 days)	20 Nℓ /kg DS
Calorific Value	6000 KJ/kg DS
TOC	5% DS of TOC

$SOUR_4$* is the respiration index at 4 days.

Stegmann (2005) presents the target values for landfilling of mechanically-biologically pretreated municipal solid waste in German in Table 2.6.

Table 2.6 Waste activity values for Germany

Parameter	Limit Value
Respiration Activity (RA_4*)	5 mgO_2/g DS
Gas Formation Potential (GF_{21})	20 N ℓ /kg DS
Gross Calorific Value	6000 KJ/kg DS
TOC_{eluate} (L/S 1:10 over 24 hours)	250 mg/ℓ
TOC_{solid}	18 Mass-%

RA_4* is the respiration index at 4 days

Table 2.4 presents the limit values before the implementation of the limit values on MBP waste, whilst Tables 2.5 and 2.6 present specific considerations particularly on the biological activity of waste. The important biological parameters, which give waste stability characteristics, are respiration activity and gas production. The readily aerobically biodegradable portion of organic substances represents the respiration activity of waste whilst the gas production corresponds to the anaerobically biological portion of organic substance (Bidlingmaier and Scheelhase, 1999). Unfortunately in developing countries biological waste stability criteria are still not applied.

2.4 Mechanical biological pretreatment of waste

In general, waste pretreatment prior to landfilling is achieved by thermal and biological processes. Biological methods comprise of anaerobic and aerobic treatments. For the purpose of this research the focus was directed on aerobic pretreatment, specifically MBP. Raninger and Nelles (1999) define MBP as a combination of mechanical and biological operating processes used in the pretreatment of waste. The purpose of the mechanical processes is to mix, homogenize, grind, sort, separate, size and remove contaminants that could impair the efficiency of the biological treatment for example hazardous waste, metals, plastics, stones etc. Stegmann (2005) give a schematic presentation of the processes of MBP concept as given in Figure 2.4.

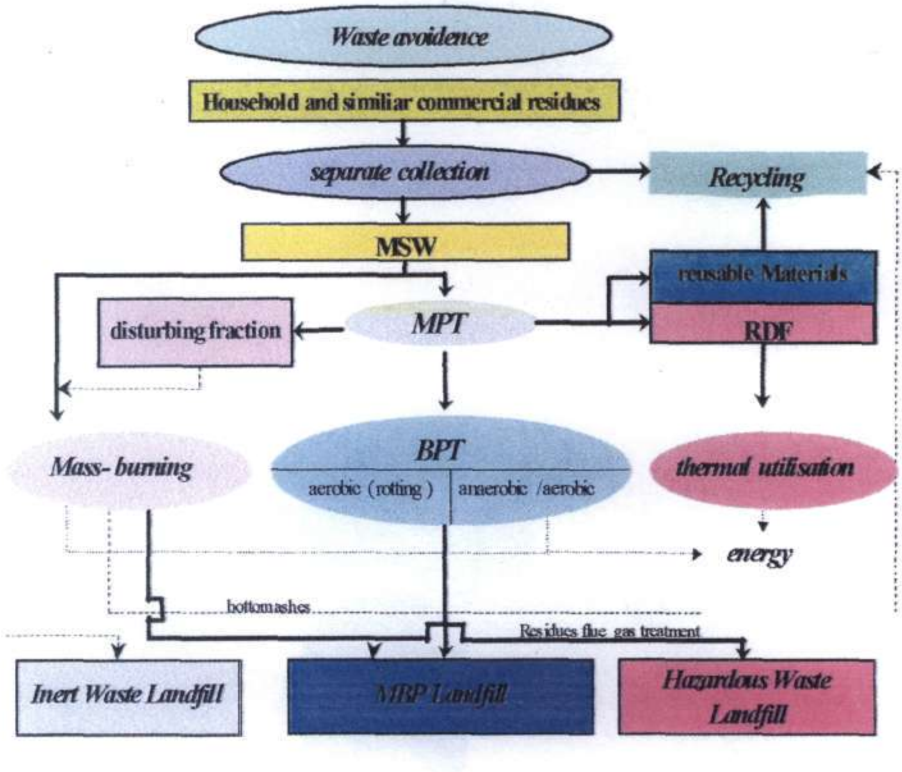

Figure 2.4 Presentation of MBP processes, adapted from Stegmann (2005)

Usually waste is pretreated for 8 weeks, 16 weeks, 24 weeks (Munnich *et al,* 2005, Binner et al, 1997, Griffith and Trois, 2005).

Scheelhaase and Bidlingmaier (1997) outline the following effects on material of MBP in relation to prevailing climatic conditions, nature of the waste and available technology.

- Reduction of weight and volume,
- Homogenization (and comminuting depending on the concept),
- Reduction of water content,
- Meeting hygienic requirements,
- Reduction in biodegradable components,
- Biological stabilization,
- Reduction of gas formation potential,
- Reduction of leachable components,
- Increased particle grain size
- Increased bulk, landfilling and storage density,
- Reduction of hydraulic conductivity (depends on density).

There are many methods of composting that can be used, Polster and Trois (2007) summarize the methods as presented in Table 2.7

Table 2.7 Classification of the Dome Aeration Technology (DAT) into conventional composting systems (Polster and Trois, 2007)

Non-reactor systems (Open)				**Reactor systems (Enclosed)**			
Agitated solid beds		**Static solid beds**		**Vertical solid flow**		**Non-flow (compost boxes)**	**Horizontal and inclined solids flow**
Passive aeration	**Forced aeration**	**Passive aeration**	**Forced aeration**	**Agitated solid beds**	**Packed beds**		
		Triangular Windrow					Tumbling solids bed
		Mat windrow					
		Sole aeration					Agitated solids beds
		Chimney aeration					
		Dome Aeration Technology					Static solids bed

The most important parameters that indicate directly the degree of stabilization of residual municipal solid waste are the gas production potential and the respiration index. Gas production potential is normally measured after 21 and 90 days in the laboratory using a waste sample. The respiration index (RI) determines oxidizable organic matter usually measured at 4 and 7 days in the laboratory. Other useful parameters that determine the suitability of MSW for landfilling after MBP are total organic carbon in the eluate and the calorific value. Table 2.8 below shows reported reductions on waste activity and gas production potential.

Table 2.8 Observed reduction on waste biological activity

Waste Type	Parameter	Value	Author
Non pretreated MSW	Gas production	64 Nℓ /kg D.S	Binner *et al* 1997. Austria
MBP 6 months windrow		5 Nℓ /kg D.S	
MBP 10 weeks forced aeration		2 Nℓ /kg D.S	
65 mm 3 weeks forced aeration	RI_4	20 mg O_2/g DS	
MBP 100 mm 5 weeks		47 mg O_2/g DS	
MBP 20 weeks		2.5 mg O_2/g DS	
2 Months Pretreated MSW	Gas production at 21 days	14.3 Nℓ /kg D.S	Cossu *et al* 1999. Italy
3 Months pretreated organics from separate collection		20.2 Nℓ /kg D.S	
		50.9 Nℓ /kg D.S	
		0	
MBP, RMSW 4 months treated		0	
		0	
2 Months Pretreated MSW	RI_4	9.0 mg O_2/g DS	
3 Months pretreated organics from separate collection		37.2 mg O_2/g DS	
		21.4 mg O_2/g DS	
		2.9 mg O_2/g DS	
MBP, RMSW 4 months treated		1.8 mg O_2/g DS	
		1.5 mg O_2/g DS	
< 15 mm particle, 14 days anaerobic, 7 weeks forced aeration	Gas production at 21 days	2-5 ℓ /kg T.S	Muller *et al* 2001. Germany
< 50 mm, particle14 days anaerobic, 7 weeks forced aeration		2-5 ℓ /kg T.S	
< 15 mm particle, 14 days anaerobic, 7 weeks forced aeration	RI_4	1-3 mg O_2/g DS	
< 50 mm, particle14 days anaerobic, 7 weeks forced aeration		1-3 mg O_2/g DS	

From the observed parameters, as presented in Table 2.8, it can be inferred that the longer is the pretreatment period the better is waste stabilization; forced aeration produced more stabilized waste than self aerated system; smaller sized particles enhanced the biological activity; organic waste collected by separate collection is more biologically active than residual municipal waste; and anaerobic digestion can be inculcated with aerobic stabilization to achieve better results.

At the Bisasar Road landfill site in Durban, South Africa, a study was initiated in 2002 to identify suitable technique for waste pretreatment in local authorities and rural settings. The DAT was found to be suitable because of its low costs, zero/low energy input during the composting period, potential for labour intensive operations and reduced machinery requirements (Griffith and Trois, 2005). The DAT was firstly developed by the Institute of Chemical Engineering and Environmental Engineering at the University of Technology in Dresden (Mollekopt *et al*, 2002)

2.5 The Dome Aeration Technology

The DAT method converts open rotting windrows into self-aerated systems by using the thermal buoyancy of the hot gases found during the aerobic degradation of waste. The DAT windrow has vertical standing exhaust domes with chimneys and horizontal channels made out of steel. The domes permit flow of gases in the waste material by creating voids and allowing accumulation of hot air. Fresh air enters through the channels and moves by hydrostatic pressure difference through the hotter waste mass to central domes, hence promoting self-aeration. The efficiency of the aeration within the dome depends on ambient weather conditions more particularly air temperature and prevailing wind. Figure 2.5 below shows the cross structure of a typical DAT windrow.

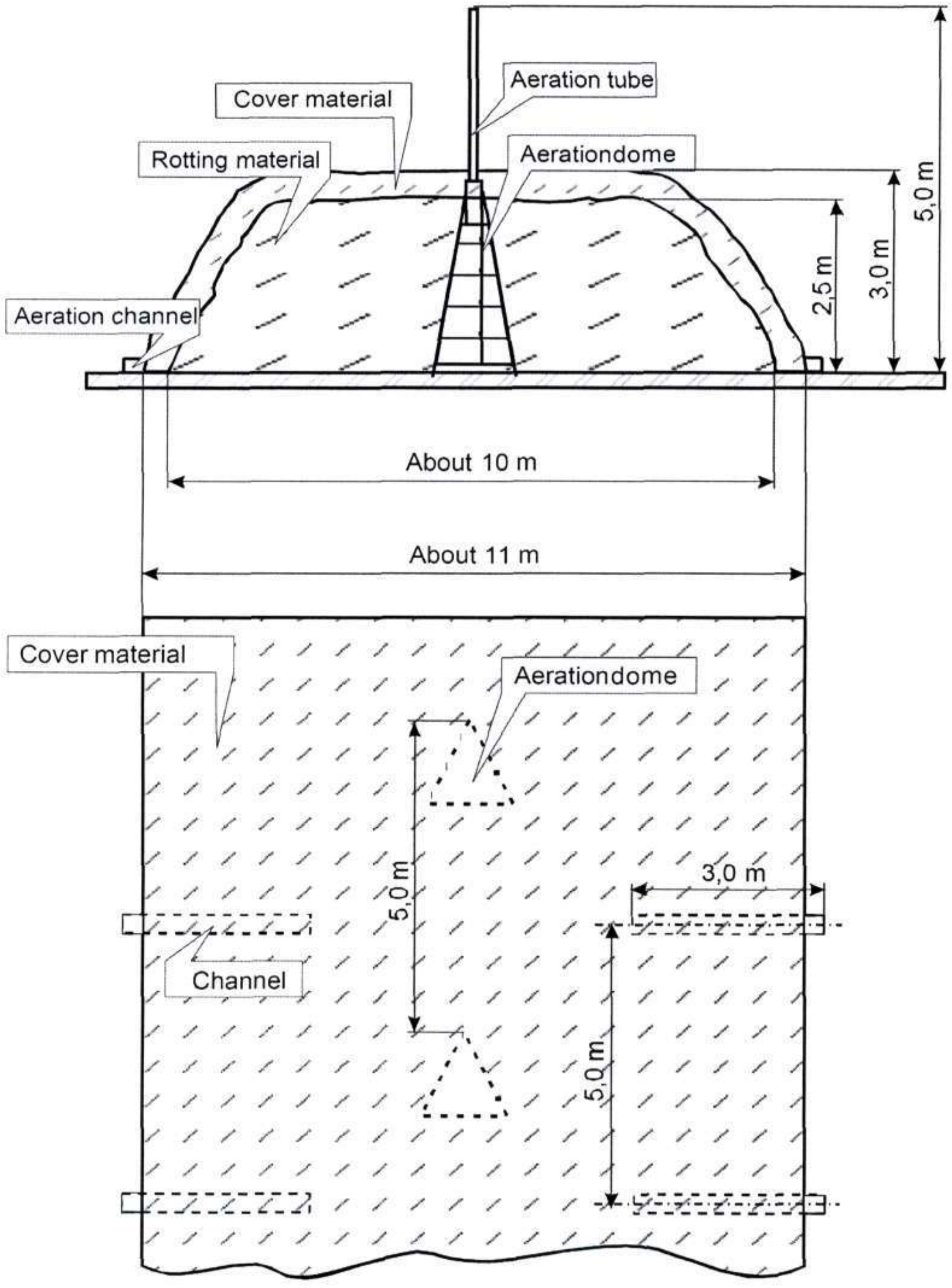

Figure 2.5 The structure of the DAT (Paar, 2000)

The patterns of airflow in a windrow are showed in figure 2.6.

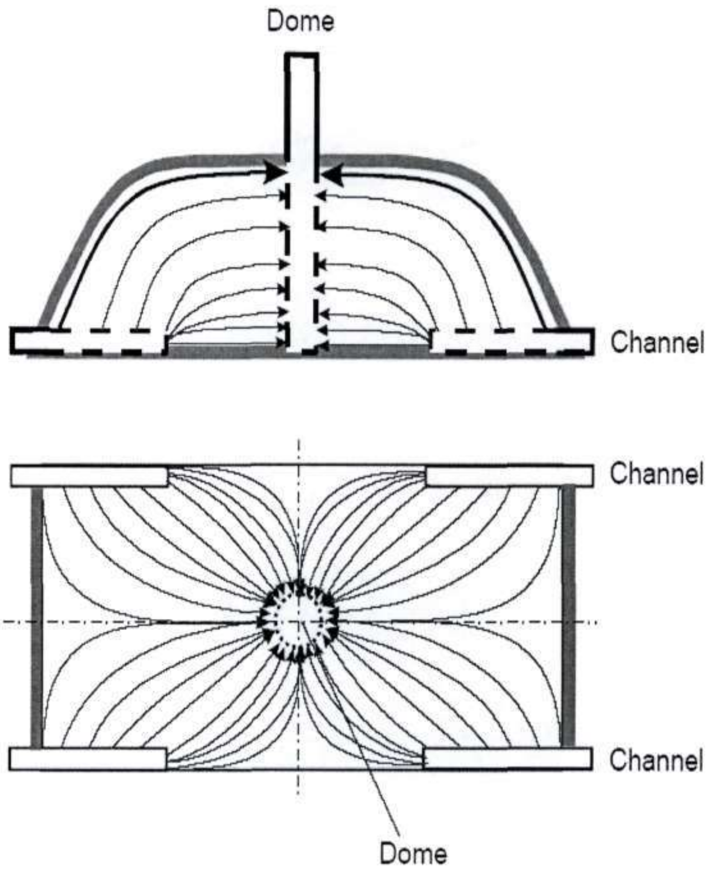

Figure 2.6 Air flow patterns in a windrow (Paar, 2000)

In order to achieve the flow patterns depicted in Figure 2.6 the waste material and to minimize dessication problem has to be covered. Screened compost material can be used as cover. Mollekopt *et al* (2002) give an outline of the benefits of compost covering below:

- Covering minimizes emissions such as odour, harmful gaseous substances and flying light material,
- Covering ensures high rotting temperatures, even on the outer part of the rotting material, and complete treatment and hygienization,
- Climatization of windrow, i.e protection against drying, wetting, cooling and heating by weather effects and
- Emissions are defined and controlled by covering, hence there is an absence of diffusive emission.

Structural material is mixed with the waste during windrow setup in order to promote ventilation and to give structure to the windrow. Griffith (2005) recommends a mixing ratio of MSW: Structural Material of 2:1 because it is suitable to Durban's environmental conditions and waste composition. The structural material can be obtained from dry materials of wood, planks and garden refuse. Ventilation is not uniform within the domes due to preferred air pathways. Some areas are poorly ventilated whilst some are well ventilated, as shown in figure 2.7 below.

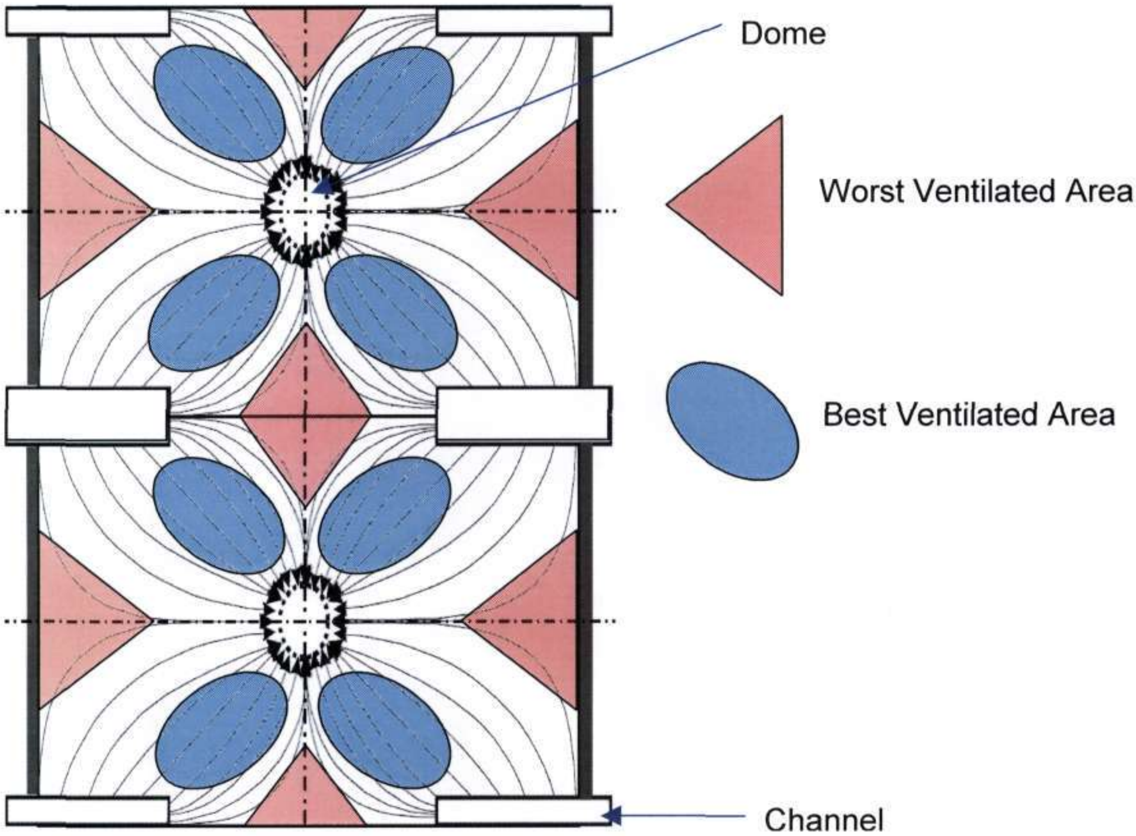

Figure 2.7 Variation of ventilation inside a windrow (Griffith, 2005)

2.5.1 Setting-up a windrow in the landfill

The way of setting up a windrow depends on the availability of suitable technology. The flow sheet presented in figure 2.8 presents a summary of the operations involved in setting up a windrow at the Cottbus landfill site in Germany (Mollekopt *et al*, 2002).

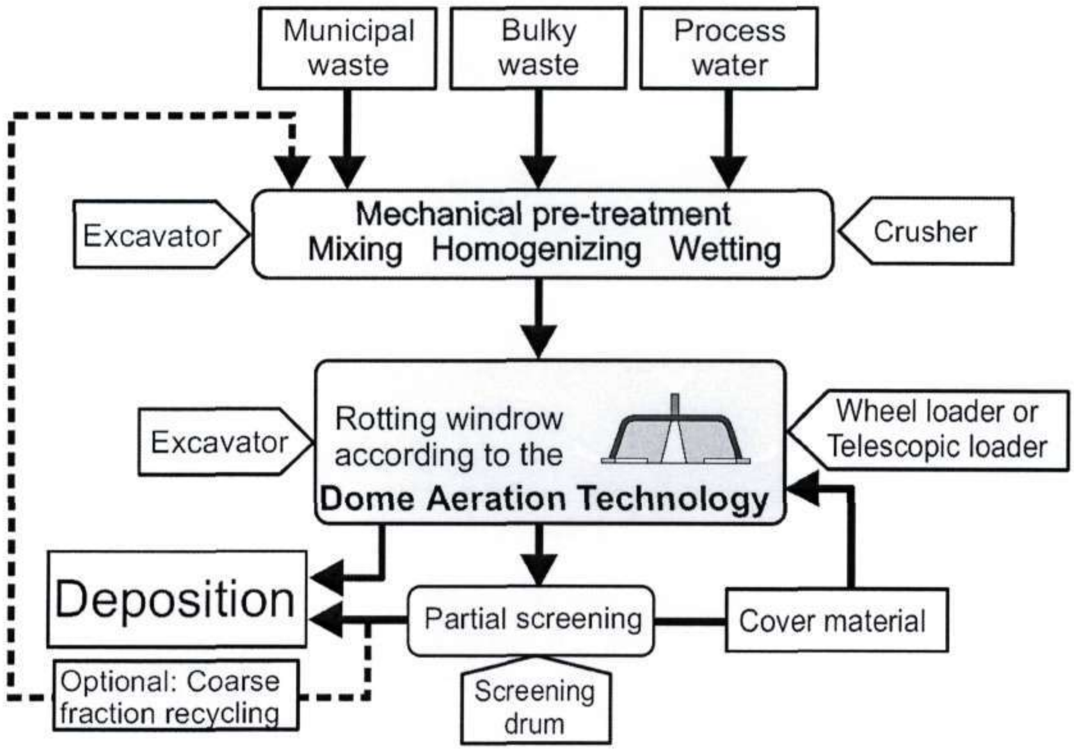

Figure 2.8 Operations of setting up a windrow in as suggested by Mollekopt *et al* (2002)

Household waste is received and mixed with bulky waste, crushed and moistened by a shredder with a spraying device. The desired moisture content is 55 percent by mass for components absorbing moisture, hence stones and plastics are removed. In South Africa, however, separation of undesired material like plastics is not practicable due to the mixed waste stream and lack of technology to segregate waste. Moisture control is very crucial and it can only be done during mixing and may not be replenished during composting. However, in a pilot study done in Brazil, irrigation was done to replenish lost moisture (Münnich *et al*, 2005). Water accounts for degradation, heat generation and loss by evaporation. Moistened and homogenized material is transported using a loader for piling up. Before piling, channels and domes are fixed on position by an excavator.

After the windrow has been constructed the degradation starts then temperature, gas velocity and gas composition may be monitored from the chimneys. DAT composting can take 3 to 6 months depending on the desired quality of the output. After composting, windrows are dismantled with a wheel loader or appropriate machinery. Screening of fine covering material is done. The particle size of fine material varies from landfill to landfill. In Austria waste fine fractions that are less than 24 mm diameter meet landfilling requirements (Raninger *et al*, 1999). In Germany acceptable particle sizes range between 80 and 100 mm diameter (Rettenberger, 1999). Part of the coarse particles and biochemical material can be used as structural material. In South Africa, at Bisasar road landfill site, pine bark is used as cover because it is easily available and screening of treated waste as to be used as covering material is not possible.

2.5.2 Monitoring progress in the DAT

Oxygen and carbon dioxide content, temperature and gas velocity are monitored within the windrow body, everyday for the first two or three weeks (maturing phase) and weekly thereafter.

Temperature and oxygen content

Bacterial activity starts immediately after the material has been stacked in the windrow, subsequently, an increase in temperature is observed. Golueke (1972) reports temperature increase from ambient to 50^{0}C in 1 or 2 days and after 4 days temperature can reach a highest of 75^{0}C. In an observation by Mollekopt *et al* (2002), within 10 days of DAT composting, temperature was restricted between 70^{0}C and 75^{0}C. High temperatures are maintained until all decomposable material has broken down.

When oxygen is held above 10 percent by volume in the initial stages of composting, aerobic degradation continues without any retardation or inhibition (Mollekopt *et al*, 2002). Easily degradable organic compounds are aerobically digested liberating carbon dioxide. Oxygen demand and carbon dioxide generation decrease as the degradation process proceeds. Monitoring the content of methane is important to ensure aerobic conditions.

Monitoring the cumulated volume of carbon dioxide generation by the microorganisms' activity is important to establish the process kinetics. In order to achieve measurement of oxidisable carbon, the following parameters have to be established from exhaust air: gas velocity, carbon dioxide content and water vapor content. Paar (2000) gives equation 2.3 below for the estimation of organic compounds that can liberate carbon dioxide.

$$C_aH_bO_cN_d + vO_2 \rightarrow xCO_2 + yH_2O + zNH_3 \qquad (2.3)$$

Where a, b, c and d represent the stoichometric composition of carbon, hydrogen, oxygen and nitrogen in waste compounds, respectively. The compositions of typical compounds are shown on Table 2.9.

Table 2.9 Composition of some typical compounds found in MSW

Compound	Formula	Author
MSW	$C_{99}H_{149}O_{59}N$	EMCON (1980)
Paper	$C_{203}H_{334}O_{138}$	EMCON (1980)
Rapidly decomposable fraction	$C_{68}H_{111}O_{50}N$	Tchobanoglous (1993)
Slowly decomposable fraction	$C_{20}H_{29}O_{9}N$	Tchobanoglous (1993)
Food waste	$C_{16}H_{127}O_{8}N$	EMCON (1980)

Figure 2.9 below shows a typical trend of oxygen, carbon dioxide and temperature as observed during an experiment in Cottbus, Germany.

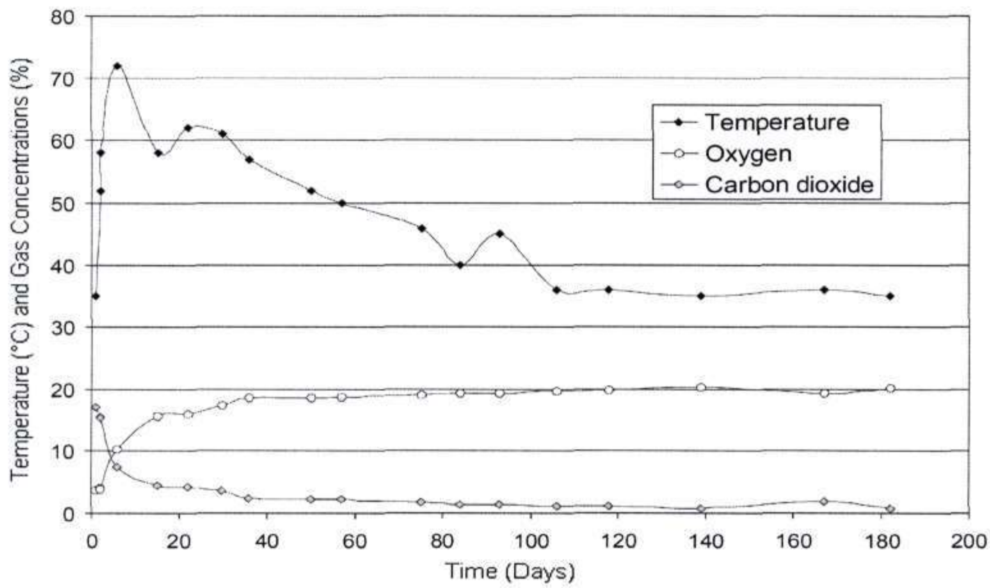

Figure 2.9 Temperature, oxygen and carbon dioxide concentration in a DAT windrow in Cottbus (Mollekopt et al, 2002)

Gas velocity

There is a linear dependency between change in temperature (chimney minus ambient temperature) and gas velocity. In a study carried out in Durban, South Africa by

Trois and Polster (2007), it was found that dome exhaust velocity increased with the temperature difference as presented in figure 2.10 below.

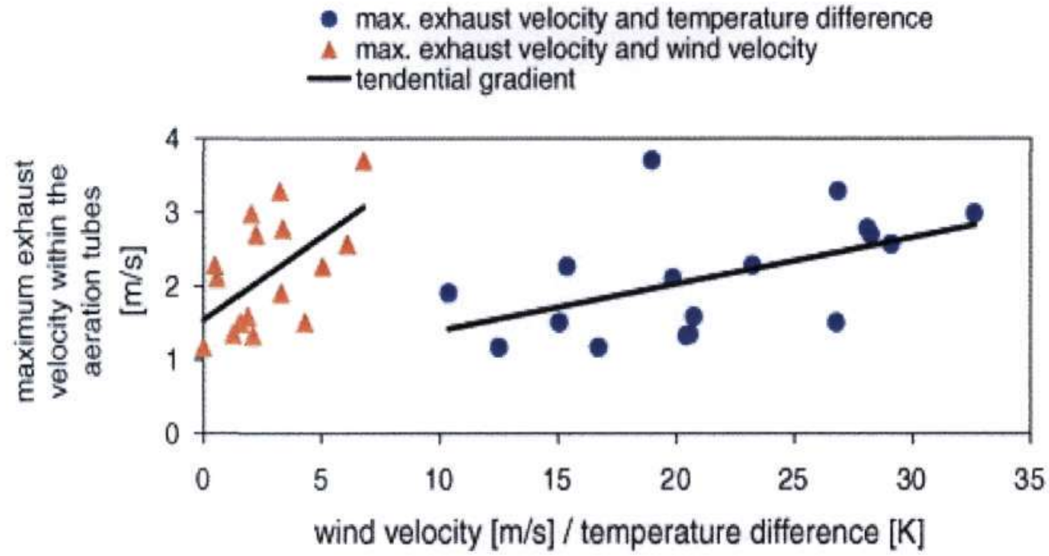

Figure 2.10 Relationship among the exhaust gas velocity, temperature difference and wind velocity (Trois and Polster, 2007)

If biological activity is high, a large amount of oxygen is required and excessive heat is generated.

2.6 Laboratory test methods for characterizing MBP waste

The main aim of waste pretreatment is to stabilize waste in order to reduce emissions potential. Several parameters are established with the aim of characterizing biological stability of pretreated waste. For comparison reasons, parameters are determined before and after waste stabilization. The tests discussed below give fundamental criteria for waste stabilization. The standard test methods used in this dissertation are discussed in section 4.3.3.

Incubation Test or Gas Production Test ($GS_{21/90}$)

The incubation test is used to determine biogas generation potential (Binner *et al,* 1999). According to Bidlingmaier and Scheelhase (1999), gas formation gives the readily anaerobically biodegradable portion of organic substances. A sample is saturated to field moisture capacity and incubated in a glass reactor under anaerobic conditions and gas generation is measured. The test is usually run for 240 days, however, at 90 days gas generation is 65 to 90 percent of the gas obtained in 240 days. Results are usually reported after 21 and 90 days.

Respiration Activity (RI_4 and RI_7)

The respiration index test is initialized as IR, RI, SOUR and AT in Italy, England, Austria and Germany, respectively. The respiration activity test is used to assess the activity of waste, i.e. oxygen consumption during degradation of the organics in the waste matrix (mgO_2/g). The respiration activity represents the readily aerobically biodegradable portion of organic substances (Bidlingmaier and Scheelhase, 1999). The testing period is 4 and 7 days, RI_4 and RI_7, respectively. According to Cossu *et al* (1999) RI_4 of less than $10mgO_2/gVS$ and RI_7 of less than $25mgO_2/gVS$ indicate well stabilized waste. Soyez *et al* (1999) state that an RI_4 of less than $5mgO_2/gDM$ is characteristic of biological stable waste.

Eluate Tests

The eluate tests give a relative amount of organic compounds that can be leached from the solid phase of waste to the liquid phase. The eluate test enables the prediction of the leachate quality and gradual release contaminants at full-scale conditions. The EU landfill directive (EN 12457-1) recommends a liquid to solid ratio of 1:10 although member states can prescribe their own ratios. The following eluate parameters are determined, Total Organic Carbon (TOC), Ammonical nitrogen (NH_4-N), Chemical Oxygen Demand (COD), Biological Oxygen Demand, (BOD), pH and hydraulic activity.

Substance Groups Test

The test gives nutritional value of waste. The sample is analyzed for easily to digestible compounds, polysaccharides, especially cellulose, and non digestible lignin. By knowing the nutritional value of waste, the decomposition behavior of organic matter can be predetermined. About 75 to 100 percent of carbohydrates are lost during MBP and cellulose, lignin, lipids and proteins are degraded in the landfill (Pichler and Kogel-Knaber, 1999).

Lead Acetate Paper Test

The test is used to determine the time taken to change lead acetate paper from white to black due to H_2S production. A sample of 50g is put in an airtight 1 liter container of at a temperature of 35^{0}C (Cossu *et al* 1999). The amount of time that lapses darken the paper shows the biological activity of organic matter.

Other parameters that are important to consider are calorific value, cellulose/lignin ratio and ignition losses to determine volatile solids (VS). The calorific value gives an amount of combustible materials hence it is a useful parameter for heat recovery processes. The cellulose/lignin ratio shows the biological stability of waste. A high cellulose/lignin ratio suggests a poor waste stability than a low value. Volatile solids are directly correlated to the amount of gasefiable compounds from waste. Table 2.10 below shows parameters and values of stabilized waste.

Table 2.10 Recommended characteristics of stabilized waste

Parameter	Value	Country	Reference
Calorific value (H_G)	< 6,000 KJ/Kg DM	Austria Landfill Ordinance	Binner *et al* (1999)
Gas production (GS_{90})	< 20 N ℓ /Kg DM	Austria Landfill Ordinance	
GB_{21}	5 N ℓ /Kg DM	Austria Landfill Ordinance	
	20 1/Kg DM	Germany, TASi	Soyez *et al* (1999)
AT_7 or specific Oxygen Uptake rate ($SOUR_7$)	15 mgO_2/g DM	Austria Landfill Ordinance	Banner *et al* (1999)
	<25 mg/VSf		Cossu *et al* (1999)
	9 mgO_2/gTS	Austria	Raninger *et al* (1999)
AT_4 or Specific Oxygen Uptake $Rate_4$	10 mgO_2/gVSf		Cossu et *al* (1999)
	5 mg/g DM	Germany, TASi	Soyez *et al* (1999)
	5 mgO_2/gTS	Austria	Raninger *et al* (1999)
COD	1-3 g/COD/Kg DM	Germany, TASi	Soyez *et al* (1999)
TOC	0.5-1.5 g/TOC/Kg DM		
NH_4N (Ammonical N)	0.1-0.2 g/DM		
VS	< 5%		
Hydraulic Conductivity	<10^{-7} m/s		
Cellulose/lignin	0.4		

2.7 Long term emissions from MBP waste

Research on the long-term behaviour of MBP waste is relatively new. Different studies have been carried out in Europe, particularly in Germany and Austria. Presented in this sub-chapter are experiments carried out in the laboratory and field scale simulation using test cells.

A study carried-out in Germany by Horing et al (1999) showed a significant benefit of landfilling MBP waste than untreated waste. Using landfill-simulation-reactors it was found that it is possible to reduce the emissions potential of MSW by 90 percent and reduce the time required to half the gasefiable compounds by a factor of 10. No acid phase occurred during decomposition. Low leachate concentration occurs for a long time with MBP waste. It was also discovered that biologically stabilized waste decomposes slowly because easily degradable organic matter is degraded to a greater extent during pre-treatment.

Nitrogen in leachate is reduced by 80 to 90 percent in MBP waste. MBP leads to very low gas formation activity and slow mobilization of organics to leachate. Nitrogen is an important factor in determining the discharge quality of leachate. During decomposition organic nitrogen is converted to ammonia by biological processes and is removed by leachate whereas carbon is mainly carried by landfill gas (Horing et al, 1999). MBP waste can be highly compacted leading to low hydraulic conductivity which retards the leaching out of materials.

A similar study carried-out in Austria by Raninger *et al* (1999) to investigate the behaviour of MBP waste under anaerobic field-scale test cells, suggests the landfill gas production started 1 month after closure of the test cells and immediately reached a stable methane production stage in 100 days. The percent composition of methane ranged between 50 and 60 percent within the first year. The rate of gas production began at 2 Nm^3 (normal cubic meters) per day and dropped to 0.4 Nm^3 after 230 days. The specific oxygen uptake rate for 4 and 7 days reduced by 50 percent in 1 year. There was no observed influence of irrigation. The observed average behaviour of leachate in test cells is presented in Table 2.11.

Table 2.11 Observed composition of leachate in test cells filled with pretreated waste, (Raninger et al, 1999)

Parameter	Starting point, (first sampling)	After first year	
		Without	With
		Leachate Recirculation	
BOD (mg/ℓ)	748	522.3	250
COD (mg/ℓ)	11427.5	9984	8112
TOC (mg/ℓ)	3755	2437	2953
NH_4 (mg/ℓ)	2217	2212	2867

During a follow up of the same study Lorber *et al* (2001) observed a drop in gas production for the non-irrigated test cells from an average of 1.85 Nm^3 to 0.08 Nm^3 after 700 days. Whereas there was an increase in gas production with the irrigated test cells. At the beginning of the experiment the GS_{90} was 35.2 Nℓ/kgDS (dry solids) and it dropped to 35 Nℓ/kgDS after 700 days. The observed average behaviour of leachate during the subsequent years is presented on table 2.12 below.

Table 2.12 Observed composition of leachate in test cells filled with pretreated waste (Lorber et al, 2001)

Parameter	Starting Point, (first sampling)	Irrigation and Leachate Recirculation			
		without		with	
		1^{st} year	2^{nd} year	1^{st} year	2^{nd} year
BOD (mg/ℓ)	748	522.3	307	250	204.5
COD (mg/ℓ)	11427	9984	7974	8112	3323
TOC (mg/ℓ)	3755	2437	2748	2953	1167
NH_4 (mg/ℓ)	2217	2212	2206	2867	1686

Hence it may be concluded that landfilling MBP waste eliminates the acid stage, reduces gaseous emissions, reduces the organic load of leachate, can shorten the half life of emissions hence after care period and increases the placing density of waste. However, increasing the placement density can be undesirable because it retards the leaching of organics from the solid phase to the liquid phase.

2.8 The PAF model (Pre-treatment Aeration and Flushing)

The need for a sustainable landfill has brought about gradual change in the way landfills have been managed in order to improve the rate of waste stabilization. Acceleration of waste stabilization has been improved by moisture addition in landfilled waste (Blakey et al, 1997) and similarly with continuous watering (Santen and Fricke, 2005). Catalani and Cossu (1999) carried-out a lab-scale test and discovered that flushing pre-treated waste, either MBP or thermally treated, can reduce COD and TKN by at least by 90 percent. In another development it was found that semi-aerobic landfills enhance the aerobic biodegradation of organic substance and reduces generation of odours, biogas and leachate pollution (Hanashima, 1999). Bidlingmaier and Scheelhaase (1997) also found that it is possible to lower landfill emissions with mechanical biological pre-treatment of domestic waste.

A pre-treatment, aeration and flushing combination was developed with the aim of exploring the three methods of accelerating degradation of landfilled MSW. An investigation by Cossu *et al* (2001) is briefly discussed in the following paragraphs. The research treatments were untreated MSW, MBP waste under anaerobic condition, flushed MBP waste, aerated MBP waste, MBP waste under semi-aerobic conditions and MBP waste which was flushed and aerated (PAF). The research was carried in the laboratory using columns.

Cossu *et al* (2001) concluded that:

- Untreated MSW showed highest concentrations of BOD, COD and ammonia and biogas production was delayed by an initial acid phase;
- Although MBP waste under anaerobic conditions had reduced BOD_5, COD and ammonia, the BOD_5 value was equal to 1500 mg/l, i.e relatively high;
- The inception of methanogenesis was accelerated except for untreated MSW;
- Flushing MBP waste rapidly reduced emissions on COD, BOD, ammonia, TKN and biogas;
- Aeration improved the oxidation of organics and nitrogen and
- The PAF model optimizes the advantages of pretreatment, aeration and flushing.

The main constraints that arise from the use of the PAF method would be the field application. The main constraints include incorporation of an aerating system during landfill design, designing a sustainable system for flushing, hydraulic properties and stability of landfilled waste, the life span of landfill linings etc. Interesting suggestions have been given by Tankler *et al* (2005) that open cells located in tropical rainy areas with thin disposed layers of waste can expect reasonable flushing during the rainy season. Cossu et al (2005) report a full-scale application of in situ aeration at Legnago, Province of Verona, North Italy.

CHAPTER 3

CASE STUDIES

This chapter presents a brief discussion of cases of management of municipal solid employed in the United Kingdom and Austria. Austria and the UK have been selected because the researcher made field visits to landfills of these countries. The purpose of this chapter is to give an insight about municipal waste management in those countries where MBP is well established.

3.1 Landfilling of municipal solid waste in England

Currently more than 70 percent of the municipal solid waste in England is disposed in landfills (Defra, 2006). Nonetheless, the Landfill Directive requires the UK to have reduced biodegradable municipal waste landfilling by 75 percent of 1995 levels in 2010, 50 percent in 2013 and 35 percent in 2020 (Rose, 2005). If the UK fails, the European Commission could impose significant fines. The English waste strategy was set in the year 2000 to reduce landfill waste by recycling and composting. To give a formative assessment of the recycling and composting progress, English local authorities claim to have recycled or composted 23 percent of the household waste by the year 2004/05 but the target was 25 percent reduction (Rose, 2005).

New technologies meant to divert the biodegradable municipal waste from landfills have been developed in England. Defra (2006) defines biodegradable municipal waste (BMW) as the fraction of MSW that will break down, either in the presence of air or under anaerobic conditions (such as that within a landfill, where oxygen is absent). A figurative composition of typical BMW is shown in figure 3.1 below.

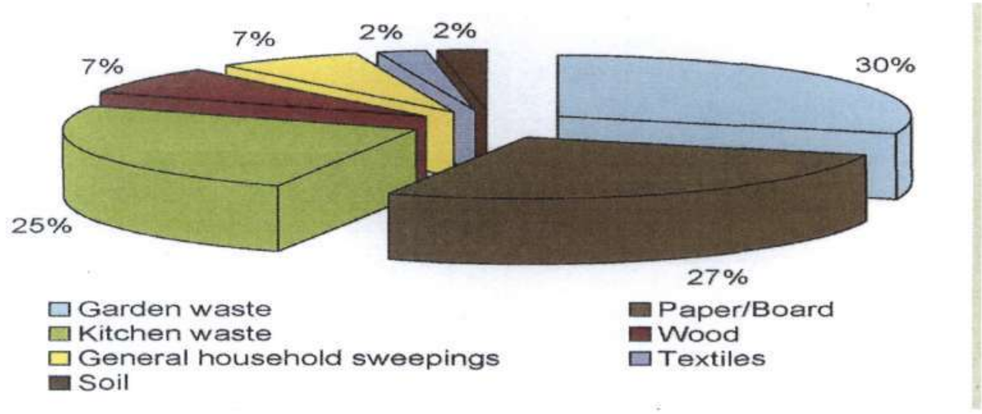

Figure 3.1Composition of biodegradable municipal waste (Defra, 2006)

From Figure 3.1, the major components of the BMW are garden waste, paper and kitchen waste.

The hierarchy of waste management options, beginning with the most desirable to the least desirable, comprise of reduction, re-use, recovery and disposal. There are strategies that can be used two extremities. Waste management options rely mostly on the waste collection system. Figure 3.2 gives an illustration of waste management available to English local authorities based on mixed collection or segregated collection.

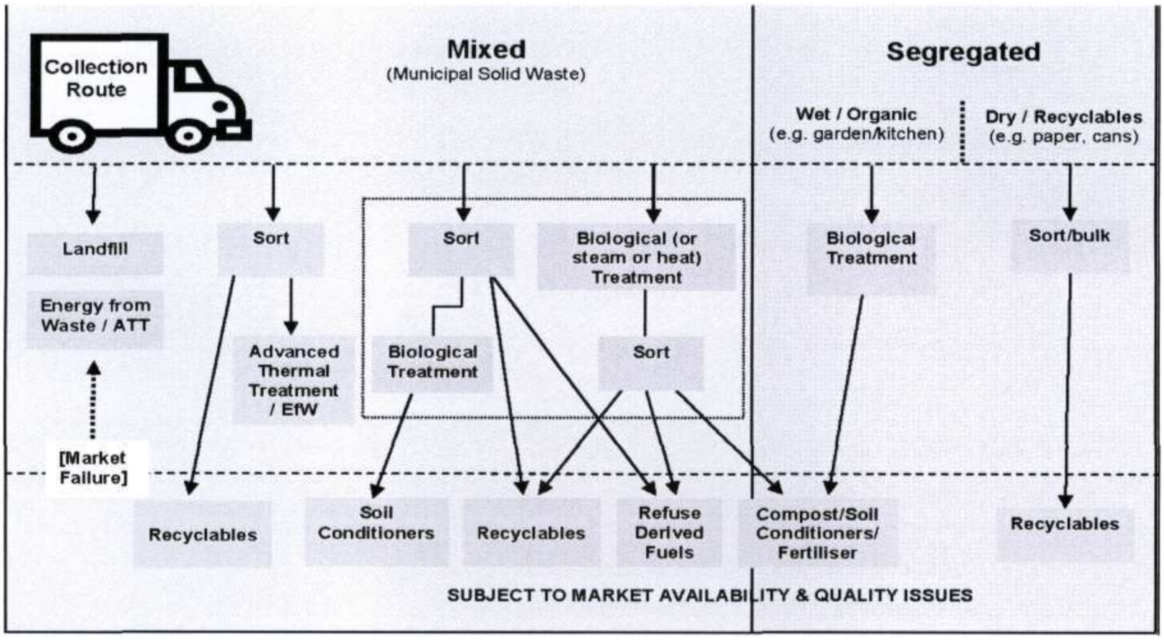

Figure 3.2 Options for recovery and disposal of municipal solid waste (Defra, 2006)

From figure 3.2, mixed waste collection would require further sorting for the recovery of recyclables and composting of organic material. The recyclables and compost achieved through mixed collection can be of lower quality compared to segregated collection. Segregated collection involves separation of wet or organic waste from dry or recyclables at the waste generation point. The wet and dry component can be composted and recycled, respectively.

A landfill tax and landfill allowance trading scheme (LATS) was introduced in the UK in order to implement the higher recovery and recycling targets (Rose, 2006). There is also extra funding for local authorities and the institution of government's waste and resource action programme to provide markets for recycled materials. The waste implementation programme assists authorities to make recycling and composting schemes.

To implement composting technologies, the UK has commissioned the implementation of mechanical biological treatment plants. According to Rose (2006), 15 local authorities could be using the mechanical biological treatment (MBT) option by the year 2010. Currently, a largest plant has been commissioned in east London with a capacity of 6 MBT plants. The 6 plants have a summative capacity of processing 360 000 tonnes a year. Other MBT projects which are in the planning or construction phase are located in Cambridgeshire, Cumbria, Dumfries and Galloway, Essex, Greater Manchaster, Lancashire, Leicester, Newcastle etc.

The MBT involves sorting separating and aerobically treating waste. The final product of MBT is refuse derived fuel and compostable material. MBT harness the use of aerobic biological processes to degrade organic components of waste into residual components and during the decomposition carbon dioxide, heat and water are produced. A picture showing an advanced biological treatment plant or in-vessel composting tunnel is shown in figure 3.3 below.

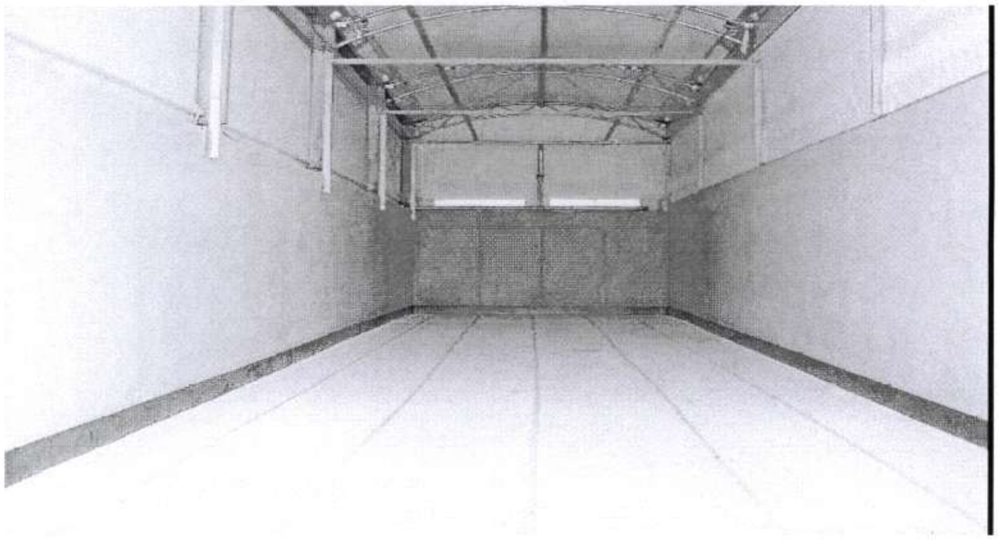

Figure 3.3 In-vessel composting tunnel (Defra, 2006)

Other new technologies that have been implemented by the UK in order to divert waste from landfills include advanced thermal treatment and anaerobic digestion. Advanced thermal treatment (ATT) involves pyrolyis and/or gasification to process MSW (Defra, 2005). Pyrolysis, often involving gasification, is a medium temperature (400-700^{0}C) thermal process in which organic derived materials in the waste are broken down under the action of heat in the absence of oxygen (Defra, 2005). Whereas gasification uses higher temperatures, typically 800-1200^{0}C, and oxygen or air is used to partially combust waste.

Advanced thermal treatment excludes incineration which is an already established technology. Incineration of MSW in the UK involves energy recovery from waste in the form of electricity generation and/or heat (Defra, 2006). On the other hand, pyrolyis and gasification involves the production of charcoal, coke gas. Advanced thermal treatment maybe used inline with sorting processes of the mechanical biological treatment technology. Figure 3.4 and 3.5 show an advanced thermal treatment plant and refuse derived fuel, respectively.

Figure 3.4 ATT plant (Defra, 2006)

Figure 3.5 Refuse fuel (Defra, 2006)

Anaerobic biological digestion involves the fermentation of organic material from residual solid waste and/or slurry in the absence of oxygen to liberate methane, carbon dioxide and water. The anaerobic digestion process can be a single step or multi-step process which takes place in sealed digesters.

3.2 Waste management in the city of Vienna, Austria

Like most of the European cities, the city of Vienna has challenges of the ever increasing volumes of municipal solid waste. A natural response to increasing waste volumes would be to build more landfills and incinerating plants. To curb the problem of waste, Vienna adopted a local Waste Management Act in 1994, mandating the separate collection of recoverables and "residual waste" (Wien, 2006). The Act was meant to define and regulate separate collection of waste.

To ease the separate collection of waste in Vienna, there are waste collection bins for plastics bags, plastic bottles, organic or garden waste, kitchen waste. Figures 3.6 to 3.11.

Figure 3.6 Dry household waste

Figure 3.7 Plastic bags only bin

Figure 3.8 Separately collected E-waste

Figure 3.9 Plastic bottles only bin

Figure 3.10 Garden refuse bin

Figure 3.11 Dry planks pile

The efficiency of separate waste collection is not 100 percent. The residual waste that is mixed is incinerated and the ash is taken to the landfill. Waste incineration can reduce the waste volume by over 80 percent hence less landfill volume requirement. Some of the plastic collected separately is not worth recycling hence it is incinerated. Only polyethylene terephtalate plastic (PET) is worth recycling. Further separation by hand, after collection, is done in order to obtain the plastic which is worth recycling. Figure 3.12 up to 3.15 show further separation of recyclables, recycled material and ash that finally goes to the landfill after incineration.

Figure 3.12 Hand separation of recyclables

Figure 3.14 Recyclable plastic (PET)

Figure 3.13 Ash from incineration

Figure 3.15 Landfilled material

Separately collected plant material is crushed to reduce its size for composting purposes. Size reduction of plant material is done by machinery, which reduces the material in to fine particles less than 50 mm. The quality of compost is graded according to its final use and contaminant content. According to the Compost Ordinance, FLG II Nr. 292/2001 the three different quality classes for compost based on the content of heavy metals are: Class A+ (top quality; limit values taken from Council Regulation); Class A (high quality; suitable for use in agriculture) for food production areas and Class B (minimum quality; suitable for non-agricultural use) for non-food areas. The compost quality is maintained by constantly determining presence of stones, pathogens, the C: N ratio, organic contaminants, weeds etc.

3.3 Summary of Chapter 2 and 3

From what was observed in England and Austria, separate waste collection enhances recycling and pretreatment of waste before landfilling. Despite the application of separate waste collection, there is always a residual amount of waste that is unsorted. Further separation by hand can be done in-house after initial separate collection from waste generators. Thermal pretreatment can be used in combination with aerobic pretreatment to cater for the unsorted residual waste. It is also possible to apply aerobic waste pretreatment at full-scale. Waste volumes that go to the landfill can be reduced significantly after waste pretreatment. With proper waste pretreatment, it is possible to reduce also the long-term emissions of landfills after closure. The period of emissions production after landfill closure is of major concern to landfill managers.

The generation of gaseous emissions from landfills goes through the stages of aerobic (I), anaerobic non-methanogenic (II), unsteady anaerobic methanogenic (III) and steady anaerobic methanogenic (IV) as stated by Farquhar and Rovers (1997). Stage (I) involves the production of organic acids from the hydrolysis of organic compounds and it is the limiting stage for the duration of gas production stages. Landfilling MBP waste can effectively reduce the limiting stage of biogas production. An after care period of 30 to 50 years, however, can be hardly achieved as stated by Kruempelbeck and Ehrig (1999).

Biogas production is of less concern during after care period, especially after degassing, however, the critical factor is the persistence of high levels of ammonical nitrogen. The biological activity and long term production of biogas by MBP waste can be determined by a standardized SAPROMAT test and gas production test, respectively (Cossu *et al*, 1999). Reduced volume and mass of landfilled material, improved waste placement density hence minimization of differential settlement are other benefits of MBP. Table 3.1 presents reported reduction of emissions after MBP.

Table 3.1 Reported reduction of emissions after MBP.

Country	Report	Author
Germany, Luuneburg	Respiration activity reduce by 95% to $5mgO_2/gDM$	Von Felde and Doedens (1997)
Germany	MBP can shorten landfill after-care of approximately 30 to 50 years	Horing *et al* (1999)
Austria, Loeben	Respiration activity reduced to 6.6 mgO_2/gTS and gas production reduced by 77%	Raninger *et al* (1999)
Brazil, Rio de Janeiro	COD, BOD_5, TOC, N_{TOTAL} in the leachate and gas production rate, were reduced to values < 90%	Münnich *et* al (2005)

CHAPTER 4

MATERIALS AND METHOD FOR WINDROW CONSTRUCTION

The purpose of the research was to study the kinetics of degradation of waste using test cells. The test cells were operated according to the PAF model (Cossu *et al*, 1999). The study objectives were:

- To asses the efficiency of the windrows in waste pretreatment using different periods of pretreatment, i.e 16 and 8 weeks.
- To compare the degradation properties of pretreated MSW, fines and global waste, with traditional landfilling of un-pretreated MSW.
- To study the efficiency of the pretreatment, aeration and flushing (PAF) model in the reduction of long-term emissions from MBP waste.

The efficiency of waste pretreatment was studied in aerobic windrows, constructed following the Dome Aeration Technology method (Mollekopt *et al*, 2002). General MSW was treated for 8 and 16 weeks in three windrows. In Austria aerobic pretreatment lasts for 14 to 22 weeks (Raninger *et al* ,1999); in Germany windrow digestion can last up to 6 months (Paar *et al*, 1999); and in a pilot study in Brazil decomposition took 6 to12 weeks in high-tech plants and 4 to 9 months in windrows Münnich *et* al (2005). The different aerobic treatment duration show the variability of the process. Process monitoring involved weekly testing of composting temperature, gas composition and gas flow for the duration of the treatment. Input and output material to the windrows was sampled and characterized using standard tests on solid and eluate form as outlined in section 4.3.3.

Prolonged pretreatment in passively aerated shallow landfills was simulated in 5 tests cells, filled with fresh untreated MSW, global (unsorted) samples of 8 and 16 weeks pretreated waste as well as their respective under sieved fractions, which were sieved through a 50 mm sieve. The kinetics of decomposition in the test cells were determined by monitoring gas composition, leachate quality and quantity. Biogas and respirometric tests of the "landfilled" pretreated waste were also conducted in laboratory scale. Tables 4.1 and 4.2 show the parameters measured during the monitoring of windrows and cells.

Table 4.1 Data collection table for windrows

Date	WINDROW NUMBER:										
	Dome No.	Temperature (^0C)				% Gas Composition			Pressure (mBar)		Gas Flow (m/s)
		Top	1 m	2 m	Bulk	CO_2	O_2	CH_4	Gas pressure	Ambient pressure	
	1										
	2										
	3										
	4										
	5										
	6										

Temperature was monitored at the brim of windrow chimneys, and at depths of 1 m, 2 m and within the compost mass. Percent volumetric gas composition was measured for carbon dioxide, oxygen and methane. Gas flow was measured at 1 m from the top of the windrow chimney

Table 4.2 Data collection table for test cells

Date	Cell No.	Gas Probe I.D	Gas Concentration % Vol			Pressure (mBar)	Temp. ^0C	Leachate (Litres)	Runoff (Litres)
			CH_4	CO_2	O_2				
		1							
		2							
		3							
		4							
		5							
		6							
		7							
		8							
		9							

Data gathered from the test cells included percent volumetric composition of methane, carbon dioxide and oxygen, temperature and the volume of leachate produced. Gas composition and temperature were monitored on gas probes as indicated on Figure 4.1.

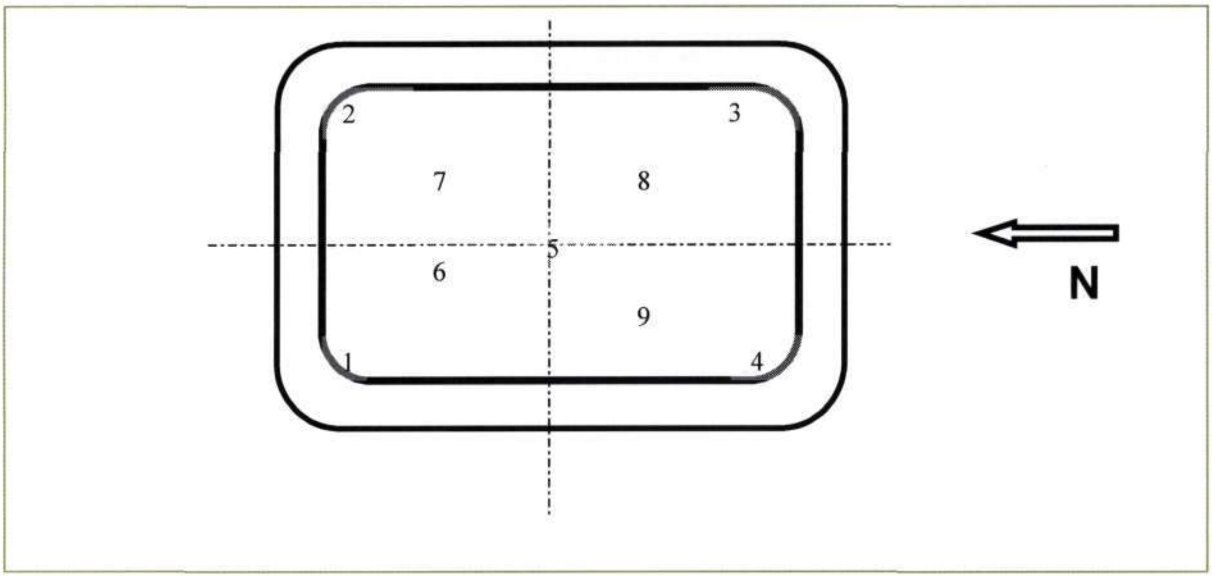

Figure 4.1 above shows the plan view of a test cell and the positioning of 9 gas probes

Chapters 4 and 6 give in detail the methodology and material used for windrows and test cells. The stages of the research comprised pretreatment of waste in windrows, which ran concurrently with the construction of the test cells. Input and output material of the windrows was characterized in the laboratory. The windrows' output material was used as input material to the test cells. The test cells were filled with unsorted non-pretreated waste, unsorted (global) sample of pretreated waste and under-sieved (fine) fractions. After carrying out infiltration rate test, the waste was irrigated and passively aerated and the waste composition monitored over a period of 8 months. Results were obtained from test cells and windrows and conclusions were made. A summary of the methodological approach followed for the study is presented in a flow chart, as shown in Figure 4.2.

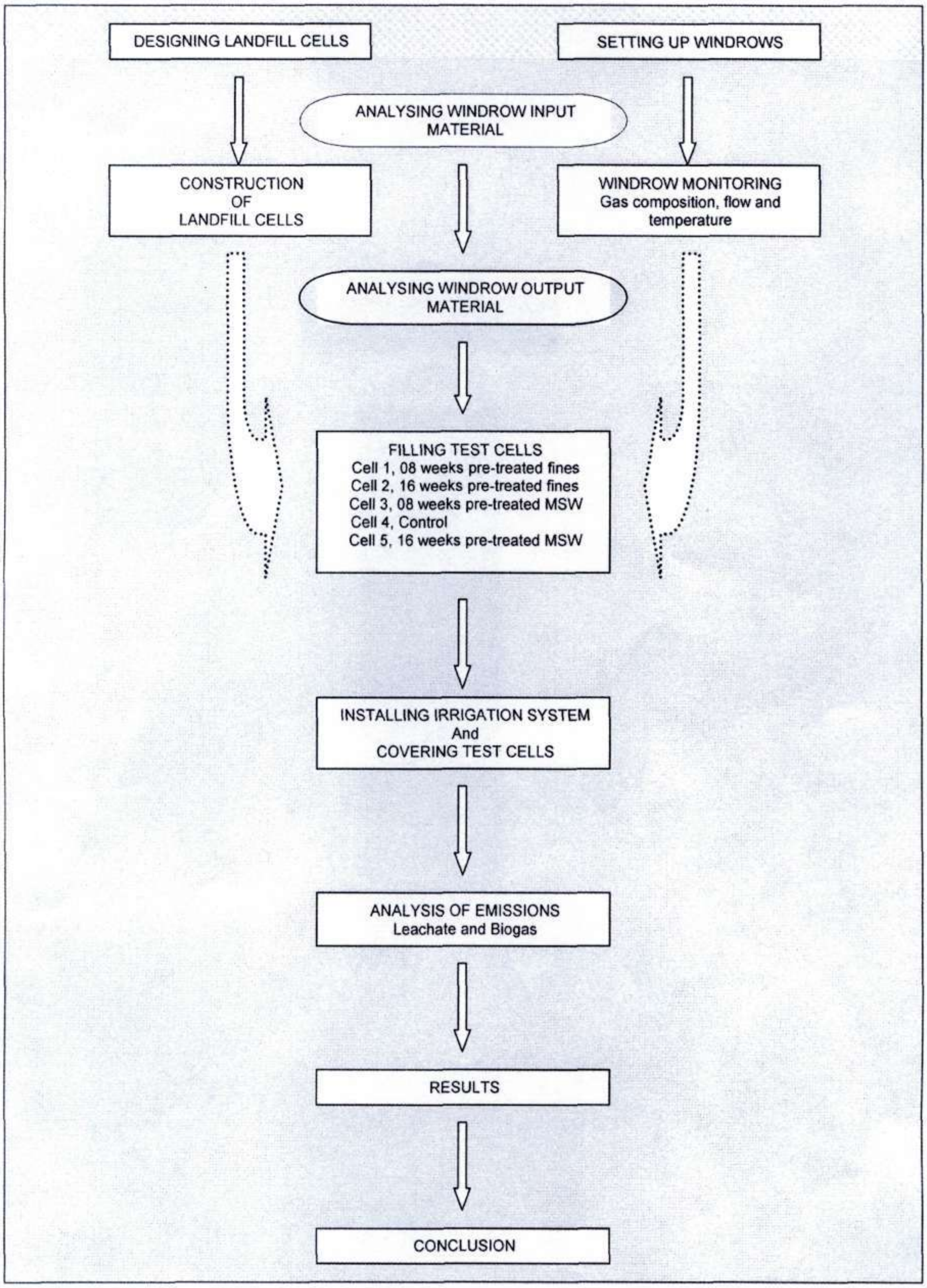

Figure 4.2 The methodological approach followed in this study

4.1 Windrow construction and monitoring

Three windrows were constructed at the Bisasar Road landfill site in Durban. Locally available machinery was used during construction. General municipal solid waste (MSW) and pine bark were treated, separately, in the windrows. The aerobic decomposition of waste in the windrows was monitored for periods of 8 and 16 weeks. A first set of two windrows was constructed at the beginning of April 2005 and dismantled at the end of July 2005, after a period of 16 weeks. The last windrow was constructed in mid September 2005 and dismantled in mid November 2005, after a period of 8 weeks. Consequently, the windrows were monitored under different prevailing climatic conditions, typical of winter and summer months.

4.1.1 Windrow construction

The procedure for windrow construction involved mixing, wetting, shredding, placement of mixed waste and covering of the windrow. Table 4.3 below presents dimensions and material composted in the three windrows.

Table 4.3 Windrow sizes

Windrow No.	Dimensions (L X B X H)	Domes No. Of	Waste Type	Dome Dimension (L X B X H)
1	30 m x 10 m x 2m	6	MSW	5m x 10m x 2m
2	15 m x 10 m x 2m	3	MSW / Pine bark	
3	25 m x 10 m x 2m	5	MSW	

Mixing of waste

The input material was typical municipal solid waste (MSW) that is disposed daily at the Bisasar landfill site from ROTOPRESS trucks, that were preferred to other general collection vehicles because they comminute the waste on route, delivering well mixed and partially shredded material. The MSW was mixed with structural material on a tipping truck (ADT) and loading on the truck was done with an excavator. Further mixing was performed when an ADT offloaded the mixture on to a prepared site.

Griffith (2005) recommended a mixing ratio of MSW: Structural Material of 2:1 because it is adaptable to Durban's environmental conditions and waste composition. The structural material portion provided air-spaces, enhanced aeration and gave structure to the compost pile and comprised of dry wood, mainly planks and garden refuse. Dry structural material was preferred to wet material because of its biological stability hence it would not contribute to the degradation of MSW.

Wetting and shredding

After mixing, the waste was spread on hard ground using an excavator and a water tanker moved on top of the waste spraying a known volume of water. The back and forth movement of the water tanker also enhanced shredding and further mixing. It is important to achieve the right moisture content during construction of the windrow because low contents of water can limit microbial activity. From experience in Germany, moisture content dropped from 55% to 35% in 180 days, without any intermediate addition of moisture (Paar *et al*, 1999). To achieve the recommended moisture content of 55%, 20 kℓ of water were added to 80 m^3 of waste assuming a Loose Bulk Density of 0.5 ton/m^3.

According to Münnich *et al* (2005) intensive and evenly distributed watering of the windrows is necessary in order to ensure adequate water content for biological processes during the summer months with high evaporation rates. To maintain the correct amount of moisture and avoiding desiccation, due to high temperatures and dry summer, Windrow 3 was irrigated. Irrigation scheduling was based on moisture content results and the trend of windrow temperature also revealed the intensity of biological processes. The irrigation was greatly influenced by prevailing ambient weather conditions, especially precipitation and evaporation. Volumes of 60 Kℓ and 40 Kℓ of water were sprayed on the five dome windrow only at day 35 and day 55 of composting, respectively. A 20 Kℓ water tanker was used to spray water on the windrow. A summary of materials for the 3 windrows is presented in Table 4.4.

Table 4.4 Summary of input material per dome of the three windrows

Windrow No.	Material	Mixing Ratio (MSW : SM)	Material Volume (M^3)	Water (M^3)
1	MSW + Structural Material (SM)	2:1	120	30
2	MSW + Structural Material (SM)	2:1	120	30
3	MSW + Structural Material (SM)	2:1	120	30

Placement and covering of waste

Wet waste was then placed on the site prepared for the windrow construction using a front-end loader. In order to avoid negative influence of local weather conditions, the windrows were covered with 0.5 m thick layer of pine bark using a front-end loader and manual labour. Probes were inserted in well and poorly ventilated areas of the windrow to measure gas composition and rotting temperature. Figure 4.3 and 4.4 show the plan view and cross section of a finished windrow.

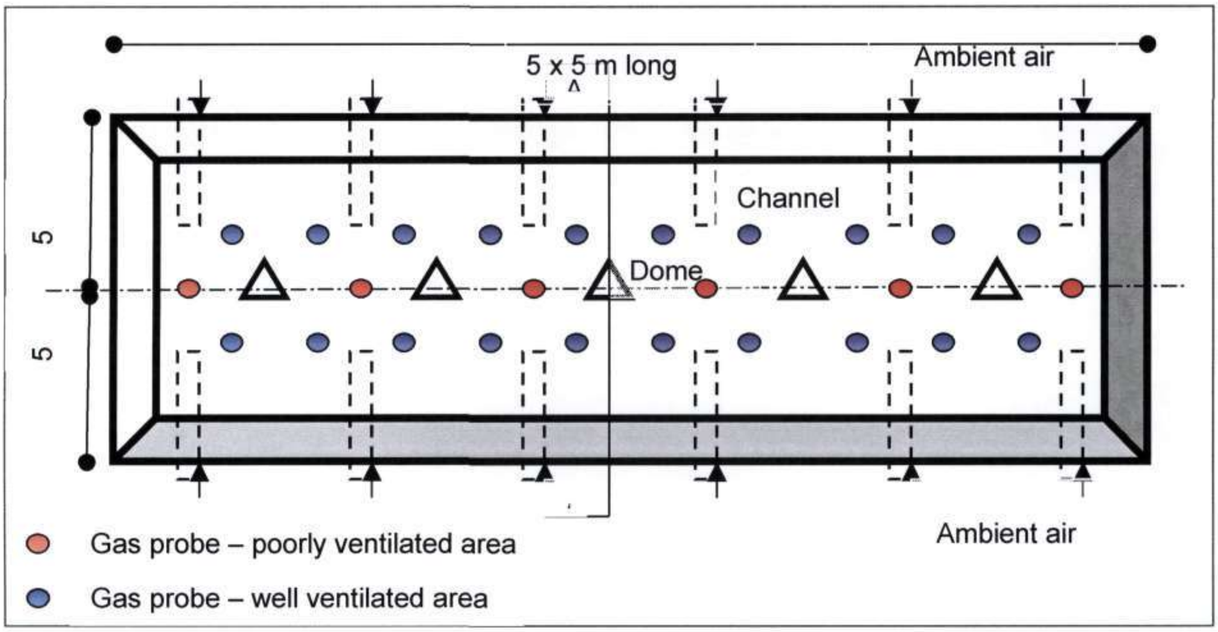

Figure 4.3 Plan view of a typical windrow

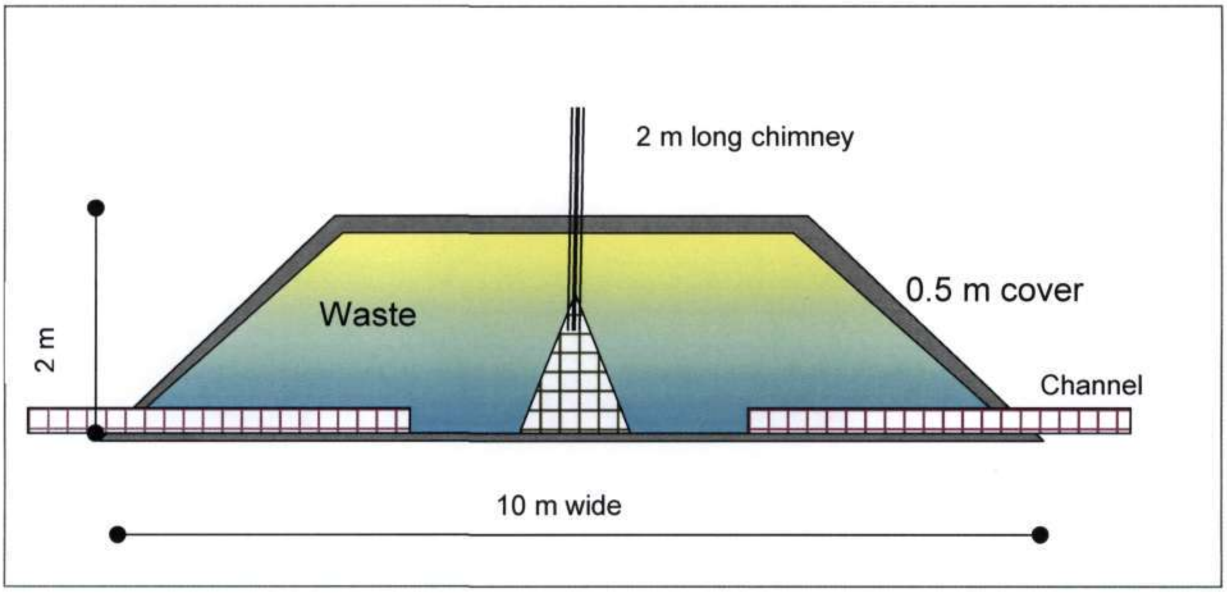

Figure 4.4 Cross sectional view of the typical windrow (section A-A)

Figure 4.5 to Figure 4.8 show the different steps of windrow construction. The construction process began from receiving waste from a ROTO-PRESS truck as seen on Figure 4.5. Figure 4.6 shows wetting and further mixing of structural material and MSW using a water tanker. Figure 4.7 shows the placing of the wet mixture, while the completed windrow is shown in Figure 4.8.

Figure 4.5 Receiving waste from Roto-press truck

Figure 4.6 Wetting and mixing waste using a water tanker

Figure 4.7 A front-end loader placing the wet mixture

Figure 4.8 A completed windrow

Table 4.5 presents a summary of activities carried-out during the windrows construction and the machinery used.

Table 4.5 Summary of windrow construction activities

Operational Steps	Machinery Used
Mixing	Excavator and a tipping truck (ADT)
Wetting	Water tanker
Placement of wet mixture	Front – end loader
Covering of windrow	Front – end loader / manual labour

With the suitable machinery and labour force (two general labourers supervised by the researcher), the rate of windrow construction was one dome a day. Fricke *et al* (2001) classifies investment and operational costs in Germany and in emerging nations and developing countries of MBP treatment plants into low-tech and high-tech methods. According to Paar *et al* (1999) DAT windrowing is a low cost technology. Low-tech plants are characterised by low degree of automitization, low expenditure for pollution control, low to high space requirement, low investment and operation costs and they require low to high personnel. The investment and operation costs for emerging nations and developing countries are 10 – 30 U$/t and 8 – 12 U$/t, respectively. For this research, investment costs were not considered, however, operational cost are estimated as shown in table 4.6 below.

Table 4.6 Operational cost for windrow construction during the research

Machinery / Labour	Operation Cost U$/H	Effective Hours Per Day	Amount Of Wastes (T/Day)	Operation Cost U$/Ton
Truck (ADT)	35	4	60	2,35
Front-end loader	45	1		0,75
20KL water tanker	30	2		1,00
Excavator	45	6		4,50
General labourers	2,5	8		0,35
TOTAL COST				8,95

4.2 Monitoring waste decomposition in the windrows

Temperature developed in the windrows, as gas temperature, was monitored in the chimneys and in the well ventilated and poorly ventilated areas using a Major Tech MT-630 thermometer. Figure 4.3 shows the location of the well and poorly ventilated areas. Within the chimney, the decomposition temperature was checked at the following depths: on the brim, 1m, 2m and at the centre of bulk material. Gas flow and gas composition were measured at a depth of 1m within the chimneys using an anemometer (Type GA94) and a gas analyzer and (Type GA2000).

Carbon dioxide, oxygen and methane percent compositions by volume were also monitored. During the first week of rotting, data was collected daily and there-after weekly for a maximum of 16 weeks. The high frequency of data collection during the first week was due to the expected rapid increase to the maximum of the rotting temperature as suggested by other investigations (Mollekopt *et al,* 2002). Exhaust temperatures in the starting phase of rotting reached less than 70^0C to 75^0C in Germany (Paar et al, 1999); whilst in Brazil 60^0C and 75^0C, were recorded (Mu¨nnich *et al*, 2005). Data collection was performed at the same time of the day to ensure data reliability.

4.3 Waste characterization

Representative samples were obtained from the field for waste characterization. Tests were performed on dry matter and eluate. The main purpose for testing was to assess the degree of stabilization of the waste, during composting.

4.3.1 Sampling Procedure

Bulk samples of waste were obtained by Stratified Random Sampling from the field (EPA530-D-02-002). Furthermore, a representative sample was obtained in the laboratory by homogenizing the waste (quartering) to be used for the eluate preparation. As required by the EU Landfill directives (EN 12457-1) eluate tests (leaching tests) on MBP waste must be conducted using a solid to liquid ratio of 1:10. However, member states of the EU can prescribe their preferred solid to liquid ratios. In this dissertation the two liquid to solid ratios were used and compared. Section 4.3.3 presents, in detail the eluate tests.

4.3.2 Dry matter tests

These are tests performed on dry matter and aimed at obtaining data on moisture content, volatile solids and waste stability. To obtain the moisture contents, a sample of known mass was oven-dried for 24 hours at a temperature of 105 ^{0}C. Oven-dry material was further incinerated at 550 ^{0}C in order to determine the volatile solids.

Respiration Index Test

The test was performed in order to measure the activity or the degree of stabilization of readily biodegradable fraction in the waste. The test is usually performed using a SAPROMAT test for a period of 4 to 10 days. According to Von Felde and Doedens (1997) an observation period of 4 days with the sapromat is not sufficient to fully describe the waste activity. Binner *et al* (1997) found that the standard deviation of results reduces with an increase in the duration of the testing period with better results obtained in 7 to 10 days. A broader deviation may be attributed to longer lag periods for oxygen consumption. Binner *et al* (1999) mention that lag-phases are caused by toxic compounds that decrease over time so that in 7 days this influence is negligible. Mechanical processing of waste, size reduction and wetting, increase waste activity. Binner *et al* (1997) recommend particle size of 20 mm with 50% moisture content and a wet mass of 40 g. If the waste characteristics are not well known, triplicates observed over 10 days are recommended but with a well known sample duplicates can be used (Binner *et al* ,1999).

The sapromat method can be viewed in the Operating Manual Sapromat, (hp-lab, 2006). A sample is agitated in a vessel to allow penetration of a required amount of oxygen. Microbial metabolic processes liberate carbon dioxide which is absorbed by sodium hydroxide creating a partial vacuum. The partial vacuum activates the production of oxygen from electrolyses of copper sulphate. A control unit then calculates the BOD from the sample in mg/ℓ.

Due to unavailability of a Sapromat a different method to measure biological stability of waste, using BOD bottles, was used for this research. The BOD method is based on the principle that microorganisms feed on the organic compounds contained in a waste sample in the presence of oxygen hence the compounds are biochemically oxidized. A complete breakdown of organic compounds releases carbon dioxide. The carbon dioxide is removed from the gas phase by the use of potassium hydroxide, resulting in a pressure drop. BOD sensors are used to measure the proportional amount of oxygen consumed in mg/ℓ.

The major difference between the traditional SAPROMAT method and the method adopted for this research is the mode of oxygen supply. With the SAPROMAT, oxygen supply is stimulated by microbial activity and with electrolysis of copper sulphate, the exact required amount of oxygen is liberated. With the method adopted for this research, there is free oxygen which is available for microbial activity and the amount of oxygen used is based on demand by micro-organisms rather than a supply responding to the need of oxygen. Figure 4.9 shows a picture of the experiment set-up when conducting the respiration index test.

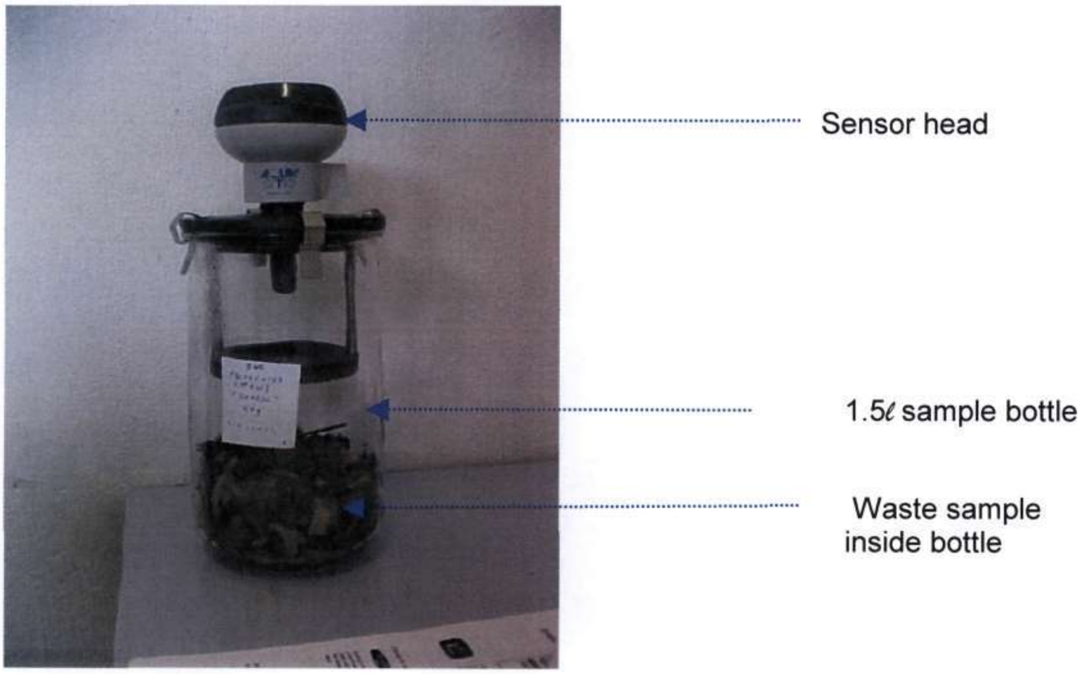

Figure 4.9 Experiment set-up for respiration index test

Trials were conducted to determine a proper sample size, moisture content, availability of oxygen and duration of test using waste samples of 10 g, 20 g and 50 g (Xulu, 2005 and Motsoane, 2006). Actual field moisture capacity and theoretical field moisture capacities (FMC) were used in order to find the optimum moisture content to perform the test. The FMC was established by putting a known mass of a waste sample on a funnel. Water was gradually added until it dripped through the waste mass in to a collecting vessel below. At the point of dripping, it was assumed that samples could no longer hold water against the force of gravity hence FMC was reached. FMC ranged from 45% to 55% moisture and it was dependent on waste composition and pre-treatment period. The moist samples were then kept in a digester at 20^0C for 4 to 7 days. A nitrification suppressant, thiourea, was used to exclude oxygen demand for nitrification. Results were obtained as BOD in mgO_2/ℓ and reported as mgO_2/gDM (milligrams oxygen per gram dry matter). After trial tests, the 20 g sample at FMC was considered an appropriate sample size (Xulu, 2005 and Motsoane, 2006).

Biogas Production (Fermentation / Incubation) Test

The test describes the effects of mechanical-biological pretreatment of waste and it allows the estimation of gas production under anaerobic conditions (Scheelhaase and Bidlingmaier, 1997). In Germany, a 1.5 kg of waste with particle size of 20 mm wetted to field capacity is incubated. Within 21 days 10 to 60 percent of potential gas production is obtained (Binner *et al*, 1999). The reactivity rate of the waste depends on the substrate type. The minimum observed time should be 90 days but tests can be terminated when the cumulative gas production graph reaches equilibrium showing a plateau. Daily amount of gas production and gas quality are measured and gas analysis done at an interval of 1 to 3 weeks (Binner *et al*, 1999).

Waste at field moisture capacity (FMC) was incubated under anaerobic conditions for at least 21 days. Incubation temperature was kept at 30^0C by means of a warm bath with a temperature control unit. Daily gas production was measured by liquid displacement method. A mixture of 1l H_2O, 30 ml H_2SO_4 and 20 g NaCl was used as displacement liquid. Water, sulphuric acid and sodium chloride served as solvent, inhibitor of carbon dioxide dissolution and inhibitor of methane dissolution, respectively. Methyl orange was added to the solution for legibility purpose.

The incubator was connected to the solution reservoir and to a measuring cylinder by a 5 mm diameter flexible pipe. The quantity of liquid displaced was read in mm. The influence of pressure build-up between the reservoir and the measuring cylinder was avoided by leveling the liquid heights, by adjusting the vertical position of the measuring cylinder, before taking results, hence maintaining an atmospheric pressure. Gas composition analysis was conducted every 1 to 3 weeks by measuring the percent composition of methane and carbon dioxide using a gas analyzer (Type GA2000). These tests were conducted together with Motsoane (2006).

Figure 4.10 shows a picture of the experiment set-up when conducting the biogas production test.

Figure 4.10 Experiment set-up for biogas production test

4.3.3 Eluate tests (UNI 10802)

The eluate test gives a proportional amount of organic compounds, solids and minerals that can be extracted or leached from the solid phase of waste into solution. Distilled water is used as a solvent. With the eluate test the estimation of available organic matter that can be emitted as leachate or gas can done by determining COD, BOD, volatile solids, total solids and nitrogen. By establishing the pH value of the eluate it is possible to confirm the stage of anaerobic degradation of waste. According to the *Norma Nazionale Italiana Metodo* UNI 10802 (Ottobre 2004) the mass ratio of Liquid/Solid ratio is 10:1.Eluate was prepared by mixing solid waste and distilled water at a liquid : solid ratios of 10:1 and 100:1. The mixtures were stirred for periods of 24 hours and 72 hours. Comparisons of eluates obtained from the different solid to liquid ratios and stirring periods were performed. The actual establishment of the eluate characteristics was done according to the American Public Health Association, APHA-methods (Clesceri *et al*, 1989).

COD (APHA method 5220)

The Chemical Oxygen Demand test gives the amount of oxygen consumed during the chemical oxidation of organic substances using a strong oxidant, potassium dichromate ($K_2Cr_2O_7$).COD is important because it gives an estimate of the initial organic content of waste, useful in the modeling of mass balances during the process of waste degradation and is also used as a leachate quality parameter. A sample is oxidized with a known excess amount of $K_2Cr_2O_7$. After oxidation the $K_2Cr_2O_7$ is titrated with ferrous ammonium sulfate to determine the amount of $K_2Cr_2O_7$ consumed and expressed in terms of its oxygen equivalence.

BOD_5 (APHA method 5210)

Biological Oxygen Demand is the measure of dissolved oxygen used by micro-organisms in the biochemical oxidation of organic substances. BOD_5 gives the content of easily degradable organic compounds and is used as leachate discharge quality. The procedure is based on the principle that available organic compounds contained in a water sample are oxidized to carbon dioxide by microorganisms (bacteria, fungus, arachaea and protozoa). The oxygen that is converted to carbon dioxide is removed from the gas phase of the sample by the use of potassium hydroxide, hence a drop in pressure occurs within the reactor. A BOD sensor is used to measure the pressure drop thus giving the proportional amount of oxygen that can be consumed.

Conductivity(APHA method 2510) and pH

Conductivity measures the ability of an aqueous solution to carry an electric current. The conductivity depends on the presence, concentration, mobility, temperature and valence of ions. The test was carried at a temperature of 20^0C. The results are measured in ohms. The conductivity was measured using a Corning Checkmate II sensor. There is a positive correlation between conductivity and the content of total solids. The value of pH gives the concentration of hydrogen ions in a solution. pH is related to the stage of anaerobic degradation of waste and microbial processes (Andreottola and Cannas, 1999). The pH in leachate was measured using an electronic meter Orion LABTEC model 410A.

Ammonia and NOx(SABS method 217: 1990)

Naturally nitrogen exists as organic nitrogen contained in proteins found in a waste sample. With exposure to an aerobic environment, organic nitrogen metamorphosis to ammonia and finally nitrates, depending on the age of the sample. Ammonia and NOx test gives the content of nitrogen in the form of ammonia and nitrites/nitrates dissolved in eluate or leachate. A 50ml sample of eluate/leachate was distilled under mildly alkaline conditions and a distillate of 250ml was collected in boric acid solution. The distiller is run for plus or minus 10 minutes to collect a 250ml distillate. Under alkaline conditions and continuous removal of ammonia by distillation, ammonia is converted to ammonium.

After titrating the ammonia in the boric acid distillate using a standard acid (HCl) solution, the ammonical nitrogen was determined. After the removal of ammoniacal nitrogen by distillation under alkaline conditions, the nitrate and nitrite were determined by reducing the sample with Devardas Alloy. Following, there is a quantitative conversion of nitrates and nitrites to ammonia that is distilled over with the distillate into boric acid. After titration with a HCl, the content of NOx is determined.

Total Solids (TS) and Volatile Solids (VS) (APHA method 2540)

Total solids refer to the solid fraction of a waste sample after the removal of available water in an oven. Total solids includes total dissolved solids and total suspended solids. Incinerating total solids gives a residue of non-volatilable solids hence volatile solids content can be determined.

Total Solids - A well mixed sample of 25 ml and a well dried crucible dish of known weight were oven dried overnight at a temperature of 105 ^{0}C. After which a weight increase was obtained which represents the total solids.

Volatile Solids- After obtaining total solids, oven-dried material was further incinerated at 550 ^{0}C in order to determine volatile solids content. Volatile content solids is used as a parameter for waste stabilization in European Union and allows estimation of biomass content.

For typical values of COD, BOD_5, pH, conductivity, ammonia, NOx, Total Solids and Volatile Solids after pretreatment refer to Section 2.5

4.4 Precision, accuracy and summary statistics

In order to verify precision and bias of the results, laboratory experiments were performed in duplicates, triplicates or more. The number of samples tested was limited by the cost of carrying out the experiment, particularly for tests as TKN and TOC that were carried out by external laboratories. Standard deviation, range, variance and coefficient of variation were computed to summarize data and determine precision.

4.4.1 Calculating standard deviation, range, variance and coefficient of variation

Standard deviation was calculated to measure the variability and dispersion of data. The standard deviation gives the root mean square deviation of values from their arithmetic mean in the same units as the data. Whereas variance gives variability and data dispersion as a squared deviation from the mean. Equations 4.1 and 4.2 give the formulas used for calculating standard deviation and variance, respectively (Moolman, 2002).

$$S_D = \sqrt{\frac{\Sigma(X-M)^2}{n-1}} \qquad (4.1)$$

Where

S_D = standard deviation

X = observed value

M = arithmetic mean

n = sample size

$$S = \frac{\Sigma(X-M)^2}{n-1} \qquad (4.2)$$

Where

S = variance

X = observed value

M = arithmetic mean

n = sample size

The ratio of the standard deviation to the arithmetic mean was calculated. The ratio gives the coefficient of variation which was expressed as a percent to measure the overall percent dispersion of data from the mean. Equation 4.3 gives the formula for determining the coefficient of variation (Moolman, 2002).

$$C = \frac{S_D}{M} \times 100 \qquad (4.3)$$

Where

C = coefficient of variation

S_D = standard deviation

M = arithmetic mean

The range was used to calculate the extent of data spread by computing the difference between the largest value and the smallest value. Equation 4.4 shows the formula used for calculating the range.

Range = largest value – smallest value (4.4)

The accuracy tests were done for BOD_5, COD, total solids, volatile solids, moisture content, N-NH_3 and N-NOx. In chapter 5 (windrow results) and chapter 7 (test cells results) the results are reported with their respective standard deviation, variance, range and coefficient of variation.

COD

The COD test was performed from a multiple analysis on standard solutions and blanks of known COD values and on eluate and leachate samples of unknown COD values. For the unknown samples, an expected value of COD was estimated in order to determine the sample size. The COD test was conducted according to the APHA method 5220 as outlined in Section 4.3.3 tests on eluate. From experimentation by Clesceri *et al* (1989), the precision control for COD gave a standard deviation and coefficient of variation of 17 to 20 and 8.7 to 9.6 percent, respectively.

BOD_5

The ranges of measurement of BOD were selected to ensure that expected results fall within the upper half of the scale. The BOD test was done according to the APHA method 5210, for reference see section 4.3.3 tests on eluate. Generally, the BOD results were dispersed, and the dispersion may be due to the heterogeneity of the waste. According to Clesceri *et al* (1989) when using the APHA 5210 method precision and bias control of BOD_5 gave a standard deviation of 30.5 mgO_2/ℓ and BOD tests can have extreme variability.

N-NH_3 and N-NOx,

N-NH_3 and N-NOx were determined according to the SABS method 217:1990. There were no reported results for bias and precision control for N-NH_3 and N-NOx.

Moisture content, total solids and volatile solids

Experiments were carried out following the APHA method 2540. According to an accuracy control done by Clesceri *et al* (1989), the standard deviation for total solids was 6.0 mg/ℓ.

CHAPTER 5

RESULTS AND DISCUSSION OF WINDROW PROCESSES

In order to assess the efficiency of the aerobic treatment using the DAT, data on temperature, gas velocity and gas composition, particularly percent composition by volume of CO_2, O_2 and CH_4 were obtained throughout the composting period. The frequency of data acquisition was dependent on the age of the decomposition. Results were obtained daily during the first week of aerobic treatment and weekly thereafter.

5.1 Windrow results on temperature, gas flow and percent gas composition

Windrow 1

Figures 5.1 up to 5.8 show results on temperature, gas velocity for windrow 1 obtained from the domes. Accompanying the figures are data on the maximum temperature, minimum temperature and the days on which the temperatures were recorded. A summary of the general trend in temperature is also given by average temperatures obtained from probes located in poorly and well aerated zones of the windrow.

Figure 5.1 shows the results of temperature and gas velocity obtained for dome 1 in windrow 1.

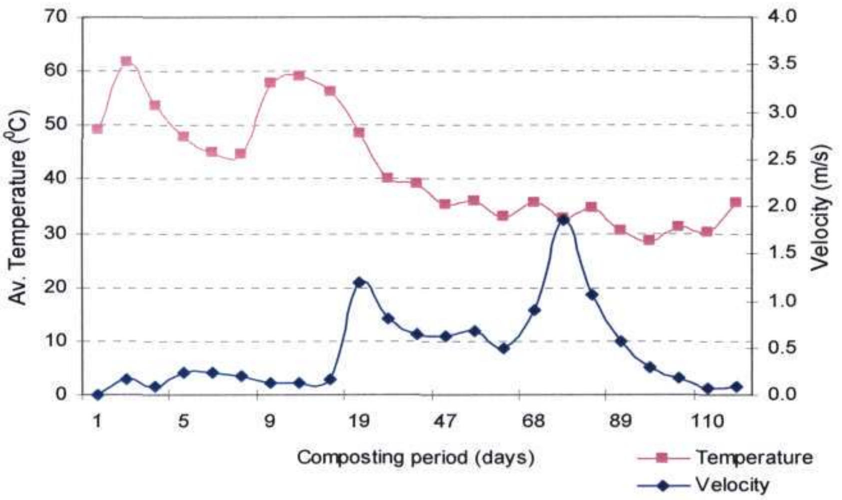

Figure 5.1 Gas temperature and gas velocity for 16 weeks for dome1 windrow1

Maximum and minimum temperatures were 61.5 ^0C and 30.3 ^0C on day 2 and day 112, respectively. Initially, gas velocity increased with the composting period and reduced towards the end of the process.

Figure 5.2 shows the trend of temperature and gas velocity from dome 2 in windrow 1.

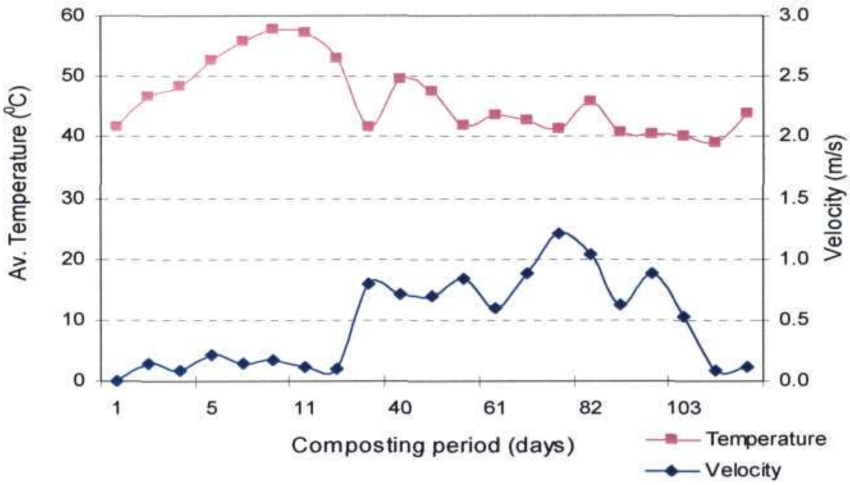

Figure 5.2 Gas temperature and gas velocity for 16 weeks for dome 2 windrow 1

The maximum and minimum temperatures of 57.9 ^{0}C and 39.0 ^{0}C occurred on day 10 and day 112, respectively. The gas velocity is bell-shaped reaching maximum after 75 days of composting but gradually reducing with the age of composting as temperature reduces.

From Figure 5.3 the evolution temperature and gas velocity with time for dome 3 in windrow 1 are presented.

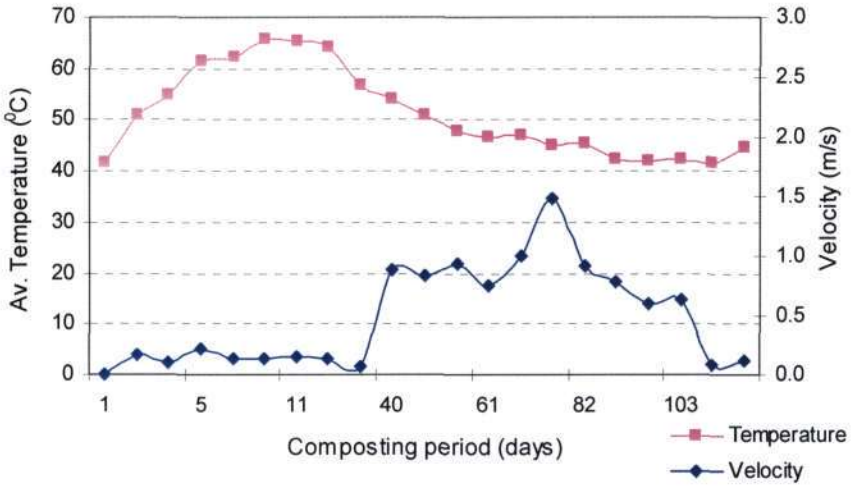

Figure 5.3 Gas temperature and gas velocity for 16 weeks for dome 3 windrow 1

The maximum and minimum temperatures of 65.8^{0}C and 41.5 ^{0}C were obtained on day 10 and day 105, respectively. Gas velocity was low at the extreme ends of composting and peaking after 75 days of composting. Velocity increased as temperature decreased as noted for each dome.

The trends of temperature and gas velocity for dome 4 in windrow 1 are presented in Figure 5.4.

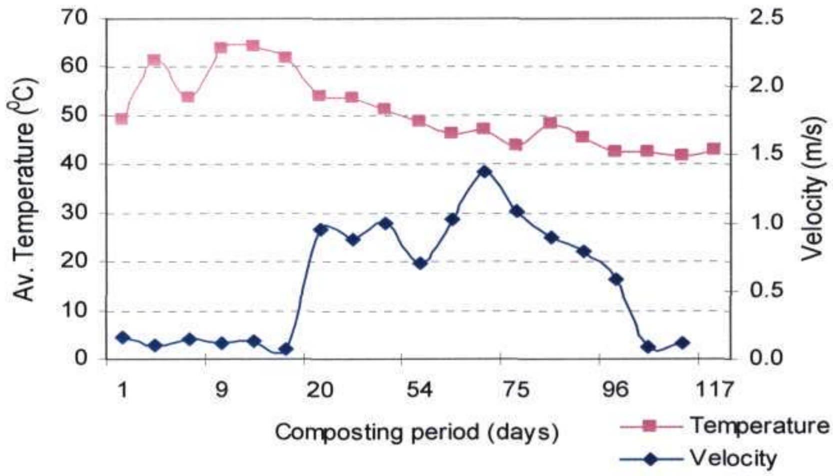

Figure 5.4 Gas temperature and gas velocity for 16 weeks for dome 4 windrow 1

The maximum and minimum temperatures of 64.5°C and 41.7 °C were obtained on day 10 and day 115, respectively. Gas velocity gradually increased with the age of composting and declined at the end of composting. The Peak gas velocity was obtained after 10 weeks of composting.

Figure 5.5 shows the changes in temperature and gas velocity in time for dome 5 in windrow 1.

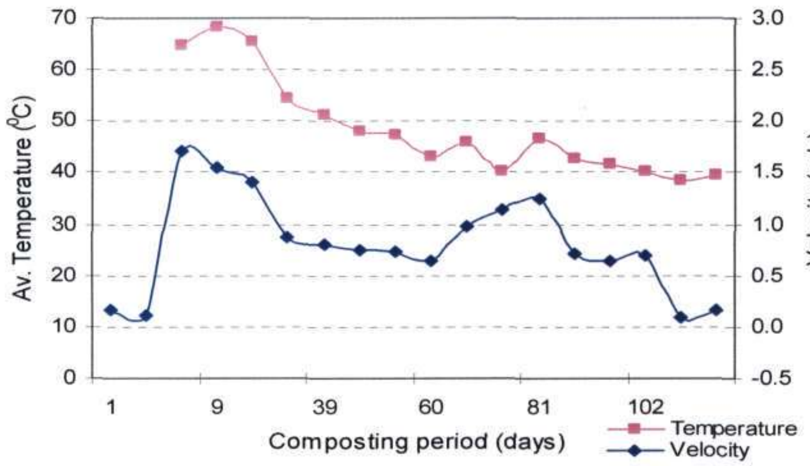

Figure 5.5 Gas temperature and gas velocity for 16 weeks for in dome 5 windrow 1

Maximum and minimum temperatures were 68.4 °C and 38.3 °C recorded on day 9 and day 115, respectively. The highest gas velocity occurred during the initial heating stage and generally reduced with the composting age. On day 81 the gas velocity increased with an increase in dome temperature. Dome 5 constitutes an anomaly with respect to gas velocity, whereby a constant high velocity is detected during the composting process.

From Figure 5.6 the evolution of temperature and gas velocity for dome 6 in windrow 1 is shown.

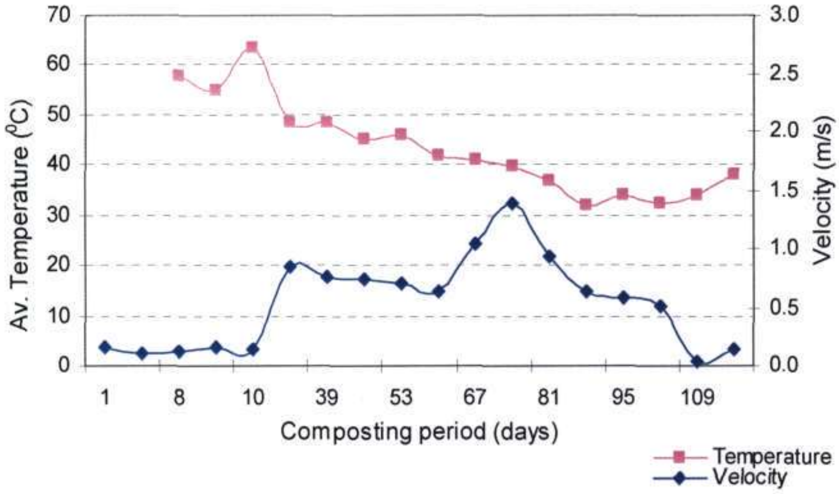

Figure 5.6 Gas temperature and gas velocity for 16 weeks for dome 6 windrow 1

Maximum and minimum temperatures of 63.5 ^{0}C and 39.0 ^{0}C occurred in day 10 and day 115, respectively. The gas velocity increased gradually with the age of composting but was low initially and at the end of composting.

A summary of the mean temperature and gas velocity, obtained from the domes for windrow 1, is shown in Figure 5.7. Figure 5.8 shows a summary of temperature changes in time that were recorded from the probes.

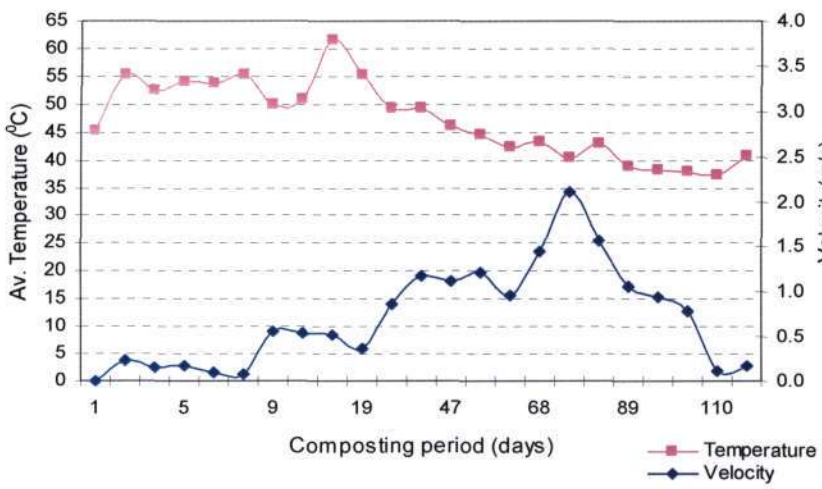

Figure 5.7 Mean dome gas temperature and gas velocity for windrow 1

The average maximum and minimum temperature for windrow 1 were 63.6 ^{0}C and 37.5 ^{0}C, respectively. Again, it is evident that at any decrease in temperature corresponds a relative increase in gas velocity from the exhaust pipes. The velocity decreases when the process slows down (day 100).

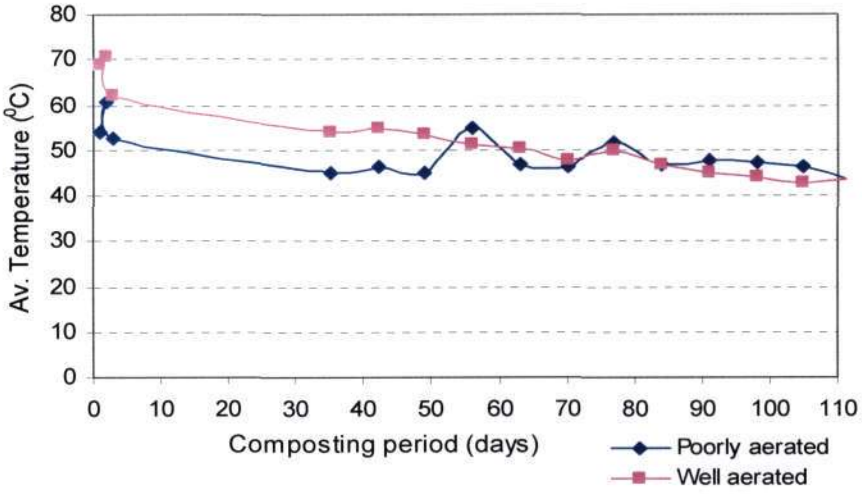

Figure 5.8 Mean probe gas temperature for 16 weeks in windrow 1

Maximum and minimum temperatures recorded in the well aerated area are 70.5 ^{0}C (day 3) and 43.5 ^{0}C (day 115), respectively. Maximum and minimum temperatures recorded in the poorly aerated area were 60.9 ^{0}C (day 3) and 43.3 ^{0}C (day 115), respectively. Clearly there were no marked differences in temperature obtained from poorly and well aerated areas, especially after day 50 suggesting that all areas in the windrow were ventilated equally (see Figure 4.3 and Figure 2.7 for the location of poorly and well ventilated areas). From the domes and probes results it can be observed that the composting process developed as expected with high temperature material stage followed by lower temperature around of 40^{0}C. Out of the total 6 domes, 4 recorded the peak temperature around day 10. Only 2 domes reached peak temperature on day 2 probably attributed to a concentration of readily degradable material and good supply of oxygen.

Windrow 2

The second windrow was made of one dome of MSW. The results of temperature and gas flow are shown in Figure 5.9. Figure 5.10 shows the average probe temperature located in poorly and well aerated areas. Accompanying the temperature results are the days on which the minimum and maximum temperatures were recorded.

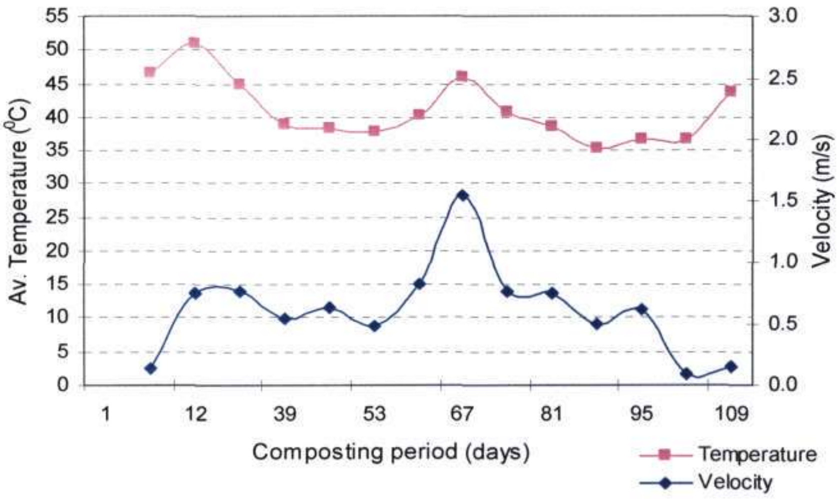

Figure 5.9 Gas temperature and gas velocity for 16 weeks for windrow 2

Maximum and minimum temperatures recorded for windrow 2 were 51.0 ^{0}C (day 12) and 36.6 ^{0}C (day 110), respectively. Windrow 2 did not reach sanitation temperatures (70 – 75^{0}C). The temperature ranged around 40^{0}C throughout the trials. Like in windrow 1, gas velocity increased with temperature decrease.

Figure 5.10 Average temperatures recorded in poorly and well-aerated areas of windrow 2.

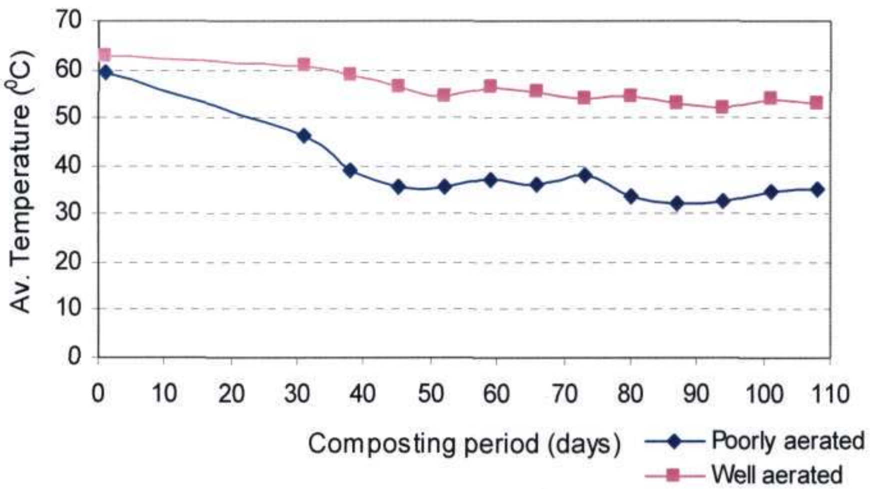

Figure 5.10 Gas temperature for 16 weeks in probes for windrow 2

Maximum and minimum temperatures recorded in well aerated area are 62.8 ^{0}C (day 1) and 54.2 ^{0}C (day 109), respectively. Maximum and minimum temperatures recorded in poorly aerated area are 59.3 ^{0}C (day 1) and 34.3 ^{0}C (day 109), respectively. From the results of the probes, the mean gas temperature from poorly aerated areas was always lower than well-aerated areas to suggest that windrow 2 was not uniformly aerated as windrow 1.

Windrow 3

The results of windrow 3 are shown from Figure 5.11 to 5.16. The results show gas velocity, mean gas temperature and percent gas composition of oxygen and carbon dioxide obtained from the domes. The days on which key temperatures were recorded are shown, i.e maximum and minimum temperature. The ranges of percent gas composition are highlighted.

Figure 5.11 shows the changes in gas composition, gas velocity and gas temperature for dome 1 in windrow 3.

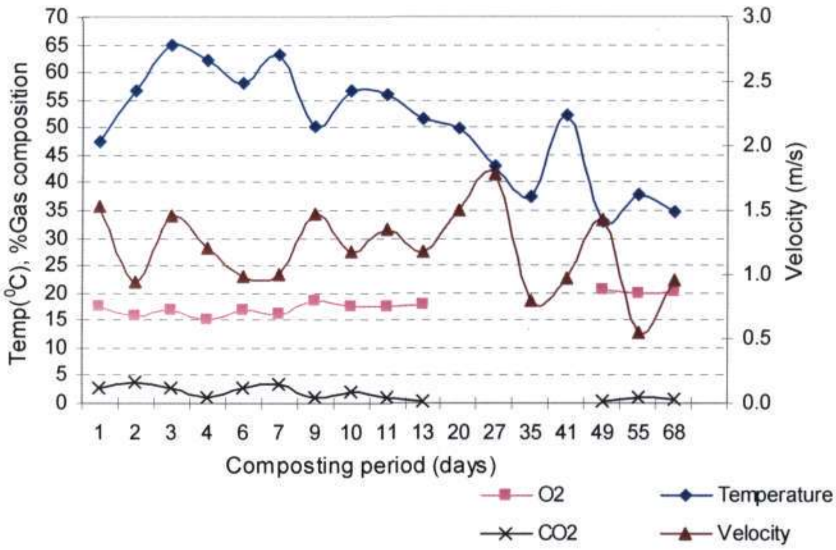

Figure 5.11 Gas temperature, gas velocity and percent gas composition (Vol/Vol Air) recorded during 8 weeks in dome 1 windrow 3

The maximum and minimum temperatures of 65.0 ^{0}C and 32.9 ^{0}C occurred on day 3 and day 68, respectively. Percent ranges of O_2 and CO_2 were 15.1 to 20.7 and 0.4 to 3.9, respectively. It may be concluded that the dome was aerobic throughout the composting period. Gas velocity kept fluctuates between 0.5 and 1.8 m/s. The high oxygen concentration and high gas velocity may justify the absence of a clear plateau in the temperature during the intense composting phase.

Figure 5.12 presents gas temperature, gas composition and gas velocity for dome 2 in windrow 3

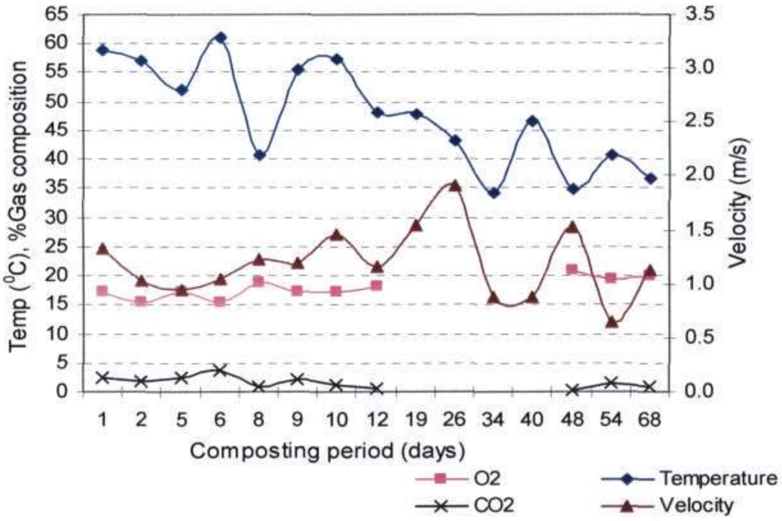

Figure 5.12 Gas temperature, gas velocity and percent gas composition (Vol/Vol Air) recorded during 8 weeks in dome 2 windrow 3

The maximum and minimum temperatures were 61.0 ^{0}C *and* 35.8 ^{0}C *recorded on day* 6 *and day* 68, respectively. The percent ranges of O_2 and CO_2 were 15.4 to 20.8 and 0.4 to 3.7, respectively. The oxygen supply is again higher than optimum (10%), so to induce a rapid decrease in temperature within the waste body, that never reached sanitation levels.

Figure 5.13 shows gas temperature, gas composition and gas velocity in dome 3 in windrow 3

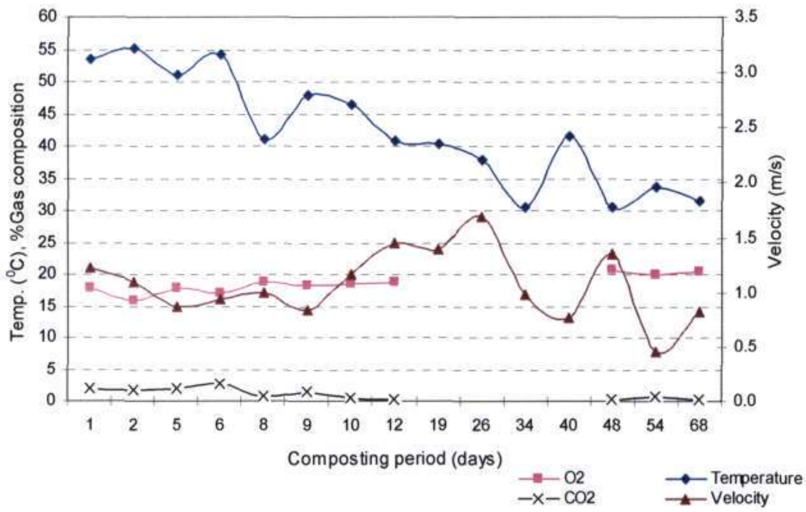

Figure 5.13 Gas temperature, gas velocity and percent gas composition recorded during 8 weeks in dome 3 windrow 3

Maximum and maximum temperatures of 55.2 ^{0}C and 31.4 ^{0}C occurred on day 2 and day 68, respectively. Percent ranges of O_2 and CO_2 were 15.9 to 20.8 and 0.3 to 2.6, respectively. The dome was therefore fully aerobic throughout the composting period. The same trend noted for dome 1 and 2 is evident for dome 3.

Figure 5.14 presents gas temperature and gas composition and gas velocity for dome 4 in windrow 3.

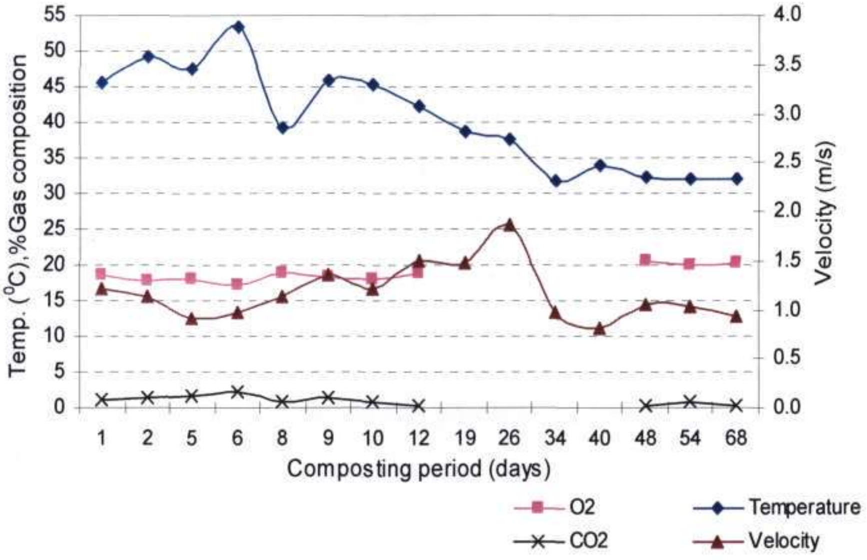

Figure 5.14 Gas temperature, gas velocity and percent gas composition (Vol/Vol Air) recorded during 8 weeks in dome 4 windrow 3

The maximum and minimum temperatures of 53.3 ^{0}C and 31.7 ^{0}C were recorded on day 6 and day 68, respectively. Percent ranges of O_2 and CO_2 were 17.3 to 20.6 and 0.4 to 2.3, respectively. The dome was fully aerobic and gas velocity reduced with the age of composting as noted for previous domes.

A mean maximum temperature of 56.5 ^{0}C, is reached in 6 days. The mean minimum temperature was 33.3 ^{0}C obtained at the end of the 8 weeks composting. The ranges for percent O_2 and CO_2 range were 17.3 - 20.6 and 0.4 - 3.9, respectively. Hence the windrow remained aerobic through out the composting period, but the high gas velocity and oxygen levels prevented the waste body to reach sanitation temperatures.

Analysis of weather influence on windrow processes

In order to understand the influence of irrigation (moisture addition) on gas temperature Figure 5.17 shows the gas temperature change observed in gas probes after irrigation. The gas temperature results were obtained from the probes located in well aerated and poorly aerated areas (see Figure 4.3 for the location of gas probes). Figure 5.18 shows how ambient wind velocity influenced gas velocity from domes, but the high gas velocity and oxygen levels prevented the waste body to reach sanitation temperatures.

Figure 5.17 below shows the change in temperature after moisture addition by irrigation.

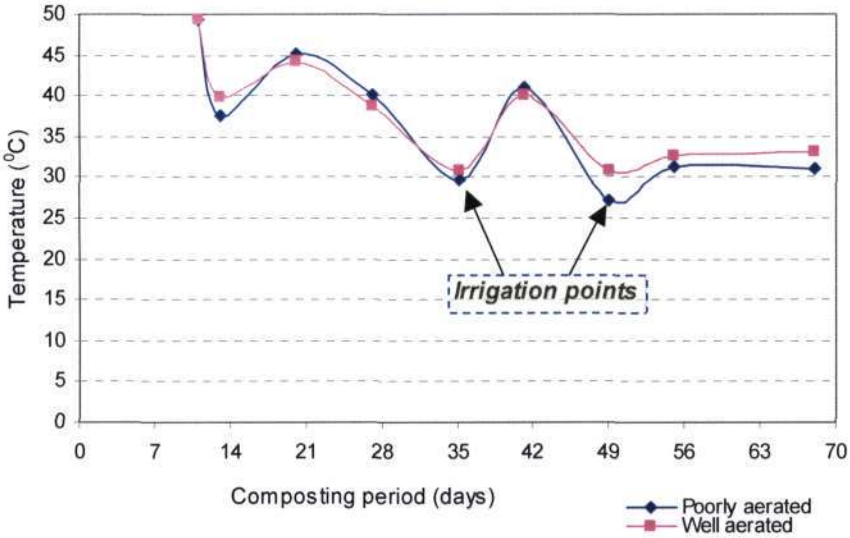

Figure 5.17 Probes temperature recorded during 8 weeks for windrow 3

Maximum and minimum temperatures recorded on well aerated area were 49.2 ^{0}C and 32.7 ^{0}C, respectively. Maximum and minimum temperatures recorded in poorly aerated area were 49.2 ^{0}C and 31.3 ^{0}C, respectively. From Figure 5.17 it can be observed that there was no remarkable difference between well aerated and poorly aerated areas hence the whole windrow was equally aerated.

Following windrow irrigation with 60 m^3 of water , on day 35, temperature rose by 9.4^{0}C within 7 days. A second irrigation with 40 m^3 of water was performed on day 55 and the windrow temperature increased by 6.0^0C within a week after irrigation. It may be inferred that adding moisture content improves the microbial activity during decomposition. There was no remarkable difference between temperature in well-aerated and poorly aerated areas.

Figure 5.18 presents the relationship between gas flow and ambient wind velocity.

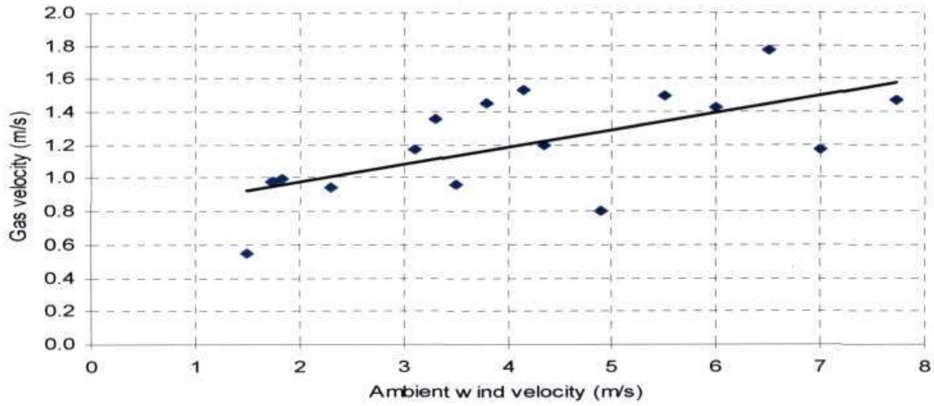

Figure 5.18 Average gas velocity for windrow 3 versus ambient gas flow

There is a linear relationship between gas velocity in the dome and ambient wind velocity. Gas velocity increases with every unit increase in ambient wind velocity due to the suction effect on the domes. This is important because it justifies the high levels of air in the waste body, that maintained the temperature down throughout the rotting process. A similar trend has been detected by other researchers (Trois and Polster, 2007 and Trois *et al,* 2005)

Figure 5.19 presents the linear relationship between ambient and dome temperature difference with ambient temperature.

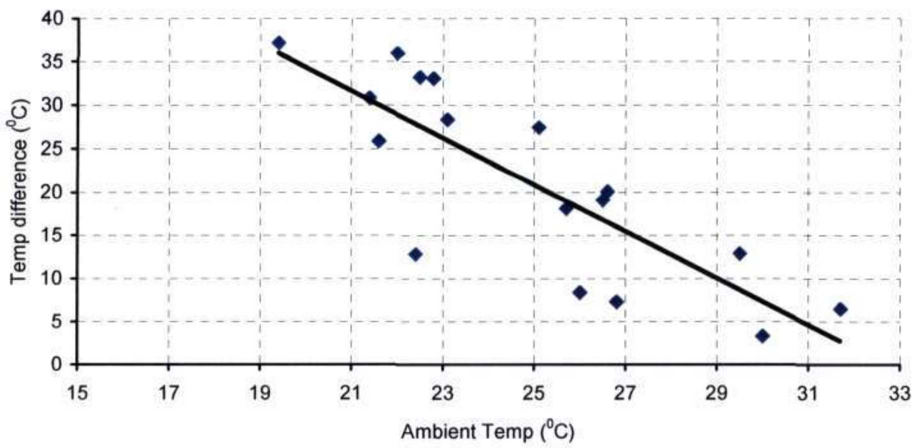

Figure 5.19 Ambient and dome temperature difference versus ambient temperature

There is a linear relationship between the temperature difference of ambient and mean dome temperature and ambient temperature. The temperature difference reduces with every unit increase in ambient temperature.

5.2 Laboratory analysis of windrow input and output material.

The results of laboratory analysis done on the input and output material for the windrows are presented on this chapter. Laboratory analyses were done on solid matter and eluate. Laboratory tests performed on solid matter to obtain moisture content, total solids and volatile solids. Eluate was prepared using solid to liquid ratios (S/L) of 1:100 and 1:10. The duration of eluate preparation was 24 and 72 hours, with the purpose of determining differences in the eluate properties with variable contact times. Laboratory results and comments are presented in Tables 5.1 to 5.13.

Windrow 1 and 2

The results of tests performed on solid matter and eluate before composting, at 8 weeks of composting and at the end of 16 weeks of composting are shown in Tables 5.1 to 5.9. The eluates were tested for COD, BOD, N-NH_3, NOx, pH and conductivity. Moisture content, volatile solids and total solids were tested on the solid matter. The tests were performed in order to evaluate the efficiency of windrows in reducing the organic substances of the waste.

Before composting

Table 5.1 presents the results of moisture content, volatile solids and total solids of MSW before composting for windrows 1 and 2.

Table 5.1 Moisture content, volatile solids and total solids before composting

Parameter *Statistics*	**Percent Moisture Content**	**TS (g DM/g)**	**VS (g/gDM)**
1	59.1	0.409	0.538
2	60.3	0.397	0.564
3	55.7	0.443	0.652
4	37.8	0.622	0.715
5	82.1	0.179	0.657
6	51.4	--	0.540
Mean(Arithmetic)	***57.7***	***0.410***	***0.611***
Std dev.	*14.4*	*0.158*	*0.074*
Variance	*208.8*	*0.0249*	*0.005*
Range	*44.3*	*0.443*	*0.177*
%Coefficient of variation	***25.0***	***38.5***	***12.1***

An initial moisture content of 57.7 percent was found favourable for the decomposition to occur. The percent variation from the mean of the total solids and moisture content were above 20 percent. The high variation can be attributed to the heterogeneous property of the waste.

The results obtained form the eluate tests performed using a solid : liquid (S/L) ratio of 1:100 before composting are presented on Table 5.2 below.

Table 5.2 Eluate characteristics before composting using S/L 1:100

Parameter ***Statistics***	**COD** (mg/ℓ)	**BOD_5** (mg/ℓ)	**NH_3** (mg/ℓ)	**NOx** (mg/ℓ)	**pH**	**Cond. (μS/cm)**
1	243.8	86.9	2.805	2.596	7.04	2.63E-04
2	375.4	193	2.805	2.884	7.04	3.28E-04
3	358.0	75.9	2.454	4.038	7.07	2.83E-04
4	397.4	113	5.61	2.307	7.00	3.02E-04
5	331.4	89.9	4.908	2.884	7.15	3.22E-04
6	453.4	127	2.805	3.461	6.98	3.31E-04
Mean(Arithmetic)	***360***	***115***	***3.57***	***3.03***	***7.05***	***3.05E-04***
Std dev.	*70.26*	*42.95*	*1.338*	*0.625*	*0.060*	*2.739E-05*
Variance	*4936.8*	*1844.4*	*1.791*	*0.391*	*0.00359*	*7.502E-10*
Range	*209.6*	*129.1*	*3.156*	*1.731*	*0.170*	*6.800E-05*
%Coef. Var	***19.5***	***37.4***	***37.5***	***20.7***	***0.8***	***9.0***

The BOD_5 / COD ratio = 0.319

The BOD and nitrogen results showed the largest spread of results from the mean, while pH gave a minimum variation as seen from the percent coefficient of variation from Table 5.2.

After 8 weeks of composting

Table 5.3 presents results obtained from tests on the solid matter after 8 weeks of composting.

Table 5.3 Moisture content, volatile solids and total solids after 8 weeks of composting

Parameter *Statistics*	Percent Moisture Content	TS (gDM/g)	VS (g/gDM)
Windrow 1	--	--	0.289
	--	--	0.186
	--	--	0.446
	19.7	0.803	0.249
Windrow 2	--	--	0.234
	--	--	0.186
	--	--	0.287
	24.4	*0.756*	0.172
Mean(Arithmetic)	***22.1***	***0.775***	***0.256***
Std dev.	*3.32*	*0.033*	*0.0891*
Variance	*11.0*	*0.00110*	*0.00793*
Range	*4.70*	*0.0470*	*0.274*
%Coefficient of variation	***15.1***	***4.3***	***34.8***

The low moisture contents show that the windrow dried out within the first few weeks of decomposition. All the results showed a good central tendency as observed from the percent variation, except fro the VS. The different sublimation properties of the heterogeneous waste could have resulted in a high dispersion of the VS results.

The results obtained form eluate test performed using a solid : liquid ratio of 1:100 after 8 weeks of composting are presented on Table 5.4 below.

Table 5.4 Eluate characteristics after 8 weeks composting using S/L 1:100

Parameter ***Statistics***	**COD (mg/ℓ)**	**BOD5 (mg/ℓ)**	**NH_3 (mg/ℓ)**	**NOx (mg/ℓ)**	**pH**	**Cond. (μS/cm)**
Windrow 1	226.6	74.9	1.454	0.449	6.44	1.914E-04
	226.2	71.9	1.515	0.399	6.86	1.721E-04
	188.3	30.0	1.030	0.399	--	--
	194.8	35.9	1.030	0.299	--	--
Windrow 2	174.5	35.9	1.757	0.598	6.80	2.230E-04
	170.6	35.9	1.757	0.548	6.86	2.050E-04
	165.5	21	1.272	0.449	--	--
	171.6	24	1.272	0.399	--	--
Mean(Arithmetic)	***190***	***41.2***	***1.39***	***0.443***	***6.83***	***2.14E-04***
Std dev.	*24.58*	*20.7*	*0.287*	*0.094*	*0.042*	*1.273E-05*
Variance	*604.4*	*427.4*	*0.0823*	*0.00881*	*0.0018*	*1.620E-10*
Range	*61.1*	*53.9*	*0.727*	*0.299*	*0.42*	*5.100E-05*
%Coef.Var	***13.0***	***50.2***	***20.7***	***21.2***	***0.62***	***5.95***

The BOD_5 / COD ratio = 0.259

The BOD_5 / COD ratio reduced notably after the first 8 weeks of composting. The BOD_5 has the highest coefficient of variation of the results from the mean, followed by NH_3, NOx and COD. The results are in line with Clesceri *et al* (1989) who reports extreme variability and high dispersion of BOD results. The pH and conductivity results show a smaller spread from the mean.

The efficiency of aerobic treatment, eluate characteristics before and after 8 weeks of composting are presented in Table 5.5, as a comparison between Table 5.2 and 5.4.

Table 5.5 Percent reduction of MSW properties after 8 weeks treatment

Waste characteristic	**Percent Reduction**
Volatile Solids	58.1
C O D	47.3
NH3	61.2
NOx	85.4
Conductivity	39.8
BOD5	64.1
BOD_5 / COD ratio	19.8

From Table 5.5, there is notable reduction of 64.1 percent in the BOD, hence aerobic treatment was effective in reducing the easily biodegradable fraction of MSW. The 47.3 percent reduction in COD suggests an overall reduction in organic contents. A consistent reduction in NH_3 and NOx by 61.2 and 85.4 percent, respectively, suggests an overall high efficiency of the process within the first 8 weeks.

After 16 weeks of composting

After 16 weeks of composting waste properties were established on solid matter and the results are presented in Table 5.6 below.

Table 5.6 Moisture content, volatile solids and total solids after 16 weeks of composting

Parameter *Statistics*	Percent Moisture Content	TS (g DM/g)	VS (g/gDM)
Mean(Arithmetic)	***17.8***	***0.822***	--

There is a notable reduction of moisture content after 16 weeks, which clearly showing that the windrows dried out during the composting process during the first few weeks of composting.

Table 5.7 shows eluate characteristics after 16 weeks of composting. The eluate was prepared using a solid : liquid ratio of 1:10.

Table 5.7 Eluate characteristics after 16 weeks composting using S/L 1:10 prepared in 24 hours

Parameter *Statistics*	**COD (mg/ℓ)**	**BOD_5 (mg/ℓ)**	**NH_3 (mg/ℓ)**	**NOx (mg/ℓ)**	**pH**	**Cond. (μS/cm)**
1	2171	385	0.936	0.05	--	--
2	2367	427	0.949	0.06	--	--
Mean(Arithmetic)	***2269***	***406***	***0.943***	***0.1***	***7.14***	***1.37E-04***
Std dev.	*139*	*29.7*	*0.01*	*0.01*	--	--
Variance	*19208*	*882*	*0.0*	*0.0*	--	--
Range	*196*	*42.0*	*0.013*	*0.010*	--	--
%Coef.Variation	***6.11***	***7.31***	***0.98***	***12.9***	--	--

BOD_5 / COD = 0.179

The BOD_5 / COD reduced remarkably from the value before composting. All the parameters from Table 5.7 recorded a percent coefficient of variation of less than 10 percent except for the NOx. The low coefficient of variation signifies a low spread of results from the mean.

After the 16 weeks of composting, eluate was only prepared using the solid : liquid ratio of 1:10. Hence the basis for comparisons to deduce the percent reduction in eluate characteristics after 16 weeks was only the BOD/COD ratio. A 43.9 percent reduction in the BOD/COD ratio was noted between 8 and 16 weeks.

To compare the effect of preparation time on the characteristics of eluate, using a solid : liquid ratio of 1:10, the eluate was prepared over a period of 24 and 72 hours. Table 5.8 to 5.10 show the comparisons.

Table 5.8 Eluate characteristics after 16 weeks composting using S/L 1:10 prepared in 72 hours

Parameter ***Statistics***	**COD (mgO_2/ℓ)**	**BOD_5 (mg/ℓ)**	**NH_3 (mg/ℓ)**	**NOx (mg/ℓ)**	**pH**	**Cond. ($\mu S/cm$)**
1	2739	374	1.318	0.234	7.3	--
2	2729	374	1.355	0.234	--	--
Mean(Arithmetic)	***2734***	***374***	***1.32***	***0.234***	***7.3***	*1.46E-03*
Std dev.	*7*	*0.0*	*0.03*	*0.00*	--	--
Variance	*50*	*0*	*0.0*	*0.0*	--	--
Range	*10*	*0.0*	*0.037*	*0.000*	--	--
%Coef.Var	***0.26***	***0.00***	***1.958***	***0.0***	**--**	**--**

The comparison on the eluates prepared over 24 and 72 hour is presented on table 5.9 below

Table 5.9 Comparison of waste eluate prepared over 24 and 72 hours using solid : liquid of 1:10

Parameter ***24/72 hrs***	**COD ($mgO2/\ell$)**	**NH_3 (mg/ℓ)**	**NOx (mg/ℓ)**	**pH**	**Cond. ($\mu S/cm$)**	**BOD_5 (mg/ℓ)**
24 hours	2269	0.9	0.1	7.14	1.37E-03	385
72 hours	2734	1.3	0.2	7.3	1.46E-03	374
Difference(Δ)	465	0.4	0.1	0.16	8.9E-05	11
(Δ /24 hours)%	**20**	**44**	**100**	**2**	**6**	**3**

Less than 20 percent difference in eluate characteristics prepared over 24 hours and 72 hours was noted. However, there were 44 and 100 percent difference for NH_3 and NOx, respectively. The marked differences for the nitrogen species maybe due to volatility behaviour of nitrogen and aeration effects with time.

Windrow 3

The results of tests on the solid matter and eluate tests from windrow 3 are presented from Table 5.10 to 5.12. The eluate was prepared using a solid : liquid ratio of 1:10 prepared over 24 hours.

Before composting

Results on solid matter are presented in Table 5.10 below.

Table 5.10 Moisture content, volatile solids and total solids before composting

Parameter *Statistics*	**Percent Moisture Content**	**TS (gDM/g)**	**VS (g/gDM)**
1	40.7	0.593	0.698
2	60.3	0.397	0.712
3	36.6	0.634	0.763
4	47.9	0.521	0.628
Average (Arithmetic)	***48.2***	***0.518***	***0.701***
Std dev.	*11.7*	*0.119*	*0.068*
Variance	*140.7*	*0.014*	*0.05*
Range	*23.7*	*0.237*	*0.050*
%Coef.Var	***24.6***	***22.9***	***9.7***

From Table 5.10 the moisture content was initially adequate for the compost process to start. The heterogeneity of waste could have resulted in the high dispersion of the moisture content and TS results.

Table 5.11 below presents results obtained from eluate tests on the input material to windrow 3, performed using a liquid : ratio of 1:10 prepared in 24 hours.

Table 5.11 Eluate characteristics before composting

Parameter *Statistics*	**COD (mgO_2/ℓ)**	**BOD_5 (mg/ℓ)**	**NH_3 (mg/ℓ)**	**NOx (mg/ℓ)**	**pH**	**Cond. ($\mu S/cm$)**
1	2263	947	0.382	0.16	--	--
2	2210	1036	0.394	0.136	--	--
3	2335	1065	--	--	--	--
Average	***2269***	***1016***	***0.388***	***0.148***	***6.37***	***1.91E-03***
Std dev.	*62.7*	*61.490*	*0.008*	*0.017*	--	--
Variance	*3952*	*3781.0*	*0.0*	*0.0*	--	--
Range	*125*	*118.0*	*0.012*	*0.024*	--	--
%Coeff variation	***2.77***	*6.1%*	***2.187***	***11.5***	--	--

$BOD_5/COD = 0.448$

The initial organic load of the windrow input material was high as observed from the COD, BOD_5 and BOD_5/COD results.

After 8 weeks composting

The solid matter and eluate characteristics obtained after 8 weeks of composting are presented on Table 5.12 and Table 5.13 below.

Table 5.12 Moisture content, volatile solids and total solids after 8 weeks of composting

Parameter *Statistics*	**Percent Moisture Content**	**TS (g DM/g)**	**VS (g/gDM)**
1	27.1	0.730	0.360
2	23.1	0.769	0.357
3	34.1	0.659	0.486
4	29.1	0.709	0.621
5	32.7	0.673	0.459
6	31.0	0.690	0.414
Average(Arithmetic)	***29.5***	***0.705***	***0.449***
Std dev.	*0.0403*	*0.0403*	*0.987*
Variance	*0.0016*	*1.62E-04*	*9.74E-03*
Range	*11.0*	*0.110*	*0.264*
%Coefficient of variation	***13.6***	***5.7***	***22.0***

There was a reduction of moisture content after 8 weeks of composting due to depletion by microbial activity and high ambient temperatures. Only the volatile solids content showed a deviation of results from the mean by over 20 percent. It may be observed that the moisture content of the MBP waste is more uniformly compared to untreated waste.

Table 5.13 presents the eluate characteristics of the MBP after 8 weeks of composting for windrow 3 using a solid : liquid ratio of 1:10.

Table 5.13 Average eluate characteristics after 8 weeks of composting (Motsoane,2006)

Parameter	Arithmetic mean value
COD (mg/ℓ)	1750
BOD_5 (mg/ℓ)	653
NH_3 (mg/ℓ)	1.06
NOx (mg/ℓ)	0.250
pH	7.13
Cond. (μS/cm)	1.16E-04

BOD/COD = 0.373

The efficiency of windrow 3 in reducing the organic load of MSW is presented in Table 5.14 below. A brief discussion follows Table 5.14

Table 5.14 Percent reduction of MSW properties after 8 weeks treatment

Waste characteristic	Percent Reduction
V.S	35.9
C O D	22.9
BOD_5	35.7
NH_3	--
NOx	--
Conductivity	93.9
BOD_5 / COD ratio	16.7

There was a 35.7 percent reduction in the BOD suggesting that the aerobic treatment was effective in reducing the biodegradable component of MSW. The volatile solids content and conductivity reduced by 35.9 and 93.9 percent. Consequently it may be inferred that there was an overall reduction in the solids content. The COD also reduced by 22.9 percent hence the COD/BOD ratio reduced by 16.7 percent. The DAT was therefore effective in reducing the carbon content of MSW.

5.3 A summary of windrow results

The windrows were effective in reducing the biodegradable compounds of waste as observed from significant reductions in the BOD_5/COD ratio. There is also a noticeable reduction in the overall organic load as exhibited by reductions in the COD, TS, VS and nitrogen. Although there was enough waste moisture at the beginning of the composting process, the windrows are prone to dessication. Irrigating windrows is recommendable to replenish water lost. Despite the degradation of waste in the windrows the windrow output required further stabilization. The passive aeration and irrigation in the test cells would help to further degrade the biodegradable compounds which might have escaped composting.

CHAPTER 6

WASTE DEGRADATION IN TEST CELLS

The purpose of the research was to investigate the applicability of shallow landfills operated using the PAF model to complete stabilization of waste. Five test cells were constructed at the Bisasar Road landfill site in Durban to simulate shallow landfills. MBP waste that had been treated using the DAT technology for 8 and 16 weeks was aerated and flushed in the test cells. One test cell was filled with untreated MSW and served as experiment control. In order to investigate the degradation of easily biodegradable component of MSW and non- separated MSW, treated waste was sieved through a 50 mm sieve. The finer material, which went through a 50 mm sieve, was considered to be easily biodegradable. The assumption that the finer material was easily biodegradable was based on the fact that it contained less plastics, paper and metal, that are slowly or non biodegradable (see also Figure 7.1 to 7.4 for waste composition). The flushing / aeration operation of test cells is shown in figure 6.1 below.

PROCESS	*CELL 1*	*CELL 2*	*CELL 3*	*CELL 4*	*CELL 5*
AERATION	Covered immediately	12 weeks aeration	Covered immediately	13 weeks aeration	14 weeks aeration
FLUSHING	Volume of water 600 Liters	Volume of water 2420 Liters	Volume of water 320 Liters	Volume of water 1650 Liters	Volume of water 3020 Liters
AERATION	Aeration 24 weeks	Aeration 24 weeks	Aeration 24 weeks	Aeration 24 weeks	Aeration 24 weeks
FLUSHING					

Figure 6.1 The aeration/flushing process of the test cells

6.1 Construction of the test cells

The criteria of design comprised of: containment of leachate, leachate drainage, geotechnical stability of the cell walls, and ease of sampling leachate and biogas after filling the test cells.

The procedure adopted the cells construction involved:

- Site clearing and marking of dimensions
- Construction of cell walls
- Installation of Geosynthetic Clay Liner (G.C.L)
- Installation of protective layer (Geofabric liner)
- Installation of leachate drainage layer (53 mm stone and leachate pipe)
- Installation of biogas probes

The overall dimension of the cells is 12.5 m x 12.5 m x 1 m high with an average volume of 35 m^3. Pictures showing the construction stages of the test cells are shown from Figure 6.2 up to 6.5. The design and supervision of the cells construction was performed by the author of this dissertation. The construction of cells was sponsored and carried out by DSW.

Figure 6.2 Construction of cell walls

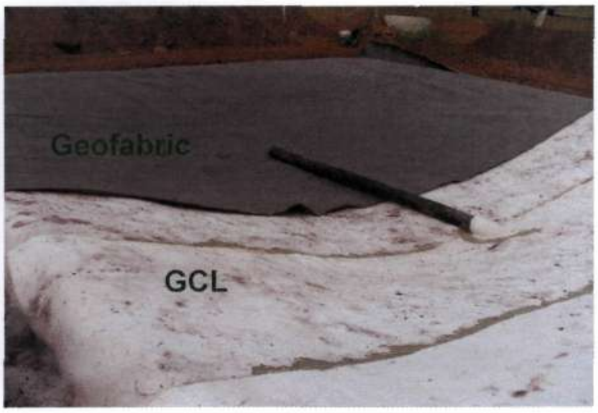

Figure 6.4 GCL and protective layer

Figure 6.3 Drainage protective layers

Figure 6.5 A completed cells

6.2 Filling of the test Cells

The test cells were filled with different types of waste. The different waste types were differentiated according to waste treatment period and particle sizes. The cells were filled with non-pretreated waste (control), unsorted global waste pre-treated for 16 and 8 weeks and fines passed through a 50 mm sieve pretreated for 16 and 8 weeks. Fines were obtained by sieving the global waste through a 50 mm sieve and using only the under-sieved fraction. The raison d'être for the separation to the fines from the global MSW was based on the need to investigate different degradation properties, since It was assumed that the fines contained more readily biodegradable fractions than the global MSW.

In Austria waste particles greater than 180 mm are considered high calorific valued compounds. After 14 to 22 weeks of pre-treatment only fine fractions less than 24 mm meet landfilling requirements (Raninger et al, 1999). In Germany in pre-treatment plants, the largest particles are between 80 and 100 mm (Rettenberger, 1999). Filling test cells was done using manual labour and an excavator provided by DSW. Minimum contact with waste when filling the untreated MSW cell was maintained and proper safety clothing was used. Table 6.1 shows a summary of the nomenclature, volume and mass of waste in the test cells.

Table 6.1 Summary of the nomenclature, volume and mass of waste in the test cells

Test Cell No.	Type Of Waste	Volume Of Waste (m^3)	Mass Of Waste (Metric Tonnes)
1	08 weeks treated fines	41.1	20.6
2	16 weeks treated fines	40.1	20.1
3	08 weeks treated MSW	35.5	17.8
4	Un treated MSW	32.1	16.1
5	16 weeks treated MSW	38.8	19.4

The general layout of the cells is shown in Figure 6.6 overleaf. Figure 6.7 shows a cross section of a typical cell taken as section A-A from cell 1. The cells were layers of 53 mm diameter stone, a plastic polymer (HDPE 2mm thick), soil and vegetation. A subsurface drip irrigation system was laid on top of the stone layer.

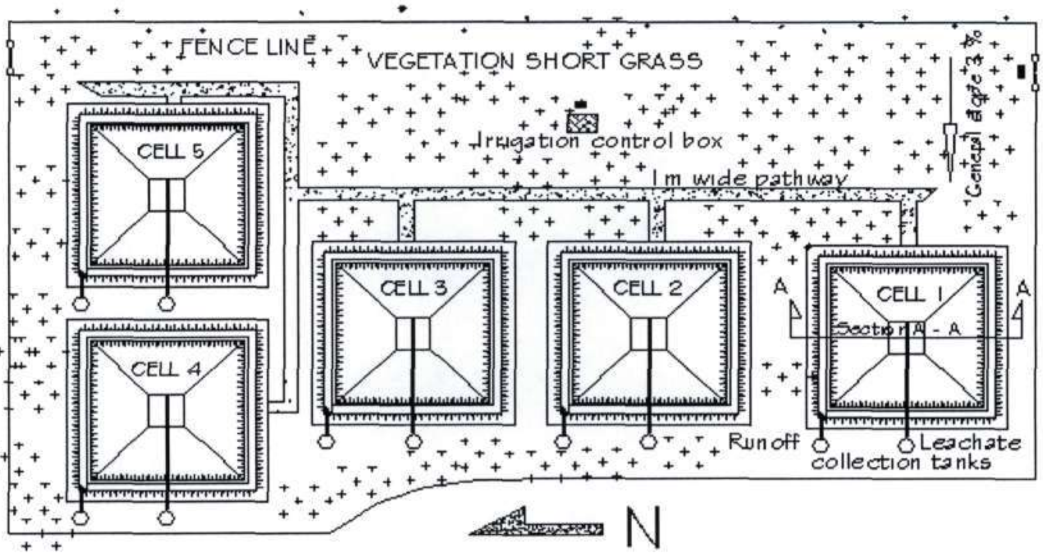

Figure 6.6 General layout of the test cells

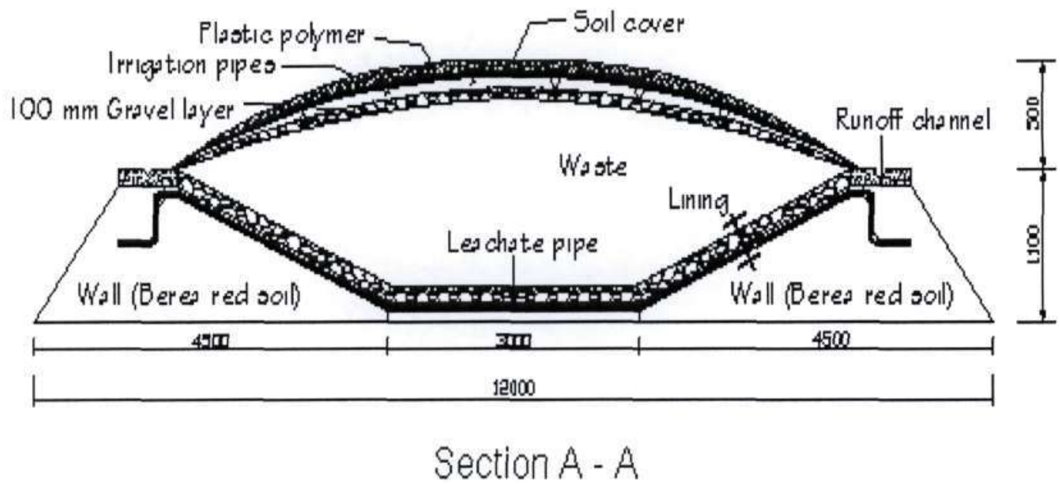

Figure 6.7 Cross section of a typical test cell

6.3 Irrigation design and scheduling

A subsurface drip irrigation system was installed and the cells were covered to exclude undesired influence from ambient weather conditions. The irrigation rate was based on the waste hydraulic properties, microbiological processes within the waste mass, potential leachate volume and in order to simulate 50 years of typical landfill processes in 1 year of field testing. In Leikam and Stegmann (1997) it was considered that a monitoring period of 250 days corresponds to approximately 50 years in a large-scale landfill of a 20m height with an annual leachate production of 250l/m^2 using a water flow : dry matter ratio of 1:1 for MBP waste. The same consideration was used when calculating the volume of water for flushing in the test cells.

1.0 According to (Leikam and Stegmann, 1997)

Liquid : Solid = 1:1

250 days of flushing is equivalent to 50 years in a 20m deep large-scale landfill = 50 years

Leachate production =	250	ℓ/m^2 for 20 m landfill
Assume placement density =	0.6	ton/m˘
Waste mass in 20m landfill =	12000	Kg
Hence water requirement =	600	ℓ/m depth would approximate 50 years large scale landfi

2.0 Experimentally

Precipitation (in Durban) =	1000	mm/m˜/year
Cross-sectional area for cells =	64.0	m^2
Expected precipitaion for 1 cell =	64000	ℓ
Average mass of waste per cell =	18760	Kg
Average mass of waste per sqm =	293	kg/m˜/m deep

In order to have L : S of 1:1 a volume of 18760 ℓ of water must be applied

Water volume per day =	51.4	ℓ/day
Considering a five week day =	257	ℓ/Week.Cell
Total number of flushing days in a year =	260	days

There for in the experimental case, 1 year of flushing = 102 years in a large-scale landfill

Comparison of critical irrigation and flushing rate

Crtical infitration rate =	3.33E-05	m/s
Cross-sectional area of cell =	64.0	m^2
Rate of water application =	0.257	m^3/week
Water application per m^2 =	4.02E-03	m/week
	9.30E-09	m/s

Conclusion rate of application 9.30E-09 m/s << 3.33E-05, hence OK.

Infiltration rate

A modified double ring infiltrometer technique, traditionally used for soils, was used to measure the rate of infiltration. According to ASTMD5093-02, Standard Test Method for Field Measurement of Infiltration Rate, the double ring infiltrometer test method is useful for soils with infiltration rates in the range of 1 x 10^{-7} m/s to 1 x 10^{-10} m/s. The infiltration rate test is important when calculating the rate of leachate discharge. Parameters which govern water movement in pretreated waste must be considered (DWAF, 2005).

The infiltration rate test gives a one dimension vertical movement of water. Water is filled in two rings, inner and outer rings, having a diameter ratio of 1:2. For the experiment diameters of 1 m and 2 m were used. The rate of downward movement of water was obtained by recording water levels within the rings, at preset time intervals of at 1, 2, 5, 15, 30, 45 and 60 minutes. Generally the movement of water in waste is influenced by landfill cover, specific weight, density, initial water content, concentration of putrescible substances and so on.

Irrigation scheduling

Results gathered from the irrigation design and infiltration rate test were compared to assess if the waste column would be able to allow for the passage of water at critical infiltration rate. The rate of application, 257 ℓ /week, is equivalent to 9.03E-09 m/s and the critical infiltration rate is 3.33E-05 m/s. Since the application rate was found to be less than the critical infiltration rate the water applied was not expected to pond in the cells, but allowing good flushing. Beside the critical infiltration rate, the rate of irrigation was also constrained by storage capacity of leachate and liquid residence time. Based on the critical rate of infiltration and height of waste mass (1 m), the liquid residence time was found to be 8.33 hours.

Each irrigation cycle lasted for a week and water was discharged in pulses and spread evenly through out the irrigation period. Effectively irrigation was carried in 5 days giving 2 days a week to allow acclimatization of microorganisms. A computer controlled timer controlled the irrigation times. Irrigation water was supplied by a network of pipes laid across the cell superficial area (64 m^2 in area) forming a grid of nozzles spaced at a square distance of 1m.

Water balance

A Water balance model was used to estimate the amount of leachate that can be produced in a typical shallow landfill in Durban. The model considers moisture flow as one dimensional system and predicts water percolation through waste. The source of water is precipitation and part of which is lost through evapo-transpiration, surface runoff and the remainder percolates. Downward movement of water only happens when field capacity is reached. A negligible fraction of moisture is used by microorganisms. Important factors that govern the rate of percolation comprise of type of cover, topography and compaction of waste mass. See Figure 6.8 for a schematic presentation of the water balance in a typical landfill.

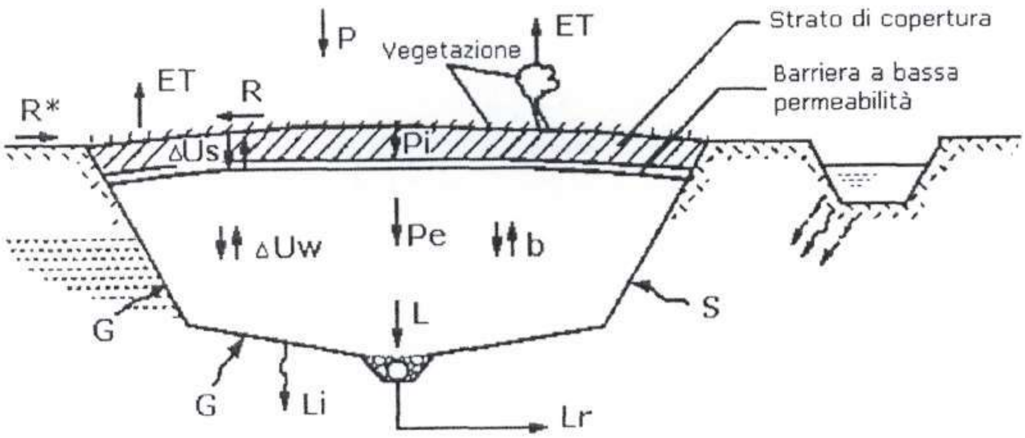

Figure 6.8 A schematic presentation of water balance in a typical landfill (Ghiani, 2006)

The variables of shown in figure 6.8 are defined below:

P = precipitation

R = runoff

E, T = evaporation and transpiration

S = infiltration of superficial water

G = infiltration of ground water

R* = runoff from adjacent area

ΔUs = variation of moisture content of cover material

ΔUw = variation of moisture content within waste mass

b	= production or consumption of water due to degradation processes
Li	= percolation lost to the ground water
Lr	= collected water that percolated (leachate)
L	= global percolate
Pi	= rain that infiltrate cover
Pe	= rain that percolate the refuse mass

Hence $L = Pi + S + G + (\Delta Us + \Delta Uw) + b$ 6.1

In which $Pi = P + R^* - R - E - T$ 6.2

For this research R*, R, E, G, Lr, S, T and ΔUs were treated as constants equal to zero because the cells were covered, constructed above the water table and lined to exclude seepage. Subsequently the water balance for the cells could be calculated as by equation 6.3 below:

Leachate volume = Irrigation volume – water lost during biodegradation 6.3

The volume of water that has to be flushed through the waste in order to receive leachate depends on the placement density and initial moisture content. With emplacement density of 0.6 to 0.8 ton/m^3, the initial absorptive capacity of waste ranges from 0.16 to 0.27 m^3 per ton of waste increasing with prolonged infiltration to 0.4 to 0.6 m^3 per ton of waste (Bakey, 1992).

A water balance was also calculated for a typical large-scale landfill in the Durban area. Data obtained over a 30-year period from the Durban weather station [0240808A2] – DURBAN were used for the water balance calculations (see Appendix I). Figure 6.9 shows daily average precipitation and evapotranspiration for the Durban area.

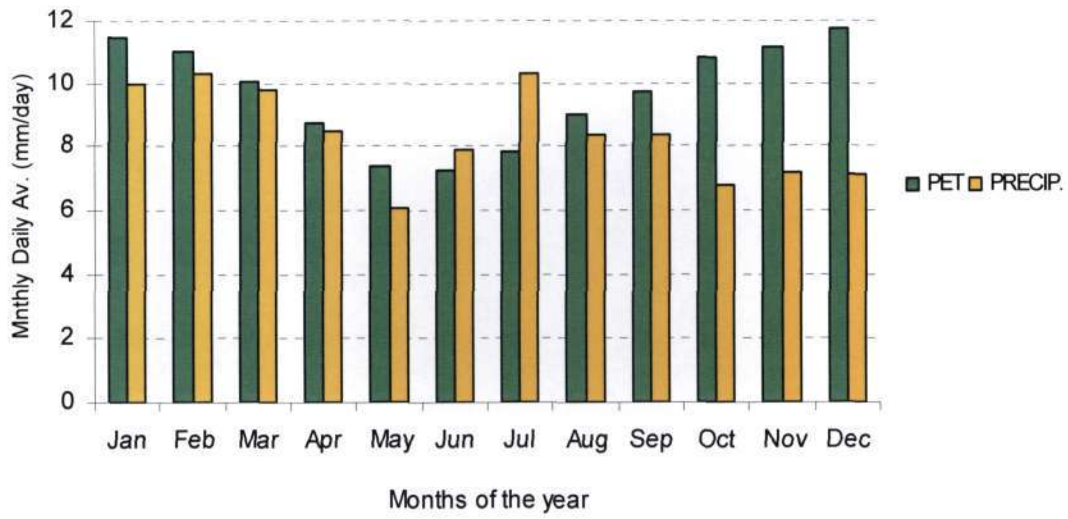

Figure 6.9 Potential evapotranspiration and precipitation for Durban

From Figure 6.9 it can be observed that most of the rain falls during some of the summer months in Durban (December to January). During the same summer months evapotranspiration is at its highest, hence theoretically leachate production is very low. However, field data do not agree with theoretical calculations. The theoretical calculation of leachate production is presented below, also see Appendix I.

Table 6.2 Water balance for a large-scale landfill in Durban

PARAMETER	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PET (mm/day)	11.5	11.0	10.0	8.74	7.40	7.26	7.85	8.97	9.73	10.8	11.2	11.7
Rain days, No. of	14	12	12	9	6	3	5	6	9	15	15	16
Precipitation (mm/day)	9.97	10.3	9.79	8.49	6.09	7.86	10.3	8.37	8.36	6.78	7.18	7.09
Runoff (mm/day)	1.99	2.07	1.96	1.70	1.22	1.57	2.07	1.67	1.67	1.36	1.44	1.42
Infiltration (mm/day)	7.97	8.26	7.84	6.79	4.87	6.29	8.27	6.70	6.68	5.42	5.75	5.67
Leachate (mm/day)	**-3.5**	**-2.7**	**-2.2**	**-1.9**	**-2.5**	**-1.0**	**0.42**	**-2.3**	**-3.1**	**-5.4**	**-5.4**	**-6.1**
Available moisture (mm/day)	43.9	41.2	39.0	37.0	34.5	33.6	34.0	31.7	28.6	23.3	17.8	11.8

Table was prepared considering a cubic meter of waste, with 50 percent FMC, assuming that the system is at FMC at end of December

6.4 Monitoring Decomposition in the test cells

The decomposition of waste in the test cells was monitored by weekly measurement of the emissions characteristics. Biogas composition was monitored by measuring percent composition of methane and carbon dioxide using a gas analyzer (Type GA94 and GA2000). The decomposition temperature was also obtained using a thermocouple. The water balance was obtained by recording the amount of leachate produced per week and weekly irrigation volumes. Laboratory tests for leachate quality were performed as explained under Section 4.3.3 Eluate tests.

CHAPTER 7
RESULTS AND DISCUSSION OF WASTE DECOMPOSITION IN TEST CELLS

The degradation of MSW was studied using 5 miniature landfills called test cells. The test cells were constructed in order to simulate a flushing bioreactor and prolonged aeration to assess the feasibility of employing shallow landfills for stabilization of waste. The waste input material was aerobically treated using the DAT for 8 and 16 weeks. Fine material obtained by sieving treated MSW waste through a 50 mm sieve was also landfilled. The waste was sieved based on the assumption that the fine material had a higher content of easily biodegradable fraction than the global sample. One cell was filled with untreated MSW in order to establish the differences of landfilling treated and untreated MSW. Table 7.1 presents the characteristics of MSW filled in the test cells.

Table 7.1 Cells characteristics

Test Cell No.	Type of Waste
1	08 weeks treated fines
2	16 weeks treated fines
3	08 weeks treated MSW
4	Control – non treated MSW
5	16 weeks treated MSW

7.1 Cells input material

Results on the material composition of the waste, waste mechanical properties (infiltration rate test), degree of stabilization (respiration index and gas production) and laboratory tests performed on the solid matter and eluates are reported in this chapter.

Waste composition

Figures 7.1, 7.2 and 7.3 show the composition of materials retained on the 50 mm sieve, passing through the 50 mm sieve and global sample that were used to fill the test cells. The percent composition (Mass/ TotalMass) was obtained by weighing the different fractions after separation. Material composition from the control cell could not be performed because of hygiene reasons, so the results presented on Figure 7.4 are derived from the waste stream analysis conducted by DSW in 1998 and 2002 (SKC, 2002).

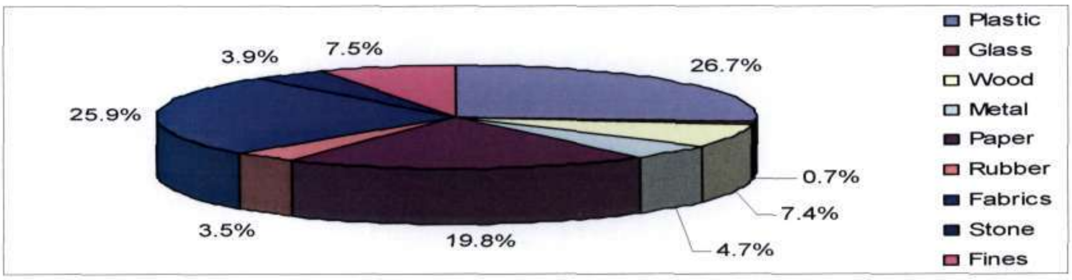

Figure 7.1 Percent composition of the waste fractions retained on a 50 mm sieve

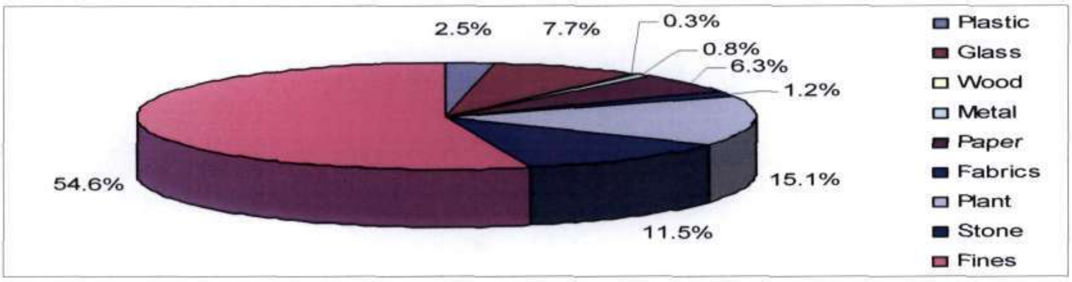

Figure 7.2 Percent composition of the waste fractions passing through a 50 mm sieve

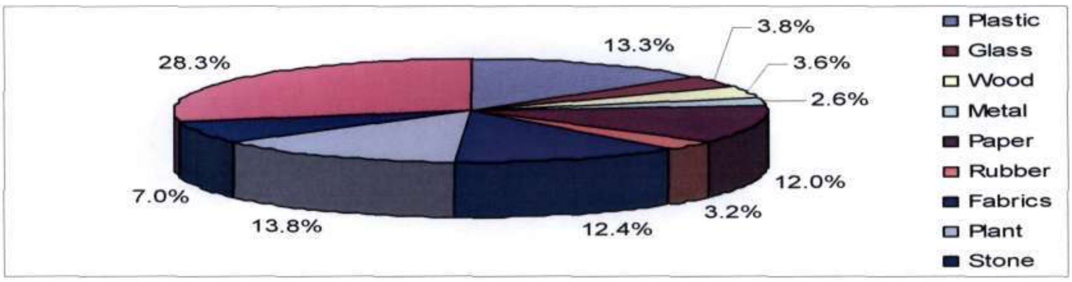

Figure 7.3 Percent composition of the unsorted and unsieved global waste

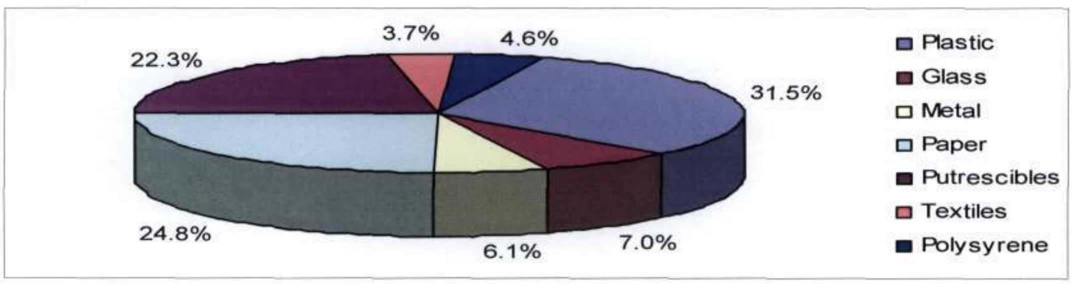

Figure 7.4 Percent composition of untreated, unsieved and unsorted MSW (SKC,2002)

From figure 7.1 it can be observed that the major components of the waste retained on a 50 mm sieve were plastic, fabrics and stone (inert material). There is also a recognizable fraction (4.7 percent by weight) of recyclable material, i.e metals. More than half of the materials that passed through the 50 mm sieve were fines as seen from Figure 7.2. The fines comprised of small particles of plant material, broken glass, plastic and paper, soil etc. From the global sample the top five components comprised of fines, plastic, plant, fabrics and paper as observed from Figure 7.3. Only a handful of recyclable material, metals, making 2.8 percent of the total was observed from the global sample. The top five most common materials for untreated MSW were plastics, paper, putrescibles, glass and metals.

Mechanical property

The rate of infiltration of the material in the cells was measured as explained in Section 6.3. The reported results are from the 16 weeks treated fines. The rate of infiltration was also done on the global material, however, water quickly seeped through the waste mass without any ponding. Figure 7.5 shows the results of the rate of infiltration test and the relevant calculations are presented in Appendix H.

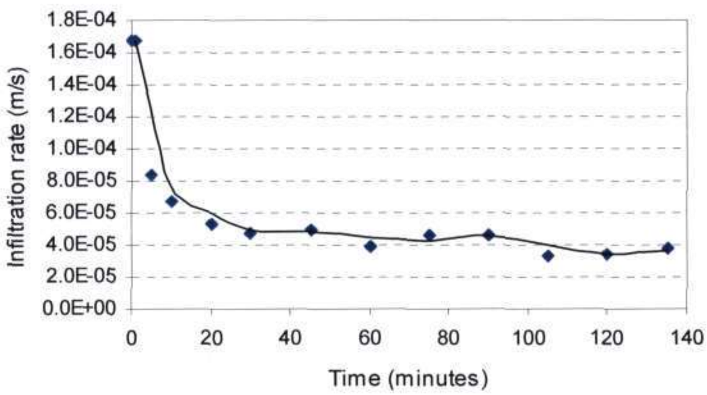

Figure 7.5 Infiltration rate test

Critical infiltration rate that was used for the irrigation design was 3.33×10^{-5} m/s. The mean residence time of water within the cell was computed to be 8.33 hrs.

Respiration index (RI)

Trials were carried out on 10 g, 20 g and 50 g samples as presented in Table 7.2. A brief explanation accompanies the to clarify why the 20 g was considered an appropriate sample size for subsequent tests. Figures 7.6 to 7.10 present the summary results of the RI tests on 20 g samples. Table 7.2 presents a summary of the test trials.

Table 7.2 A summary of $RI_{4/7}$ tests (Xulu, 2005 and Motsoane 2006)

Waste Type	Parameter / *Statistic*	20 g RI_4	20 g RI_7	50 g RI_4	50 g RI_7
Cell 1 - 8 weeks fines	1	3.02	4.18	2.39	2.78
	2	2.09	3.25	2.56	2.95
	3	2.32	3.95	3.56	3.67
	Mean	***2.48***	***3.79***	***2.84***	***3.13***
	Std Dev.	*0.484*	*0.484*	*0.632*	*0.472*
	Variance	*0.235*	*0.235*	*0.400*	*0.223*
	Coef. Variation	***19.6%***	***12.8%***	***22.4%***	***15.1%***
Cell 2 - 16 weeks fines	Parameter / *Statistic*	10 g RI_4	10 g RI_7	20 g RI_4	20 g RI_7
	1	12.1	--	6.82	--
	2	11.2	--	5.98	--
	3	12.5	--	8.21	--
	Mean	***11.9***	--	***7.00***	--
	Std Dev.	*0.666*	--	*1.13*	--
	Variance	*0.443*	--	*1.27*	--
	Coef. Variation	***5.6%***	--	***16.1%***	--
Cell 3 - 8 weeks global	Parameter / *Statistic*	20 g RI_4	20 g RI_7	50 g RI_4	50 g RI_7
	1	8.21	8.62	1.10	0.795
	2	7.09	7.37	1.10	2.419
	3	7.23	8.60	1.05	1.856
	Mean	***7.51***	***8.20***	***1.08***	***1.69***
	Std Dev.	*0.610*	*0.716*	*0.029*	*0.825*
	Variance	*0.372*	*0.513*	*0.001*	*0.680*
	Coef. Variation	***8.1%***	***8.7%***	***2.7%***	***48.8%***
Cell 4 - Untreated MSW	Parameter / *Statistic*	20 g RI_4	20 g RI_7	10 g RI_4	10 g RI_7
	1	7.54	--	13.6	--
	2	5.96	--	14.2	--
	3	9.03	--		--
	Mean	***7.51***	--	***13.90***	--
	Std Dev.	*1.54*	--	*0.424*	--
	Variance	*2.36*	--	*0.180*	--
	Coef. Variation	***20.4%***	--	***3.1%***	--
Cell 5 - 16 weeks global	Parameter / *Statistic*	10 g RI_4	10 g RI_7	20 g RI_4	20 g RI_7
	1	3.06	--	5.28	--
	2	6.12	--	8.34	--
	3	10.8	--	4.17	--
	Mean	***6.66***	--	***5.93***	--
	Std Dev.	*3.90*	--	*2.160*	--
	Variance	*15.2*	--	*4.664*	--
	Coef. Variation	***58.5%***	--	***36.4%***	--

Before running the trials, the availability of oxygen in the reactor was determined as presented in the calculation below. The maximum oxygen was 116 mgO_2, far less than 450mgO_2 available hence the available oxygen was adequate for the estimates of oxygen demand. Even though the amount of available oxygen seems satisfactory, a conservative approach was adopted by using RI_4 instead of RI_7 with some tests. Appendix F is attached for further reference.

At STP, 1mole of gas =	22.4	ℓ/mole
Reactor volume =	1.5	ℓ
Number of gas moles =	0.07	moles
% concentration of O_2 in the reactor =	21	pecent
Molecular mass of O_2 =	32000	mg
Maximum available O_2 =	21% x number of moles of gas x 32000mgO_2 / mole	
Standard sample volume for BOD_5 =	450	mg

From Table 7.2, when comparing the 20 g and 50 g samples, the coefficient of variation from the mean for the 20 g sample was always lower than 20 percent, whereas the 50 g sample gave 22.4 percent and 48.8 percent for 8 weeks fines and 8 weeks global sample, respectively. The 10 g sample generally showed a low coefficient of variation from the mean, however, results of the 16 weeks global give a variation of 58.5 percent. From the same 16 weeks global sample, the 20 g sample gave a highest coefficient of variation of 20.4 percent. Otherwise when compared with the 10 g sample, the 20 g sample had a highest percent coefficient of variation. The 10 g sample and 50 g were considered small and large to give reliable results. Subsequently, the 20 g sample was considered the ideal sample size when using the BOD bottles to determine waste activity.

After adopting the 20 g sample as the appropriate sample size, tests were carried out in triplicates in order to determine the biological activity of the different waste samples. Samples were tested at field moisture capacity and at a temperature of 20^{0}C, EU Directive (EN 12457-1). Figures 7.6 to 7.10 present the biological activity of waste sampled from the 5 different cells before landfilling.

Figure 7.6 below presents the RI4 for the 16 weeks global sample.

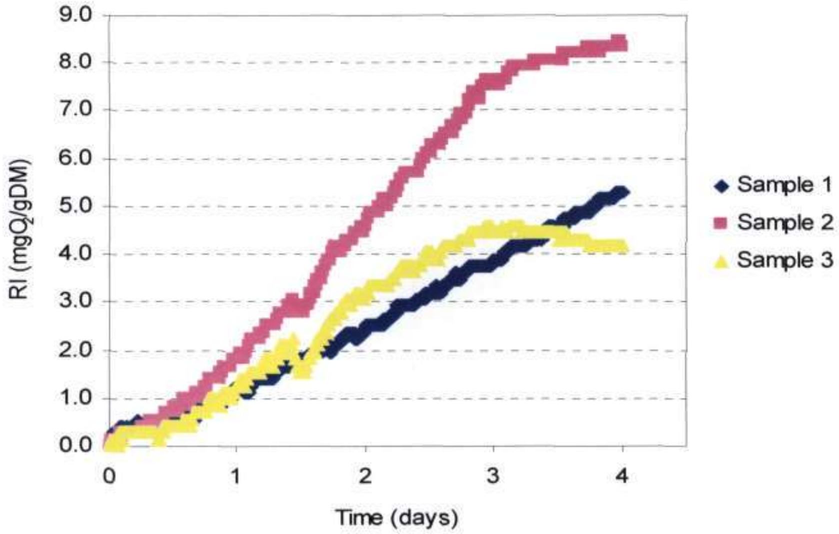

Figure 7.6 Biological activity (RI_4) of the 16 weeks unsorted global sample – cell 5

The mean RI_4 is 5,93 mgO_2/gDM.

Figure 7.7 presents the RI_4 for the 16 weeks fines.

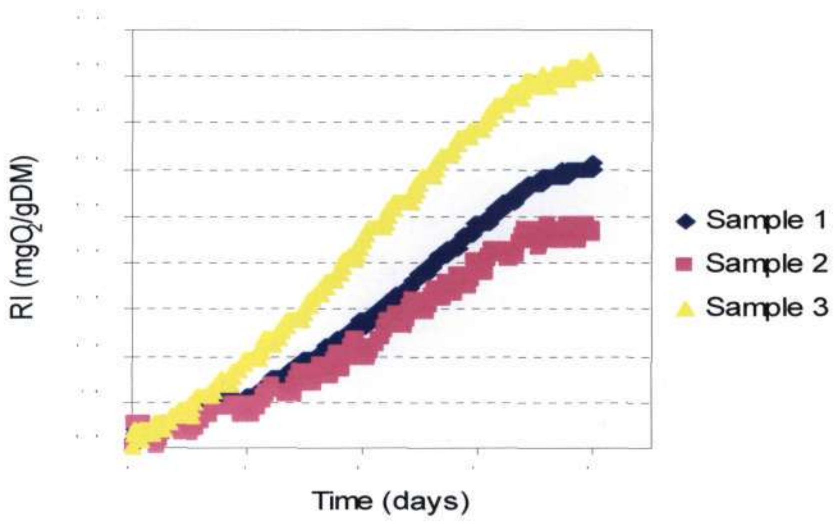

Figure 7.7 Biological activity (RI_4) of the 16 weeks fines – cell 2

The mean RI_4 is 7.00 mgO_2/gDM.

The RI_7 outcomes of the 8 weeks global sample are illustrated on Figure 7.8.

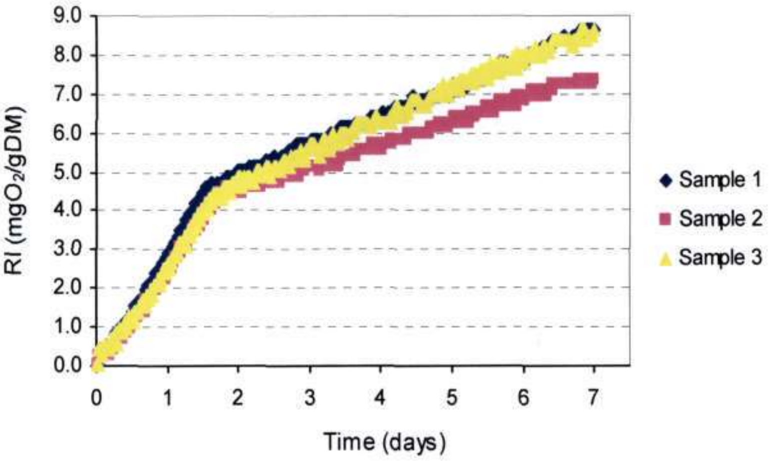

Figure 7.8 Biological activity (RI_7) of the 8 weeks unsorted global sample – cell 3

The mean RI $_7$ is 8.20 mgO_2/gDM, respectively.

Figure 7.9 below shows an illustration of the IR_7 for the 8 weeks fines.

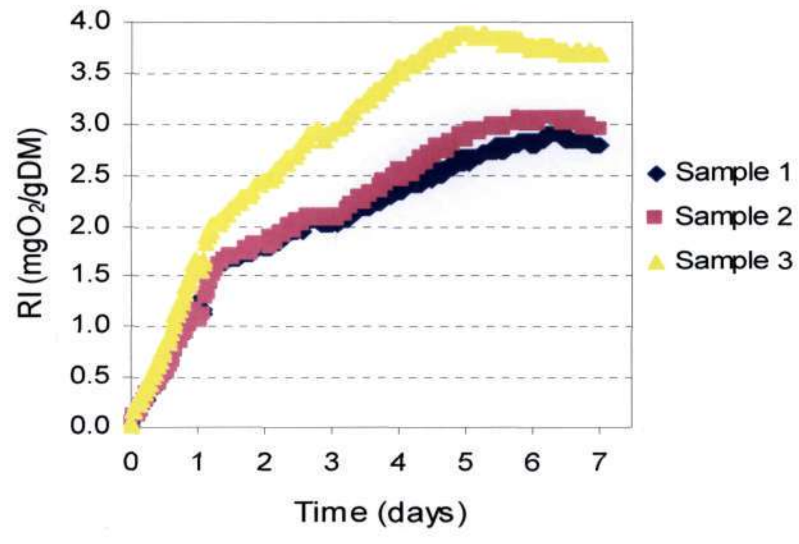

Figure 7.9 Biological activity (RI_7) of the 8 weeks fines – cell 1

The mean RI $_7$ is 3.79 mgO_2/gDM, respectively.

The RI_4 for the untreated unsorted MSW is presented in Figure 7.10.

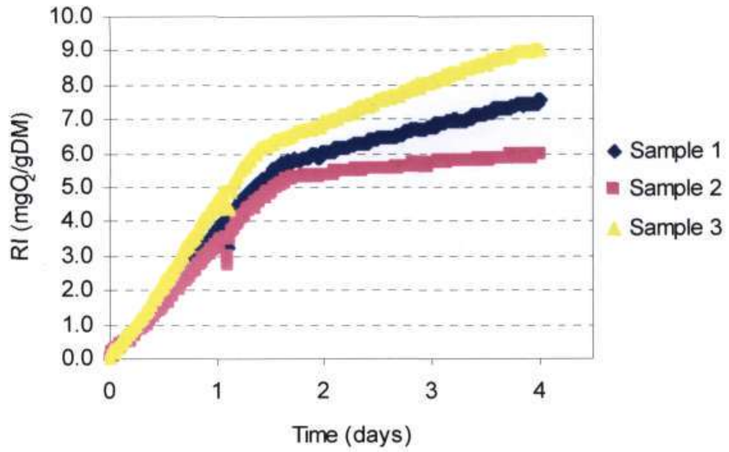

Figure 7.10 Biological activity (RI_4) of the untreated and unsorted MSW – cell 4

The mean RI_4 is 7.51 mgO_2/gDM.

A summary of the RI results is presented in Table 7.3 below

Table 7.3 The summary of the $RI_{4/7}$ outcomes

Waste Type	**RI_4 (mgO_2/gDM)**	**RI_7 (mgO_2/gDM)**
Untreated MSW – cell 4	7.51	--
16 weeks global – cell 5	5.93	--
16 weeks fines – cell 2	7.00	--
8 weeks global – cell 3	7.51	8.20
8 weeks fines – cell 1	2.48	3.79

The untreated MSW and the 8 weeks global waste had the same IR_4, i.e 7.51 mgO_2/gDM. The 8 weeks global waste results may not be representative of the entire windrow body hence results may be taken with caution. The 16 weeks global sample showed an inferior IR4 than its respective fines. The observation suggests a higher content of biodegradable fractions in the fine material than the global sample. Unlikely, the 8 week global sample showed a higher biological activity than respective fines. From table 7.3, 8 weeks global and 8 weeks fines had average RI_4 of 7.51 mgO_2/gDM and 2.48 mgO_2/gDM, respectively. Generally, the 8 weeks sample showed a better biological stabilization compared to the 16 weeks sample and the untreated MSW. Therefore longer periods of aerobic treatment do not guarantee better waste biological stability.

Gas production

Figure 7.11 to Figure 7.14 present the cumulative biogas production results. The gas productions at 21 days accompany the graphs. A brief discussion of results is presented after Figure 7.14. The untreated MSW did not produce methane gas up to 9 weeks of incubation, hence it was always at the acid stage, therefore the results of the untreated waste are not reported. Appendix G shows the percent composition of methane, carbon dioxide and oxygen obtained during the gas production test.

Figure 7.11 presents the cumulative gas production for 16 weeks pre-treated global sample.

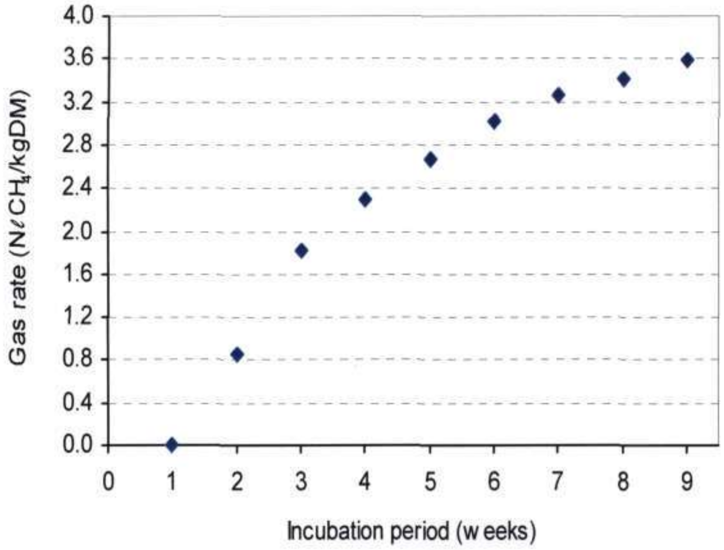

Figure 7.11 Cumulative gas production for 16 weeks unsorted global sample – cell 5

Gas production at 21 days is 1.83 NℓCH_4/kg DM

The cumulative gas production for the 16 weeks pre-treated fines is shown on Figure 7.12 below.

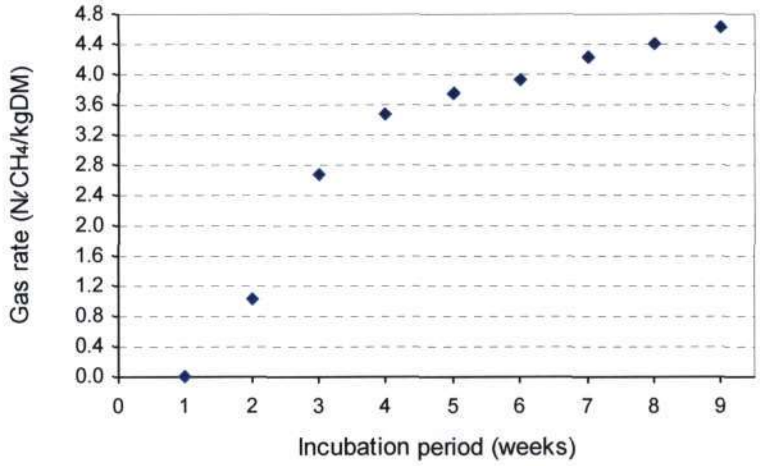

Figure 7.12 Cumulative gas production for 16 weeks pre-treated fines – cell 2

Gas production at 21 days is 2.67NℓCH_4/kg DM

Figure 7.13 presents the cumulative gas production for 8 weeks pre-treated unsorted global sample.

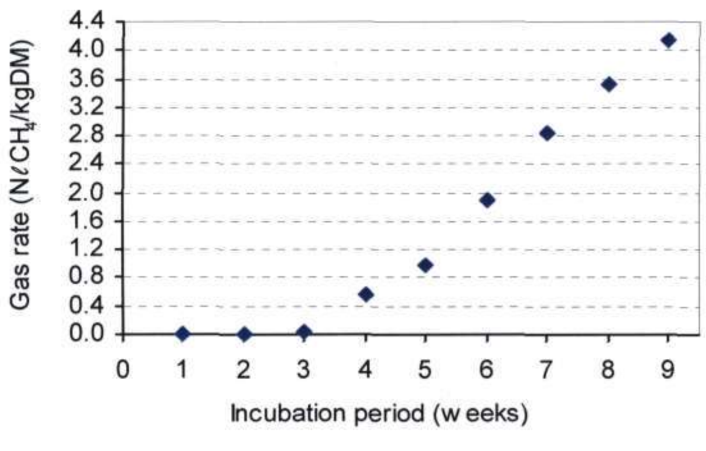

Figure 7.13 Cumulative gas production for 8 weeks pre-treated unsorted global sample – cell 3

Gas production at 21 days is 1.90 NℓCH_4/kg DM, when ignoring the first 3 weeks of testing because gas production had not begun.

The cumulative gas production for the 8 weeks pre-treated fines is presented on Figure 7.14 below.

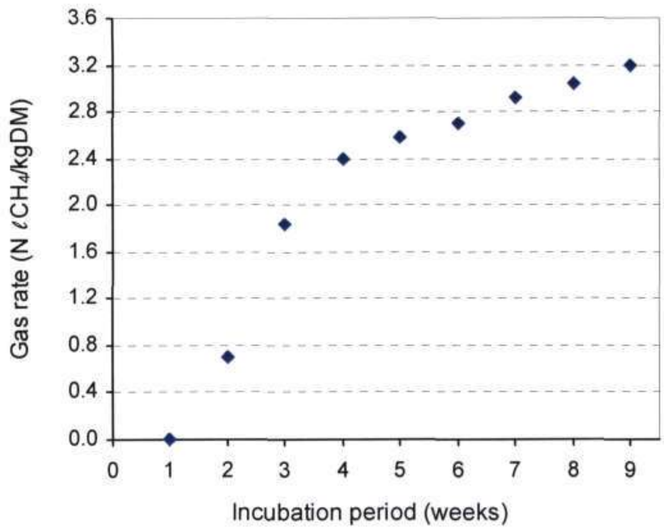

Figure 7.14 Cumulative gas production for 8 weeks fines – cell 1

Gas production at 21 days is 1.84 NℓCH_4/kg DM.

Table 7.4 below presents a summary of the gas production rates of the treated waste samples

Table 7.4 The summary of the gas production test

Waste Type	**Gas Production At 21 Days (NℓCH_4/kgDM)**
16 weeks global – cell 5	1.83
16 weeks fines – cell 2	2.67
8 weeks global – cell 3	1.90
8 weeks fines – cell 1	1.84

The rate of gas production for the 16 weeks treated fines was 45 percent higher than its global sample. The difference may be due to a higher content of readily biological degradable fraction in the fines. The gas productions for the 16 weeks pre-treated global sample and its fine material were 1.83 NℓCH_4/kg DM and 2.67 NℓCH_4/kg DM, respectively. There was no remarkable difference in the gas production for the 8 weeks pre-treated global sample and the 8 weeks fine material. The gas productions for the 8 weeks pre-treated global sample 8 weeks treated fine material were 1.90 NℓCH_4/kg DM and 1.84 NℓCH_4/kg DM, respectively. Generally, the 8 weeks pre-treated samples showed a lower gas production potential than the 16 weeks sample.

Consequently, it may be concluded that longer pre-treatment periods do not guarantee better waste stability, but it is more prone to dessication and therefore displays a lower efficiency.

Solid matter and eluate characteristics

The moisture content, volatile solids, total solids and eluate characteristics results are presented from Table 7.5 to 7.13. It is worth noting that all the eluate results presented in this section were prepared using a solid : liquid ratio of 1:10 prepared in 24 hours. Table 7.13 presents a summary of the treated MSW versus the untreated MSW.

Table 7.5 below presents the percent moisture content, volatile solids and total solids for the 16 weeks pre-treated unsorted global sample.

Table 7.5 Percent moisture content, volatile solids and total solids for 16 weeks unsorted global sample

Parameter *Statistics*	**Percent Moisture Content**	**TS (g DM/g)**	**VS (g/gDM)**
Mean (Arithmetic)	***17.8***	***0.822***	-

From Table 7.5, it can be seen that the 16 weeks global sample was dry at the beginning of the experiment.

Table 7.6 presents the eluate characteristics from the 16 weeks pre-treated unsorted global sample.

Table 7.6 Eluate characteristics for 16 weeks unsorted global sample.

Parameter ***Statistics***	**COD (mgO_2/ℓ)**	**BOD_5 (mg/ℓ)**	**NH_3 (mg/ℓ)**	**NOx (mg/ℓ)**	**pH**	**Cond. ($\mu S/cm$)**
1	2171	385	0.936	0.05	--	--
2	2367	427	0.949	0.06	--	--
Mean	***2269***	***406***	***0.943***	***0.055***	***7.14***	***1.37E-04***
Std dev.	*139*	*29.7*	*0.01*	*0.01*	--	--
Variance	*19208*	*882*	*0.0*	*0.001*	--	--
Range	*196*	*42.0*	*0.013*	*0.010*	--	--
%Coef.Variation	***6.11***	***7.31***	***0.975***	***12.9***	--	--

$BOD_5/COD = 0.179$

The 16 weeks global sample had a low biodegradable fraction of waste as shown by the low BOD_5/COD ratio. However, the COD remained high despite 16 weeks aerobic treatment. The accuracy of the results was satisfactory because all parameters, except for NOx, recorded a percent coefficient of variation of less than 10 percent from the mean as presented in Table 7.6.

Table 7.7 below shows the percent moisture content, volatile solids and total solids for the 16 weeks pre-treated fines.

Table 7.7 Percent moisture content, volatile solids and total solids for 16 weeks fines

Parameter Statistics	**Percent Moisture Content**	**TS (g DM/g)**	**VS (g/gDM)**
1	9.43	0.365	0.425
2	8.90	0.168	0.242
3	13.6	0.363	0.449
4	11.7	0.258	0.345
Mean	***11.4***	***0.263***	***0.345***
Std dev.	*2.36*	*0.098*	*0.104*
Variance	*5.56*	*0.010*	*0.011*
Range	*4.69*	*0.195*	*0.207*
%Coefficient of variation	***20.7***	***37.1***	***30.0***

The 16 weeks fines had a very low moisture content at the beginning of the experiment. All the tests done on solid matter showed a percent variation from the mean of at least 20 percent, as presented on Tale 7.7 above. This is due to the highly heterogeneous MSW.

The eluate properties for the 16 weeks fines are presented in table 7.8.

Table 7.8 Eluate characteristics for 16 weeks fines

Parameter *Statistics*	**COD** (mgO_2/ℓ)	**BOD_5** (mg/ℓ)	**NH_3** (mg/ℓ)	**NOx** (mg/ℓ)	**pH**	**Cond.** ($\mu S/cm$)
1	1882	235	0.788	0.148	--	--
2	1859	235	0.85	0.148	--	--
3	1882	224	--	--	--	--
Mean	***1874***	***231***	***0.819***	***0.148***	***7.52***	***1.35E-04***
Std dev.	*13.279*	*6.351*	*0.044*	*0*	--	--
Variance	*176*	*40.3*	*0*	*0*	--	--
Range	*13.0*	*0.012*	*0.01*	*0.012*	--	--
%Coef.Var	***0.71***	***2.7***	***5.353***	***0***	--	--

$BOD_5/COD = 0.123$

The BOD_5/COD ratio was low suggesting that the 16 weeks fines had a low content of biodegradable fraction despite the high overall value of organic compounds as shown by the high COD value. All the results showed a good central tendency as seen in Table 7.8, hence it may be concluded that the fines were less heterogeneous than the unsorted samples.

Table 7.9 shows the percent moisture content, volatile solids and total solids for the 8 weeks unsorted global sample.

Table 7.9 Percent moisture content, volatile solids and total solids for 8 weeks unsorted global sample

Parameter ***Statistics***	**Percent Moisture Content**	**TS (g DM/g)**	**VS (g/gDM)**
1	27.1	0.730	0.360
2	23.1	0.769	0.357
3	34.1	0.659	0.486
4	29.1	0.709	0.621
5	32.7	0.673	0.459
6	31.0	0.690	0.414
Mean	***29.5***	***0.705***	***0.449***
Std dev.	*0.0403*	*0.0403*	*0.987*
Variance	*0.0016*	*1.62E-04*	*9.74E-03*
Range	*11.0*	*0.110*	*0.264*
%Coefficient of variation	***13.6%***	***5.7***	***22.0***

The moisture content of the 8 weeks global sample was not low. The waste also displayed more uniformity as seen from variation of results from the mean in Table 7.9 above.

Table 7.10 below presents the average values for the eluate characteristics of 8 weeks global sample.

Table 7.10 Eluate characteristics for 8 weeks global and fines samples

Parameter	**Mean values (Global Sample)**	**Mea values (Fines Sample)**
COD (mg/ℓ)	1750	1489
BOD_5 (mg/ℓ)	653	--
NH_3 (mg/ℓ)	1.06	0.520
NOx (mg/ℓ)	0.250	0.310
pH	7.13	7.34
Cond. (μS/cm)	1.16E-04	1.54 E-04
BOD_5/COD	0.373	--

The 8 weeks treatment was enough to lower BOD_5/COD ratio to 0.4 thus reducing the component of biodegradable matter. Both samples had a fairly high COD.

The following table, Table 7.11 presents the percent moisture content, volatile solids and total solids for the untreated MSW.

Table 7.11 Percent moisture content, volatile solids and total solids for untreated unsorted MSW

Parameter *Statistics*	Percent Moisture Content	TS (gDM/g)	VS (g/gDM)
1	40.7	0.593	0.698
2	60.3	0.397	0.712
3	36.6	0.634	0.763
4	47.9	0.521	0.628
Mean	***48.2***	***0.518***	***0.701***
Std dev.	*11.7*	*0.119*	*0.068*
Variance	*140.7*	*0.014*	*0.05*
Range	*23.7*	*0.237*	*0.050*
%Coefficient of variation	***24.6***	***22.9***	***9.7***

The moisture content of the untreated MSW was high. The variation high variation in the moisture content may be due to the different properties of MSW components to hold water. The total solids also showed a fairly high coefficient of variation from the mean whilst volatile solids gave a percent variation of less than 10 percent as observed in Table 7.11

The eluate characteristics of the untreated MSW are presented on Table 7.12.

Table 7.12 Eluate characteristics of untreated unsorted MSW

Parameter *Statistics*	COD (mgO_2/ℓ)	BOD_5 (mg/ℓ)	NH_3 (mg/ℓ)	NOx (mg/ℓ)	pH	Cond. ($\mu S/cm$)
1	2263	947	0.382	0.16		
2	2210	1036	0.394	0.136		
3	2335	1065				
Mean	***2269***	***1016***	***0.388***	***0.148***	***6.37***	***1.91E-03***
Std dev.	*62.7*	*61.490*	*0.008*	*0.017*		
Variance	*3952*	*3781.0*	*0.0*	*0.0*		
Range	*125*	*118.0*	*0.012*	*0.024*		
%Coeff variation	***2.77***	***6.1%***	***2.19***	***11.5***		

BOD_5/COD =0.448

The untreated MSW had a fairly high content of biodegradable material as shown by the high BOD_5 and the BOD_5/COD ratio. Generally the eluate results gave a low variation of results from the mean as seen from Table 7.13.

Table 7.13 below presents solid matter and eluate characteristics of the all the treated samples versus the untreated MSW.

Table 7.13 Eluate and solid matter characteristics of treated versus untreated MSW

Parameter	**(1) Untreated MSW**	**(2) 16 wks Global**	**(3) 16 wks Fines**	**(4) 8 wks Global**	**(5) 8 wks Fines**	**COMMENT (Higher or Lower than untreated)**
V.S (g/gDM)	0.701	--	0.345	0.449	--	All lower
T.S (gDM/g)	0.521	0.822	0.263	0.705	--	(2) and (4) higher, (3) lower
COD (mgO_2/ℓ)	2269	2269	1874	1750	1489	All lower, for (2) no difference
BOD (mg/ℓ)	1016	406	231	653	--	All lower
Nox (mg/ℓ)	0.388	0.055	0.148	0.250	0.310	All lower except (5)
NH_3 (mg/ℓ)	0.148	0.900	0.819	1.06	0.520	All higher
Cond. X 10^-4 ($\mu S/cm$)	1.91	1.37	1.35	1.16	1.54	All lower

From Table 7.14 above it can be observed that the untreated waste had the highest BOD than all other samples, implying that the aerobic treatment was effective in reducing the easily biodegradable fraction. Generally, the 16 weeks pretreated samples had a higher COD than the 8 weeks pretreated samples. Hence it may be concluded that longer periods of aerobic treatment do not guarantee better waste stability. Nonetheless, the untreated waste had a highest COD equal to the 16 weeks global, hence the results may be taken with caution. The untreated MSW had the highest volatile solids than the treated waste. From the conductivity results, all the treated samples had a lower conductivity. The conductivity is related to the solids content consequently it can be concluded that the aerobic treatment reduced the solids content. The untreated MSW had the highest and lowest values for NOx and N-NH3, respectively.

7.2 Emissions from the test cells

The test cells were irrigated and leachate produced was analyzed in the laboratory to determine COD, BOD, volatile solids, total solids, NOx, $N\text{-}NH_3$, pH and conductivity. Gaseous emissions were recorded in the field to determine temperature and percent gaseous composition (carbon dioxide, oxygen and methane). The results of leachate and gaseous emissions are presented below. Table 7.14 presents a summary of the flushing events for the test cells.

Table 7.14 A summary of the flushing event

Waste type	Irrigation volume (liters)
Untreated MSW	4650
16 weeks global	3020
16 weeks fines	2420
8 weeks global	320
8 weeks fines	600

Leachate

Figures 7.15 to 7.34 present the results of the leachate characteristics observed during the first flushing session. The figures show the trends of BOD and COD, solids (volatile and total) and conductivity, N-NH3 and NOx and pH. Below each figure there is a brief discussion of the results presented. There was an observed relationship between L/S ratio and lechate characteristics, which is shown by the relationship of COD, NH_3 and TS all versus L/S for each waste sample.

16 weeks global sample

Figure 7.15 below presents the trend of BOD and COD during the first flushing for the 16 weeks unsorted global sample.

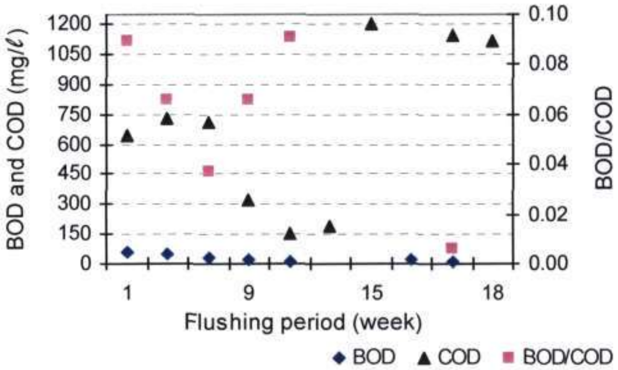

Figure 7.15 BOD and COD trend during the first flushing for the 16 weeks unsorted global sample

The highest maximum BOD_5, occurred during the first week of flushing and it gradually reduced as flushing progressed. It may therefore be concluded that the flushing event was able to further remove the biodegradable fraction of the waste. The COD started high and lowered with the progress of flushing. Following a 3 weeks break of flushing, the COD peaked and reduced gradually. The break and the changing in solubility of organic compounds may have influenced the pattern of the COD. The BOD/COD ratio was low ranging between 0.09 and 0.01.

The trends of TS, VS and conductivity for the 16 weeks unsorted global sample during the first flushing are shown in Figure 7.16 below.

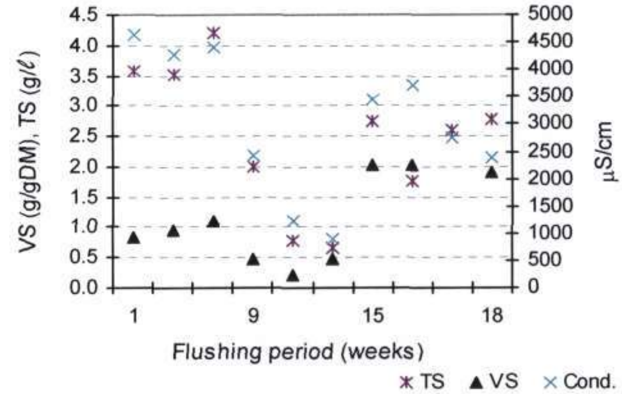

Figure 7.16 TS, VS and conductivity during the first flushing for the 16 weeks *unsorted global sample*

Conductivity, total solids and volatile solids recorded highest values during the first few week of flushing. Following a 3 weeks break of flushing, there was a local peak, and the last tail of the graph shows a descending trend, as seen from Figure 7.16. The conductivity shows a relative amount of solids in solution hence its pattern is similar to that of the TS and VS. The pattern can be attributed to the improved solubility of solids in water.

From Figure 7.17 below the changes in N-NH_3 and NOx during the first flushing for the 16 weeks global sample can be observed.

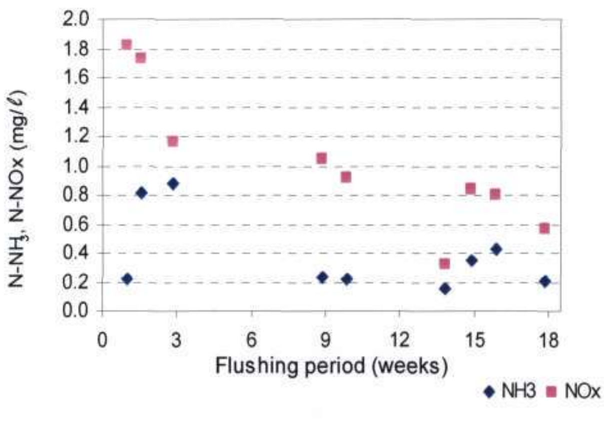

Figure 7.17 N-NH_3 and N-NOx during the first flushing for the 16 weeks global sample.

It can be observed from Figure 7.17 that both N-NH_3 and NOx reduced with the progression of flushing. Through out the flushing session, N-NOx was superior than N-NH_3 and N-NOx reduced with a reduction in N-NH_3, signifying potential oxidation of N-NH_3 to N-Nox similarly to an observation by Cappai (2005).

Figure 7.18 below shows the pH trend in the 16 weeks unsorted global sample during the first flushing.

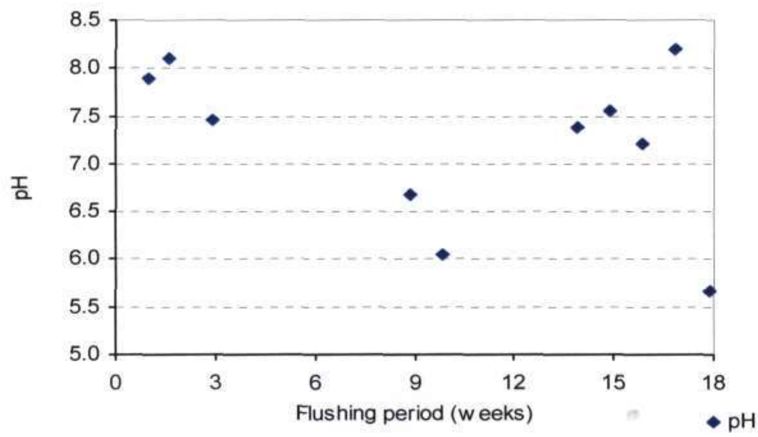

Figure 7.18 pH during the first flushing for the 16 weeks unsorted global sample

The pH ranged between acidic and alkaline conditions as seen on Figure 7.18. The highest pH was 8.11, obtained on week 2 of flushing and the lowest pH, 5.66, was recorded on week 18. Fluctuating pH may be due to the solubilization of carbon dioxide in water to form carbonic acid.

16 weeks fines

Figure 7.19, presents the BOD and COD behaviour for the 16 weeks fines.

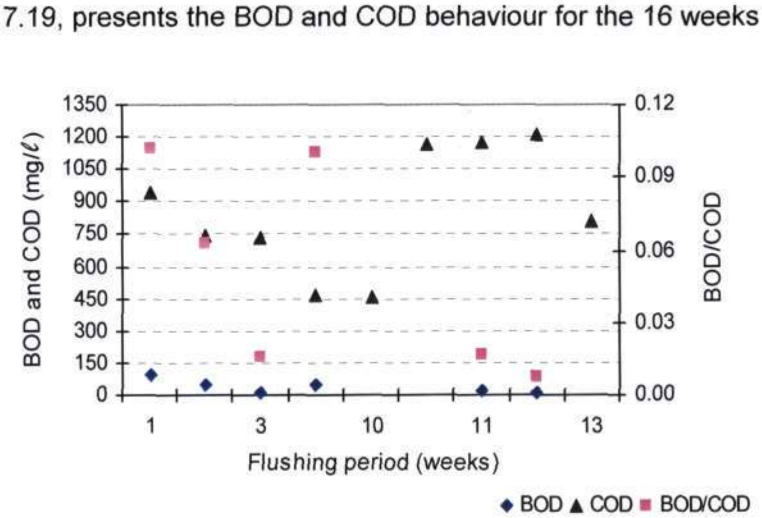

Figure 7.19 BOD and COD during the first flushing for the 16 weeks fines

The BOD_5 was highest at the beginning of flushing and gradually declined suggesting that the flushing was effective in reducing the biodegradable material of the waste. From The COD started high, declined, then it rose abruptly following a flushing break of 3 weeks. The COD reduced though as flushing continued, signifying a reduction in the organic load. The BOD/COD ratio was always low ranging between 0.01 and 0.1. Unsteady flow of water during flushing, an intermediate pause in the flushing event and solubility of solids could have resulted to the wave behaviour of the COD.

The trends for TS, VS and conductivity for the 16 weeks fines are presented the Figure 7.20 below.

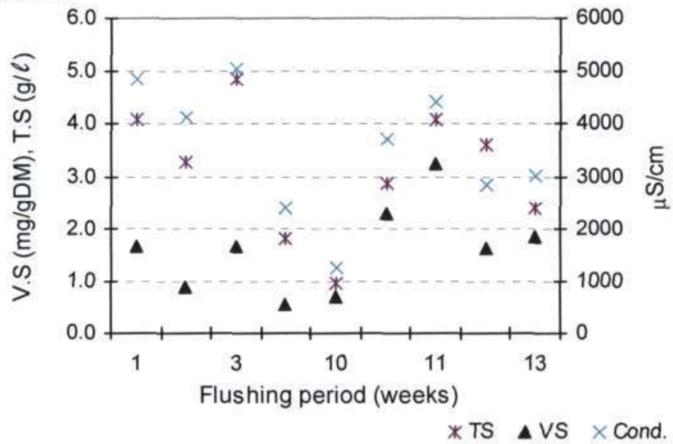

Figure 7.20 TS, VS and conductivity during the first flushing for the 16 weeks fines

The behaviour of the total solids, volatile solids and conductivity showed an initial decline to a minimum local level within 10 weeks of flushing there was a sudden rise, during week 11, to peak values and later a decline. The undulating pattern, as depicted on Figure 7.20, may due to the 3 weeks pause in flushing, variable solubility of organic compounds, efficiency of flushing and the flow pattern of water during flushing. The similar pattern of the evolution of TS, VS and conductivity suggests that all parameters represents solids in solution.

The behaviour of N-NH_3 and NOx for the 16 weeks fines is shown on Figure 7.21 below.

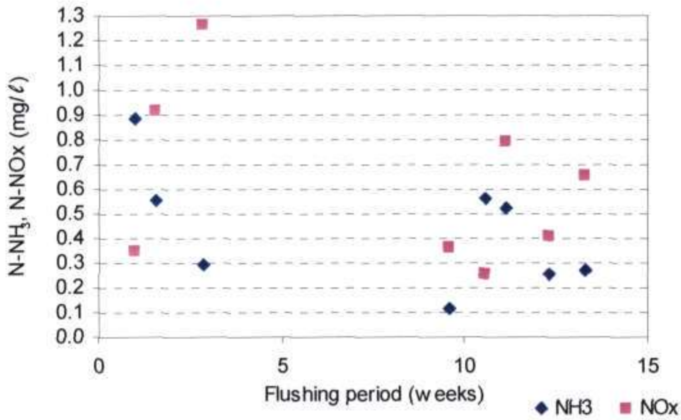

Figure 7.21N-NH3 and N-NOx during the first flushing for the 16 weeks fines

The nitrogen species showed a fluctuating pattern as seen in Figure 7.21. The range for the N-NOx is higher than for the N-NH_3. The higher range of N-NOx is likely to be caused by oxidation of organic nitrogen.

Figure 7.22 presents the pH values during the first flushing event for the 16 weeks fines.

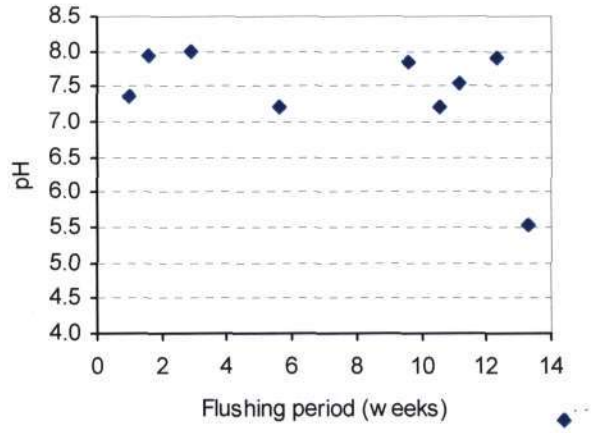

Figure 7.22 pH during the first flushing for the weeks treated fines

Generally, the pH was between 7 and 8 as shown in Figure 7.22. However, week 14 recorded a minimum pH of 5.54. The varying pH can be attributed to fluctuating flushing volumes of water and the dry periods which occurred during the flushing session.

8 weeks global

A presentation of BOD and COD for the 8 weeks unsorted global during the first flushing is given by Figure 7.23 below.

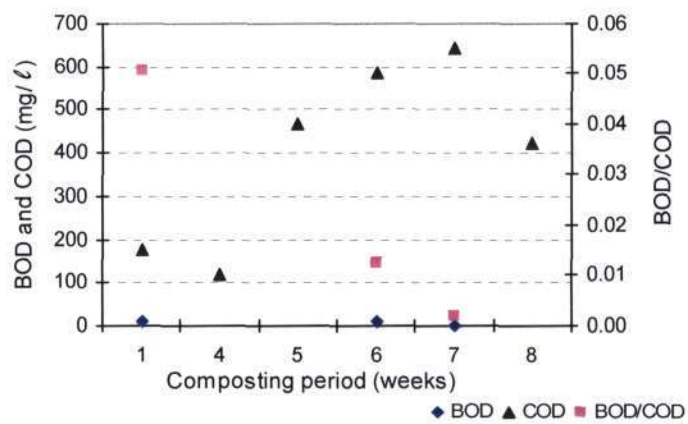

Figure 7.23 BOD and COD during the first flushing for the 8 weeks unsorted global sample

From Figure 7.23 the BOD_5 was always lower than 10 mgO_2/ℓ, signifying good biological stability of waste. The initial decline in the COD may be due to the low initial solubility of organic compounds in water, the fluctuating volume of water during flushing and the dry period during the flushing session.

The BOD/COD dropped from 0.05 to 0.002 showing a good waste stability.

Figure 7.21 gives a presentation of TS, VS and conductivity observed during the first flushing for the 8 weeks unsorted global sample.

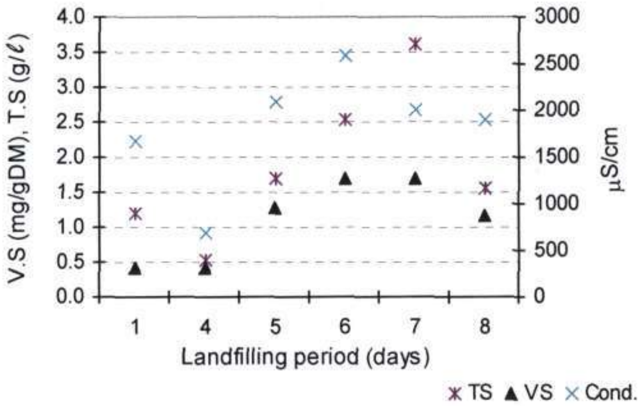

Figure 7.24 TS, VS and conductivity during the first flushing for the 8 weeks unsorted global sample

Conductivity, total solids and volatile solids were initially low and as flushing progressed, the parameters rose to a peak value after week 7 and finally declined. The 3 weeks break in flushing, improved solubility of solids and unsteady flushing volumes might have resulted in the fluctuation of these parameters. The TS, VS and conductivity showed a similar pattern suggesting that all the parameters measure dissolved solids.

The $N\text{-}NH_3$ and NOx trends during the first flushing for the 8 weeks unsorted global sample are presented in Figure 7.25.

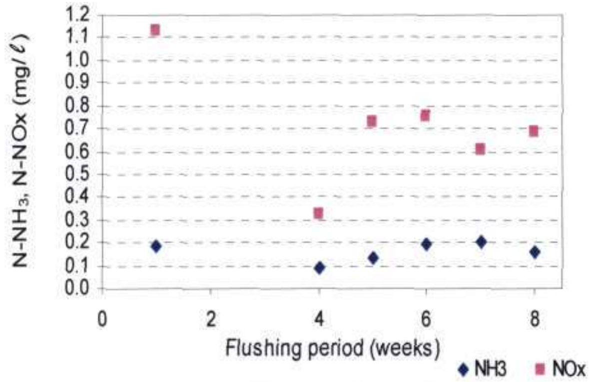

Figure 7.25 N-NH_3 and N-NOx during the first flushing for the 8 weeks unsorted global sample

There was no observed change in N-NH_3 with quantities as shown in Figure 7.25. The amount of NOx was always above NH_3, suggesting a potential oxidation of NH_3 to NOx.

The changes in pH for the 8 weeks unsorted global sample are presented in Figure 7.26 below.

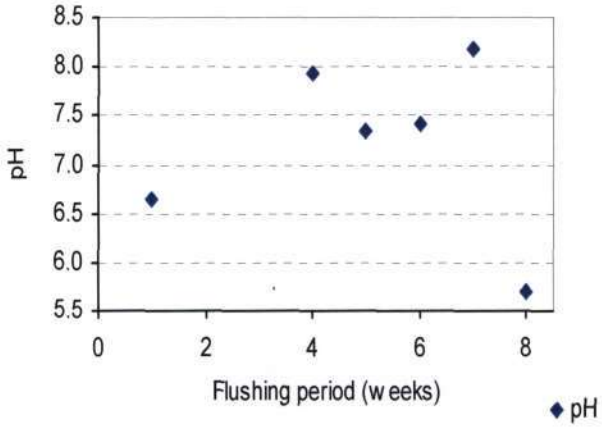

Figure 7.26 pH during the first flushing for the 8 weeks unsorted global sample

Figure 7.26 shows that the initial pH ranged between slightly acidic and alkaline conditions as seen on Figure 7.26. Leachate pH can drop due to slight fermentation of simpler organic compounds to form organic acids and dissolution of acidic gases in water to form weak acids.

8 weeks fines

The evolution of BOD and COD for the 8 weeks fines is shown in Figure 7.2.

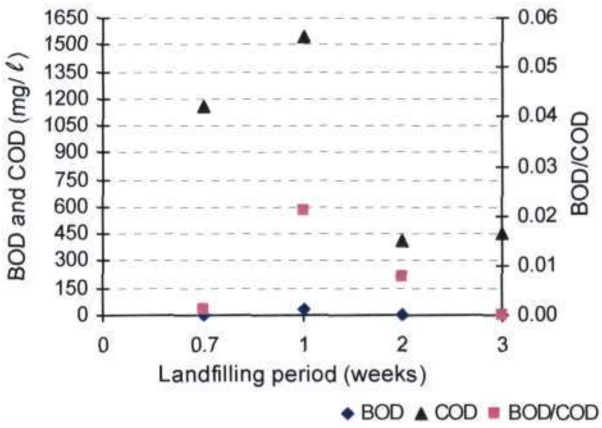

Figure 7.27 BOD and COD during the first flushing for the 8 weeks fines

There was a remarkable dcrease in BOD and COD showing the efficiency of flushing through the fines. The highest and final BOD/COD ratios were 0.02 and 0.008, respectively. The fines showed a rapid decline in the organic contents after flushing.

Figure 7.28 presents the TS, VS and conductivity behaviour of the 8 weeks fines observed during the first flushing.

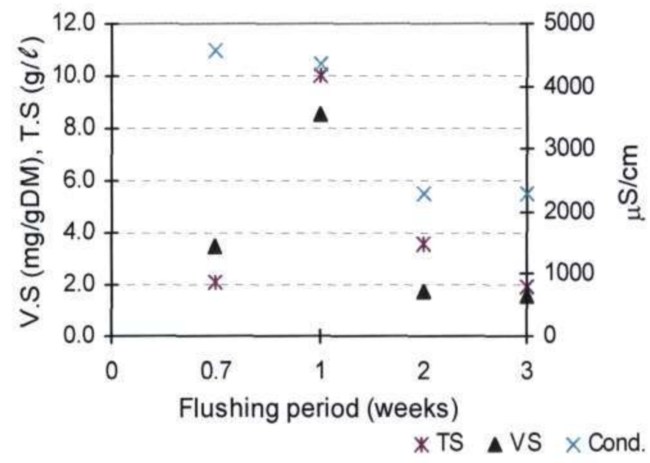

Figure 7.28 TS, VS and conductivity during the first flushing for the 8 weeks fines

Conductivity, volatile solids and total solids all reduced in a similar manner asserting that the parameters give a relative measure of solids, as shown by Figure 7.28. All the parameters reduced with the progression of flushing suggesting that the flushing was effective in removing solids.

The next figure, Figure 7.29, presents the $N\text{-}NH_3$ and NOx observed during the first flushing of the 8 weeks fines.

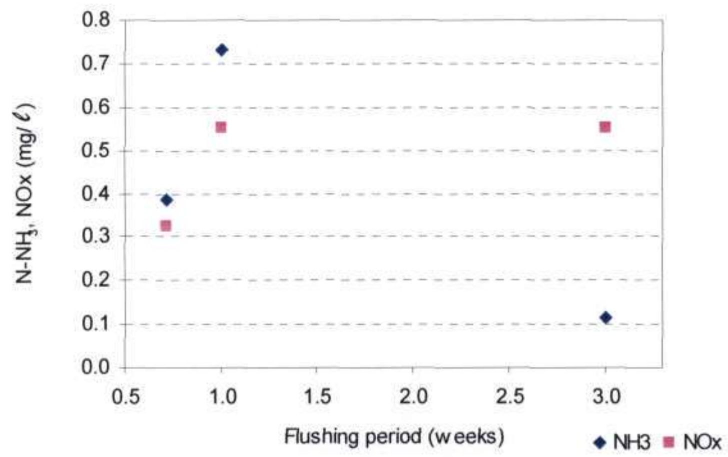

Figure 7.29 $N\text{-}NH_3$ and N-NOx during the first flushing for the 8 weeks fines

The N-NOx shows a gradual increase during the flushing session, which may be attributed to constant oxidation of organic and humic nitrogen. The $N\text{-}NH_3$ reduced drastically as flushing continued to suggest a reduction in the nitrogen content.

Figure 7.30 below presents the changes in the pH during the first event of flushing for the 8 weeks fines.

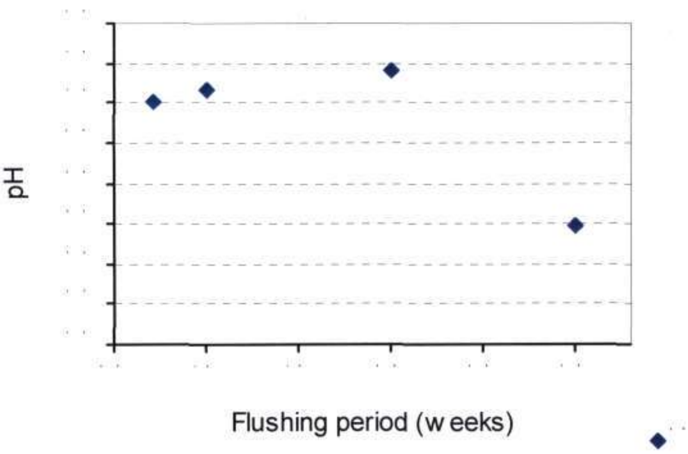

Figure 7.30 pH trend during the first flushing for the 8 weeks fines

Initially the pH was generally neutral and gradually decreased to an acidic region after 3 weeks of flushing as shown on Figure 7.30. The later reduction of the pH could be due to fermentation of organic compounds, which escaped stabilization during aerobic windrow treatment.

Untreated MSW

Figure 7.31 gives a presentation of BOD and COD for untreated MSW observed during the first flushing event.

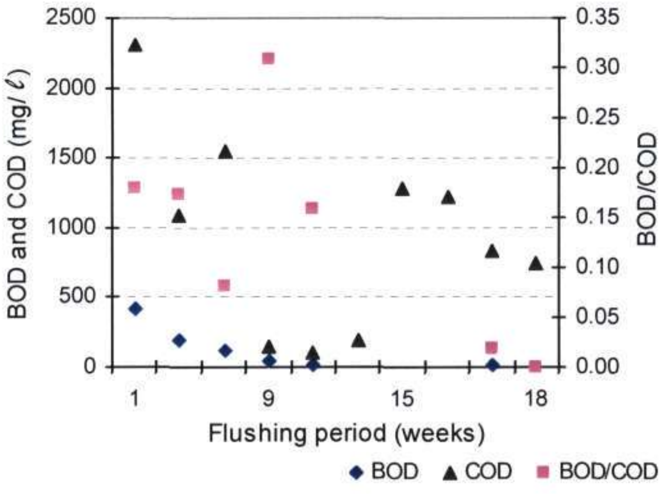

Figure 7.31 BOD and COD during the first flushing for the untreated MSW

The BOD gradually declined from an initially high value to suggest the efficiency of removal of biodegradable fractions by the flushing. The solubility of leachable compounds, unsteady flushing volume and the 3 weeks break in flushing could have result to the fluctuating pattern of the COD, as seen in Figure 7.31. The maximum BOD/COD was 0.31 and it reduced rapidly to 0.02 within 18 weeks of flushing.

The trends of TS, VS and conductivity for the untreated MSW are presented in the following figure, Figure 7.32.

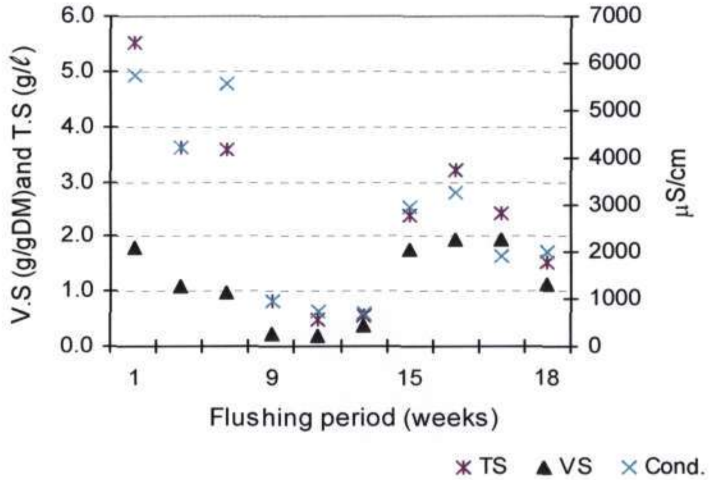

Figure 7.32 TS, VS and conductivity during the first flushing for the untreated MSW

From Figure 7.32, it can be observed that conductivity, total solids and volatile solids displayed a similar fluctuating pattern. The changing volumes of flushing, improved solubility of solids with time and the dry period during flushing could have resulted in the fluctuating pattern. The TS, VS and conductivity measure a relative amount of dissolved solids hence that defines their similar behavioural patterns as seen in Figure 7.32.

Figure 7.33 presents the trend of $N\text{-}NH_3$ and NOx observed during the first flushing of untreated MSW.

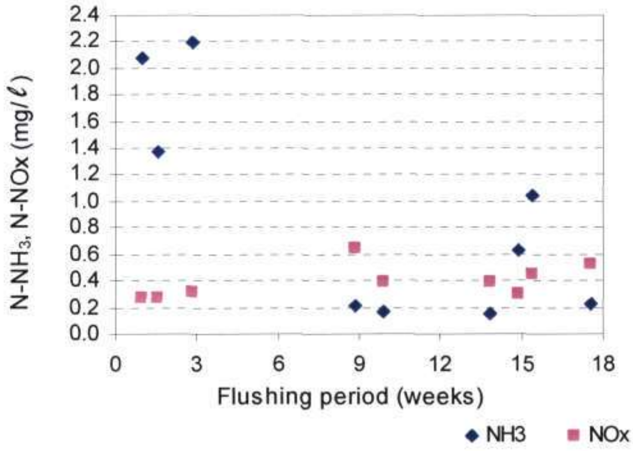

Figure 7.33 $N\text{-}NH_3$ and N-NOx during the first flushing for the untreated MSW

The $N\text{-}NH_3$ started high and reduced with the flushing due to the removal of nitrogen and an ongoing nitrification process. N-NOx slightly increased as flushing progressed. The slight increase of the N-NOx could be the product of the oxidation of organic nitrogen.

The evolution of pH during the first flushing for the untreated MSW is presented in Figure 7.34 below.

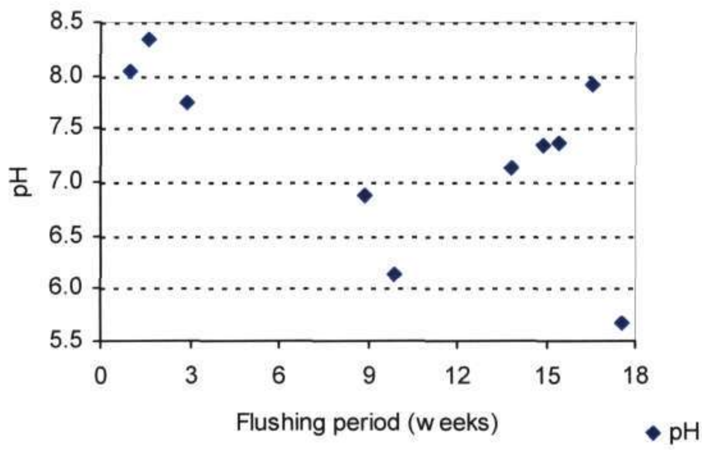

Figure 7.34 pH during the first flushing for the untreated MSW

The minimum and maximum pH were 5.8 and 8.3, respectively. From Figure 7.34, the pH kept fluctuating between the maximum and minimum pH values due to different flushing volumes of water and solubility of organics in water.

7.3A summary of the behaviour of leachate parameters

To give a general overview of the behaviour of the leachate parameters, the fluctuating trends are likely to be caused by the dry period in flushing. In a similar study by Blakey *et al* (1997) peaks of COD were observed after moisture addition. There is a possibility of the nitrification of ammonia during flushing. Cappai *et al* (2005) state that ammonia nitrification plays a major role to the small concentrations of nitrates and nitrites (NOx) in landfilled MBP waste. The flushing also contributed to the rapid reduction of organic compounds. Catalani and Cossu (1999) state that *high flushing rate caused a transfer of organic compounds from the solid to liquid* phase.

Gaseous emissions

Some of the gaseous emissions were analyzed together with (Chetty, 2006). The cells were operated as flushing bioreactors with prolonged aeration. Consequently, they remained aerobic through out the simulation. Figures 7.35 to 7.39 show percent gas composition of test gaseous emissions from the cells. The percent gas composition was measured with a gas analyzer as explained in Section 6.4. Gas probes are shown in Figure 4.1

Figure 7.35 presents the percent compositions (Volume/Volume Air) of oxygen, carbon dioxide and methane and temperature from the cells.

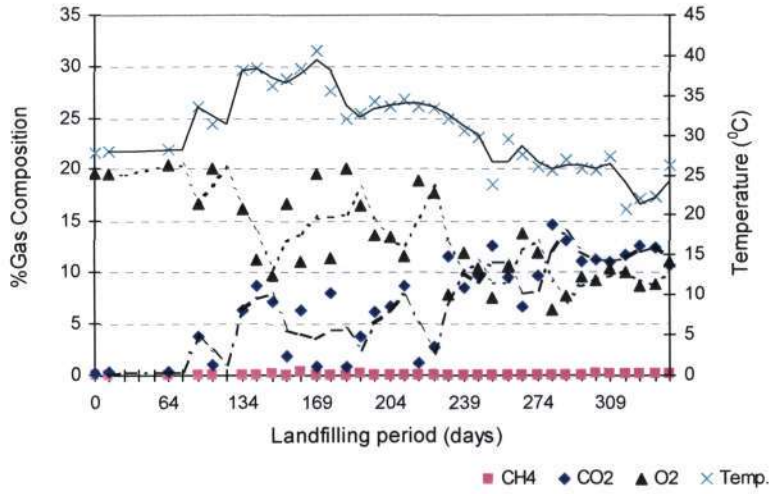

Figure 7.35 Gas emissions for cell 5 - 16 weeks unsorted global sample

The first day and last day of flushing were day 72 and day 197, respectively. The content of CH_4 was always less than 0.1%. The CO_2 and O_2 ranged between 3.78 to 14.6% and 6.23 to 20.4%, respectively. The low CO_2, content is low gaseous emission normally emitted by 'dry' landfills, suggesting that flushing and aeration can make a potential reduction in gas emission. The maximum temperature and minimum temperature were 27.7°C and 40.7°C, respectively.

The gaseous emissions and temperature for the 16 weeks fines are illustrated in the following figure, Figure 7.36.

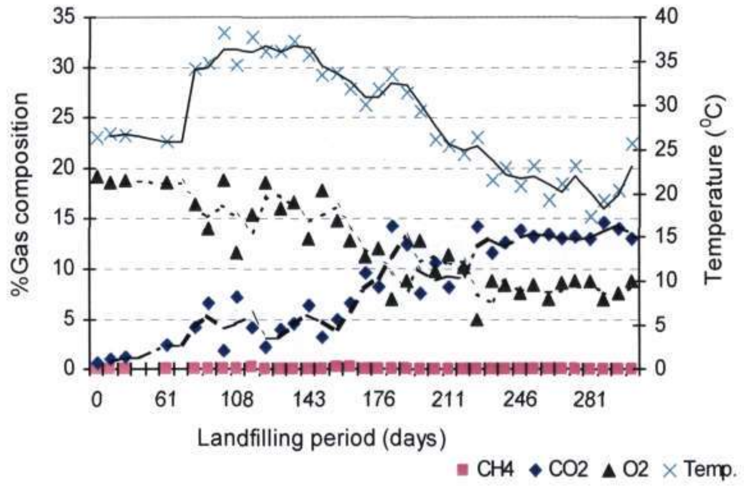

Figure 7.36 Gas emissions for cell 2 - 16 weeks fines

The first day and last day of flushing were day 69 and day 162, respectively. The duration of flushing was 93 days. The volumetric content of CH_4 was always less than 0.1%; The CO_2 and O_2 had a range of 2.4 to 14.5% and 5.03 to 19.3%, respectively. The maximum temperature and minimum temperature were 38.1^{0}C and 17.4^{0}C, respectively.

Figure 7.37 presents the percent compositions (Volume/Volume Air) of oxygen, carbon dioxide and methane and temperature for the 8 weeks unsorted global sample.

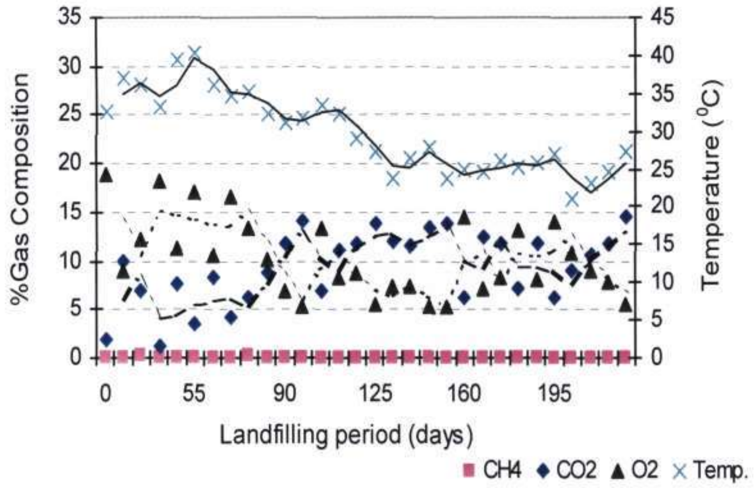

Figure 7.37 Gas emissions for cell 3 - 8 weeks global sample

First day of flushing was day 27 and the last day of flushing was day 83. The volumetric contents of CH_4 was at all times less than 0.1%; CO_2 ranged from 1.2 to 14.0%;and O_2 was between 5.63 and 18.9%. Relatively low contents of the greenhouse gases (CO_2 and CH_4) may imply that the prolonged aeration and flushing were effective in reducing the gasefiable carbon. The maximum temperature and minimum temperature were 40.2^{0}C and 21.0^{0}C, respectively.

The gaseous emissions and temperature for the 8 weeks fines are presented in Figure 7.38 below.

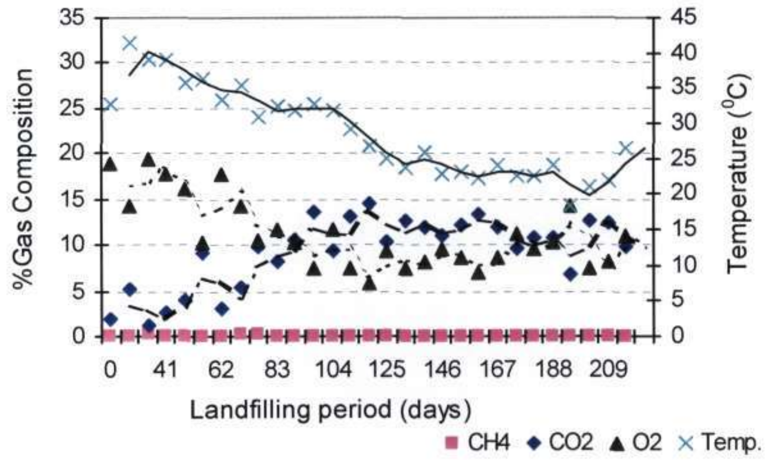

Figure 7.38 Gas emissions for cell 1- 8 weeks fines

First day of flushing was day 55 and the last day of flushing was day 76. The volumetric content of CH_4 was always less than 0.1%. CO_2 and O_2 ranged from 1.08 to 14.6% and 5.70 to 19.40%, respectively. The low contents of CO_2 and CH_4, compared to a traditional landfill, may be due to the efficiency of the passive aeration and flushing in reducing the amount of carbon that could be lost as gaseous emissions. The maximum temperature was 41.5^{0}C; with a minimum temperature of 18.3^{0}C.

The gaseous emissions and temperature for cell 4 (untreated MSW) are presented below.

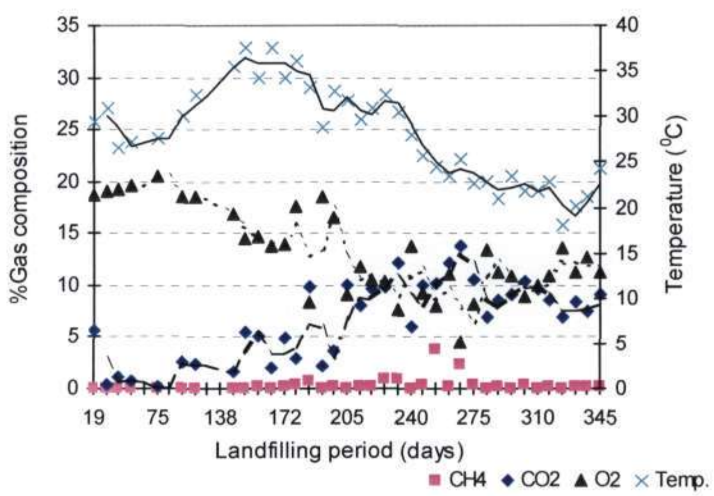

Figure 7.39 Gas emissions for cell 4 – untreated MSW.

The first day of flushing was day 75 and the last day of flushing was day 198. The volumetric contents of the gases were: CH_4 was always less than 0.1%; CO_2 ranged from 2.6 to 13.8%;and O_2 stayed between 4.46 and 18.9%. Despite having untreated waste, cell 4 showed low contents of the greenhouse gases. Such an observation could be attributed to the efficiency of flushing and passive aeration in reducing gaseous emissions. The temperature range was 40.2^{0}C to 37.6^{0}C.

7.4 A summary of the behaviour of gaseous emissions

From the figures above it is noted that all cells remained aerobic through out the landfill simulation period. There was an initial increase in temperature and gradually declined with age of landfilling. The oxygen content started at 21% and constantly declined to as low as 5.03 %. A small quantity of methane was detected (on average less than 0.1 % concentration by volume). Therefore cells were operated according to the PAF model. Unlike the traditional 'dry' anaerobic landfill, small fraction of carbon was lost as CO_2 , which was a good sign of the PAF model in reducing carbon gaseous emission. Landfill gas normally contains about 30 to 35 percent and 40 to 50 percent of CO_2 and CH_4, respectively.

CHAPTER 8

SUMMARY DISCUSSION AND CONCLUSIONS

Conclusions drawn from the analysis of the efficiency of the using of aerated windrows, the advantages of pre-treating municipal MSW over the traditional method of landfilling untreated waste and the efficiency of the PAF model in shallow landfills are presented in this chapter.

SUMMARY DISCUSSION

8.1 The efficiency of the use of windrows for waste pretreatment

The DAT functions relatively well in the climatic conditions of Durban, South Africa because composting temperatures rose to a maximum of above 60^0C within 10 days of composting.

Windrow 1 and 2

The windrows were effective in reducing the organic load of MSW. After 8 weeks of treatment, the BOD_5 was reduced by 64.1 percent, suggesting a reduction in the easily biodegradable compounds. The COD also reduced by 47.3 percent signifying a reduction in the carbon content. The ratio of the BOD_5 / COD dropped from 0.319 to 0.259 by 19.8 percent signifying a better waste stability. There was a drop in the solid contents which was shown by a decrease in volatile solids and conductivity by 58.1 and 39.8 percent, respectively. Within 8 weeks of aerobic treatment, ammonical nitrogen and NOx reduced by 61.2 and 85.4 percent, respectively. After 16 weeks of aerobic treatment the BOD_5 / COD declined from 0.319 to 0.179 making a 43.9 percent reduction.

Windrow 3

There was a 35.7 percent drop in the BOD_5 after 8 weeks of aerobic treatment. The COD lowered by 22.9 percent. The solid content showed a reduction by 35.9 and 93.9 percent in the volatile solids and conductivity, respectively. There was a 9.4^0C and 6.0^0C increase in temperature following two irrigation sessions. Hence microbial activity during aerobic treatment can be improved by moisture addition.

8.2 Biological stability of global samples, fines and untreated MSW

The 8 weeks samples showed less gas production rate when compared to the 16 weeks samples. The rates of gas production at 21 days for the 8 weeks global sample and 8 weeks fines were 1.90 $NlCH_4$/kg DM and 1.84 $N\ell CH_4$/kg DM, respectively. Whilst the 16 weeks global sample and 16 weeks fines recorded 1.83 $N\ell CH_4$/kg DM and 2.67 $N\ell CH_4$/kg DM, respectively. The 16 weeks fines had a higher rate of gas production than its global sample suggesting more biodegradable compounds in the former. There was no marked difference for gas production within the 8 weeks samples.

The untreated MSW showed a higher biological activity than all the other samples. The RI_4 for untreated MSW was 7.54 mgO_2/gDM. The 8 weeks global sample and 8 weeks fines had an RI_4 of 7.51 mgO_2/gDM and 2.48 mgO_2/gDM. Whilst the 16 weeks global and fine samples recorded 5.93 mgO_2/gDM and 7.00 mgO_2/gDM, respectively. Generally, the 16 weeks samples had a higher biological activity than the 8 weeks samples. The longer period of aerobic treatment did not achieve better waste stability. The poor waste stability of the 16 weeks samples could be attributed to desiccation of windrows 1 and 2 after 8 weeks of treatment. Notable from the 16 weeks samples was a higher Ri_4 for the fines than the global samples. It may be concluded that the fines had more biological active material than the global sample.

8.3 Efficiency of the PAF model

From the leachate emissions, untreated MSW showed an initial highest COD, the fines displayed a higher content than the respective global samples. The results of initial and final COD following the first flushing are shown n Table 8.1 below.

Table 8.1 Initial and final COD after first flushing (mg/ℓ)

COD	Untreated MSW	16 Weeks Global	16 Weeks Fines	8 Weeks Global	8 Weeks Fines
Initial	2303	640	943	178	1158
Final	747	113	806	423	452

Despite the longest flushing periods and highest flushing volumes, the 16 weeks treated global sample, 16 weeks treated fines and untreated MSW showed the highest initial and final COD values. Despite low flushing volumes and short flushing durations, the 8 weeks pretreated global and respective fines had the lowest initial and final COD values.

The BOD results show a similar trend to the COD. The results are presented in Table 8.2 below.

Table 8.2 Initial and final BOD after first flushing (mg/ℓ)

BOD	Untreated MSW	16 Weeks Global	16 Weeks Fines	8 Weeks Global	8 Weeks Fines
Initial	413	57.1	96.2	9.00	32.7
Final	16.2	7.10	9.20	1.20	3.10

The 8 weeks treated global sample and 8 weeks treated fines had the lowest initial and final BOD values. The second low BODs were the 16 weeks treated global sample and the respective fines. Untreated MSW showed the highest values of initial and final BOD.

The BOD/COD ratio for the 8 weeks fines was always less than 0.001 and for the global sample it reduced from 0.05 to 0.001. For the 16 weeks global sample and fines the BOD/COD ratios reduced from 0.09 to 0.006 and from 0.01 to 0.008, respectively. The untreated MSW had the highest BOD/COD ratio which declined from 0.18 to 0.02. From all the samples there was at least a 70 percent decrease in the ammonical nitrogen, except for the 8 weeks global sample. The NOx was always higher in concentration than ammonical nitrogen and its content was decreasing similarly to the ammonical nitrogen, suggesting a potential oxidation of ammonical nitrogen. It may be concluded that the fine material showed a rapid decline in the organic load as seen from the leachate than the global samples. The untreated MSW had the highest concentration of organic materials as shown by the leachate results. The gas composition results gave a CO_2 content of less than 15 percent, hence gaseous emissions' concentration is reduced with shallow flushed landfills.

CONCLUSIONS

Landfilling untreated MSW can result in long periods to reduce organic loads in leachate than MBP waste as suggested by literature. Separate collection of waste can also facilitate landfilling of MBP waste. Separately collected MBP waste contains more easily biodegradable fractions than the respective global unsorted samples, hence the former would result in a rapid biodegradation under landfill conditions. As suggested by literature size reduction results in a faster rate of degradation than in unreduced sizes. Flushing is an effective way of rapidly reducing the organic load in MSW Shallow landfill sites located in rainy areas. Research is needed to define the most appropriate period for aerobic treatment and the operational strategies for implementing the PAF model at full.

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