INFLUENCE OF THE DEGREE OF WASTE PRE-TREATMENT ON CARBON EMISSIONS' PRODUCTION AND NATURE

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ABSTRACT

This study was carried out to gain knowledge of the degradation processes in an anaerobic environment of pre-treated waste for different degrees of pre-treatment and the evolution of waste pre-treatment by forced aeration. Pre-sorted MSW (MSW) was pre-treated by composting for 16 weeks in a laboratory scale using forced aeration. Oxygen concentrations were maintained at 15-18% of oxygen in air for the first 8 weeks and 10-15 % for the later 8 weeks. The ambient temperature was kept constantly between of 20-35 °C. Representative samples of waste from the reactor were collected every fortnight wherein analysis and full characterisation on the solid matter (C/N ratio, TS and VS, RI7, Biogas) and on the eluate (BOD, COD, TOC, TKN, Conductivity, pH, NOx and $NH_{3)}$) were conducted.

The process showed a sharp increase in temperature in the first 6 weeks, ranging from 30-70 °C indicating a period of high biological activity, a decrease from day 30 to day 50 from 70 to 30 °C and a consistent decrease throughout the later days of the process from 35-25 °C. The sharp increase in temperature signifies a period of maximum biological activity, where readily biodegradable material decomposes as well as some of the resistant materials pointing out the success and efficiency of the forced aeration process. For the first 25 days in an anaerobic environment, waste pre-treated for four weeks was the most active, indicated by a large volume of gas produced. For the MSW pre-treated for 8, 10, 12 and 16 the volume of gas produced remained basically similar throughout the length of the experiments. CH_4 production in an anaerobic reactor shows an increasing trend for all degrees of stabilisation up to 6 weeks, after that the gas production and quality deceases and is comparable to the remaining degrees of treatment.

A gradual decrease in concentration of key parameters (organics) analogous to the European limit in Europa (1998), were observed after 5 weeks pre-treatment. The study highlighted that the highest efficiency of pre-treatment is achieved in 6 to 8 weeks and, therefore it is not recommended to prolong the treatment any further.

PREFACE

I, Miranda Kahndi Asah, hereby declare that the whole of this dissertation is my own work and has not been submitted in part, or in whole to any other University. Where use has been made of the work of others, it has been duly acknowledged in the text. This research work was carried out in the School of Civil Engineering, Surveying and Construction, University of KwaZulu-Natal, Durban, under the supervision of Dr Cristina Trios.

....	....
Miranda Kahndi Asah	Date

As the candidates supervisor I have approved this dissertation for submission

....	....
Dr Cristina Trois	Date

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TABLE OF CONTENTS

ABSTRACT ii
PREFACE iii
ACKNOWLEDGEMENTS iv
TABLE OF CONTENTS v
LIST OF FIGURES x
LIST OF TABLES xii
LIST OF PLATES xiii
LIST OF ABBREVIATIONS

CHAPTER 1 1

INTRODUCTION 1

- 1.1 General Background 1
- 1.2 Aims and Objectives of Study 3
- 1.3 Methodology 4
- 1.4 Scope of the Dissertation 4

CHAPTER 2 5

LITERATURE REVIEW 5

- 2.1 Introduction to Waste Management 5
- 2.2 Waste Biodegradation Processes in the Landfill 6
  - 2.2.1 Hydrolysis or Aerobic Degradation 6
  - 2.2.2 Hydrolysis and Fermentation 7
  - 2.2.3 Acetogenesis 7
  - 2.2.4 Methanogenesis 8
  - 2.2.5 Oxidation 9
- 2.3 Site Characteristics 10
- 2.4 Waste Characteristics 11
  - 2.4.1 Moisture Content 11

2.4.2 Temperature and Acidity 11
2.4.3 Gaseous Emissions 11
2.4.4 Leachate 12
2.4.5 Biogas 12

2.5 Waste Management Legislation in SA 16

5.6 The European Landfill Directives (ELD) 16

CHAPTER 3 20

STABILISATION AND PRE-TREATMENT OF WASTE 20

3.1 Introduction 20

3.2 Mechanical Pre-treatment 20
3.2.1 Sorting 21
3.2.2 Shredding 22

3.3 Thermal Pre-treatment 22

3.3 Biological Pre-treatment 23
3.3.1 Anaerobic Degradation 24
3.3.2 Aerobic Degradation 24
3.3.2.1 The Mesophilic Phase 24
3.3.2.2 The Thermophilic Phase 25
3.3.2.3 The Cooling Phase 25
3.3.2.4 During the Maturation Phase 25
3.3.3 Composting 26
3.3.4 Factors Affecting Composting 26
3.3.4.1 Oxygen 27
3.3.4.2 Nutrient Concentration and Balance 27
3.3.4.3 Moisture 29
3.3.4.4 pH 29
3.3.4.5 Temperature 29
3.3.4.6 Particle Size 31
3.3.5 Types of Composting System 31
3.3.5.1 Reactor Type 31

Aeration Supply 32

3.4.1 Forces Aeration 32
3.4.2 The Dome Aeration Technology (DAT) 33

3.5 Environmental Problems associated with Composting 36
3.5.1 Pathogens 36
3.5.2 Odour 37
3.5.3 Leachate 38
3.5.4 Occupational and Health Aspects 38

Behaviour of Pre-treated waste in a Landfill 38
3.6.1 Landfill Volume Reduction 39
3.6.2 Landfill Leachate 39
3.6.3 Biogas Emissions 39

3.8 Summary of the Literature Review 40

CHAPTER 4 41

MATERIAL AND METHODS 42

4.1 Introduction 42

4.2 Waste Collection 44

4.3 Reactor set up and waste preparation 45

4.4 Aeration 47

4.5 Analysis on Fresh and Pre-treated Solid Matter 48
4.5.1 Moisture Content and Field Capacity 48
4.5.2 Total Tolids (TS) and Volatile Solid (VS) (ASTM Method B2450) 50
4.5.3 Carbon to Nitrogen ratio (C/N) 51
4.5.4 Respiratory Index (RI 7) 52
4.5.5 Biogas Test 54
4.5.5.1 Liquid Displacement 54
5.5.6 Temperature and Gas Composition from the Reactor 55

4.6 Analysis on Eluates 55
4.6.1 Chemical Oxygen Demand (COD) (ASTM methods 5220B) 56
4.6.2 Biological Oxygen Demand (BOD)(Al 99005) 56
4.6.3 Total Organic Carbon, Total Kjeldahl Nitrogen(TOC, TKN) 57

4.6.4 Ammonia and Nitrates (NH3 and NOX)(SABS Method 217:1990) 58
4.6.5 pH 59
4.6.7 Conductivity 59
4.7 Accuracy/Repeatability Check 60
CHAPTER 5 62
RESULTS AND DISCUSSION 62
5.1 Introduction 62
5.2 Composition of Waste 62
5.3 Treatment Process 64
5.4 Analysis of the Solid Matter 68
5.4.1 Field Capacity and the Moisture Content 68
5.4.2 Respiration Index Seven (RI7) 68
5.4.3 Biogas 69
5.4.3.1 Displacement Method 69
5.4.4 Volatile Solids (VS) 79
5.4.5 Carbon to Nitrogen ratio 80
5.5 Summary of Results on test on the Solid Matter 82
5.6 Analysis of the Elaute 82
5.6.1 TOC and TKN 82
5.6.2 COD and BOD 83
5.6.3 Nitrate (NOx) and Ammonia (NH_3) 85
5.6.4 pH and Conductivity 86
5.6.5 Total Solid (TS) and Volatile Solid (VS) on Eluate 88
5.7 Summary of the Analysis on Eluates 89
CHAPTER 6 90
SUMMARY AND CONCLUSION 90
6.1 Introduction 90
6.2 Composition of Waste 90

6.3 The Treatment Process 91

6.4 The Organic Content 92

6.5 The Nutrient Content 92

6.6 Conclusion 93

REFERENCES 91

APPENDIX 109

LIST OF FIGURES

Figure 2-1: Hierarchy of Waste Management (Williams, 1998) 5
Figure 2-2: The Main Stages in a Landfill Process (Williams, 1998). 10
Figure 2-3: Product of Catabolism of Landfill Leachete (Christensen and Kjeldsen, 1992). 13
Figure 2-4: Product of Catabolism of Landfill Gases (Christensen and Kjeldsen, 1992). 14
Figure 3-1: Temperature Fluctuations and the Stages of Bacteria Action. (NRCS, 2000) 31
Figure 3-2: A Cross Section plan of Typical Windrows used for DAT (Mollekopt *et al*, 2002) 35
Figure 3-3: The MBP operations utilizing Dome Aeration Technology (Mollekopt *et al*, 2002) 36
Figure 4-1: Flow Chart Illustrating the Research Framework 43
Figure 4-2: Diagrammatic Representation of the Reactor 45
Figures 5-1: Variation of Temperature and Ambient Temperature in the Top part of the Reactor over the Period of the Study (point A, D, and G). 65
Figures 5-2: Variation of Temperature and Ambient Temperature in the Middle of the Reactor over the Period of Study (Points B, E, H). 66
Figures 5-3: Variation of Temperature and Ambient Temperature at the Bottom of the Reactor over the Period of Study (points C, F, I). 67
Figure 5-4: Percentage Composition of O_2, CO_2 and CH_4 against Cumulative Volume for Raw MSW. 70
Figure 5-5: Percentage Composition of O_2, CO_2 and CH_4 against Cumulative Volume for Two weeks Pre-treated Waste. 71
Figure 5-6: The Percentage Composition of O2, CO2 and CH4 against Cumulative Volume for Four week Pre-treated MSW Sample 72
Figure 5-7: The Percentage Composition of O_2, CO_2 and CH_4 against Cumulative Volume for Six weeks Pretreated MSW Sample. 73
Figure 5-8: The Percentage Composition of O_2, CO_2 and CH_4 against Cumulative Volume for Eight weeks Pre-treated waste. 74
Figure 5-9: The Percentage Composition of O_2, CO_2 and CH_4 against Cumulative Volume for Ten weeks Pre-treated waste. 75

Figure 5-10: The Percentage Composition of O_2, CO_2 and CH_4 against Cumulative volume for Twelve weeks Pre-treated Waste. 75
Figure 5-11: Evolution of the Cumulative Volume of biogas during the Pre-treatment. 76
Figure 5-12: Evolution of Oxygen during the Pre-treatment. 77
Figure 5-13: Evolution of Carbon dioxide during the Pre-treatment. 78
Figure 5-14: Evolution of Methane during the Pre-treatment. 79
Figure 5-15: Evolution of Volatile solids (%) for the Period of Study. 80
Figure 5-16: Carbon to Nitrogen Ratio for the Period of Study. 81
Figure 5-17: Evolution of TOC and TKN for the Period of the Study. 83
Figure 5-18: Evolution of COD and BOD for each Sample over the Period of Study. 84
Figure 5-19: Evolution of NH_3 and the NOx for the Period of Study. 86
Figure 5-20: The pH and Conductivity for the Period of the Study. 87
Figure 5-21: The Total Solids and the Volatile Solids for the Period of the Study. 88

LIST OF TABLES

Table 2-1: Typical landfill Leachate Compositions (Quasim et al, 1994). 15
Table 2-2: Typical Constituents of a Biogas (Lee and Jone Lee 1995). 16
Table 2-3: Criteria for Waste Acceptance at Landfills for Hazardous Waste (EU Official Journal 1999). 18
Table 2-4: Criteria for Waste Acceptance at Landfills for non Hazardous Waste (EU Official Journal 1999). 19
Table 3-1: Showing C:N Ratio for Different Substances (EPA,1998) 28
Table 3-2: Temperature Ranges and Effects on Biodegradation (Stentiford, 1993) 30
Table 3-3: Range of Organic carbon, nitrogen and chlorine transfer by gas and Leachate; Minimum values represent the Stabilisation degree reached by state of the art MBP (Soyez and Plickert, 2003). 40
Table 4-1: Approximate Daily intake of MSW into the Marianhill Landfill Site 44
Table 4-2: Composition of the MSW in the Reactor 47
Table 4-3: Accuracy checks carried out on the COD Results. 61
Table 4-4: Accuracy Check carried out on the NH_3 Results. 61
Table 5.1: Average Daily intake of MSW at the Marianhill landfill 63
Table 5.2: Output from the MRF 63
Table 5.3: Composition of the Waste in the Reactor 64
Table 5-4: Moisture Content of Sample for the Period of Study. 68
Table 5-5: Amount of oxygen produced over the period of Pre-treatment. 69
Table 5-6 Volatile solids for the Period of Study 79
Table 5-7: Percentages of Carbon and Nitrogen for the Period of Study 81
Table 5-8: Total organic carbon (TOC) and total Kjeldahl Nitrogen (TKN) for the Period of Study. 82
Table 5-9 Chemical oxygen demand and biological oxygen demand for the period of the Study. 84
Table 5-10: The Ammonium and Nitrogen Content for each Sample throughout the Period of Study. 85
Table 5-11: pH and Conductivity for Different Degrees of Pre-treatment. 87
Table 5-12: Table Total Solid and Volatile Solids the Period of Study 88

LIST OF PLATES

Plate 4-1: The Reactor. 45
Plate 4-2: The Thermocouple. 46
Plate 4-3: Quartered MSW. 46
Plate 4-4: The Field Capacity Test Setup. 50
Plate 4-5: The Furnace used to Determine Volatile Solids. 51
Plate 4-6: An example of the Respiration Index 53
Plate 4-7: The Liquid Displacement Setup 55
Plate 4-8: The Gas Analyser 55
Plate 4-9: A BOD Bottle. 57
Plate 4-10: An Incubator with BOD Bottles. 57
Plate 4-11: Nitrate and Ammonia Distiller. 58
Plate 4-12: Distillation Phase in Progress. 58
Plate 4-14: The Corning Checkmate Sensor. 60

LIST OF ABBREVIATIONS

BOD	Biological Oxygen Demand
BOD5	Five Days Biological Oxygen Demand
C	Carbon
CH_4	Methane
CO_2	Carbondioxide
COD	Chemical Oxygen Demand
DAT	Dome Aeration technology
DM	Dry Mass
DWAF	Department of Water Affairs and Forestry
ELD	European Landfill Derinative
FAS	Ferrous Ammonium Sulphate
Fe	Iron
H2	Hydrogen
H_2O	Water
H_2S	Hydrogen Sulphide
LOI	Loss Of Ignition
MBP	Mechanical Biological pretreatment
Mn	Manganese
MPT	Mechanical Pretreatment
MSWI	Intergrated Municipal Solid waste Management
MSWM	Municipal Solid Watse Management
MSW	Municipal Solid Waste
NH_3	Ammonia
Ni	Nickel
Nor N_2	Nitrogen
NOx	Nitrates
O_2	Oxygen
P	Phosphorous
pH	Acidity and alkalinity
TS	Total Solids

RI7	Respiratory Index Seven
SA	South Africa
TDS	Total Dissolve Solids
TKN	Total Kjeldahl Carbon
VS	Volatile Solids
US	United Sates

CHAPTER 1

INTRODUCTION

This chapter introduces the research carried out for this dissertation as well as the motivation behind the research. The main objectives and key issues are introduced. An outline of the dissertation concludes the chapter.

1.1 General Background

Waste is defined as anything that is discarded by an individual, household or organisation. As a result waste is a complex mixture of different substances, which are intrinsically hazardous to health (Aguilera-Corroles *et al.,* 2005). The German Waste Act (1972) defines waste as "portable objects that have been abandoned by their owners or requiring orderly disposal to protect the public welfare". In the Resource Conservation and Recovery Act (EPA, 1995) waste is defines as "any garbage refuse sludge from a waste treatment plant, water supply treatment plant or air pollution control facility and other discarded material including solid, liquid, semisolid or contained gaseous material resulting from industrial commercial , mining and agricultural operations and from community activities". Seadon (2006) defines wastes as any material, solid, liquid or gas that is unwanted and or unavailable and discarded or discharged by its owner (Seadon, 2006).

Waste is generated by actions in all sectors and often signify the ineffective use of natural resources, loss of material and energy in production processes and unsound consumption patterns (Cossu 1995). MSW management (MSWM) is a major problem being faced by municipalities because it involves high cost of collection, storing, processing and disposal (Bezama *et al.,* 2007). The evaluation on the usage of raw materials in the US show that only 6 % ends up as product and 1 % as durable products, the rest is discarded as waste (Seadon, 2006). The US Environmental Protection

Agency (US EPA) confirms that 220 billion tons of MSW was produced in the US in 1998(EPA 1998)

Due to limited resources, ever increasing population, urbanisation and industrialisation worldwide, the management of MSW is becoming a global challenge (Honda *et al.,* 1993). The annual waste generation increases in proportion to the rise in population and urbanization and issues related to disposal have become challenging. The waste management crisis in developing countries is becoming of more serious concern (Sarika, 2006).

Waste management is strongly subjective to political, legal, socio-cultural environmental and economic factors, as well as availability of resources (Mshandete *et al,* 2005). As problems intensify, waste policies become more numerous and complex. In the past 30 years, MSW decision making in many countries has undergone significant changes (Aoustin *et al.,* 2005). The current global challenges of urban solid waste demands a people centred approach. On the one hand this involves a change in public attitude to consumption and on the other hand it requires decision makers to recognise the importance of people. Solid waste management is becoming a major challenge for local governments. Almost all cities in the world are struggling to meet waste related targets for waste collection, safe disposal, and reduction or recycling (Bougrier *et al.,* 2006). Increasing quantities of waste, higher expectation from the public, changing waste characteristics and increasing cost of waste management are some of the major challenges faced by society. New approaches to waste management demand a new relationship between people and government (Bovea and Powell, 2006).

Currently most countries send the majority of their waste to landfills. This raises the concerns about the potential health effects of landfill and land filling very large amount of waste (Cossu *et al.*, 2001). In the United Kingdom, 67 % of MSW (MSW) generated is land filled, 9 % incinerated and 23.5 % is recycled or composted (Marchettini *et al.,* 2007). This is also the case in South Africa; over 95% of all urban solid waste is disposed of in landfills (DWAF, 1998). In recent years there has been substantial interest in the enhancement of refuse decomposition in landfills (Melloni *et al.*, 2003). Landfilling is an essential part of solid waste management and landfills are frequently considered for urban development but have limited end uses due to large differential settlement, leachate generation and gas emissions (Stegmann, 1995; Wall and Zeiss, 2000). To reach the aim of an ecologically sound waste management, the material to be disposed in a landfill should show minimum emission potential even in the long term. In South Africa, and most of the other countries, minimum quality standards are given for waste to be disposed of into landfill sites through the SA Minimum Requirements for Disposal of Waste by Landfill (DWAF, 1998). The Minimum Requirements ensure that cost effective means are used to protect the environment and public health from the adverse impacts of waste disposal (Fourie *et al.,* 2001). The design, operation and monitoring of landfills are also governed by the minimum requirements (Mbuligwe *et al.,* 2002). The major challenges encountered by landfills are the biogas emitted and highly toxic leachate produced. The main gases from landfill are CH_4 and CO_2, which are green house gases. The increasing awareness of the effects of greenhouse gases (global warming) has raised the concerns for the management of these gases. Pre-treatment of waste is seen as a solution to landfills emissions, this is a means of waste stabilization, making waste inert, reducing the leachate and biogas produced. There are basically 3 types of pre-treatment mechanical, biological and thermal pre-treatment. Pre-treatment is widely used in developed countries owing to the European landfill directives (ELD). The ELD stipulates standards which member countries must meet when landfilling (Europa, 1998). In South Africa (SA) and most of the developing countries pre-treatment of waste is not mandatory. Studies have been carried out over the years to implement pre-treatment in SA (Mollekopf *et al.,* 2002; Trois *et al.,* 2004; Trois and Polster, 2005; Griffiths, 2005) and a pilot project was initiated at the Bissasar Road Landfill Site in Durban in 2002. As part of the pilot project this study explores the evolution of waste pre-treatment using forced aeration at laboratory scale and the degradation processes in an anaerobic environment of pre-treated waste for different degrees of pre-treatment (2, 4, 8, 10, 12, 14 and 16 weeks). Similar studies showed a small amount of carbon emission from pre-treated waste than fresh waste.

1.2 Aims and Objectives of Study

The study aims at assessing the effect of aerobic waste pre-treatment (composting) using forced aeration on the long term behaviour of land filled waste in relation to the nature of carbon emissions (CO_2 and CH_4 in particular) produced during the biodegradation process. The efficiency of this pre-treatment process was also analysed in relation to its potential for reduction of green house gasses from the land filled waste. In particular, the objectives were;

- To study the evolution of waste pre-treatment using forced aeration at laboratory scale
- To study degradation processes in anaerobic environment of pre-treated waste for different degrees of pre-treatment (2, 4, 8, 10, 12, 14 and 16 weeks).

1.3 Methodology

This research is based on laboratory processes carried out in the Department of Civil Engineering from March 2007 until July 2007. The procedure involves collecting pre-sorted MSW from Marainnhill landfill site, building a reactor (aerobic composting plant), composting the waste in the plant while monitoring the temperature and biogas produced. Samples were collected every two weeks, wherein full characterization of the solid and eluate analysis were carried out. Biogas production from the pre-treated samples was monitored in anaerobic reactors using the liquid displacement method.

1.4 Scope of the Dissertation

In order to address the objectives defined above a detailed description of the waste biodegradation processes in the landfill, landfill emissions, leachate and biogas characterisation is presented in Chapter 2. A brief description of composting and waste stabilization – Mechanical Biological pre-treatment processes with particular emphasis on the Dome Aeration Technology (Aerobic treatment), biogas analysis using batch tests and anaerobic reactors, is presented in Chapter 3. The methodological approach to the study is presented in Chapter 4. Chapter 5 presents the results in the form of tables, graphs and descriptions while Chapter 6 gives a summary of the findings and conclusions.

CHAPTER 2

LITERATURE REVIEW

Chapter two discussed the importance of waste management, summarises landfill processes with emphasis on the main parameters to achieve successful and efficient waste stabilisation, and reviews landfill legislation in South Africa and Europe .

2.1 Introduction to Waste Management

The hierarchy of waste management places waste reduction at the ‘top’ followed by reuse, recycling, recovery, treatment and finally disposal as seen in Figure 2.1 (Williams, 1998).

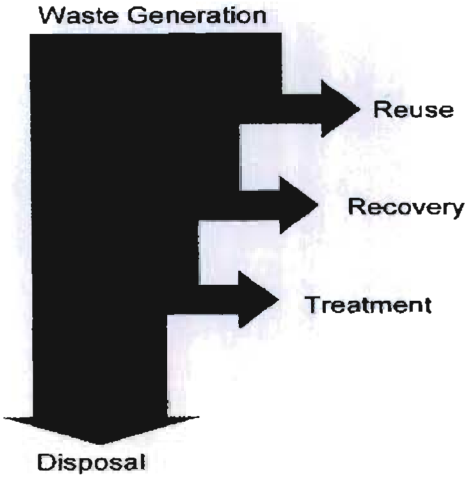


Figure 2-1: Hierarchy of Waste Management (Williams, 1998)

“Waste reduction” is synonymous of “waste minimization” and has been defined as any technique which avoids, eliminates or reduces a waste at its source (Abdennaceur, 2001).”Reuse” involves using a product or package more than once or in another application. “Recycling” is the collection, separation, clean up and processing of waste materials to produce marketable material and products. Read *et al.,* (2000) defined waste disposal as the transfer of matter from society to nature. Disposal is the easiest and most common method, however landfilling is said to be the best option to develop controllable disposal (Anex, 1996). Basnayake and Ekanayak (2005), also assert sanitary landfilling in developing countries remains one of the most economical waste disposal techniques in current use, as opposed to the ancient tradition of refuse deposited in open dumps. Landfill systems and processes are complex and will be outlined in the sections to follow.

2.2 Waste Biodegradation Processes in the Landfill

Studies have shown that the organic fraction of waste present in dry landfills degrades slowly generating both leachate and landfill gases at a low rate while, wet landfills demonstrate higher production rates of landfill gas and leachate. The infiltration of rainwater into waste in a landfill site coupled with the biochemical and physical breakdown produces leachate which contains soluble compounds of waste, suspended solids and micro organisms. Chemical constituents and biodegradability of organic fractions vary depending on the type and source of waste (Cappai *et al.,* 2005). The biodegradability of organic fractions depends on the physical and chemical properties as well as environmental factors such as temperature, moisture and pH. According to Caballero *et al.,* 1997, there are several phase of biological degradation in a landfill site. The first phase is aerobic, followed by an acid anaerobic phase, and lastly the methane producing phase. However, Powrie and White (2004) divided landfill processes into five simpler phases, involving hydrolysis/aerobic degradation, hydrolysis/fermentation, acetogenesis, methanogenesis and oxidation. These five stages will be discussed in detail in the following sections. Each stage is a characteristic of the intermediate and final break down of products, the quality and rate of generation of leachate and the landfill gas.

2.2.1 Hydrolysis or Aerobic Degradation

Hydrolysis or aerobic degradation is the first process and generally occurs during or after waste has been disposed at a landfill site. The organic fraction of the waste is metabolized by aerobic organisms, converting readily degradable carbohydrates to simple sugars. Intense metabolism (exothermic reaction) generates heat which leads to an increase in temperature, of up to 70-90 °C. Well compacted waste result in a low availability of O_2 which in turn results in low temperatures (Wall and Zeiss, 1992). The duration of this stage depends on the availability of O_2 and can also be influenced by the management practices of the landfill site. Lu *et al.*, 1995, states that the length of the aerobic phase depends on the compacted of the landfill and since the O_2 penetration is low in high density landfills, the anaerobic processes usually dominate. The major decomposition products are CO_2 and H_2O. CO_2 can be released as gas or is absorbed into water to form carbonic acid which gives acidity to the leachate. The CO_2 produced has approximately the same moles as the O_2 used with very little displacement of N_2 (Eriksson *et al* ., 2004). The odour emitted at this stage is due to the formation of organic esters. As the concentration of O_2 decreases creating an anaerobic condition, aerobic micro organisms are replaced by facultative anaerobes and consequently obligate anaerobic micro organism (Loukidou and Zouboulis, 2001).

2.2.2 Hydrolysis and Fermentation

This occurs in the absence of O_2 (anaerobic condition) as a result of the depletion of O_2 from stage one. During this stage carbohydrates, lipid and proteins are hydrolyzed to simple sugars. Simple sugars are consequently decomposed to CO_2, H_2, NH_3 and organic acids with soluble intermediates like acetone, inorganic salts and sulphates (Peavy *et al.,* 1985). The organic acids are mainly propionic, butyric, lactic and fomic acids and their formation depends on the composition of the waste that was put into the landfill (Flyhammar 1989, 1989). The volume of CO_2 produced increases as the O_2 is consumed and N_2 displacement is greater. There is no formation of CH_4 at this stage as equal amounts of CO_2 are needed in solution to act as a hydrogen acceptor. The leachate derived at this stage is rich in ammoniacal nitrogen. The temperature in the landfill drops to between 30 °C and 50°C. CO_2 and H_2 concentration at this stage may rise by 80 % and 20 % respectively.

2.2.3 Acetogenesis

The organics formed in hydrolysis and fermentation is converted by acetogen micro organisms to acetic acids, acetic acids derivatives, CO_2 and H_2 in an anaerobic condition. Some other bacteria convert carbohydrates, to acetic acid in the presence of H_2 and CO_2. H_2 and CO_2 concentration decrease throughout this stage, as methane producing bacteria use it at a rapid rate. The low H_2 concentration promotes the formation of methanogens, which generate CH_4 and CO_2 from organic acids and organic acids derivatives produced in stage two (Hutter, 1994). The increased acidic conditions in this stage cause metal ions to be more soluble, increasing their concentration in leachate. Also organic acids, chlorides ions, ammonium ions and phosphates ions are all in high concentration, forming complexes with metal ions increasing their solubility (Neil, 2005). There is a possibility for the formation of hydrogen sulphide in this stage because the sulphate compounds found in the waste are reduced to hydrogen sulphide by sulphate reducing micro organisms. The presence of organic acids generates an acidic solution with a pH of 4 or lower (De Guardia *et al.*, 2006).

2.2.4 Methanogenesis

As the concentration of hydrogen produced in stage three decreases it promotes the formation of methanogen micro organisms which produce CO_2 and CH_4 from organic acids and their derivatives such as acetone and formate acid generated in stage three. CH_4 can also be formed directly by micro organism's conversion of CO_2 and H_2 to CH_4 and H_2O. This causes the concentration of H_2 produced in stage two and three to fall in stages four (Dahab and Woldt, 1994). Throughout this stages two classes of micro organism are active, the mesophilic bacteria, active in the temperature range of 20-45 °C, and the thermophilic bacteria, active between 45-65 °C. Therefore landfill gases are generated at a temperature range of 30-65 °C, with an optimum temperature of gas production between 30-45 °C. At very low temperature, for example 15 °C, biological degradation decreases. Organic acids produced from stage two and three are degraded by the methanogens micro organisms (Castaldi *et al.,* 2005). As the acids are depleted the pH rises to about 7-8. However the ideal pH range for the action of methanogens is between 6.8 and 7.5. Methanogenesis is the longest stage in all the landfill processes taking from six months to several years for this process to commence after the waste has been land filled, depending on the water content and the water circulation. Most often, a considerable amount of CH_4 is produced only after three to twelve months depending on the development of the anaerobic organisms and waste degradation products (Richard 1992). Buenrostro and Bocco (2003) suggested that stages one to four occurs in approximately 180 days, while Loehr and Haikola (2003) suggested a time of approximately 250 days and Tzipi *et al.,* (2006) 500 days.

2.2.5 Oxidation

This stage marks the end of the landfill processes and final waste degradation process, as the acid is used up by methanogens to produce CH_4 and CO_2 which are the main landfill gases. At this stage new aerobic micro organisms slowly replace anaerobic forms and aerobic conditions are re- established (USEPA, 1998). Aerobic micro organisms, which convert residual CH_4 to CO_2 and H_2O, may become re-established. Landfill gas is typically composed of CO_2, CH_4, some other minor components and water vapour. This stage marks the end of the reaction and a return to the aerobic conditions (Xuede *et al.*, 2003). In cases where waste has a high concentration of sulphate, hydrogen sulphite gas may be formed. All the processes in a landfill site can be described diagrammatically as in Figure 2-2. There are many factors which affect the landfill processes that will be analysed in this study

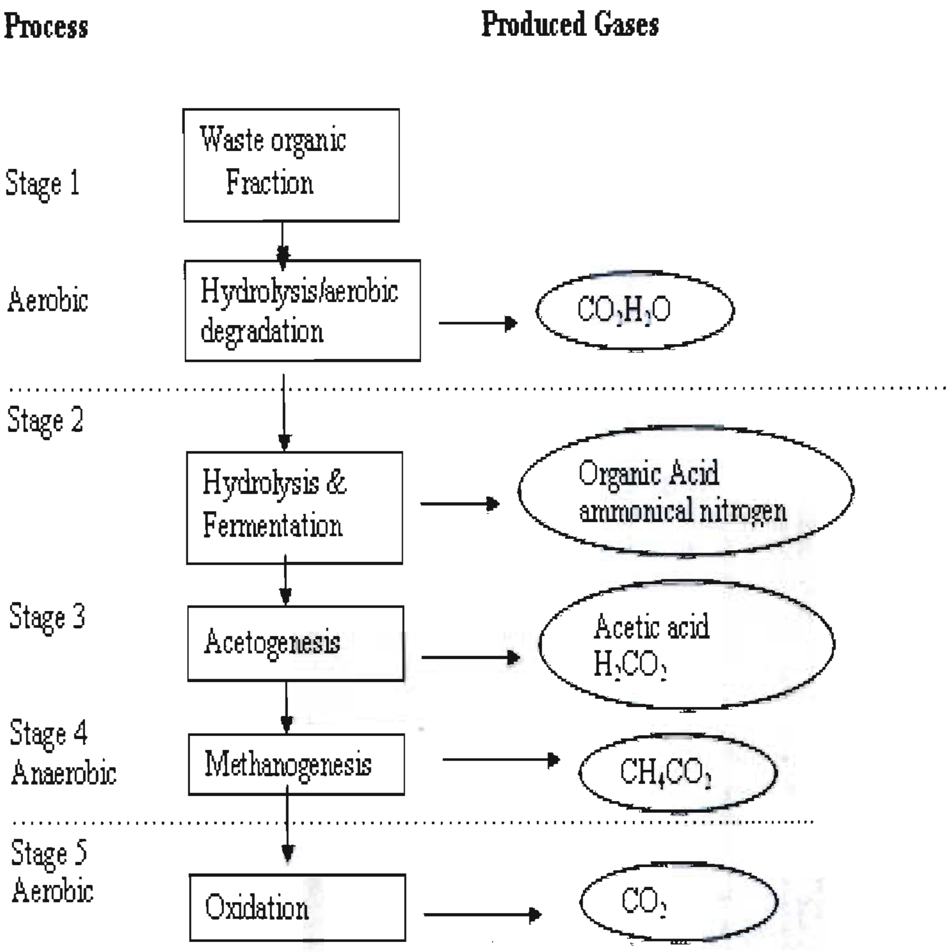


Figure 2-2: The Main Stages in a Landfill Process (Williams, 1998).

2.3 Site Characteristics

The depth of the landfill site effects the penetration of oxygen. Landfill sites with considerable depths have a lower possibility of anaerobic condition and consequently decreases the aerobic stage, production of landfill gases (Powrie and White, 2004). Also rapid covering decreases the length of the aerobic stage, since the aerobic stage increases temperature, and the rate of temperature increases will decrease. Rapid covering also reduces rainfall penetration, moisture content and lowering the rate of biodegradation (Honda *et al.,* 1993).

2.4 Waste Characteristics

When the waste in the landfill site is dense and well compacted, the amount of material available for biodegradation is higher and consequently a greater volume of landfill gases per unit void space will be produced. However, when the compactment becomes too high, it becomes difficult for water to percolate into the landfill site and consequently reduces the flow of nutrients for the micro organisms (Williams, 1998).

2.4.1 Moisture Content

This is a main factor which affects directly the micro organisms and determines the production of landfill gases and leachate. As the moisture increases biodegradation process increases, the volume of landfill gases increases (Hamoda *et al.*, 1998). Moisture is important but how moisture percolates and distributes nutrients to the micro organisms is very important.

2.4.2 Temperature and Acidity

Micro organisms occur in certain temperature ranges in a landfill site, the mesophilic range of 20 - 45 °C and thermophilic is 45 - 65 °C. The ambient temperature for the reactor of this study will be kept between 25 and 35°C. Acidity also affects the activity of micro organisms and also determines the rate of biodegradation (Hayles, 2002).

2.4.3 Gaseous Emissions

Bacterial decomposition, volatilization and chemical reactions are the processes responsible for the formation of landfill gases. Most landfill gases (biogas) are produced by bacterial decomposition, which occurs when organic waste is broken done by bacteria naturally present in the waste and soil used to cover the landfill. Landfill gases can also be formed when certain waste, particularly organic compounds change from liquid or solid into water vapour (Couth, 2000). Hamoda *et al.,* (1998) describes this process as volatilization. Williams (1998) confirms that non methane compounds found in landfill gases are formed as results of volatilization. Lastly landfill gas including the non methane organic compounds can be formed by the reactions of certain chemicals present in the waste. The types and amounts of gas produced are influenced by the refuse composition (Beidou *et al* ., 2005). The constituent of a typical landfill leachate is given in Table 2-2.

2.4.4 Leachate

leachate from a landfill site is formed as a result of liquid that percolates through the waste and may contained dissolved or suspended material from the refuse (Ehrig, 1983; Cossu *et al.,* 1995). The composition and nature of the leachate varies in concurrence to the composition and type of waste which is in contact with the liquid, the state of biodegradation, the moisture content of the waste and the procedures used in operating the landfill (Lee and Lee Jone, 1995). For the sake of this study emphasis will be given to the biogas produced in a landfill site. The major constituent of a biogas is found in Table 2-1.

Sound leachate management requires the following:

- Leachate, once collected, must undergo a treatment process
- If a sewer line is available in the vicinity of the site, leachate can be fed into the sewer system and undergo treatment at the sewer treatment works
- Alternatively, there are various methods of treating leachate on site

  - Sequencing Batch Reactor
  - Leachate recirculation
  - Aerobic Lagoons

While biogas management requires the following

- Control of gas migration most important
  - Lined sites now assist in containing landfill gas
- Passive venting, combustion and energy use(Bisasar Road Landfill Site)
  - Generally confined to shallow landfills
- Active extraction
  - Most effective at controlling landfill gas (Trois, 2007).

2.4.5 Biogas

A study carried out by Faquhar and Rovers (1973) to investigate the production of gas during refuse decomposition showed that gas production increased with increased moisture content. The changes in biogas production in a landfill site over time are due to waste degradation. However conditions of high infiltration are often conducive to the reduction in gas production caused by modification to the microbial environment. The gas production in a landfill site can also be affected by factors which affect the microbial activity of the landfill processes discussed above. It is evident that the anaerobic environment produced in a landfill site moderates the production of landfill gases (Lombard, 2000). From the example of a typical sample of biogas produced from a landfill site given in Table 2-2, it is evident that the main landfill emission is carbon compounds which include CO_2 and CH_4, and obvious that in the 4th stage of biodegradation, the production of carbon emissions is highest: 50 - 70 % of CH_4 and 30-50 % of CO_2(Lee and lee Jones, 1995). Studies on landfill sites in Hong Kong are minimum concentration of 0-69.1 mg/m^3 and maximum of 69-10 mg/m^3 of CH_4. This corresponds well with 66 % of CH_4 and 34 % of CO_2 for the gas produced in other experiments e.g. (Christensen and Kjeldsen, 1996). Small amounts of N_2 and H_2S may also be present. Studies have shown that if the amount of CH_4 produced is below 50 %, the production of CH_4 is only being retarded particularly because of detected of H_2 and abrupt environmental changes (McInerney and Bryant, 1983). Figures 2-3 and 2-4 below shows the concentration of leachate and gases at different phases of biodegradation.

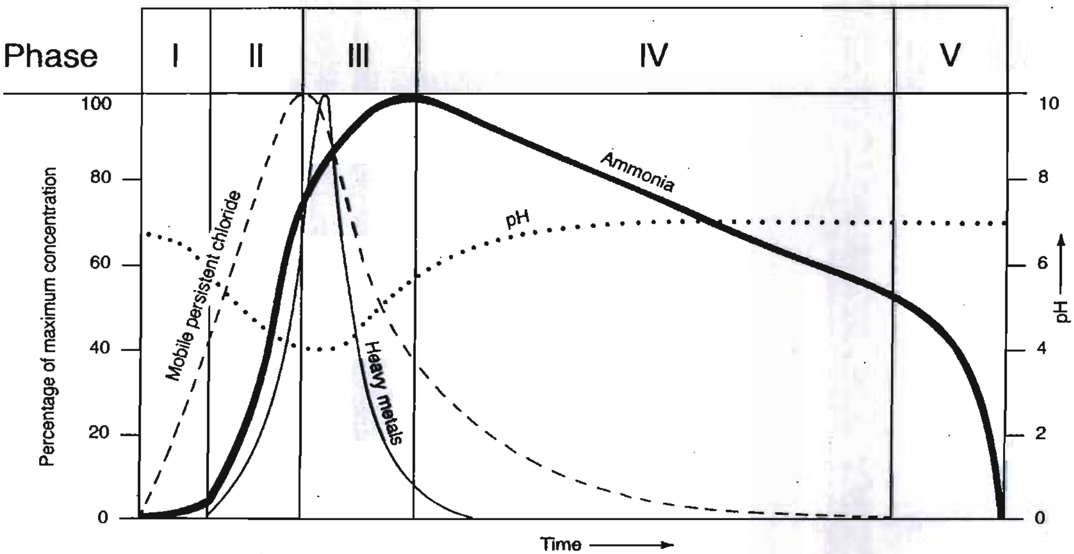


Figure 2-3: Product of Catabolism of Landfill Leachete (Christensen and Kjeldsen, 1992).

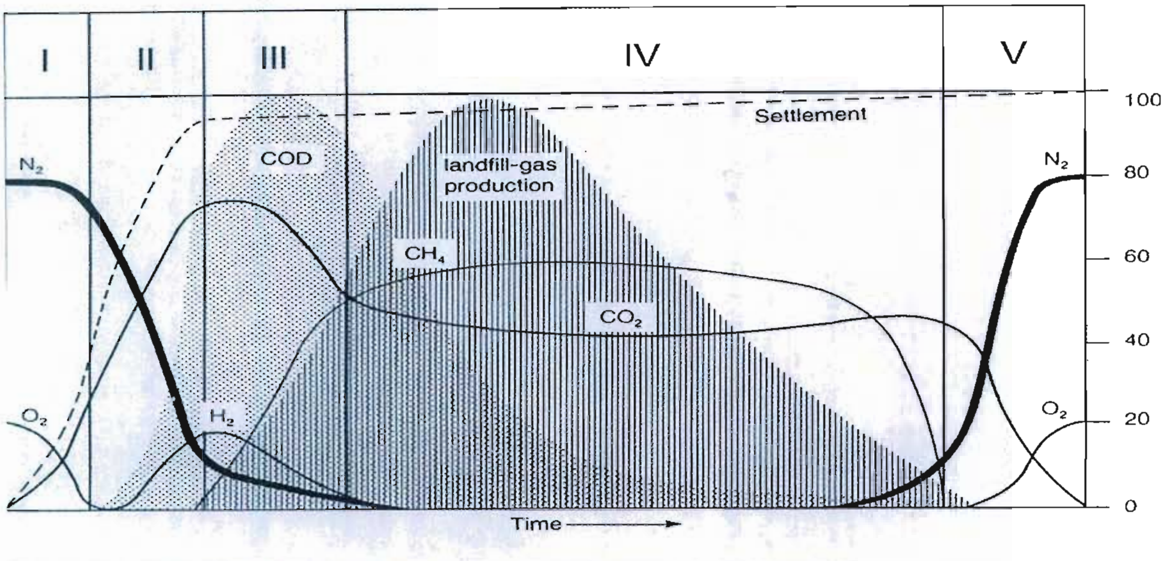


Figure 2-4: Product of Catabolism of Landfill Gases (Christensen and Kjeldsen, 1992).

Table 2-1: Typical landfill Leachate Compositions (Quasim *et al,* 199

	Value, mg/l		
	New landfills (Less than 2 years)		Mature landfills (greater than 2 years)
Constituents	**Range**	**Typical**	**Range**
BOD5	2000-30000	10000	100-200
TOC	1500-20000	6000	80-160
Total suspended solids	200-2000	500	100-400
Organic Nitrogen	10-800	200	80-120
Ammonia Nitrogen	10-800	200	20-40
Nitrates	5-40	25	5-10
Total Phosphorous	5-100	30	5-10
Ortho Phosphorous	4-80	20	4-8
Alkalinity as CaCO3	1000-10000	3000	200-1000
pH	4.5-7.5	6.0	6.6-5
Total Hardness as in CaCO3	300-10000	3500	200-500
Calcium	200-3000	1000	100-400
Magnesium	50-1500	250	50-200
Potassium	200-1000	300	50-400
Sodium	200-2500	500	100-200
Chloride	200-3000	500	100-400
Sulphate	50-1000	300	20-50
Total Iron	50-1200	60	20-200

Table 2-2: Typical Constituents of a Biogas (Lee and Lee Jones, 1995).

Constituent		**Volume Range (%)**
Methane	CH_4	0-85
Carbon dioxide	CO_2	0-88
Carbon monoxide	CO	0-3.0
Hydrogen	H_2	0-3.0
Oxygen	O_2	0-3.6
Nitrogen	N_2	0-31.0
Ammonia	NH_3	0-0.35
Hydrogen Sulphide	H_2S	0-70

2.5 Waste Management Legislation in SA

In South Africa, the legislation which governs landfills management are; The Constitution (Act 108 of 1996) , The Bill of Rights, National Environmental Management Act (Act 107 of 1998), The Environment Conservation Act (Act 73 of 1989) and Regulations; Atmospheric Pollution Prevention Act (Act 45 of 1965), Water Act (Act 54 of 1956 and its 1985 Amendments), National Water Act (Act 36 of 1998), The Occupational Health & Safety Act (Act 85 of 1993)(DWAF, 1989; Blight, 2006), the Minimum requirements for landfill. In this legislation more emphasis are placed on planning waste managements strategies in order to create jobs opportunities and improve waste management (Soyez and Plickert, 2003).

2.6 The European Landfill Directive (ELD)

The European Landfill Directive intends to harmonize controls on the landfill of waste throughout the European Union, and its focuses are on general standards for the design, operation and aftercare of landfill sites. Moreover, it aims to prevent or reduce as much as possible negative effects on the environment from the landfilling of waste, by introducing severe technical requirements for waste and landfills. It is intended to prevent or reduce the adverse effects of the landfill on the environment, in particular on surface water, groundwater, soil, air and human health. It defines the different categories of waste and applies to all landfills, defined as waste disposal sites for the deposit of waste onto or into land (Europa, 1998: EU Official Journal, 1999; Basak, 2007). The ELD sets three progressive targets for Member States to reduce the amount of biodegradable municipal waste sent to landfills. It requires a reduction of 75 %, 50 % and 35 % of the 1995 baseline figures of biodegradable MSW within 5, 8 and 15 years, respectively from 2001 which was the date when the ELD had to be bought into law i.e 2006, 2009, 2016 (Official Journal, 1999). However countries which relied heavily on landfill in 1995 e.g. UK, were given a four year derogation on these dates to 2010, 2013, 2020. Table 2-3 and 2-4 gives limits of some parameter stipulated by ELD and adopted by Germany and many other EU countries. For example in Germany the legislation 'closed cycle economy and waste act' lays more emphasis on waste avoidance, the waste which cannot be avoided has to be recycled or reused materially or energetically with respect to the overall economy and ecology, and lay more stricter parameters for landfills (Soyez *et al.*, 1997: Munnich *et al.,* 2005). The ELD prohibits the landfilling of untreated waste and any waste to be landfill must be in accordance with the limits given in the ELD and also the classification of the sites it may be disposed into.

In order to minimize the effect of landfill gas and leachate and to meet the requirements of the ELD pre-treatment is necessary. The different types of pre-treatment will be discussed in the following chapter.

Table 2-3: Criteria for Waste Acceptance at Landfills for Hazardous Waste (EU Official Journal, 1999).

Parameter	EU requirements			Germany requirements
Leaching test analysis	**L/S=2 l/kg**	**L/S=10l/g**	**C_0 (Percolation test)**	**[mg/l]**
	mg/kg dry substance	**mg/kg dry substance**	**mg/l**	
pH [–]			7.5-8	5.5–13.0
El. Cond. [/S/cm]	-	-	<50000	
Fluoride	200	500	120	
Chlorides	17000	25000	15000	
DOC	480	1000	320	<250
Hg	0.5	2	0.3	<1.5
As	6	25	3	<0.5
Zn	90	200	60	<5
Pb	25	50	15	<1
Cd	3	5	1.7	<0.1
Cu	50	100	60	<5
Ni	20	40		<0.10
Cr	25	70	15	<0.1
Sulphate	2500	50000	17000	
TDS	70000	10000	-	
Analyses in Solid material	**Values**			
TOC [%]	6%%			35 –
LOI(loss of ignition)	10%			<5
Respiration rate [mg/g]				<20
Acid neutralisation capacity	Must be evaluated			

Table 2-4: Criteria for Waste Acceptance at Landfills for non Hazardous Waste (EU Official Journal 1999).

Parameter	**EU requirements**			**Germany requirement**
Leaching test analysis	L/S=2 l/kg	L/S=10l/g	C_0(Percolation test)	[mg/l]
	mg/kg dry substance	mg/kg dry substance	mg/l	
pH [–]			7.5-8	5.5–13.0
El. Cond. [/S/cm]	-	-	<50000	
Fluoride	60	150	40	
Chlorides	10000	15000	8500	
DOC	380	800	250	<250
NH4–N				<200
Hg	0.05	0.2	0.03	<1.5
As	0.4	2	0.3	<0.5
Zn	25	50	15	<5
Pb	5	10	3	<1
Cd	0.6	1	0.3	<0.1
Cu	25	50	30	<5
Ni	5	10	3	<0.10
Cr	4	10	2.5	<0.1
Sulphate	10000	20000	7000	
TDS	40000	60000	-	

Solid to liquid ratio(L/S), Percolation constant(Co)

CHAPTER 3

STABILISATION AND PRE-TREATMENT OF WASTE

This chapter presents mechanical biological and thermal pre-treatment as the best option to increase the quality and to reduce the quantity of MSW being land filled. It also defined aerobic and anaerobic pre-treatment and goes further to explain the technology behind composting and DAT

3.1 Introduction

Biodegradation of the waste involves degradation of the waste, reducing the gaseous emissions and leachate produced. There are different types of pre-treatment processes; these involve mechanical, biological and thermal pre-treatment processes. In all pre-treatment processes emphasis is on the reduction of biogas and leachate produced, in order to meet the requirements for landfilling (Adani *et al.,* 2004). In Duren, Germany, mechanical and biological pre-treatment of waste was carried out for a commercial scale plant (Dimitris, 2006); the result showed a considerable reduction of waste components in accordance with the minimum requirements for landfilling in Germany. In another study carried out in Austria using thermal and biological processes, it was found that the requirements of the legislation were also met (Fourie *et al.,* 2001).

3.2 Mechanical Treatment

During mechanical pre treatment the waste is conditioned for further biological or thermal pre-treatment. The waste can be separated according to composition into different waste streams and conditioned (Bone *et al.,* 2003). According to Heerenklage and Stegmann (1995) the aim of a mechanical pre-treatment should be

- Removal of contaminated and large waste components prior to treatment
- Separation of contaminants and reusable material
- Separation of the waste mixture (into light fraction containing plastic, heavy metals minerals and biological degradable waste)

- Creating optimal conditions for biological pre-treatment (by adjusting carbon and some major nutrients). Also addition of water if necessary.
- Shredding of the waste to improve landfill properties and also to save the landfill volume

Delia and Osman (2005) divide mechanical pre-treatment into process steps:

- Receiving and pre-sorting of waste: this can be done in flat bins or conveyer belt, it homogenize waste roughly and controls the delivery of waste;
- Sorting of waste, hand sorting is problematic for hygienic reasons; this can be done on a sorting belt is aimed at removing recyclables and reusable;
- Separation: this is done through air classification to separate material streams of high calorific value and high material content;
- Screening: sieve drums can be used for screening, magnetic separator can be installed at several places to sort out and remove fractions;
- Shredding and homogenization of waste is also important.

All mechanical treatment is aimed at removing undesirable fractions of waste and further prepares the waste for biological activity. Mechanical treatment can be described in terms of sorting, shredding and regulation of biological parameters (Bramryd and Binder, 2001).

3.2.1 Sorting

Waste types appropriate for biological waste treatment are those with suitable quantities of biological degradable organic dry matter (Lunde, 1995). Most of the times MSW includes inorganic, plastics and lots of waste which could be slowly degradable or are not degradable at all. Sorting the waste separates the waste into its various components (Cavaggion *et al.,* 2005). Screening is decreasing relatively the amount of oversized waste retained on the topmost screen (60mm). The manual separation of the input waste by using a 50mm sieve from which a light fraction (>50mm) and heavier organics fraction (<50mm) are obtained (Tenzin *et al.,* 2005). Studies have shown that in order to get a full portion of the organic waste in solid waste the sieve should be between 60-100mm (Clarke *et al.,* 1999). Most organic matter is of this grain size. Sieving can also be done by means of a rotating sieve (60mm). Sorting of waste may also include separation of recyclable fractions or fractions with high calorific value, sorting reduces the quantity of the waste to be treated, and sometimes the use of magnet to remove ferrous material is very important. Sorting can be done after or before the biological pre-treatment of MSW (Soyez and Plickert, 2003).

3.2.2 Shredding

Most often MSW is made up of very large and complex material. Shredding is aimed at reducing the volume of the waste (homogenization of waste) consequently increasing the surface area for bacterial action (Lornage *et al.,* 2005). Shredding can be done through;

- High speed hammer/impact mills
- Low speed knife shredders
- Screw, worm and cascade mills (Griffith, 2005).

3.2.3 Thermal Pre-treatment

Like biological and mechanical pre-treatment, thermal pre-treatment is also used as a pre-treatment method for MSW before landfilling. The objectives of thermal pre-treatment are mainly to reduce the amount of waste and to decrease the biological activity of the waste (Bramryd and Binder, 2001). The two main thermal pre-treatment which will be discussed are incineration and carbonization. Several countries such as Switzerland, Japan, Sweden have introduced MSW incineration (MSWIs) as a method of waste pre-treatment (Hwang and Matsuto, 2006). Incineration is the controlled burning of waste in a furnace, boiler, or container specifically designed for that purpose with the end product being ash and gases (Delia and Osman 2005). Incineration is considered to be remarkably effective at reducing waste volumes and increasing sanitation. It's the best option in countries having difficulties in securing proper waste disposal sites. But critical issues such as emission of secondary pollutants and the high cost for their control still remain (Bilitewski and Schirmer, 2005). Bertolini 2003, noted that the gross national product of countries treating more than 50% of waste at MSWI corresponds to more than USD 10,000 per capita.

Carbonization is a thermal process that produces carbonaceous materials commonly called "char". The actual carbonization plants for the treatment of solid wastes has rotary kilns or furnaces operated in the range of 400–500°C (Neyens and Baeyens, 2003). During the heating process, under an inert atmosphere, moisture and volatiles are exhausted in their gas phases, whereas fixed carbon, ash, and some volatile matter form residual materials with porous surfaces. In some facilities, the gas is re circulated in the carbonization system to be used as subsidized fuel or atmospheric gas (Bilitewski and Schirmer, 2005).

Carbonisation is seen as having a positive effect on immobility of heavy metals due to the high H^+ buffering capacity and alkaline nature of slaked char (Sales *et al.,* 2006). Richard, 1992 asserts that heavy metals except mercury are safely enclosed in the solid residues by pyrolysis. And also noted that that the release of heavy metals such as chromium, cadmium and lead was significantly reduced by carbonisation regardless of the type of waste, and carbonization could degrade a considerable amount of raw waste (Hwang *et al.,* 2005). In a research to investigate carbonization residues as a thermally pre-treated material for landfilling using column tests it was realized that a potential release of organic and inorganic constituents from organic waste could be reduced by carbonization, and the carbonization residue is low that and is nearly equal to that of incineration ash, it also shows carbonization can take a role as one of the thermal treatment methods for landfilling (Miguel *et al.,* 2003).

3.3 Biological Pre-treatment

Biological treatment involves biological processes and ensuring an atmosphere suitable for bacterial action (Panza *et al*, 2005). Biological treatment is defined by the German Federal Environmental Minister as the processing or conversion of waste from human activities with biologically degradable components through biological processes (Lornage *et al*, 2007). Biological treatment aims at achieving the following,

- Inactivation of biological and chemical processes of the waste in order to prevent the formation of gas and strong leachate;
- Immobilisation of contaminants of the waste in order to reduce leachate contaminant loading;
- Higher tipping density with immediate consequence of reduced settlement processes within the landfill; and
- Reduction of leachate generation and extension of service life of the landfill site for waste disposal (Munnich *et al*, 2005)

Biological pre treatment of MSW can be done, aerobically, which involves biodegradation in the presence of oxygen and anaerobically in the absence of oxygen.

There is also a possibility of the presence of bacteria which sustain both aerobic and anaerobic condition.

3.3.1 Anaerobic Degradation

Anaerobic pre-treatment techniques are more advantageous than aerobic pre-treatment because there is allowance for the production of energy and nutrient recovery from the residual waste streams and minimal odour problems (Iannelli *et al.*, 2005). In cases with lack of space anaerobic degradation will be more practical, but most often aerobic pre-treatment follows anaerobic pre treatment (Frike *et al*, 2005).

3.3.2 Aerobic Degradation

Biodegradation aerobically can be done for all types of organic waste matter. Here the easily biodegradable organic matter compounds are biodegraded into water and carbon dioxide. The objective of this process is to reduce the waste volume, avoid further methane production and stabilize the material (Redon *et al.*, 2005). The process is efficient for waste with high lignin content. The effectiveness of an aerobic treatment process depends on biological, chemical and physical parameters which include C/N ratio, moisture, temperature, mixing rate, supply of air etc. The supply of oxygen is a main factor in an aerobic treatment because air must be supplied constantly for bacterial activity (Trankler *et al.,* 2003). Gray *et al.*, (1971) suggested that oxygen may be supplied to an aerobic system through waste agitation (turning), forced aeration and natural (convective/diffusive) aeration. Aerobic treatment could be discussed according to the action of the bacteria involves in the biodegradation process. According to Lornage *et al.,* 2007, the process can be divided into 3 phases this include mesophilic, thermophilic and maturation.

3.3.2.1 The Mesophilic Phase

This phase is further divided into the latent phase and the growth phase. The latent phase is the time required for the waste to acclimatize and colonizes in their new environment which leads to the growth phase. This phase is characterized by biological activity and a consequent increase in temperature. The temperature increases from ambient to about 30-35 °C, with the appearance of fungi and acid producing bacteria (Metcalf and eddy, 2004).

3.3.2.2 The Thermophilic Phase

This phase in characterized by very high temperature, the highest temperature experience in the process. During this stage stabilization and pathogen destruction are most effective. High metabolic activity (exothermic processes) and insulation against heat loss produces an increase in temperature. Chang *et al.*, 2006 asserts that the heat generated is as a result of microbial activity, microbes are not completely efficient in converting and utilizing the chemical energy bond in the substrate, therefore rise in temperature is an indicator of microbial activity, the more active the microbial population the greater the amount of heat released. The high temperatures allow only for the thermophilic bacteria, thermophilic fungi and actinomycetes macro organisms to be active. The temperature ranges from 40 °C to 70 °C. The reaction involved is:

$(COHNS) + O_2$ + aerobic bacteria $\rightarrow CO_2 + NH_3$ + other end products + energy

(Organic matter) (Slivertri *et al.,* 2005)

3.3.2.3 The Cooling Phase

During the cooling stage temperature drop below 60 °C, thermophilic fungi become re established which degrades cellulose fractions, temperature continues to drop to ambient temperature. At 40 °C mesophilic organisms become active which starts the maturation process (Metcalf and Eddy, 2004).

3.3.2.4 During the Maturation Phase

Here the temperature decreases to mesophilic, then to ambient. Cellulose, pectin, lignin and starch are degraded by fungi and actinomycetes (Williams, 1998). There is also a decrease in moisture and pH during this phase. Cellulose is decomposed throughout the other phases but more decomposition is experience during this final stage. NH_3 produced is biologically oxidized to become nitrites (NO_2^-) and finally nitrates (NO_3^-), (Metcalf and Eddie, 1996). The main bacteria involved are the nitrosomanas (NH_4^+ to NO_2^-) and the nitrobacters (NO_2^- to NO_3^-). The nitrifying bacteria have a long growth rate and are inactive at temperatures above 40°C, and normally are present only after the mesophilic and the thermophilic phases (Metcalf and Eddy, 2004). The most widely used aerobic treatment process is composting. Composting will be discussed in details below

3.3.3 Composting

Composting is a controlled aerobic biological decomposition and stabilization of organic matter into stable, humus like product called compost (NRCS, 2000). Conditions that allow for the development of thermophilic temperatures as a result of the production of heat e.g. moisture and aeration. The final product compost is stable, free of pathogen, and can be beneficial when applied to land (Haug, 1993).

Mechanical biological treatment of waste does not represent a predetermined and prescriptive waste treatment process but it is a fairly flexible concept that takes into account and accommodates the integration of existing infrastructure, local, regional conditions as much as possible. Composting is used as a treatment component to convert manure and other organic material into a more environmentally stable product. It is considered a method used for managing manure and other organic waste such as poultry or livestock and mortalities and crop residue.

Home composting is a tradition in many countries, and is recommended as an important waste management option in the European Union policy. Advantages are that the waste does not have to be transported and that home gardens are provided with nutrients and humus (Stegmann, 2005). Furthermore, it has an educationally importance in improving environmental awareness. Limiting conditions to its adoption are the availability of space for composting and compost application, and the lack of knowledge as to the correct composting procedure. This includes the selection of substrates that are suitable for home composting and the provision of suitable process conditions (Korner *et al.,* 2006).

3.3.4 Factors Affecting Composting

During the past decades, the understanding on composting process has greatly advanced. The effect of major factors such as aeration rate (Wael *et al.,* 2005; Yuan-Song *et al* 2000), mode of aeration (Bari *et al.,* 2000), heat evolution (Vlyssides and Karlis, 2004), moisture content (Gray *et al.,* 1971), and C/N ratio (Srinath and Prashant, 2006), on the composting process can be experimentally well related to temperature pattern, volatile solid degradation and compost maturity (Bari and Keonig, 2005). The success of composting depends on the stability and quality of the final product, the efficacy of the odour control and the cost effectiveness of the whole process (Iannelli *et* *al.,* 2005). The goals are met by managing factors such oxygen, C/N ratio, moisture content, pH, temperature, and particle size will be further discussed.

3.3.4.1 Oxygen

Microorganisms in a composting process require oxygen to biodegrate the organic compounds in the composting feedstock. Without sufficient oxygen these micro organism will diminish and anaerobic conditions will prevail, slowing the composting process and producing odours (NRCS, 2000). Generally, a minimum oxygen composition of 5 % is required to maintain aerobic conditions (NRCS, 2000). EPA, 1998 asserts that when oxygen concentrations in the waste between 5-15 % (ambient air contains 21% oxygen) anaerobic microorganisms will replace aerobic micro organism. Oxygen can be supplied to waste through either forced aeration or passive aeration. For the sake of this study, forced aeration will be further discussed in chapter 4. Regardless of the manner in which oxygen is supplied, it may not reflect the actual amount of oxygen reaching the microorganisms (Yamada and Kawase, 2006). This is because micro organisms require an aqueous environment in which to function and as such are located within a thin liquid film on the surface of the compost particles, also the diffusion of oxygen in water is significantly slower than that through air. Sometimes air may be entering the pile at a sufficient rate to provide the required oxygen but may not reach the micro organism at a sufficient rate (NCRS, 2000;EPA, 1995). This factor should be considered when supplying air into composting plant.

3.3.4.2 Nutrient Concentration and Balance

For an efficient composting process, microorganisms require specific nutrients in an available form, in adequate concentration and proper ratio. The important nutrients needed by microorganisms include carbon (C), nitrogen (N), phosphorous (P), and potassium (K). C is a source of energy to the microorganisms, C and N are needed to synthesize proteins, build cells and reproduce. P and K are used for cell reproduction and metabolism, usually in composting are limiting factors in decomposition during composting (Richard, 1992). Some trace element or micronutrients like boron, calcium, chloride, cobalt, copper, iron, magnesium, manganese, molydenuim, selenium, sodium and zinc can be needed by the micro organism in minute amounts. When the concentrations of these trace elements become more than minute it becomes toxic to the microorganisms (EPA, 1998).

Chemical forms of nutrients are also important because the nutrients can be available to some micro organisms and not other. The ability to use the nutrients present depends on the microorganisms' enzymatic capacity. Most often C/N ratio is used as an indicator for microbial use (Zimin *et al.,* 2007). High C/N ratio inhibits growth of micro organisms and low C/N ratio initially accelerates microbial growth, when oxygen is depleted anaerobic conditions results in the pile. Excess N can be transformed into NH_3 which is toxic to micro organisms. C/N ratios for different types of substances are given in the Table-3 below.

Table 3-1: Showing C:N Ratio for Different Substances (EPA,1998)

Type of feed stock	**Ratio High carbon Content**
Foliage	40 -100 :1
Leaves and weeds(dry)	90:1
Mixed MSW	50-60:1
Paper	170:1
Sawdust	500:1
Straw (dry)	100:1
Wood	700:1
High Nitrogen Content	
Cow manure	18:1
Food Scraps	15:1
Fruit scraps	35:1
Grass Clippings	12-20:1
Horse Manure	25:1
Humus	10:1
Leaves (fresh)	30-40:1
Mixed Grasses	19:1
Vegetable scraps	11-12:1
Poultry manure	15:1

3.3.4.3 Moisture

The moisture content of the composting feedstock is interconnected with other parameters like microbial activity of the pile, oxygen level, and temperature. Moisture is required by micro organisms to assimilate nutrients, metabolise new cells and to reproduce. Moisture can also be produced as part of the decomposition process and can be lost by evaporation (EPA, 1998). When water accumulates more than it is eliminated either by aeration or evaporation, oxygen flow is impeded and anaerobic conditions can prevail. The moisture content is usually between 50 and 60 % (Trios, 2007). Rynk *et al.,* 1992 assert that water usually accumulates when the moisture content is more than 60 %, and the pile becomes water logged.

Also water is the key ingredient that transports substances within the composting plant and makes the nutrients physically and chemically accessible to the microbes. When the moisture content is between 40-45 % the microbes are no longer in aqueous medium, activity decreases and the composting process decreases below 20 %, very little or no microbial activity occur (Haug, 1980). Moisture problems can be overcome by turning the pile when the moisture content is high or spray water into the pile when the moisture content is low (NRCS, 2000).

3.3.4.4 pH

The pH is important because there is an optimum pH which micro organisms can react. Bacteria prefer pH of between 6-7.5 while fungi thrive a wider range of pH of between 5.5-8 (EPA, 1998). At pH lower than 6 micro organisms die off and decomposition is slow, and if pH is more than 9, N is converted to NH_3, and slows the decomposition process. The pH during a composting process follows a successional pattern during the start the pile is acidic because organic acids (pH of about 5, fungi are more active) are formed, as the process continues micro organisms decompose acids and the pH concentration rises to more than neutral bacteria become more active (Slater and Frederickson, 2001).

3.3.4.5 Temperature

The temperature during composting depends on the heat created by the micro organism during decomposition, and it can be offset by heat lost through controlled aeration, surface cooling and moisture losses. The most effective composting temperatures are between 45-59 ^{0}C (Richard, 1992). At temperatures lower than 20^{0}C the microbes do not proliferate and decomposition is slowed and if the temperatures are more than 59^{0}C some microbes are inhibited or killed, diversity and decomposition rate of the microbes can be reduced. Thermophilic temperature indicates an intense microbial activity while very high temperatures indicate the pile is unable to control its temperature (Probert *et al.,* 2005). Different temperature ranges and their effect are given in the Table 3-2 below,

Table 3-2: Temperature Ranges and Effects on Biodegradation (Stentiford, 1993)

Temperature range (°C)	Results
>55	Max sanitation
45-55	Max biodegradation rate
35-40	Max diversity

Pathogen destruction or sanitization occurs due to competition between the different microorganisms during composting. Fluctuation in temperature can be control through the use of smaller size composting feedstock. Larger piles generate and conserve more heat than smaller piles. Airflow can also affect temperature (EPA, 1998). Temperature variation and the different stages of bacteria action is shown in Figure 3-1 below.

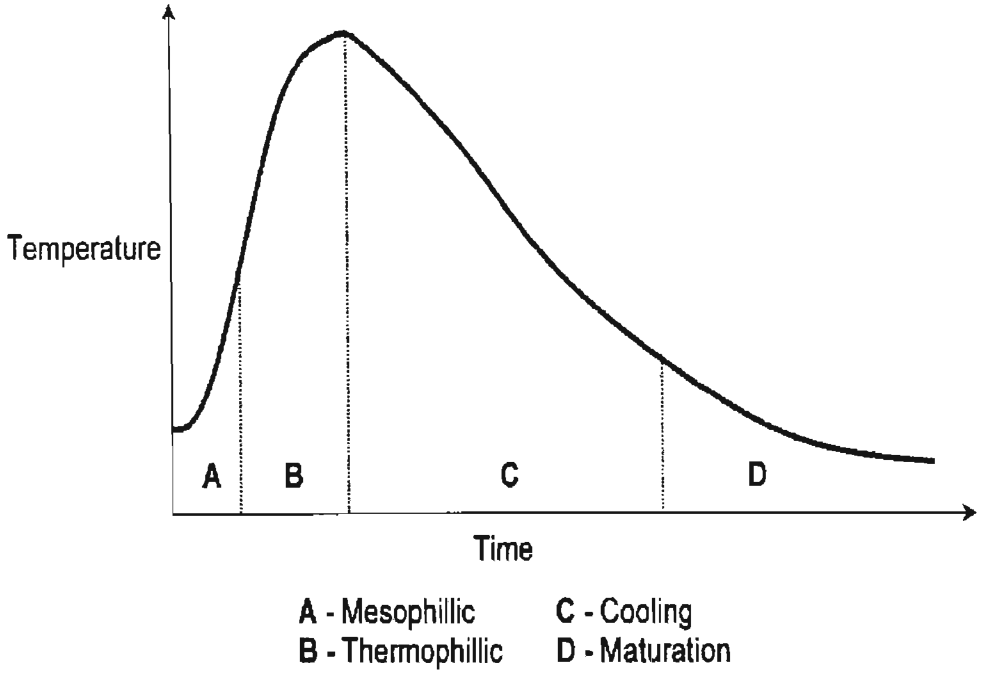


Figure 3-1: Temperature Fluctuations and the Stages of Bacteria Action. (NRCS, 2000)

3.3.4.6 Particle Size

The particle size influences the composting process. Reducing the size of the composting material increase the surface area to which the bacteria will act on, consequently increase biodegradability (Williams, 1998). Also smaller particle size result in homogenous mixture and improve insulations. The particle size should not be very small so as to be too compact which will exclude oxygen from the void spaces (EPA, 1998).

3.3.5 Types of Composting System

There are many composting systems; the systems used for aerobic composting will be discussed below;

3.3.5.1 Reactor Type

The composting reactor is the vessel in which the feedstock is put into during composting. There are several types of reactor which could be used during composting. This includes silos, drums, digester bins and tunnels (NRCS, 2000). The vessels can retain the moisture, mixing can be properly done, and aeration can be controlled. The reactor can allow for rapid degradation; odour and leachate can be controlled. Reactor vessel usually requires an additional curing period. Reactors are also disadvantageous because of the high cost incurred in construction or purchase, operation and maintenance (EPA, 1998). The four broad methods of composting developed for use in large-scale composting are passive piles, windrows, aerated static piles, and in-vessel systems.

3.4 Aeration Supply

Oxygen is a very important parameter in aerobic composting. Oxygen can be supplied through several methods which increase the sophistication and control the cost of the process. Oxygen supply method includes agitation, forced aeration (airflow), or the combination of the two. Agitation is a process by which the feed stock is exposed to air, this can be through mixing. Agitation eliminates the composting gas and replenishes the void spaces. This is mostly employed invessel systems (Williams, 1998). Some invessel systems can use agitation and forced aeration while open systems rely on mechanical turning using augers, paddles or tines. Turning piles are advantageous over static pile in that moisture can be easily applied when needed. While tuning piles are disadvantageous in that it is difficult to control the temperature, because the temperature rises steadily and drops sharply after turning.

3.4.1 Forced Aeration

During aeration, atmospheric air is blown into the pile which supplies it with oxygen, while the composting gas is being removed in the process. This can be done either by exploiting the thermal convection of atmospheric air or by using a compressor which is connected to a system of tubes which runs through the pile. There are positive and negative forced aeration, positive is forcing air through the pile and negative is by drawing air through the pile (Stentiford, 1996). Air being drawn into the pile serves to contain the odour in the system allowing for control and treatment, but when air is blown through the compost pile it serves to transfer the heat from the inner area to the outer pile (Williams, 1998). Air flow in a composting plant can also be passive, the use of passive aeration has a disadvantages, the airflow depends on the movement of the air through the external layers, these disadvantage and many more are exploited by the Dome Aeration Technology DAT (Bari *et al* ., 2000).

3.4.2 The Dome Aeration Technology (DAT)

The DAT is an open, non reactor system where the degradation process takes place in static windrows. It uses convection of heat energy as a means to drive the aeration process during compositing (Paar, 2000). Aeration is achieved naturally by thermally driven advection, which is caused by a temperature difference between the degrading material and the outside environment. And a rotting time of 3-4 months indicated high efficiency.

The DAT is aimed at creating large airspaces within the windrows using steel mesh structures called domes and channels. (Paar *et al.,* 1999; Mollekopf *et al.,* 2002). The domes are placed vertically in the centre of the pile, extending throughout the windrows height and two channels are placed horizontally at the base, on opposite sides of the pile extending from the edge toward the centre (Trois and Polster, 2005). Air flow pathways are created by the domes and the channels into the piles of waste. The dome creates a free space inside the windrows where the hot process gases accumulate. There is a cover grid around the dome which permits the gas flow within the waste body and prevents clogging due to solid material come in. A column of hot gas rises, and it's forced by density difference of the air between the interior and the exterior of the windrows. Since density is a function of temperature, a difference in density in the interior and the exterior causes air to flow into the windrows (Mollekopf *et al.,* 2002).

The main advantage of the DAT over a conventional composting process is that optimal conditions for biological degradation are ensured through reduced maintenance. In the composting process sufficient moisture, surface and micro pore volume in the bulk structure are needed to provide optimal environmental conditions for micro organisms active in the composting process (Trois and Polster, 2005).

Mollekopt *et al.*, (2002) use the scheme in Figure 3-2, in setting the windrows for a dome aeration technology in Germany at Cottbus Landfill Site. Municipal waste and bulky waste are mixed, shredded and crushed while being sprayed with water. The moisture content is keep between 55 – 60 %. Moisture control is very important, in a pilot study carried out in Brazil, irrigation was done to replenish lost moisture and the moisture content was maintained between 50 – 60 % (Munnich *et al.,* 2005). Water is lost through degradation, heat generation and evaporation. In South Africa due to the lack of technology separation is not homogenous. This moistened and homogenized material is transported to the loader for piling, channels and domes are put in place by an excavator. Once the windrow is constructed for DAT, temperature, gas velocity, gas composition can be monitored from the chimney. The process may take 3-6 months depending on the quality of the product (compost). From the scheme it is seen that deposition of coarse particles can be recycled back to the mixing, homogenizing and wetting process.

The environmental problems related to a DAT process are similar to the problems encountered in a conventional composting process. Theses problems will be discussed in the following section.

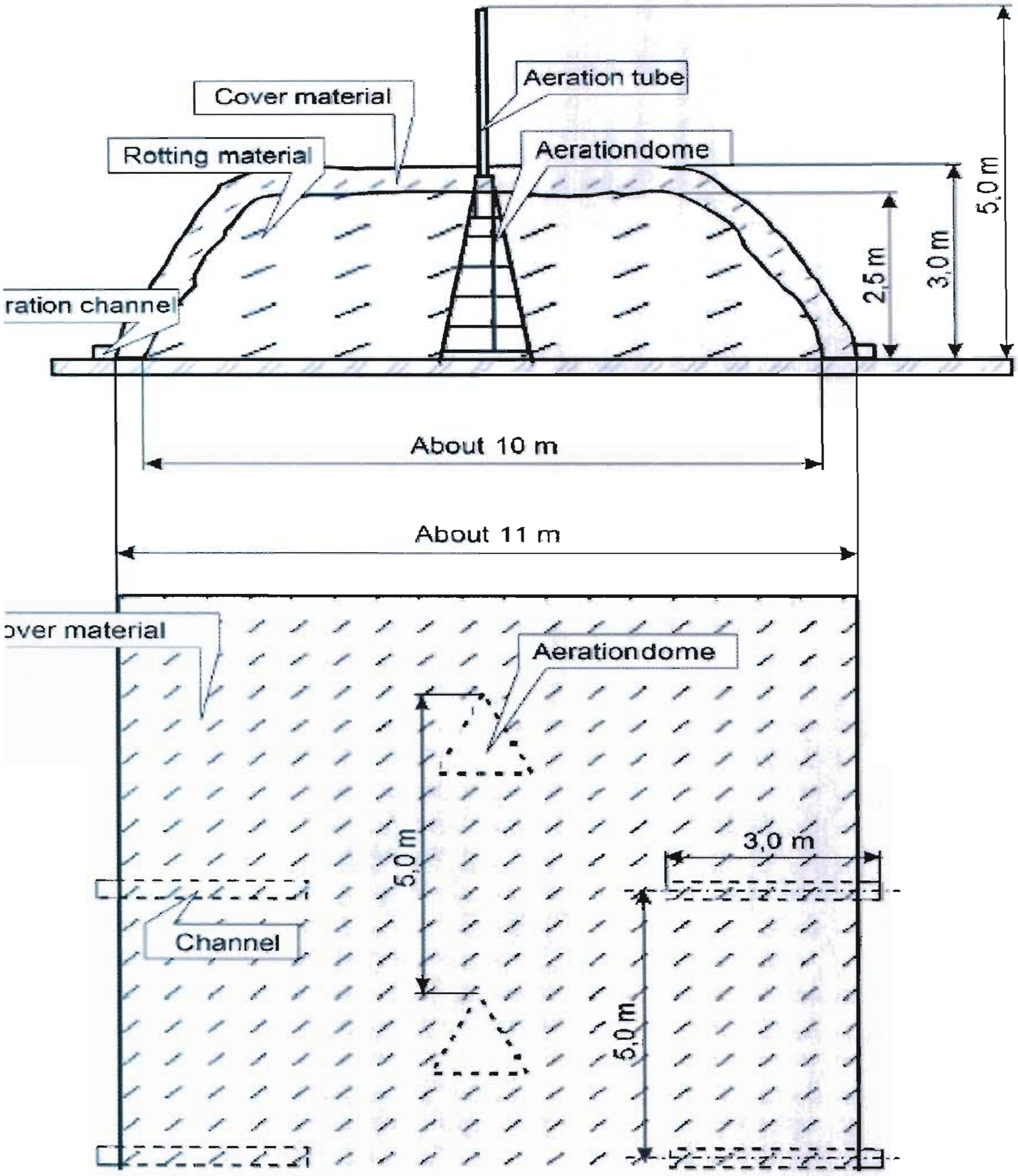


Figure 3-2: A Cross Section plan of Typical Windrows used for DAT (Mollekopt *et al*, 2002)

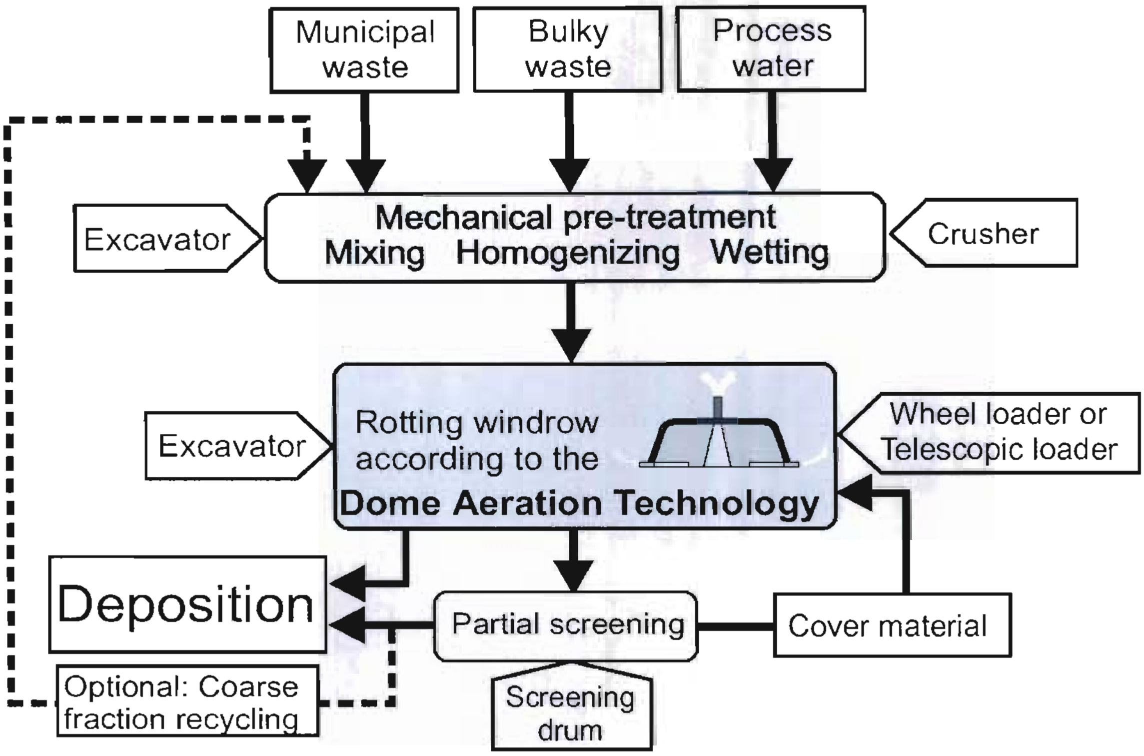


Figure 3-3: The MBP operations utilizing Dome Aeration Technology (Mollekopt *et al,* 2002)

3.5 Environmental Problems associated with Composting

Environmental problems associated with composting are related to mismanagement of the composting process which could result in conditions of odour, pathogens, leachate and biogas production. These conditions are unhealthy to human health and to the environments. These conditions will be discussed in the following sections.

3.5.1 Pathogens

Pathogens are destroyed when the composting operation is well managed. This makes the use of compost more attractive than the application of untreated manure. Pathogen content of compost is very important because it could be a treat to the environment, humans and animals. This depends on the type and quantity of the pathogens in the initial pile of waste. Pathogen that may be in compost includes bacteria, viruses, fungi, and parasites. Parasites and viruses can not reproduce apart from their host but they can survive long and extended periods. If they are not destroyed during composting, then when applied to the ground they may get new host and start reproducing. Bacteria and fungi on the other hand do not require a host, even if their numbers are reduced during composting, with time and in favourable conditions the population could be recovered. So reducing their numbers is not enough, they should be destroyed. Conditions necessary for their destruction include lack of organic matter and moisture content of about 30 %. Such conditions are difficult to achieve during composting. Pathogens can be destroyed by heat, competition, destruction of nutrients, antibiosis, and time (Hoitink *et al.*, 1991).

3.5.2 Odour

Odour generation is a primary concern during composting. Odours are caused by the nature of the material which is being composted. Odours are as a result of production and release of odorous compounds through either biological or non biological means. Odours can be in gaseous forms or associated with particulates. The main compounds associated with odour generation are sulphur compounds, nitrogen compounds and volatile fatty acids (Gillett, 1992).

Odour is produce biologically through the decomposition of sulphur compounds or the assimilation of sulphur compounds. Aerobic processes produce less sulphur compounds than anaerobic processes. Volatile fatty acids which are intermediates in carbohydrates metabolism produce odour when they accumulate in the piles during the anaerobic process. The volatization of ammonia produces odour, the decomposition of proteins produces ammonia (NH_3) or ammonium (NH^+_4), NH_3 and NH^+_4 interconvert based on the pH, NH^+_4 is preferred form in alkaline conditions while NH_3 is preferred form in acid condition (Kissel *et al.,* 1992).

Also ecological factors influence the amount and type of odour that is being produced. The compost mix, oxygen concentration, oxygen diffusion rate, particle size, moisture content and temperature influences odour production. Bio filters have been proven to be effective methods for removal of odours in piles during composting. They used micro organisms to decompose odorous organic compounds. Peat absorbs ammonia, which reduces ammonia losses and it works best when used to filter air coming from the piles.

Soil filters control odours caused by gaseous products like ammonia, and organic fatty acids (EPA, 1998).

3.5.3 Leachate

Leachate is liquid that is in the rotting material and has not been used for the biodegradation process. Leachate can cause an environmental problem when it comes in contact with ground water, or when it accumulated it can attract flies, and cause a breeding ground for mosquitoes (NCRS, 2000). In cases when composting is done in an open system, provision should be made to collect the resulting leachate to avoid the environmental problems associated with it.

3.5.4 Occupational and Health Aspects

The problem related to occupational and health aspects include bio aerosols, potential toxic compounds and other substances. Excessive noise and injuries from equipment used at the facilities also can be of concern. These problems can be minimized by proper setting, design, and operation of the facility and by appropriate worker training and education (EPA, 1998).

3.6 Behaviour of Pre-treated waste in a Landfill

The key advantages of landfilling pre-treated waste are the reduction in biogas production, reduction in leachate amount and quality, and reduction of the volume of waste being land filled. The degree of these benefits depend on the extend to which the thermal, mechanical or biological pre-treatment process was carried out (Bone *et al.*, 2003). These benefits will be analysed below.

Some studies have shown the behaviour of pre-treated waste in a landfill site in comparison with the disposal of untreated waste (Adani *et al.*, 2002; Bone *et al.*, 2003; Felske *et al.*, 2003; Höring *et* al., 2003; Munnich *et al.*, 2003; Adani *et al.,* 2004) as follows

- The volume of a waste can diminish by more than 60 %
- Due to the homogenization resulting from the MBT process a much higher storage area with lower permeability. Felske *et al.*, (2003) assert that the conductivity of pre-treated MSW in landfill is between 10^{-6} and 10^{-10} m/s.

Landfilling of pre-treated waste is also characterized by practical and operational conveniences, these are

- Easiness in transport and disposal operation,
- Significant decrease in covering material,
- Reduction in animal present,
- Odour reduction,
- Decrease in clogging in the leachate collection system,
- Reduces wind dispersion of light fractions.

3.6.1 Landfill Volume Reduction

Shredding of waste through mechanical pre-treatment reduces the volume of the waste enabling more airspace to be available in the landfill for more waste. Also removing recyclables by sorting, reduction of organic fraction and moisture content of the waste by biological treatment can reduces the waste volumes to about 20-30 % (Leikam *et al.,* 1997). The additional space produced as a result of MBT process is advantageous to countries that have limited landfill sites or are lacking in space.

3.6.2 Landfill Leachate

As stated above, mechanical biological pre-treatment reduces the toxicity and amount of lecheate. The organic and total nitrogen content in leachate can be reduced to about 90% by means of pre-treatment. The leachate resulting from landfilling pre-treated waste has lower bio reactivity, lower organic strength as compared to landfilling untreated waste. Even though the COD of MBT landfills are high as compared with that of untreated landfills, the BOD is always below 100 mg/l. The high COD concentration signify a slow biodegrading process and it is reflected in the BOD (Bone *et al.*, 2003).

3.6.3 Biogas Emissions

The biogas produced from landfilling of pre-treated waste is generally within methane to carbon dioxide ratio (0.2: 1.25 ratio) (Mollekopt, 2002). Studies have shown that the gas emissions from a treated residue are reduced by more than 98 % as compared to an untreated waste. The Table 3-3 below shows the difference in biogas emission of a treated and untreated waste.

Table 3-3: Range of Organic carbon, nitrogen and chlorine transfer by gas and Leachate; Minimum values represent the Stabilisation degree reached by state of the art MBP (Soyez and Plickert, 2003).

Emission Potential	**Unit**	**Untreated MSW**	**Mechanical biological pre-treated MSW**
Carbon from Gas	[L/kg DM] [gCorg/KgDM]	134-233 71.7-124.7	12-50 6.4-26.8
In leachate TOC	[g/KgDM]	8-16	0.3-3.3
N	[g/KgDM]	4-6	0.6-2.4
Cl^-	[g/Kg DM]	4-5	4-6

Panza *et al.*, (2005) asserts that MBT is a good option for landfilling because it reduces the organic content and fermentability strength of leachate and the amount of biogas as well as the settlement extends of the waste. Also the quality of the MBT will depend on the following

- Extent of source separation
- Waste source (either urban or rural) and period of collection (summer or winter)
- Type of mechanical treatment
- Type, characteristics and duration of the biological treatment

MBT also depends on the available landfill legislation, and the application of the legislation.

3.7 Summary of the Literature Review

The literature review highlights the different methods of MSW management influenced by the characteristic of the different types of waste. MSW management is a global issue due to emission resulting from waste degradation processes having a high polluting potential and are responsible for negative impacts on the environment and consequently contribute to the increasing global carbon dioxide and methane. Limits to parameters are laiddone in legislations to control the quantity and quality of MSW being land filled. Effective and efficient waste management methods which meet these parameters in the EU legislation have been the priority of most European countries in recent years. MBT is seen as an option to achieve these limits. In South Africa there is no mandatory legislation for MSW to be land filled but the DAT technology initiated MBT in South Africa.

The need for sound waste management, reducing the negative impacts of waste to the environment and to human health is highlighted by the demand for new technologies. With the present rate of urbanisation South Africa risk filling all their landfill sites; this calls for more sustainable methods of waste management to be established.

CHAPTER 4

MATERIAL AND METHODS

Chapter four presents the laboratory procedure and techniques associated with samples of MSW for the different degrees of pre-treatment and instrumentation. The collection of MSW, building of a reactor and monitoring of the stabilisation process is included.

4.1 Introduction

The material and methods chapter deals with the experimental procedures carried out to achieve the main objectives, which are:

- To study the evolution of waste pre-treatment using forced aeration at laboratory scale
- To study degradation processes in anaerobic environment of pre-treated waste for different degrees of pre-treatment (2, 4, 8, 10, 12, 14 and 16 weeks)

The study involved setting up a reactor for composting of slightly sorted general waste from the Mariannhill Landfill site Durban, representative samples were collected every two weeks, and fully characterised for leachate and biogas production. Mariannhill Landfill site in the eThekwini municipality of KwaZulu-Natal has successful combined engineering methods with daily –operation to creat the first South african landfill site Conservancy. The site contains a Closed Loop Landfill Design (the plant rescue unit and the conservancy), the Leachate Treatment Plant and Gas to Electricity Plant.

The experimental set up was designed according to the EU standards of waste pre-treatment and EU Landfill Directives (Basak, 2007; Munnich, 2005).The Civil Engineering Department's Environmental Laboratory was utilised for the majority of preparation, analysis and storage of equipment and samples. The Standard Methods for Examination of Water and Wastewater 20th Edition were used as guide for all laboratory procedures and analysis (Clesceri *et al.*, 1989). Figure 4-1 summarises the approach to the research work.

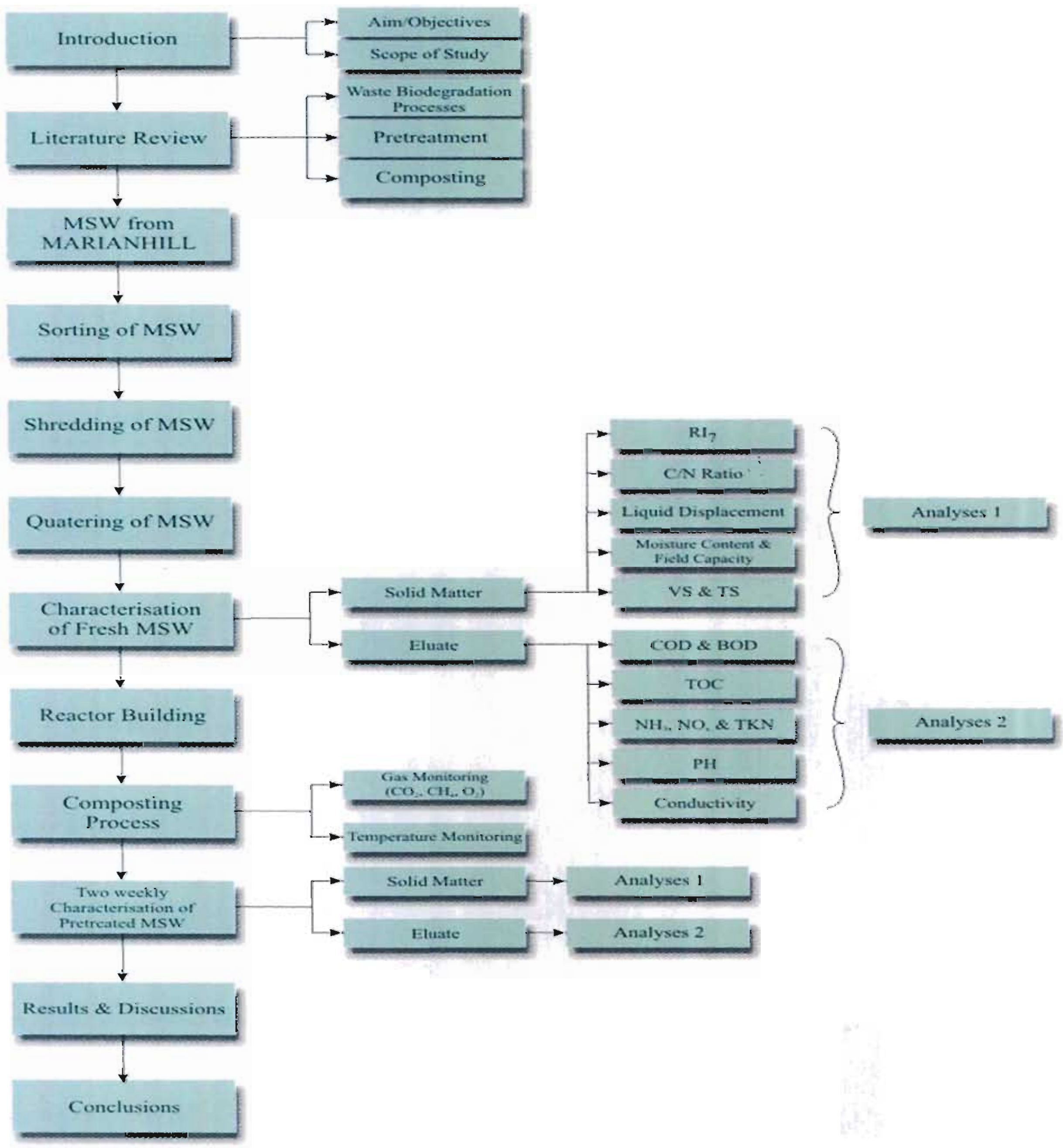


Figure 4-1: Flow Chart Illustrating the Research Framework

4.2 Waste Collection

Pre-sorted waste from a Material Recovery Facility (MRF) at the Mariannhill Landfill site in Durban was used as the global sample for this research. The percentages of the waste deposited into the landfill site each month (comprising the non recyclables or biodegradable), and recyclables and the percentages of the waste used for the research are presented on the Table below.

Table 4-1: Approximate Daily intake of MSW into the Marianhill Landfill Site

Components	Kg	Percentage (Mass)
Plastic	241	32.47
Glass	10	1.34
Wood/dry leaves	15	2.02
Rubber	19	2.56
Fabrics	50	6.73
Stone	10	1.34
Tin /Aluminum/metal	30	4.04
Cardboard	220	29.64
Paper	30	4.04
Prutrescible	112	15.09
Others	5	0.67
total	742	100

Collection of four 200L MSW samples from MRF and the following activities were carried out.

- The global sample was weighed
- Sorted to remove large cardboard and plastic fractions
- Shredded to an homogeneous size distribution of approximately 40-50 mm
- Filled into the composting reactor

4.3 Reactor set up and waste preparation

A simple 200l wheelie-bin commonly used for waste collection was chosen as the reactor for the research as seen in Plate 4-1. The reactor was equipped with sampling properties to facilitate gas and temperature measurements along its length. Forced aeration was guaranteed by a system of pipes placed into the waste and linked to a compressor which provided air at a rate of 11 l/min (Bari *et al., 2000*; Adani *et al.*, 2004; Lornage *et al.,* 2007; Adani *et al.*, 2002).

Plate 4-1: The Reactor.

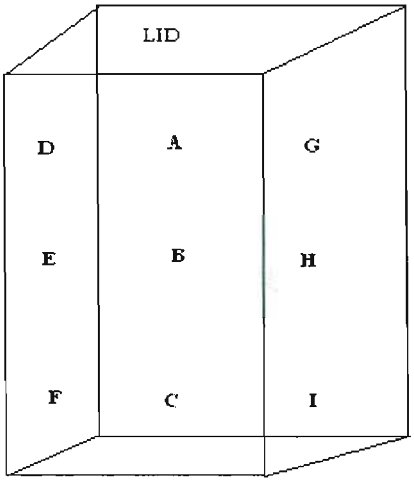


Figure 4-2: Diagrammatic Representation of the Reactor

Temperature and oxygen concentration are key indicators in the development of biodegradation process. The oxygen concentration throughout the treatment process was maintained between 10 – 15 % for optimal microbial activity. For a successful stabilisation of the MSW, monitoring of the reactors internal and ambient temperature is of prime importance (Mollekopf *et al.,* 2002). The sampling points are indicated in Figure 4-2. The reactor room was acclimatized at 30 °C using a thermostat and ambient temperature monitored everyday. Temperature measurement in the reactor was achieved through the use of a thermocouple, type (MT -630) in Plate 4-2.

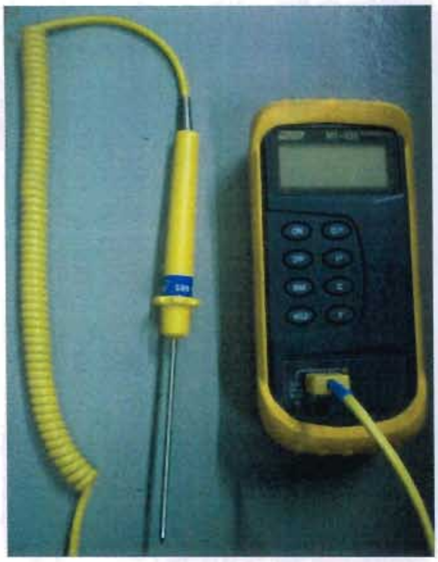


Plate 4-2: The Thermocouple. **Plate 4-3: Quartered MSW.**

The non-homogeneity of the MSW is a matter of concern in studies of this nature. To determine a representative sample of the waste, the global sample was accurately quartered. Plate 4-3 represents the quartering process and Table 4-2 gives the percentages of waste in the reactor. Quartering involves dividing waste in four equal parts (1, 2, 3, and 4); the 1st part is mixed with the 3rd part while the 2nd part is mix with the 4th part. Each part (1st, mixed with 3rd and 2nd mixed with 4th) is divided again into 4 equal parts. A quarter of each of the four parts is combined and divided into 4 equal parts. A quarter of the later is used as the representative sample to carry out the analysis (Trois, 2007).

Table 4-2: Composition of the MSW in the Reactor

Components	kg	%
Plastic	30	16.57
Wood/dry leaves	10	5.52
Rubber	10	5.52
Fabrics	18	9.94
Paper	15	8.28
Prutrescible	95	52.48
Others	3	1.65
Total	181	100

4.4 Aeration

According to Bari *et al., (*2000); Adani *et al.*, (2004); Trois, (2007); the supply of air into a waste pile during composting should meet the following requirements:

- The oxygen demands for aerobic decomposition
- Removal of moisture to facilitate drying
- Removal of heat produced during decomposition to control the process temperature and to prevent microbial inactivation.

The first requirement for aeration is also called the stoichiometric oxygen demand. It is a complex parameter because of the heterogonous nature of MSW and also due to the fact that the oxygen supplied does not necessarily reflects the amount of oxygen that reaches the microorganism due to the different diffusion rates of oxygen in water and in air. To avoid excessive removal of moisture, the aeration rate is estimated taking into consideration the initial moisture content of the waste, the amount of water that normally is dissipated with heat and other environmental aspects. Furthermore it is assumed that the amount of moisture in saturated air increases with increasing air temperature, which means that at thermophilic temperatures a large amount of moisture is removed (Bari *et al.,* 2000).

Excessive temperature destroys beneficial micro-organism; to avoid this, aeration is required for its removal. Temperature is due to the heat produced in the decomposition process which also depends on the amount of oxygen supplied. Heat loss by vaporisation to the surroundings is considered negligible and if the heat generated is greater than that lost to vaporisation and heating of air and water, then the temperature in the waste pile rises. This is true to a point because the biochemical reactions rate increases exponentially and very high temperatures will cause the microbial population to be inactive.

It is difficult to determine the amount of heat removed since it depends on factors like:

- Variation of the rate of oxidation;
- Difficulties in determining the composition of the waste pile due to its heterogeneity;
- Difficulties to follow up raw waste through all the aerobic conditions.

To determine the oxygen required for temperature removal, the amount of heat released is required. This can be derived from the primary chemical formula for decomposition. Huag, (1986) calculated the amount of heat energy released per kilogram of compost produced to be 13644.3 KJ/kgO_2 for garden refuse. This value involves the heat for vaporisation.

The aeration of the reactor was maintained between 15 – 19 % of oxygen for the first 3 weeks and reduced to 10-15 % of oxygen for the following weeks up until week 16, as recommended by other similar studies (Haug, 1980; Bari *et al.,* 2000; Mollekopf *et al.,* 2002). To meet these requirements the system of pipes in the reactor was connected to a compressor and a flow regulator to achieve a flow rate of approximately 11 l/min.

4.5 Analysis on Fresh and Pre-treated Solid Matter

The characterisation of the solid matter includes the following analyses: moisture content test, field capacity, total solids and volatile solids (TS and VS), carbon to nitrogen (C/N) ratios, respiration index at 7 days (RI7) and biogas production. The analyses were conducted according to the American Standard Methods for Waste Water Analysis (Clesceri *et al*, 1989).

4.5.1 Moisture Content and Field Capacity

The moisture content test aims at determining the amount of pore water in the waste sample. A representative sample is placed in a beaker, weighed and dried for 24 hours at a temperature of 110 ^{0}C in an oven. After 24 hours the mass of the sample is recorded and the moisture content calculated using equation 4-1.

$$W\,(\%) = \frac{Mw - M_D}{Mw} \times 100 \qquad (4\text{-}1)$$

Where:
W (%) is the moisture content
M_W is the mass of the wet sample
M_D is the mass of the dry sample

According to Novella (1995), field capacity is the maximum moisture content held in compacted waste in a landfill by capillary action. In cognisance that waste in landfill is at field capacity, analysis are carried out on waste at field capacity to stimulate landfill conditions. As shown on Plate 4-4 below, the equipment used in carrying out the test consists of a conical flask, a filter paper, and a funnel. The bottom neck of the funnel is sealed firmly with a filter paper and weighted. A known amount of MSW is placed into the funnel. Water is poured gently unto the waste until it starts dripping out at the bottom of the funnel. The funnel is placed into a conical flask; the top of the funnel is sealed to prevent evaporation and left for 24 hours. After 24 hours the funnel and waste are weighted. The amount of water absorbed by the waste can be determined by difference in the weights of funnel and waste before and after the experiment. This can be divided by the amount of waste and multiplied by 100 to get the field capacity.

Plate 4-4: The Field Capacity Test Setup.

4.5.2 Total Solids (TS) and Volatile Solid (VS) (ASTM Method B2450)

Following the Standard Method B2450, total solid is the volume of a sample, in percentage, after evaporating a known volume in an oven at 110 °C for 24 hours. The test to determine the volatile solids of a sample involves preparing dry samples and weighing them. The samples are incinerated in a furnace for 20 minutes at 550 ^{o}C. Plate 4-5, shows the furnace. After which the samples are cooled in a desiccator, and their masses were taken, the total solids or volatile solid can be calculated using the equation 4-2 below,

$$\text{TS (\%) or VS (\%)} = \frac{(\text{MD} - \text{MA})}{\text{MD}} \times 100 \qquad (4\text{-}2)$$

Where:

MD is the mass of the oven dry sample

MA is the mass of the remaining sample after being oven dried

TS is the total solids (Clesceri *et al.,* 1989).

Plate 4-5: The Furnace used to Determine Volatile Solids.

4.5.3 Carbon to Nitrogen ratio (C/N)

The carbon to nitrogen ratio is a measure of the total carbon and the total nitrogen in the waste sample. This method uses the Walkley – Black procedure (Horneck and Miller, 1998). An air dried sample is placed into a 500 ml Erlenmeyer flask and potassium dichromate solution is added to the sample from a burette. The sample is dispersed into the solution by swirling. 20 ml of sulphuric acid is added rapidly, but cautiously. Swirling ensure effective mixing. The sample is set in a flask to cool on asbestos sheets for about 30 minutes. 5-10 drops of an indicator and excess dichromate is added to the solution and titrated with iron (2) ammonium sulphate solution giving a dark violet brown to a sharply green colour. Repeats are made for smaller samples if the iron (2) titration is less than 5.0 ml. The organic carbon content can be calculated using equation 4-3 below. The analysis was carried out by a certified laboratory Bemlab (PTY) LTD Cape Town.

$$\text{Carbon } (\%^{m}/_{m}) = \frac{(A-B) * M * 0.3 * 1.17}{m} \qquad (4\text{-}3)$$

Where

A = Volume of the iron solution from standardisation (ml)
B = Volume of iron solution from measurement (ml)
M = Molarity
m = Mass of the sample

For the measurement of total nitrogen a Leco FP528 nitrogen analyser which analyses small samples (less than 250 mg) can be used used. 0.25 g could be used in very low nitrogen concentration or weight of the sample used is reduced for samples with very high nitrogen concentration (Horneck and Miller, 1998).

4.5.4 Respiratory Index (RI7)

RI7 measures the amount of oxygen consumed by MSW during it biological activity at 20 °C in an incubator. MSW at field capacity is placed in an airtight 1500 ml vessel with a pressure sensor lid to degrade aerobically in an incubator at 20 °C for 7 days, as seen in Plate 4-6 below. The volume of oxygen consumed by biological activity is proportional to the amount of biodegradable organic matter contained in the sample. For the period of biodegradation, oxygen is used while carbon dioxide is produced. Carbon dioxide is absorbed by potassium hydroxide added in the vessel. The pressure sensor measures a negative pressure, and the pressure is equal to the amount of carbon dioxide absorbed by the potassium hydroxide which is therefore equal to the amount of oxygen consumed in the biodegradation process. After 7 days the pressure difference can be evaluated using equation 4-4.

$$\Delta P = \frac{BOD_7}{\left[\frac{M}{RT_m}\right]\left[\frac{V_t - V_l}{V_l} + \alpha \frac{T_m}{T_o}\right]} \qquad (4\text{-}4)$$

Where:
BOD_7 = results from the tests in mg/l
M = molar mass of O_2 (mg/mol)
T_0 = Reference temperature = 273.15K (STP)
Tm = 20°C = 293.15K (STP) –Testing Temperature
Vt = Volume of the vessel (m^3)

Vl = Volume of the sample (m^3)

R = 83.144 mbar/mol.k- Gas constant

α = cubic expansivity of gas (0.03103)

The number of oxygen molecules can be estimated using the ideal gas law equation

PV = nRT

Where

P = Pressure (Pa)

V = Volume of sample (m^3)

n = Moles of oxygen

R = Ideal gas constant (8.3144712 m^3.Pa.K^{-1}.Mol^{-1})

T = temperature (K)

Assuming that at the start of the experiment concentration of O_2 is 20 % and N_2 is 80 %, the RI7 is derived by dividing the amount of oxygen consumed by the amount of dry mass.

Plate 4-6: An example of the RI7

4.5.5 Biogas Test

The biogas test is the measure of the gas production during the different stages of the biodegradation process. The biogas test was done using the liquid displacement method.

4.5.5.1 Liquid Displacement

The liquid displacement test involves placing a representative sample of the waste at field capacity in a 1500 ml amber bottle in a temperature controlled room at 25-30 °C. The bottle is connected to a 1litre glass burette by a gas tube which is connected to a reservoir. To ensure that gases produced during the degradation process is not absorbed; the glass burette is filled with a solution of sodium chloride and sulphuric acid. Gas produced in the amber bottle displaces the liquid in the glass burette and the amount of liquid displaced is equal to the amount of gas produced at any point in time. Using an infrared gas analyzer (Model GA 2000) the composition of the biogas produced is determined. The gas analyser measures concentrations of carbon dioxide, oxygen, and methane as % of volume by volume in air as seen in Plate 4-8 below. The displacement method was performed for each treated sample of waste extracted from the main reactor, all samples were monitored for 2-4months. Plate 4-7 below shows the liquid displacement method setup. the

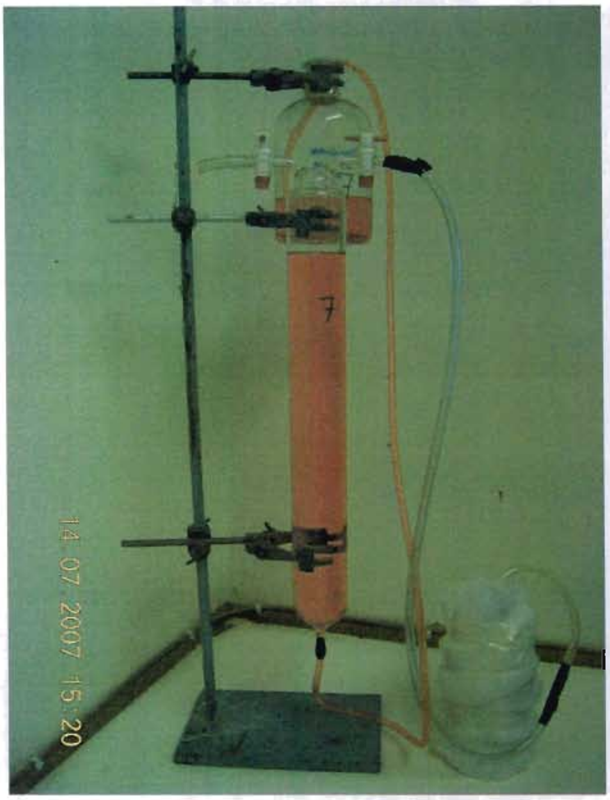


Plate 4-7: The Liquid Displacement Setup

Plate 4-8: The Gas Analyser

4.5.6 Temperature and Gas Composition from the Reactor

The temperature and gas composition were measured daily for the first 2 months and three times a week for the 3rd and 4th months for the waste in the reactor (Wheelie Bin). The temperature was measured using a thermometer while the gas composition was measured using an infrared gas analyzer (type GA 2000) shown in Plate 4-8.

4.6 Analysis on Eluates

According to the European Landfill Directives (EU official Journal, 1999), the total amount of biodegradable MSW being disposed into landfill must be reduced to 75 % in 5 years, 50 % in 8 years and 35 % in 15 years. To ensure this, MSW is pre-treated prior to landfilling. Pretreatment ensures the requirements of Europeans landfill directive listed in Tables 2-3 and 2-4 are met. Representative samples of MSW extracted from the reactor at different degrees of pre-treatment: after 2, 4, 6, 8, 10, 12, 14 and 16 weeks. To ensure that the waste is representative, the reactor is emptied and quartered. Using a shaker an eluate is formed by mixing MSW with distilled water in a solid to liquid ratio 1:10 for 24 hours. After 24 hours the eluate is filtered using a 0.07 mm coarse sieve and the filtrate is centrifuged at 600 rev. per minute for 20 minutes. After centrifugation, the eluate is again filtered with a 0.45 µm filter paper. Depending on the turbidity of the eluate and to ensure a smooth flow when filtering, centrifugation can be done twice or 3 times. The analyses carried out on the eluates are COD, BOD, TKN, TOC, NH_3, NO_x, VS and TS.

4.6.1 Chemical Oxygen Demand (COD) (ASTM methods 5220B)

The COD test measures the content of organic matter in a sample of waste. The oxygen equivalent of the organic matter that can be oxidized is measured using a strong chemical oxidizing agent in an acidic medium. Potassium dichromate ($K_2Cr_2O_7$) is used as the oxidizing agent. The sample is further titrated with ferrous ammonium sulphate (FAS). The FAS also acts as a catalyst, and the amount of dichromate consumed can be expressed in terms of the oxygen equivalent. Distilled water was used as blank samples and these acted as controls for the experiment. The principal reaction using dichromate as oxidizing agent can be represented generally as:

$$\text{Organic matter } (C_aH_bO_c) + Cr_2O_7^{-2} \rightarrow Cr^{+3} + CO_2 + H_2O$$

4.6.2 Biological Oxygen Demand (BOD)(AI 99005)

The BOD involves the measurement of the dissolved oxygen used by micro organism in the biochemical oxidation of organic matter. BOD is important and widely used:

- To determined the approximate quantity of oxygen that will be required to biologically stabilize the organic matter present
- To measure efficiency of some treatment processes
- To determine compliance to waste discharge permit

In the preparation of the eluate, after the sample has been mixed for 24 hours with distilled water and sieved with a 0.07 mm sieve, homogenous known volumes of the sample are incubated in 300 ml amber bottles at 20 °C, as seen in Plate 4-9 and 4-10 below. ATH (N- allylthiourea) is added in drops to inhibit the action of nitrifying bacteria. The pH of the sample is maintained between 6 to 9 and 5 to10 drops of KOH are added to remove the carbon dioxide produced (Hutter, 1984). A magnetic stirrer is used to ensure continuous gas exchange by agitation during incubation period. The bottle is sealed with a pressure sensor, and then incubated for 5 days, drop in pressure is proportional to the amount of oxygen consumed and therefore equal to the biodegradable organic substance present in the waste expressed in mgO_2/l (Robertz, 2000).

Plate 4-9: A BOD Bottle.

Plate 4-10: An Incubator with BOD Bottles.

4.6.3 Total Organic Carbon, Total Kjeldahl Nitrogen(TOC, TKN)

TKN is a combination of organically bound nitrogen and ammonia in eluate. TKN gives the organic nitrogen and the ammonia nitrogen in samples. TKN is lower in pre-treated waste than raw waste (Jones and Bradshaw, 1989). The procedure for TKN uses a simple digestion, distillation and titration method. As the sample is digesting, organic nitrogen, free ammonia, amino nitrogen and ammonium-nitrogen are converted to ammonium sulphate in the presence of sulphuric acid, potassium sulphate and a copper catalyst. The ammonium complex is decomposed by sodium thiosulphate.

TOC procedure involves the determination of total organic and dissolved organic carbon by oxidizing carbonaceous species to carbon dioxide using reflex digestion employing acidified potassium persulphate and ultra violet irradiation. The resulting carbon dioxide is purged out of the reflux mixture into a standard caustic absorber tube and back titrated with standard sulphuric acid to determine the CO_2 absorbed. The test was carried out by a certified laboratory B.N. Kirk in Durban.

4.6.4 Ammonia and Nitrates (NH3 and NOX) (SABS Method 217:1990)

According to SABS method 217 (1990) the sample is distilled in alkaline conditions while the distillate is collected continuously in boric acid and diluted to 250 ml in distilled water. The solution formed is titrated against standard hydrochloric acid solution. The amount of ammoniacal nitrogen can be determined. After ammoniacal nitrogen has been removed, Devarda's alloy is added into the remaining sample and distillated again in boric acid. The distillate is titrated against standard hydrochloric acid and the nitrates can be determined. The set up for NH_3 and NO_x analysis are presented in Plate 4-11 and 4-12 below.

Plate 4-11: Nitrate and Ammonia Distiller.

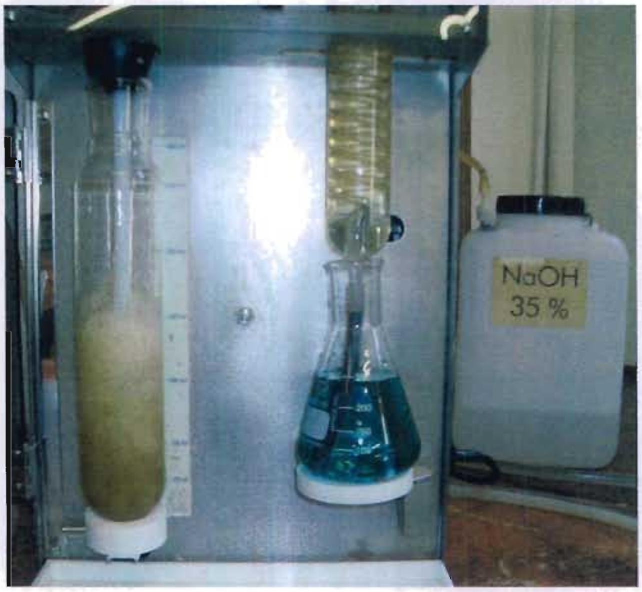


Plate 4-12: Distillation Phase in Progress.

4.6.5 pH

pH is the measure of the hydrogen ion concentration in a sample. pH is important because biological life exists in a narrow pH range. The hydrogen ion concentration in a sample is also closely connected to the way in which water molecules dissociate (Williams 1998). For this research a pH meter Orion LABTECH model 410A (in Plate 4-13 below) was used to measure pH of both eluates and solid matter in slurry form. The pH probe was calibrated between 4 and 7 before each measurement.

Plate 4-13: The pH meter

4.6.7 Conductivity

The conductivity of a sample is an indication of the soluble salts present in the sample. The conductivity was carried out using the Corning Checkmate 11 sensor as seen in Plate 4-14. The sensor is calibrated before each measurement.

Plate 4-14: The Corning Checkmate Sensor.

4.7 Accuracy/Repeatability Check

Accuracy checks are carried out to eliminate the possibility of errors. In the method for the examination of solids, eluates and SABS methods the use of accuracy checks are necessary. Each of the analysis carried out on the solid or eluate of MSW was done in triplicate and their averages are presented as results in chapter 5. Standard deviation, averages and variance were done for each set of test as a repeatability check for the analysis. The equations below were used to calculate standard deviation, variance and averages. Table 4-3 and 4-4 illustrates accuracy checks for ammonia and COD.

$$Average = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (4.6)$$

$$\operatorname{var} iance = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - x)^2 \qquad (4.7)$$

$$s\tan dard\ deviation = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - x)^2} \qquad (4.8)$$

Where

x_i is values of the analysis data

n is number of observation or data

x is average of the analysis data

An example to demonstrate the use of accuracy checks is shown below.

Table 4-3: Accuracy checks carried out on the COD Results.

DATE				AVE	STDEV	VAR	RESULT
	Raw waste						COD(mg/l)
4- April	0.114	0.123	0.111	0.116	0.0062	0.000	7117.35
4-April	0.108	0.112	0.112	0.110	0.002	0.000	6787.27
26 April	0.036	0.03	0.029	0.032	0..002	0.00	1475.84
5 June	0.036	0.03	0.029	0.138	0.001	0.000	1475.84

Table 4-4: Accuracy Check carried out on the NH_3 Results.

DATE				AVE	STDEV	VAR	RESULT
	Raw Waste						NH_3 (mg/l)
23-Apr	3.56	3.53	3.66	3.44	0.95	0.2	50.16
7-May	3.41	3.45	3.47	2.16	0.42	0	48.20
16-May	2.14	2.19	2.17	0.71	0.35	0	30.33
30-May	0.72	0.74	0.68	0.6	0.42	0	9.98
14-Jun	0.55	0.61	0.64	0.16	0.64	0	8.4
26-Jun	0.15	0.18		0.13	0.29	0	2.31
13-Jul	0.15	0.14	0.12	0.14	0.21	0	1.91

CHAPTER 5

RESULTS AND DISCUSSION

Chapter Five presents the results of the analysis carried out on fresh and pre treatment waste for the research period of 5 months (March 2007 to July 2007). The results are divided into four parts: Waste composition, Treatment process, Analysis on solid matter and Analysis of Eluate. The relationship between significant values obtained is discussed here.

5.1 Introduction

The results are in tables and figures and are averages of large quantities of collected data. These were carried out on both eluate and solid matter.

5.2 Composition of Waste

On a daily basis approximately 1-1.5 tons of MSW is disposed into the Marianhill land fill site. MSW is presorted and selected in a MRF (material recovery facility). From 2800kg of presorted MSW, 24kg is low density waste, 369kg is scrap boxes, 38.5 kg was scrap plastics, giving 26% of recyclables (DSW, March 2007). The composition of the recyclables is presented in Table 5.1, average daily intake into the landfill site while table 5.2 gives an approximation of waste from the MRF, representing the global sample for the research. From the recyclables about 600kg was collected and brought to the Civil Engineering Department, University of Kwazulu Natal. The waste was weighted, sorted, shredded, characterized and placed into in a reactor; the results of the characterization are presented in Table 5.3.

Table 5-1: Average Daily intake of MSW at the Marianhill landfill

Components	kg	Percentage (Mass)
Plastic	241	32.47
Glass	10	1.34
Wood/dry leaves	15	2.02
Rubber	19	2.56
Fabrics	50	6.73
Stone	10	1.34
Tin /Aluminum/metal	30	4.04
Cardboard	220	29.64
Paper	30	4.04
Prutrescible	112	15.09
Others	5	0.67
Total	742	100

Table 5-2: Output from the MRF

Components	kg	Percentage (Mass)
Plastic	50	18.79
Glass	8	3.07
Wood/dry leaves	13	4.88
Rubber	15	5.63
Fabrics	40	15.03
Stone	5	1.87
Tin /Aluminum/metal	10	3.75
Cardboard	10	3.75
Paper	10	3.75
Prutrescible	100	37.59
Others	5	1.87
Total	266	100

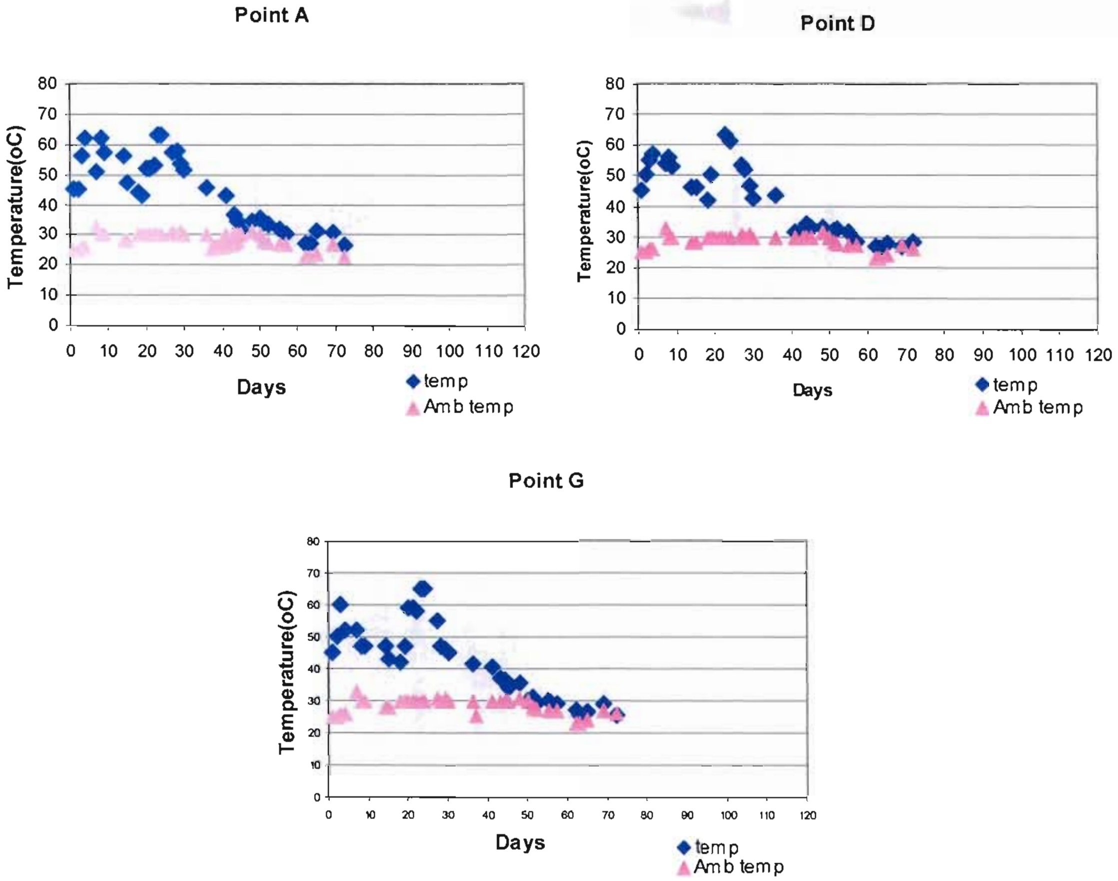
Table 5-3: Composition of the Waste in the Reactor

Components	kg	%
Plastic	30	16.57
Wood/dry leaves	10	5.52
Rubber	10	5.52
Fabrics	18	9.94
Paper	15	8.28
Prutrescible	95	52.48
Others	3	1.65
Total	181	100

The waste in the reactor and the global sample encompass a high percentage of degradables, given by 57.9 % of the MSW in the reactor and 40 % of the global sample. Illustrating that very little or no prutrescibles was removed. This is true for other components of MSW as shown in Figures 5-1 and 5-2. Prutrescibles are vital for the reason that they are highly biodegradability. This similarity indicates the representativeness of MSW in the reactor when compared with the global sample.

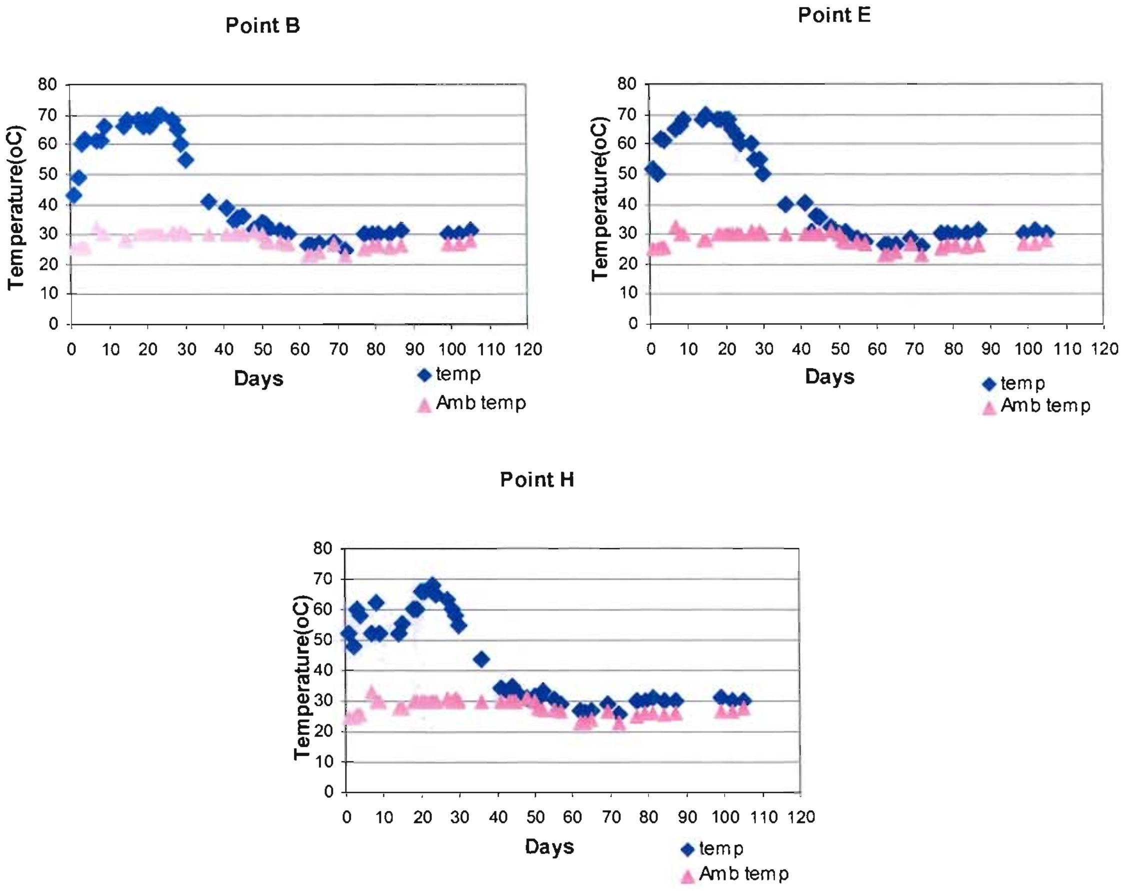
5.3 Treatment Process

Temperature and oxygen concentration are key indicators of MSW stabilization process. Oxygen is required for heat removal, moisture removal and prevention of microbial inactivity (as discussed in section 4-4). Oxygen concentration of 10% of oxygen in air was retained throughout the treatment process. Figure 5-1 (points A, D and G) shows the variation of temperature and ambient temperature in the upper part of the reactor over the period of study.



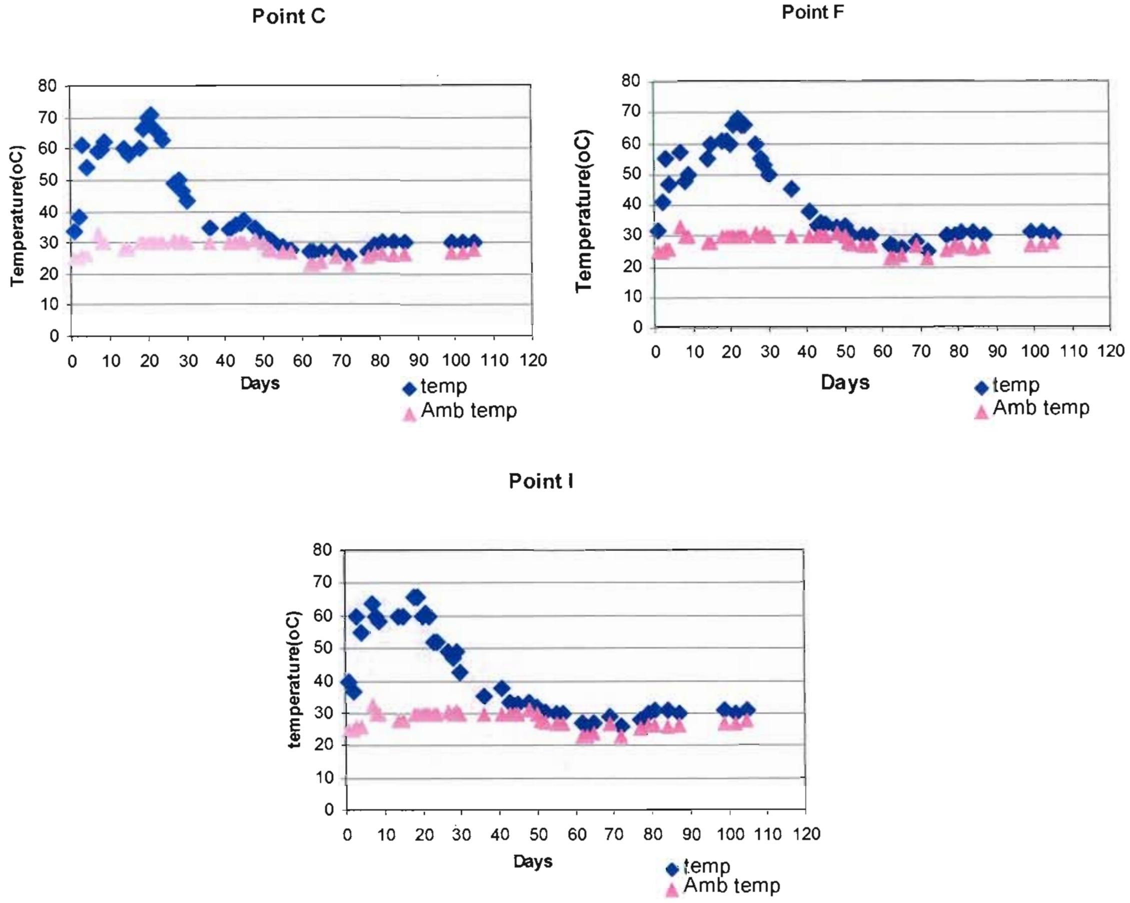
Figures 5-1: Variation of Temperature and Ambient Temperature in the Top part of the Reactor over the Period of the Study (point A, D, and G).

Figures 5.2 below show the variation of temperature and ambient temperature in the middle part (points B, E, and H) of the reactor over the period of study.



Figures 5-2: Variation of Temperature and Ambient Temperature in the Middle of the Reactor over the Period of Study (Points B, E, H).

Figures 5.3 below show the variation of temperature and ambient temperature in the bottom part of the reactor over the period of study.


Point C

Point F

Point I

Figures 5-3: Variation of Temperature and Ambient Temperature at the Bottom of the Reactor over the Period of Study (points C, F, I).

The figures illustrate an ambient temperature variation between 20-35 °C. The temperature in the reactor reaches 70 °C from day 0 to day 40 and falls gradually between 35 and 25 °C from day 40 onwards. A slight decrease in temperature, 40 to 65 °C was noticed in the upper section of the reactor, for the first 40 days. This could be attributed to heat loss through the lid of the reactor by convection and conduction. While the middle and the bottom sections of the reactor maintained high temperatures for the first 40 days.

5.4 Analysis of the Solid Matter

The results of the analysis carried out on the solids (field capacity and moisture content, RI7, biogas, TS, VS, C/N ratio) are presented in this section.

5.4.1 Field Capacity and the Moisture Content

The two weekly results of field capacity and moisture content are presented in Table 5-4. These results were used to setup the RI7, and the biogas test.

Table 5-4: Moisture Content of Sample for the Period of Study.

Time (Week)	Day	Moisture content/%
Raw	2	54
2	22	60
4	36	58
6	48	59
8	62	56
10	77	56
12	91	50
14	105	45
16	120	44

The moisture content of the waste shows a gradual decrease. Due to moisture loss as a result of the temperature increase throughout the degradation process. The moisture content decreases from 60 to 44 %.

5.4.2 Respiration Index Seven (RI7)

The respiratory index was computed as the oxygen used during 7 days incubation in an anaerobic condition for the representative samples collected every two weeks.

Table 5-5: Amount of oxygen consumed over the period of Pre-treatment.

Sample(Weeks)	mg O_2/gDry Mass
Raw	3.3
2	1.45
4	1.78
6	1.35
8	0.92
10	0.95
12	0.72
14	0.87
16	0.83

The results of the oxygen produced throughout the treatment process varied between 0.83 and 1.57 mg of oxygen. The highest 1.78 mg of O_2 was produced by the 4 week pretreated waste. This represent a period of great microbial activity and also shows that at this stage the waste has a large amount of carbon content.

5.4.3 Biogas

The biogas test uses the displacement method wherein increasing concentration of methane and carbon dioxide, and decreasing concentration of oxygen are measured through volume changes.

5.4.3.1 Displacement Method

Figure 5-4 demonstrates the cumulative results of the volume against time for every sample taken during the period of the study. This method measures composition of O_2, CO_2, and CH_4 produced. The percentage compositions for the different gases are indicated by the change in volume plotted as cumulative volume. The percentage composition of O_2, CO_2 and CH_4 against cumulative volume for raw waste is show is figure 5.4 below

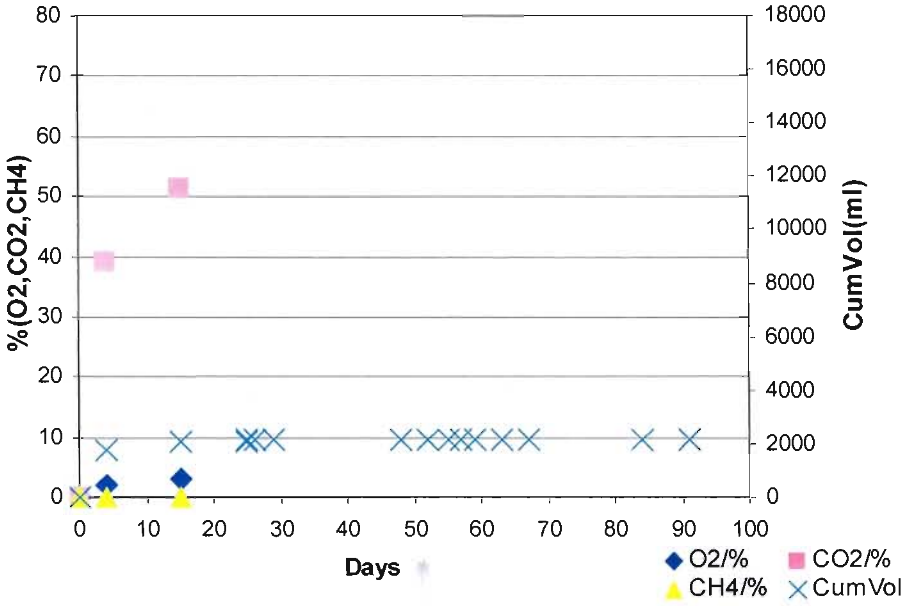


Figure 5-4: Percentage Composition of O_2, CO_2 and CH_4 against Cumulative Volume for Raw MSW.

The raw waste shows a decreasing amount of oxygen after 25 days in an anaerobic environment represent the start of the biological process and consequently an increasing amount of CO_2, and no production of methane. This is typical of the acidogenesis stage in the degradation in the landfill process. There is no production of methane because hydrolysis and fermentation are still to take place which produces acid that inhibit the production of methane. Figure 5-5, below shows the percentage composition of O_2, CO_2 and CH_4 against cumulative volume for the two week pre-treated waste.

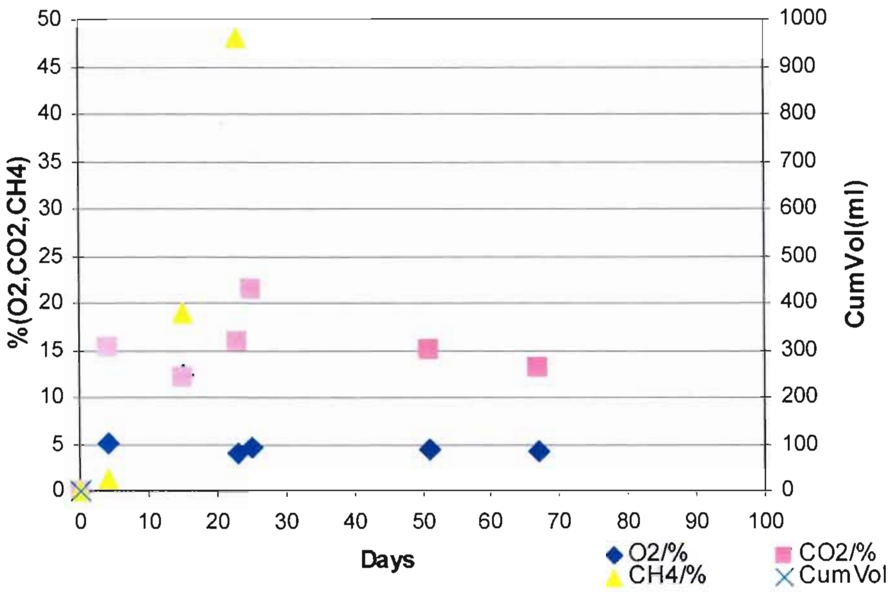


Figure 5-5: Percentage Composition of O_2, CO_2 and CH_4 against Cumulative Volume for Two weeks Pre-treated Waste.

The figure confirms a decreasing percentage of O_2, an increasing percentage of CO_2, and increasing methane for the first 25 days in an anaerobic environment. This trend continues thereafter. This is a typical characteristic of late stages of acetogenesis, with low amount of intermediates such as volatile acid, acetate and inorganic salts. In small amounts of hydrogen the intermediates are oxidized producing main food sources of methane generating bacteria, increasing the activity of sulphate reducing bacteria and methane generating bacteria. Figure 5-6 below shows the percentage composition of O_2, CO_2 and CH_4 against cumulative volume for four weeks pre-treated waste.

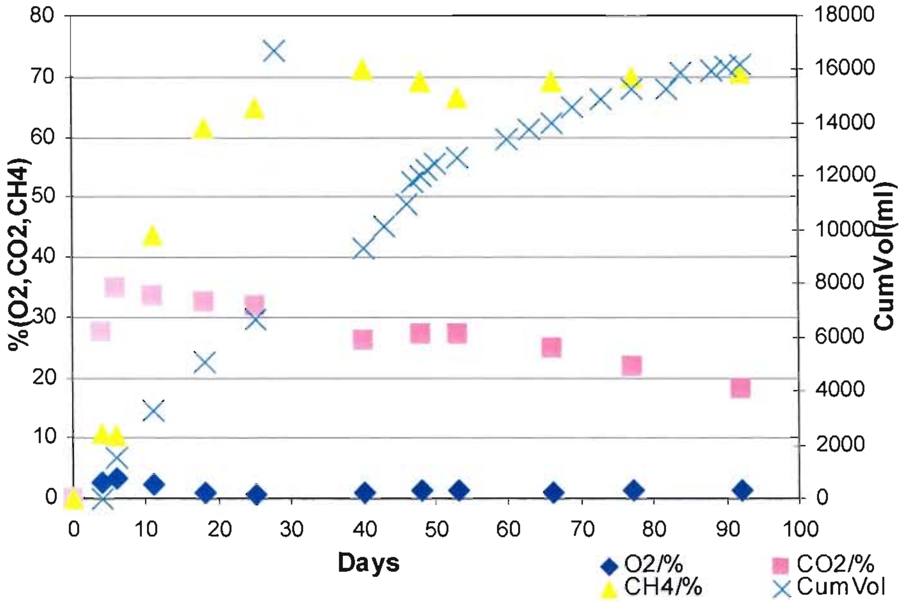


Figure 5-6: The Percentage Composition of O2, CO2 and CH4 against Cumulative Volume for Four week Pre-treated MSW Sample.

An increasing amount of CO_2 was noticed for the first 15 days in an anaerobic environment with a corresponding decrease in oxygen and an increase in CH_4. O_2 and methane continued decreasing and increasing respectively while carbon dioxide decreased over the next 10 days. Usage of oxygen results in the production of CO_2, absence of O_2 result in reduction of CO_2 indicted by the drop in the CO_2 concentration. The percentage of CH_4 increases from 10.8 to 70% within 90 days of sample setup indicating CH_4 generating bacteria metabolising acetate and formate produced in the early degradation stages to form CH_4 and CO_2. Or CH_4 can be formed from direct conversion of H_2 and CO_2 to CH_4 by methanogens. Figure 5-7 below, shows the percentage composition of O_2, CO_2 and CH_4 against cumulative volume for six weeks pre-treated waste.

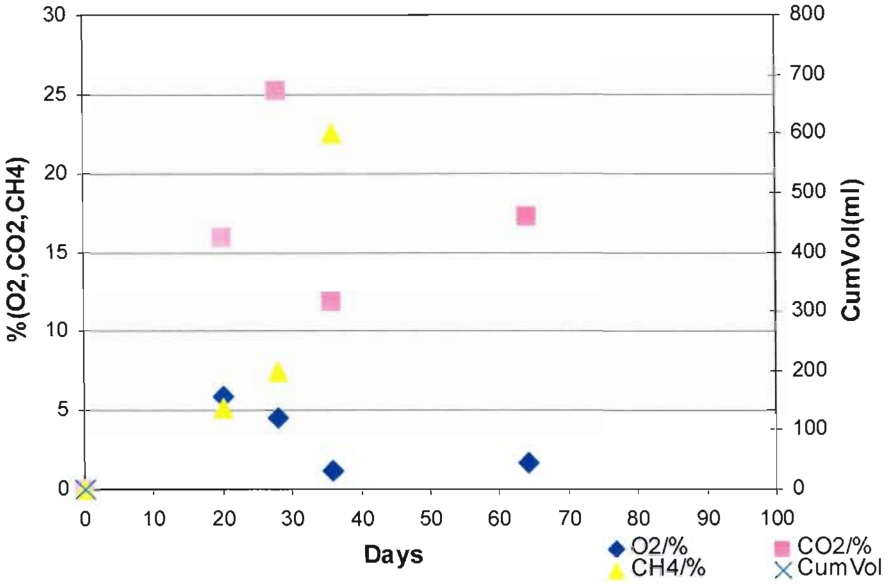


Figure 5-7: The Percentage Composition of O_2, CO_2 and CH_4 against Cumulative Volume for Six weeks Pretreated MSW Sample.

Figure 5-7 illustrates a decreasing amount of O_2, from 5.9 to 1.7 for the first 45 days, and increasing amount of CO_2 for the first week from 15 to 25 and a decrease for the remaining periods of the experiment. Increasing trends of CH_4 are observed indicating typical methanogenesis stage, it is noted that the CH_4 production is declining in this stage. Figure 5-8 below shows the percentage composition of O_2, CO_2 and CH_4 against cumulative volume for eight weeks pre-treated waste.

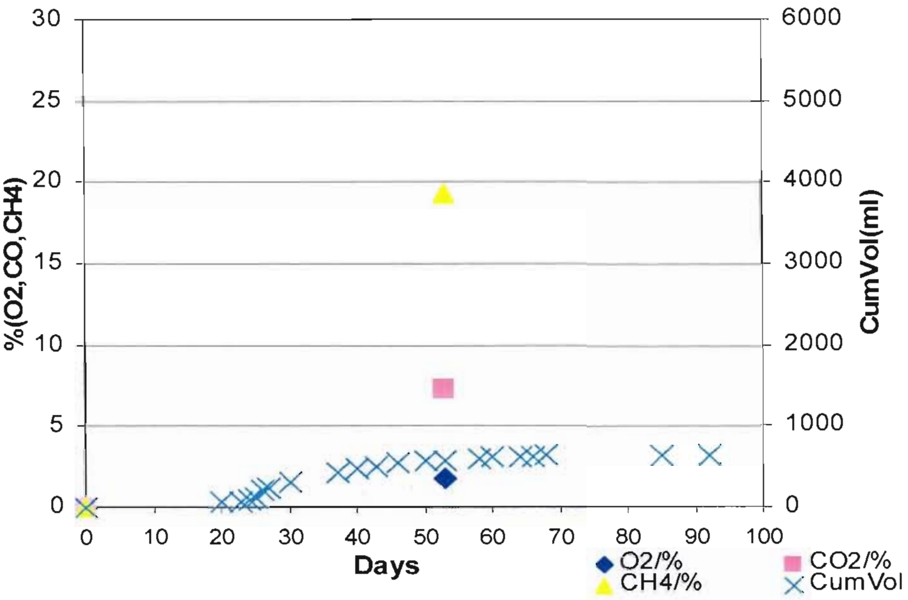


Figure 5-8: The Percentage Composition of O_2, CO_2 and CH_4 against Cumulative Volume for Eight weeks Pre-treated waste.

The figure shows a very little amount (1.8%) of O_2 after 35 days in an anaerobic environment, 7.3 % of CO_2 and 19.3 % of CH_4. Figure 5-9 below shows the percentage composition of O_2, CO_2 and CH_4 against cumulative volume for ten weeks pretreated MSW.

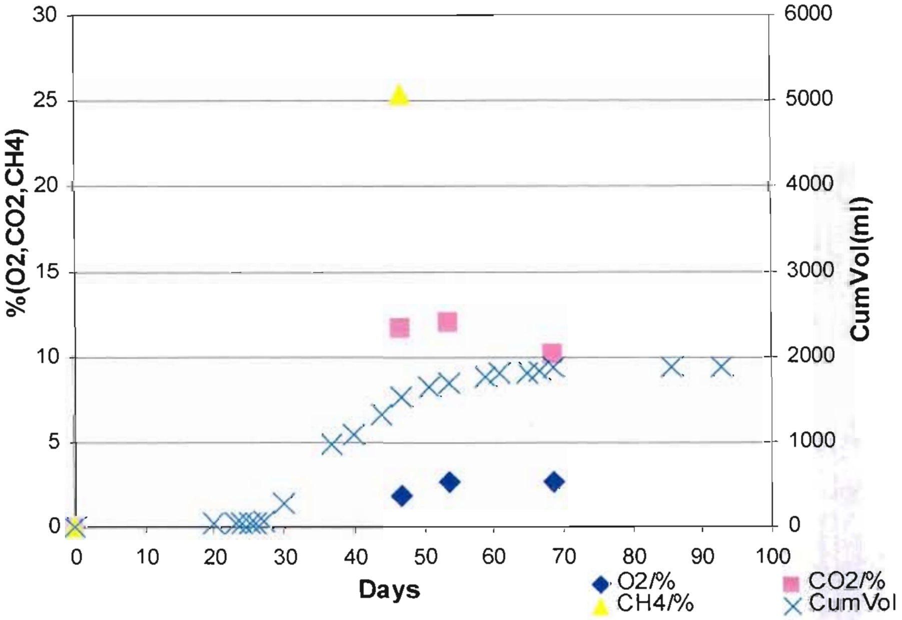


Figure 5-9: The Percentage Composition of O_2, CO_2 and CH_4 against Cumulative Volume for Ten weeks Pre-treated waste.

Decreasing trends of O_2, increasing trends of CO_2 and increasing trends of CH_4 are realized in the ten week pre-treated MSW sample after 30 days in an anaerobic environment. Figure 5-10 below shows the percentage composition of O_2, CO_2 and CH_4 against cumulative volume for twelve weeks pre-treated waste

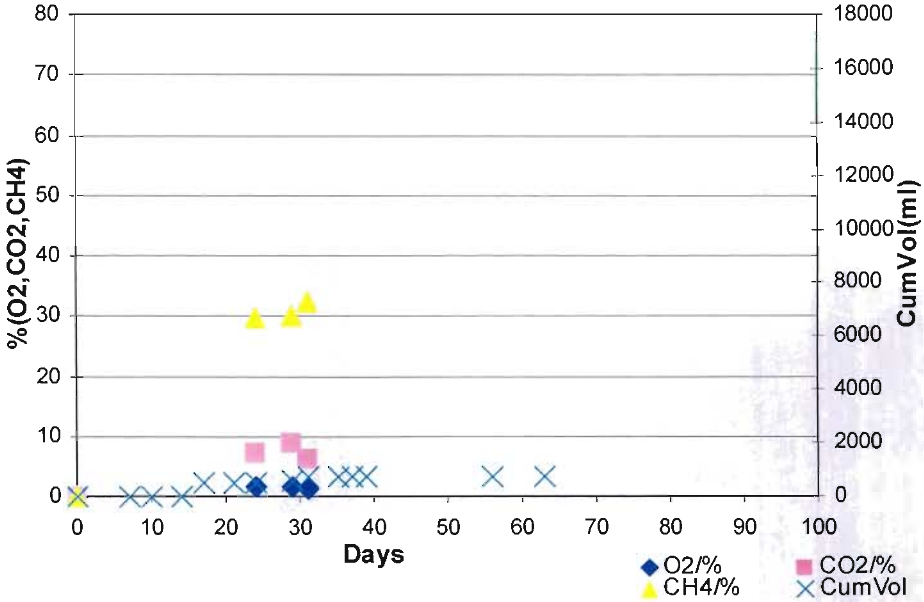


Figure 5-10: The Percentage Composition of O_2, CO_2 and CH_4 against Cumulative volume for Twelve weeks Pre-treated Waste.

The figure represents no production of gas for the first two weeks and small percentage of oxygen (1.8%), carbon dioxide (7.3 %) and methane (29.8%) was seen only after 30 days of set up of the experiment. For sixteen week pre-treated waste there was no gas production after 50 days of the sample in an anaerobic environment. After 60 days little gas was produced with negligible amounts of CO_2 and CH_4.

Figures 5-11, 5-12, 5-13, 5-14 and 5-15 illustrate a summary of the biogas test for different degrees of pre-treatment. For the first 25 days in an anaerobic environment four weeks pre-treated MSW the most active, as indicated by the volume of the gas produced. From the eight weeks of pre-treatment, the volume of the gas remained basically the same throughout the length of the experiment; this is seen in Figure 5-11.

For all the degrees of pre-treatment O_2 concentration decreased throughout the length of the experiment as observed in Figure 5-12. CH_4 shows an increasing trend for all the degrees of pre-treatment up to 6 week while consistent reduction is measured from the 8th week. While CO_2 shows an increasing trend in the early days in an anaerobic environment and decreases gradually through the later days of degradation with 2, 4 and 6 week pre-treated MSW similar and 8, 10 and 12 weeks pre-treated MSW also similar as seen in Figure 5-13, as expected.

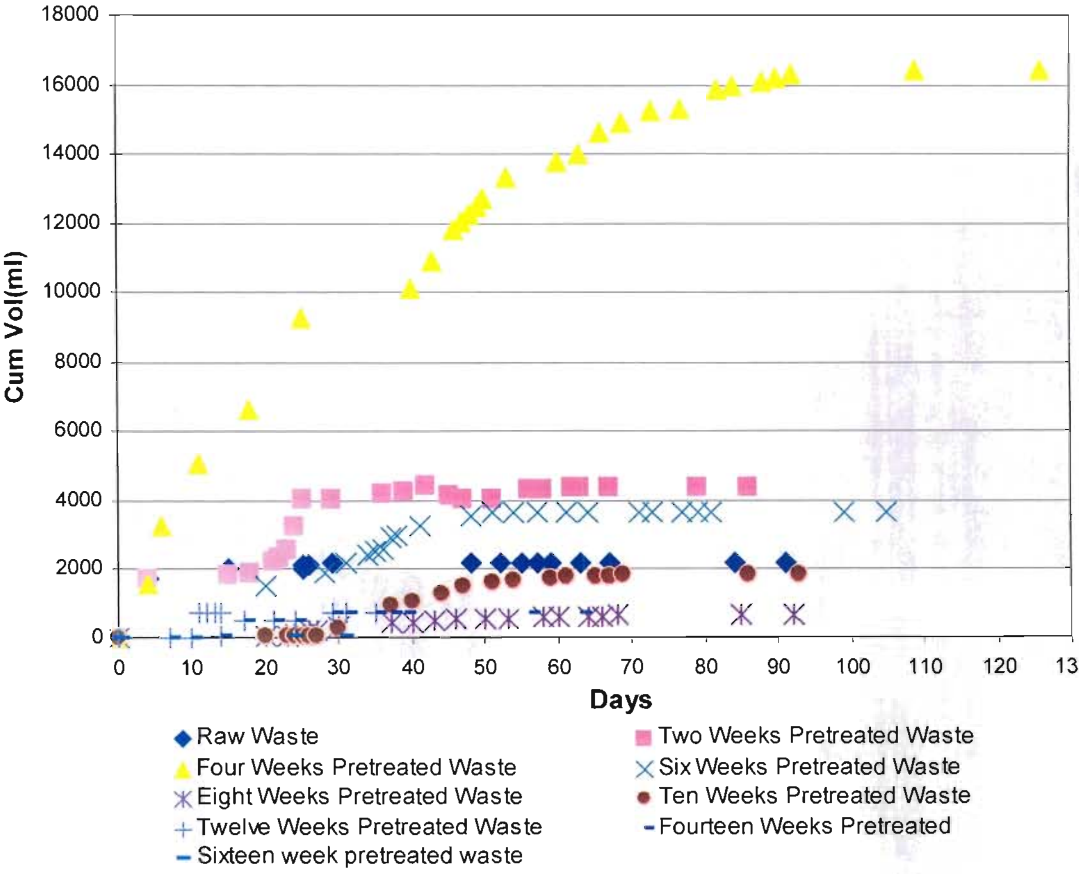


Figure 5-11: Evolution of the Cumulative Volume of biogas during the Pre-treatment.

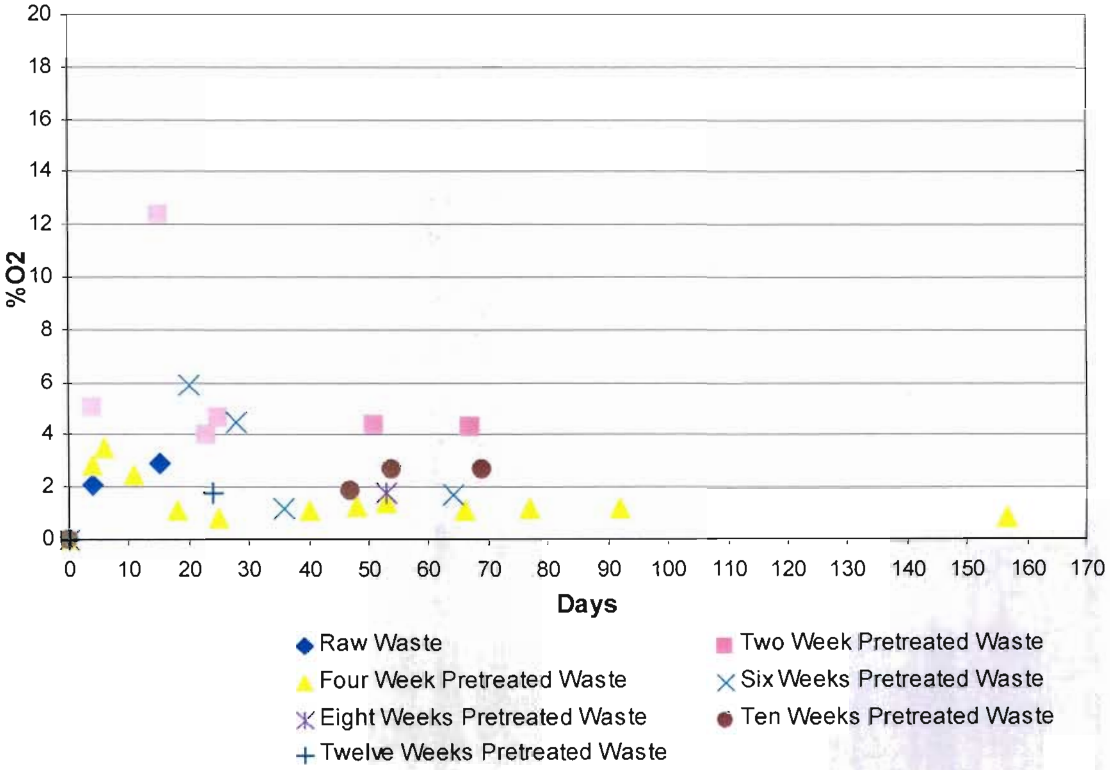


Figure 5-12: Evolution of Oxygen during the Pre-treatment.

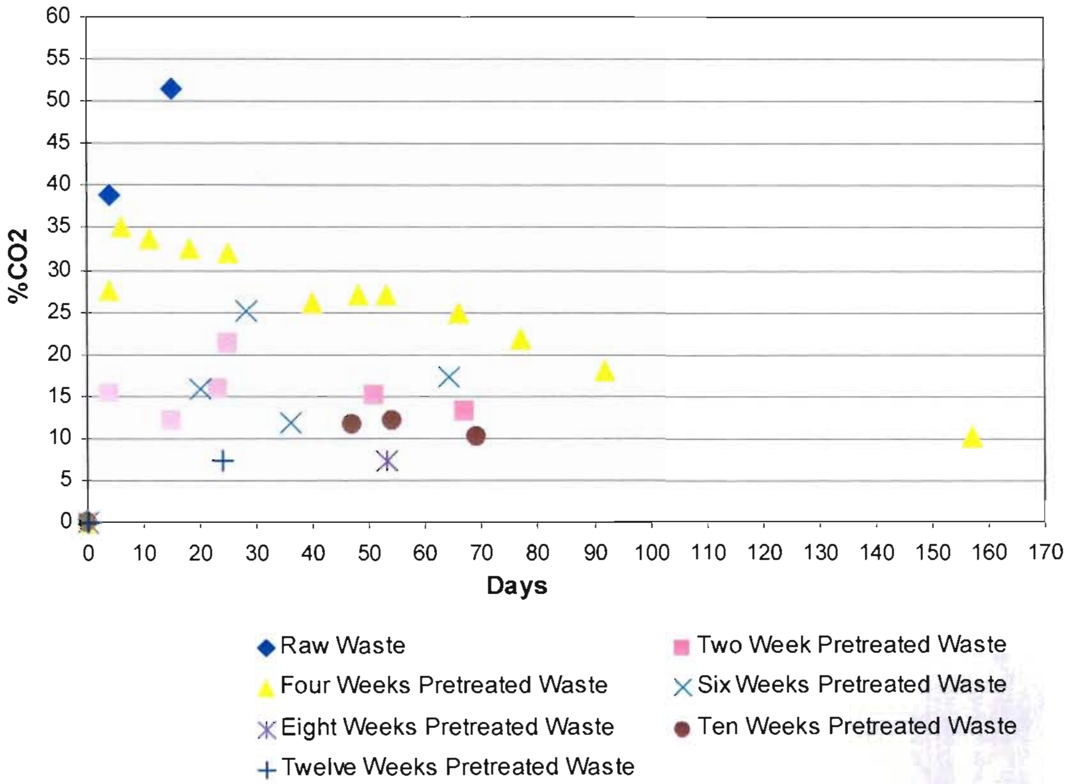


Figure 5-13: Evolution of Carbon dioxide during the Pre-treatment.

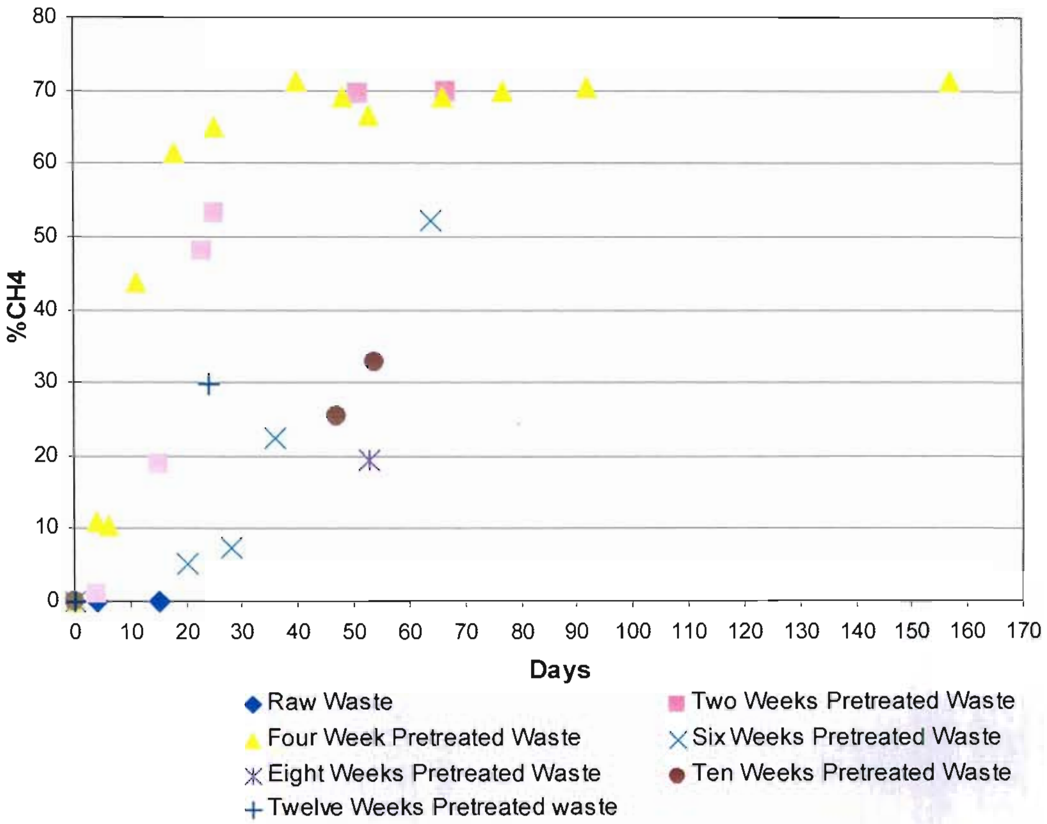


Figure 5-14: Evolution of Methane during the Pre-treatment.

5.4.4 Volatile Solids (VS)

The results of the VS test are presented in Table 5.6 and Figure 5.13;

Table 5-6 Volatile solids for the Period of Study

Time (Week)	Day	VS
Raw	2	72
2	22	66
4	36	51
6	48	46
8	62	40
10	77	40
12	91	39
14	105	40
16	122	31.1

The decrease in volatile solid is commonly associated with sanitation of the waste pile due to the high temperature is reached during the thermophilic stage of composting. In fact, the highest reduction is noted in the first 6 weeks.

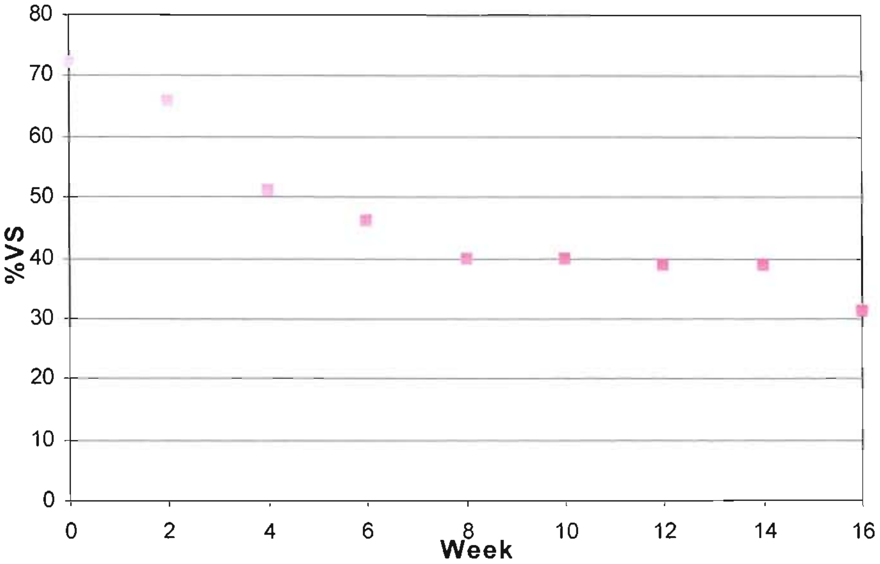


Figure 5-15: Evolution of Volatile solids (%) for the Period of Study.

The figure shows a decreasing trend of volatile solids from 72% to 31% over 16weeks pre-treatment.

5.4.5 Carbon to Nitrogen ratio

The evolution of the carbon to nitrogen ratio over time against different degrees of pre-treatment is presented in the Figure 5-16 and Table 5- 6.

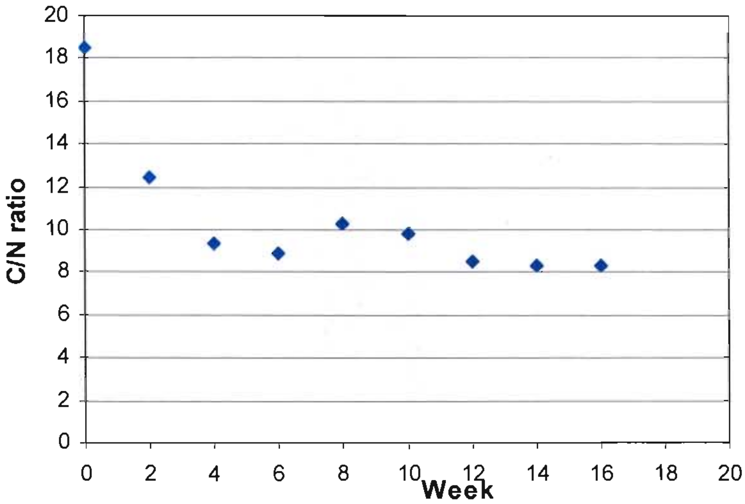


Figure 5-16: Carbon to Nitrogen Ratio for the Period of Study.

Table 5-7: Percentages of Carbon and Nitrogen for the Period of Study

Week	N (%)	C (%)	C:N Ratio
0(Raw waste)	1.27	23.53	18.52
2	1.55	19.3	12.45
4	1.71	16.02	9.36
6	1.91	16.99	8.89
8	1.85	18.97	10.25
10	1.82	17.84	9.80
12	1.75	14.9	8.51
14	1.7	14.2	8.35
16	1.69	14	8.28

It is evident that the highest reduction is achieved during the intense degradation phase while after 8 weeks the kinetics of organic removal slowdone.

5.5 Summary of Results on test on the Solid Matter

The moisture content was maintained between 60-54%, which according to Gray *et al.*, 1971; Rynk *et al.* 1992; Haug 1980 and Trios *et al* 2007 is the suitable range for maximum microbial activity. The decrease from 50-54% indicates the moisture lost due to microbial activity and evaporation throughout the experiment. The volatile solids ranged from 72-31.1 mg/l while there was a reduction in the C and N content for the reduced gradually through the weeks indicating the effectiveness of the stabilization process.

5.6 Analysis of the Elaute

The results of the analysis carried out on the elaute matter (TOC and TKN, COD, BOD, NOx and NH_3, pH and conductivity) will be presented in this section.

5.6.1 TOC and TKN

The variation of TOC and TKN for the different degrees of pre-treatment is presented in, Table 5-8 and Figure 5-17 below.

Table 5-8: Total organic carbon (TOC) and total Kjeldahl Nitrogen (TKN) for the Period of Study.

Week	Day	TOC (mg/l)	TKN(mg/l)
Raw	0	431	75.3
2	22	600	134
4	36	720	60
6	48	181	52
8	62	379	60
10	77	196	22
12	91	177	38
14	105	162	31
16	122	165	29

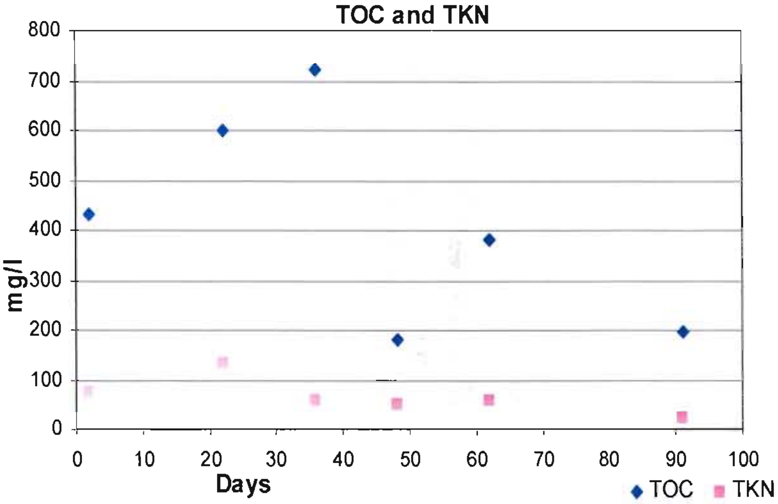


Figure 5-17: Evolution of TOC and TKN for the Period of the Study.

The TOC ranges from 177 mg/l and 750 mg/l. While the TKN ranges between 22-134 mg/l. The highest level of TKN is registered in week 2, indicating the sample had high organic nitrogen and ammonia nitrogen. Raw MSW normally has high TKN than pre-treated MSW but due to the non homogeneity of MSW 2 week pre-treated MSW was higher than that of raw MSW.

5.6.2 COD and BOD

The results of the COD and BOD in mg/l over the period of the research are shown in Table 5-9 and Figure 5-18 below.

Table 5-9 Chemical oxygen demand and biological oxygen demand for the period of the Study.

Time (Week)	Day	COD(mg/l)	BOD(mg/l)	BOD/COD
Raw	1	7832.52	1015.10	0.13
2	20	7259.47	1533.51	0.21
4	39	1399.66	1569.12	1.12
6	48	748.80	1541.12	2.05
8	62	1106.80	1470.11	1.33
10	77	895.70	1173.61	1.31
12	91	909.01	705.51	0.78
14	105	725.98	555.50	0.77
16	122	711.06	353.12	0.50

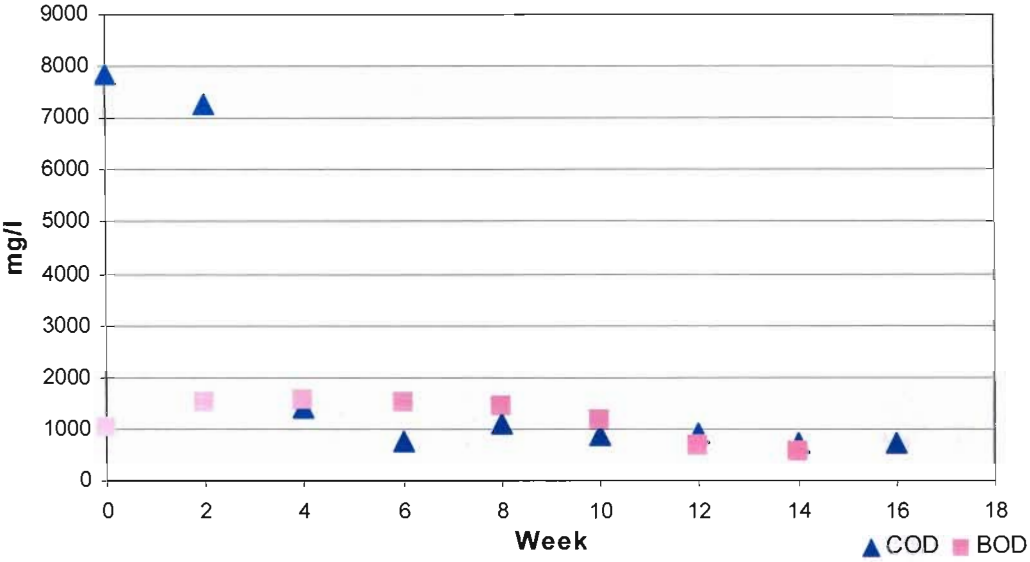


Figure 5-18: Evolution of COD and BOD for each Sample over the Period of Study.

The results of the biological oxygen demand test for a period of 5 days indicate a small increase from week zero (raw waste) up to a month (4 weeks pre-treated waste), and a gradual decrease from week six to week to week sixteen, signifying a maximum level of microbial activity up till 4 weeks pre-treatment and a gradual decrease of the organic matter thereafter. A high reduction in COD is from week zero till week four (from 7832.52

mg/l to 1399.66 mg/l) and a gradual decrease is seen throughout the later part of the experiments. The high COD for the first two weeks is attributed to the presence of partially degradable organic materials and high dissolves inorganic content.

5.6.3 Nitrate (NOx) and Ammonia (NH_3)

The results of the Nitrates and ammonia are presented in Table 5-10 and Figure 5-19 below for the period of the study.

Table 5-10: The Ammonium and Nitrogen Content for each Sample throughout the Period of Study.

Time (Week)	Days	NH_3(mg/l)	NOx (mg/l)
Raw	1	40.89	8.22
2	20	50.17	5.33
4	38	48.21	3.83
6	48	30.31	3.81
8	62	9.92	5.22
10	77	8.40	6.41
12	91	2.31	3.64
14	105	1.91	3.81
16	122	1.92	3.10

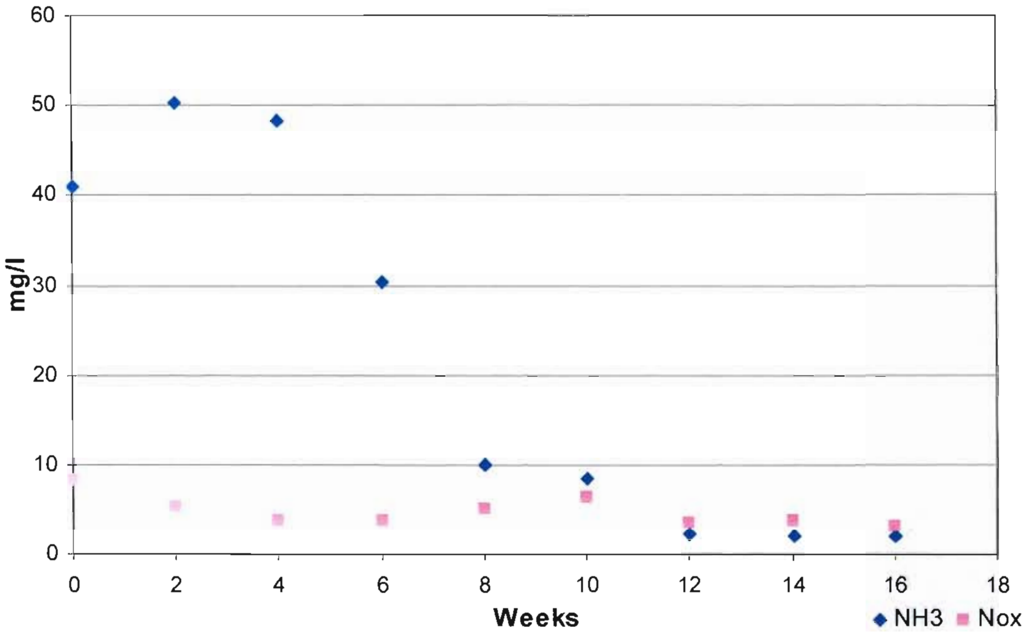


Figure 5-19: Evolution of NH_3 and the NOx for the Period of Study.

Ammonia shows small increments (48.89 mg/l to 50.17 mg/l) for the first two weeks and a gradual decrease from week two up to week sixteen (50.17 mg/l to 1.9 mg/l). The first two weeks represent early acetogenesis whereby CO_2 and H_2 are displaced by nitrogen to form high ammoniacal nitrogen. This is followed by a drop in temperature in the following weeks. While the nitrates fluctuates from 8.2 mg/l to 3.1, with a maximum registered in week zero of 8.2 mg/l and a minimum in the sixteenth week of 3.1 mg/l.

5.6.4 pH and Conductivity

The conductivity and pH for the different degrees of pre-treatment are presented in Table 5-11 and Figure 5-20:

Table 5-11: pH and Conductivity for Different Degrees of Pre-treatment.

Week	Day	pH	Conductivity
Raw	2	5.25	2.28
2	22	6.41	4.93
4	36	7.76	4.33
6	48	7.19	3.92
8	62	7.29	3.34
10	77	7.45	3.10
12	91	7.57	3.58
14	105	7.58	3.99
16	122	7.45	3.72

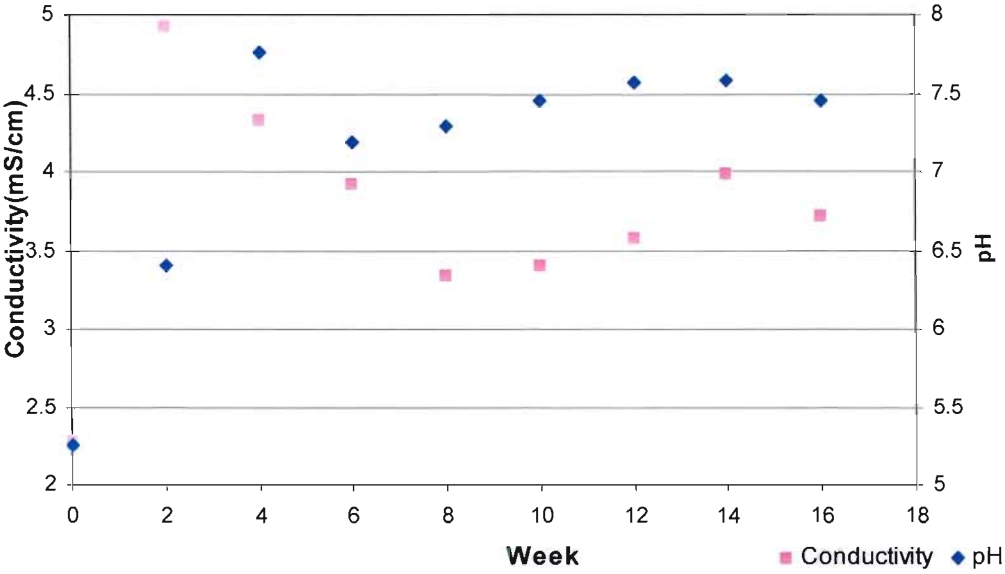


Figure 5-20: The pH and Conductivity for the Period of the Study.

The pH increases from slightly acidic values of 5.25 to 6.41 for the first two weeks and remains slightly akalinic and neutral form the third week onward. The period from the 3rd week onwards indicate the action of methanogens which are active within a pH range of 6.8-7.4. The conductivity rises from 2.2 to 4.9 mS/cm for week zero to 2 weeks pre-treated MSW and reminds between 3.1 and 3.9 for the remaining weeks of the study.

5.6.5 Total Solid (TS) and Volatile Solid (VS) on Eluate

The results of the total solid and the volatile solid for the eluate are presented below

Table 5-12: Table Total Solid and Volatile Solids the Period of Study

Week	Day	Volatile Solid	Total Solid
Raw	2	4.42	14.79
2	22	56.91	167.69
4	36	4.42	14.79
6	48	28.21	30.73
8	62	9.47	26.13
10	77	22.59	22.79
12	91	5.97	16.19
14	105	14.00	4.60
16	122	39.58	12.75

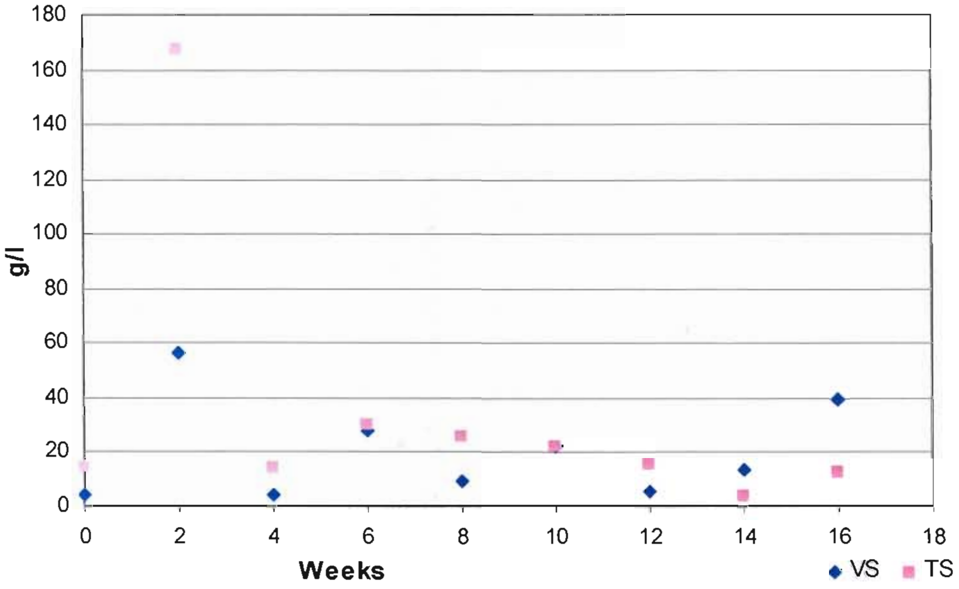


Figure 5-21: The Total Solids and the Volatile Solids for the Period of the Study.

5.7 Summary of the Analysis on Eluates

The results demonstrate decreases COD, BOD, NH_3, NOx, TKN and TOC and an increase in pH as the composting phase progresses to the end of the process. These result are seen clearly in the appendix.

CHAPTER 6

SUMMARY AND CONCLUSION

Chapter six presents a summary of the results, paying attention to conclusion and major findings of the research conclusions.

6.1 Introduction

At the onset of this dissertation two objectives were raised with the aim of measuring the effects of pre-treatment on carbon emissions, nature and potential for reduction. The specific objectives were to study:

- The efficiency of pre-treatment by forced aeration of pre-sorted MSW.
- The degradation processes in anaerobic environment of pre-treated waste for different degrees of pre-treatment (2, 4, 8 and 16 weeks)

MSW was pre-treated in a reactor aerobically and samples were collected every fortnight and characterised. This chapter presents the discussion of the results and conclusions.

6.2 Composition of Waste

The representativeness and feasibility of the waste is shown in Tables 5-1, 5-2 and 5-3. These tables show that the MSW used in carrying out this research is a representative fraction of the global sample from the landfill site. The high concentration of organic MSW increased the biodegradability of the process. Glass, stone and cardboard were removed from the sample in the reactor because they are non degradable and could slow the degradation process.

Recent studies carried out on the biodegradation of MSW shows that the biodegradability of fine fraction, below 50cm, was higher for than for large particles (Bakare, 2006).

6.3 The Treatment Process

The performance of the forced aeration process was successful because the waste in the reactor composted at the same time as shown in figures 5.1, 5.2, 5.3. The temperature of the reactor shows a continuous rise from day zero to day 30, from 30-70^{0}C, and a steady decrease from about day 30 to day 50, from 70-35°C and in the later days of the experiment the reactor's temperature remains consistently between 25-35^{0}C. The continuous rise in temperature indicates the period of high biological activity, the active period where by readily degradable material is decomposed as well as some of the more decay resistant material such as cellulose. The heat generated by the microbial activity is trapped by the waste, as the heat within the waste accumulates the temperature increases steadily. As the temperature increases through the thermophilic range the microbial activity is at peak and more efficient. The very high temperature is necessary for the destruction of pathogens such as fly larva and weed seeds. Once the peak temperature of about 70°C is reached microbial activity begins to decrease in response to the reduction of carbon content or because of the very high temperature which is detrimental to the functioning for the mesophilic microflora. Also the aerobic micro organisms are superseded by facultative micro organisms which tolerate low concentration of oxygen. As the microbial activity decreases the temperature of the waste decreases. The decrease in temperature is due to the decrease in microbial activity and little or no heat is generated. As the process continues the obligate microoraganisms which include the methane generating organisms gradually becomes established (Trois 2007). The ambient temperature is maintained between 20-35°C, because it enables the microbial activity to go through the thermophilic temperatures.

CO_2 and O_2 were not well analysed, due to the porosity of the waste the Gas analyser always detected high concentration of CO_2 and O_2. Consequently the performance of the process was not monitored inconsideration to CO_2 and O_2.

6.4 The Organic Content

The fluctuation of the results of the organic content indicates an intrinsic non homogenous nature of the sample collected every two weeks and in all of the waste. As seen by the results of the RI7 in Table 4.5, the O_2 consumed by the 14 week pre-treated waste increases due to the increase in non biodegradable in that sample. The results of the COD shows a drop from the 2 week pre-treated waste to the 4 week pre-treated waste as seen in table 5.10 and figure 5.19. This period is inline with the period of a drop of temperatures from 70 to 40°C as seen on figures 5.1, 5.2 and 5.3, which indicates a period of which the mesophilic micro organisms replaces the thermophilic micro organisms with a consequent production of methane gas. C/N ratio also shows the greatest decrease during that same period as seen on table 5.7 and figure 5.13. After the 4 week pre-treatment the C/N ratio, the COD and the BOD stabilises showing a period of low biological activity. This is confirmed by the fact that the temperature for this period ranges between 40 to 20°C. The TOC shows a similar trend, it increases from the raw wastes to the 4 weeks pre-treated waste and falls gradually through the later parts of the research. The TKN decreases gradually with the greatest value of the TKN on the second week which indicates a period of high biological activity.

6.5 The Nutrient Content

The nutrient content of the waste shows a slightly dissimilar trend. The results of the NH_3 shows an asymptotic curve with the first part of the curve from week zero to week four and a gradual decrease through the later weeks. The results of the NOx indicate a slight decrease throughout the research. The trend in the NH_3 and NO_x content indicates the resistance of NH_3 and NO_x to pre-treatment.

The organic and the nutrients level becomes stable after the 8 week pre-treated wastes and suggest that it is not necessary to prolong the treatment till the 16th week.

The efficiency of the process was also monitored by looking at the efficiency of the pre-treated waste in a landfill environment by monitoring the biogas production. The optimum biodegradation occurs for the four week pre-treated waste. The 4 week pre-treated waste produced the highest amount of gas by volume. This indicates that 4 week pre-treatment is enough to eliminate the effect of the acitogenesis and to reach the methanogenesis phase immediately. This can be seen from the biogas production by liquid displacement method in figures 5.5 to 5.9. After 4 week pre-treatment about 70% of methane gas can be produced indicates the methanogenesis stages was reached immediately after the 4 week pre-treatment. The concentration of methane are similar for the 4 and 6 weeks pre-treatment while the concentration of CH_4 production for the 8, 10 and 12 weeks pre-treatment shows a collapse in all the weeks as seen in figure 5.17. The CO_2 concentration also shows an increase from week zero to 4 weeks pre-treatment and for the rest of the research the level collapses, indicating the success of the process to attain to the methanogenesis phase after 4 weeks pre-treatment.

6.6 Conclusion

The pre-treatment of MSW after sorting by forced aeration was successful. The results of this study are similar to previous studies carried out on windrows and lysimeter (Bari and Koeing 2005). Pre-sorting removes the non degradable part of the waste leaving the more biodegradable, and high organic contents.

Accelerated degradation was attained because high temperatures were measured after 2 week pre-treatment and up to about 70% of methane gas was measured after 4 weeks pre-treatment. This also indicates that the action of the methane producing micro organisms (methanogenesis phase) after 4weeks pre-treatment. The study shows that it would be unnecessary to prolong the pre-treatment of MSW for more that 6 weeks.

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APPENDIX 1-THE TREATMENT PROCESS 1

Point A						Point D					Point G					Date
Day	T/oC	AmT/oC	%CH4	%CO2	%O2	T/oC	AmT/oC	%CH4	%CO2	%O2	T/oC	AmT/oC	%O2	%CH4	%CO2	Date
1	45	25	0.3	1.2	19.3	45	25	0.2	0.6	19.9	44.8	25	20.3	0.1	0.3	28-March-07
2	45	25	0.1	1.6	19.2	50	25	0.1	0.8	19.7	50	25	18.9	0.3	1.8	29-March-07
3	56	26	0.1	1	19.5	55	26	0.1	2.4	18.1	60	26	15.4	0.1	5.1	30-March-07
4	62	26	0	2.4	18	57	26	0	2.6	18.2	52	26	13.7	0	6.9	31-March-07
7	51	33	0.1	4.7	16.2	54	33	0.1	6	15.8	52	33	17	0.1	4	3-April-07
8	62	30	0	4.1	17.6	56	30	0	3.5	17.2	47	30	12.4	0	8.7	4-April-07
9	57	30	0.1	5	16	53	30	0.1	4	16	47	30	13.5	0.1	11.5	5-April-07
14	56	28	0.1	3.6	16.2	46	28	0.1	3.3	16.5	47	28	18.2	0.1	2.1	10-April-07
15	47	28	0.3	13.4	9.9	46	28	0.1	10.4	11.9	43	28				11-April-07
18	44	30	0.1	3.6	7	42	30	0.6	3.2	17.5	42	30	13.1	0.1	8	14-April-07
19	43	30	0.2	17.5	4.5	50	30	0.1	11.8	11.8	47	30	18.7	0.1	2.3	15-April-07
20	52	30	2.9	12	8.9		30				59	30	12.6	0.1	8	16-April-07
21	52	30	0.2	7.4	12.6		30				59	30	13	0.9	6.1	17-April-07
22	53	30	0.8	7.4	11.3		30				58	30	16.7	0.5	4	18-April-07
23	62.8	30	0.1	3	16	63.2	30	1.1	0.8	18.7	65	30	16.3	0	2.1	19-April-07
24	63.1	30	0.1	4.5	15.7	61.2	30	1	3	16.9	65	30	18.7	1	1.8	20-April-07
27	57	31	1.1	1.1	19	53.4	31	1.1	0.4	18.9	55.2	31	14.6	0.5	3.8	23-April-07
28	57.9	30	0.4	2.3	17.6	52	30	1.5	1.1	18.8	46.8	30	18.8	0.1	0.7	24-April-07
29	53.3	31	0.4	4.1	16.4	46.3	31	0.1	0.1	18.9	46	31	18.1	1.2	1.2	25-April-07
30	51.4	30	0.6	3.5	17.2	42.5	30	0.3	1.2	19.7	45	30	17.5	1.1	3.4	26-April-07
36	45.3	30	0.2	3.2	17.8	43.5	30	0.3	1.5	19.2	41.3	30	19.4	0.1	0.7	2-May-07
41	43.1	30	0.1	2.1	18.4	31.4	30	0.1	0.7	19.3	40.7	30	19.6	0.6	0.7	7-May-07
43	36.4	30	0.1	1.9	18.8	32.1	30	0.2	0.4	20.2	36.8	30	18.9	0.3	1.1	9-May-07
44	34.5	30	0.2	1.7	19	34.1	30	0.2	1.9	18.7	36.3	30	19.1	0.2	1.5	10-May-07
45	31.6	30	0.5	0.4	20.3	33.1	30	0.1	0.7	19.7	34.2	30	17.6	0.3	3.2	11-May-07
48	34.4	31.2	0.1	0.6	19.9	33	31.2	0.1	0.6	19.9	35.7	31.2	20.1	0.1	0.2	14-June-07
50	35.3	30	0	1.1	19.5	31	30	0	0.7	19.5	30	30	19	0	1	16-June-07

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Point A						**Point D**					**Point G**					**Date**
Day	**T/oC**	**AmT/oC**	**%CH4**	**%CO2**	**%O2**	**T/oC**	**AmT/oC**	**%CH4**	**%CO2**	**%O2**	**T/oC**	**AmT/oC**	**%O2**	**%CH4**	**%CO2**	**Date**
51	33.9	28	0.1	0.7	19.8	32.1	28	0.2	0.5	19.9	31.2	28	19	0.1	1	17-June-07
52	33.3	27.5	0.1	1	19.8	32.4	27.5	0.1	0.9	19.7	29.2	27.5	19.7	0.1	0.8	18-June-07
55	31.7	27.2	0.1	.7.19.9		31.4	27.2	0.1	0.6	19.9	30	27.2	19.6	0.1	1.1	21-June-07
57	30	27	0.1	1	19	28	27	0.2	0.9	19	28.8	27	19	0	0.9	23-June-07
62	27	23	1	2	18	26.8	23	0.1	2.1	17.9	27	23	18.9	0.1	1.9	28-June-07
63	27	23	0.1	1	19.8	26.4	23	0.1	1	19.8	25.7	23	19.2	0.1	1.6	29-June-07
65	31.4	24	0.1	1.2	19.6	27.9	24	0.1	1	19.7	26.6	24	19.8	0.1	1	31-June-07
69	30.5	27	0.1	1.6	18.9	26.9	27	0.1	1.6	18.9	28.8	27	18.8	0.1	1.5	4-July-07
72	26.4	23	0.1	1	19.7	28	26	0.1	0.7	19.9	25.3	23	19.9	0.1	0.7	6-July-07
	24	25.5				28	25.5					25.5				12-July-07
	25	26.5				29	26.5					26.5				20-July-07
	24	26.5				29	26.5					26.5				22-July-07
	23	26				28	26					26				25-July-07
	24	26.5				30	26.5					26.5				28-July-07
	24	27				30	27					27				29-July-07
	25	27				28	27					27				30-July-07
	24	28				30	28					28				31-July-07

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Point B						Point E					Point H					Date
Day	**T/oC**	**AmT/oC**	**%CH4**	**%CO2**	**%O2**	**T/oC**	**AmT/oC**	**%CH4**	**%CO2**	**%O2**	**T/oC**	**AmT/oC**	**%O2**	**%CH4**	**%CO2**	**Date**
1	43	25	0.1	0.2	20.2	51.5	25	0	1.9	18.6	52	25	19.6	0.1	0.9	28-March-07
2	49	25	0.1	12.1	93	50	25	0.1	1.8	18	48	25	11.6	0.1	8.8	29-March-07
3	60	26	0.1	5	15.3	62	26	0	2.4	18.1	60	26	12.7	0.1	7.9	30-March-07
4	62	26	0	5.2	13.8	61	26	0.1	6.2	13.7	58	26	16.4	0	3.5	31-March-07
7	61	33	0.1	4.5	16.4	65	33	0.1	5.6	16.1	52	33	17.6	0.1	3.5	3-April-07
8	61	30	0	5.3	15.2	66	30	0	6.4	13.3	62	30	17.7	0	2.9	4-April-07
9	66	30	0.1	4.8	19.8	68	30	0.1	4.2	16.2	52	30	19.8	0	1.2	5-April-07
14	66	28	0.1	2.8	17.5	68	28	0.1	4	16	52	28	15.4	0.2	4.8	10-April-07
15	68	28	0.1	7.5	13.3	70	28	0.1	4.9	15.1	55.3	28	18.1	0.1	2.2	11-April-07
18	68	30	0.1	3.6	16.8	68	30	0.1	2.7	17.5	60	30	16.9	0.1	3.5	14-April-07
19	66	30	0.1	10.2	11.1	68	30	0.1	10.1	10.5	60	30	11.4	0.1	9.2	15-April-07
20	68	30	0.6	6.9	12.5	68	30				66	30	9.7	1.6	10.8	16-April-07
21	66	30	0.2	3.6	16.4	68	30				66	30	14	1	5.3	17-April-07
22	68	30	0.2	5.3	14.4	65	30				67	30	16.5	0	2.4	18-April-07
23	70	30	1	1.9	18.6	63	30	0.1	0.4	19.5	68	30	18.7	1	1.8	19-April-07
24	70	30	1	3.9	16.9	60	30	0.1	2.4	17.5	65	30	14.5	1.9	4.5	20-April-07
27	68	31	0	0.2	19.3	60	31	0.1	0.5	18.6	63	31	18.7	0	0.3	23-April-07
28	65	30	1	0.7	19.4	55	30	0.1	0.7	19.1	60	30	18.4	1.3	0.8	24-April-07
29	60	31	0.3	3.8	17.2	55	31	0.1	2.2	17.9	58	31	17.4	1.2	3.6	25-April-07
30	55	30	0.1	2.1	18.6	50	30	0.7	0.9	19.9	55	30	19.7	1	0.4	26-April-07
36	40.8	30	0.1	3	18.5	40	30	0.1	1.1	19.5	43.9	30	19.2	0.4	0.7	2-May-07
41	38.7	30	0.1	2.2	18.4	40.4	30	0.2	1.2	19	34.2	30	18.4	0.3	1.6	7-May-07
43	34.6	30	0.1	1.6	19.1	30.8	30	0.2	1	19.7	32.5	30	19.3	0.2	1.4	9-May-07
44	35.2	30	0.3	2.1	18.7	35.8	30	0.2	1.8	18.2	34.6	30	16	0.2	4	10-May-07
45	36.2	30	0.2	1.5	19	35.2	30	0.7	0.7	20	33	30	18.2	0.1	1.8	11-May-07
48	31.9	31.2	0.1	1.5	19.2	32.4	31.2	0.1	0.6	19.8	31.1	31.2	19.8	0.1	0.6	14-June-07
50	34	30	0.1	0.3	19.7	30	30	0	0.8	19.4	31.5	30	18.8	0	1.2	16-June-07

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Point B						Point E					Point H					
Day	T/oC	AmT/oC	%CH4	%CO2	%O2	T/oC	AmT/oC	%CH4	%CO2	%O2	T/oC	AmT/oC	%O2	%CH4	%CO2	Date
51	33.4	28	0	0.6	19.9	29	28	0.1	0.8	19.5	30.9	28	19	0.1	1	17-June-07
52	31.7	27.5	0.1	0.9	19.7	30.6	27.5	0.1	1	19.8	33.3	27.5	19.7	0.1	1.1	18-June-07
55	30.9	27.2	0.1	0.6	19.8	28.2	27.2	0.1	1	19.7	30.7	27.2	19.7	0.1	1.1	21-June-07
57	30	27	0.1	0.6	19.5	27.3	27	0.1	1	19	28.8	27	19	0.1	1	23-June-07
62	26.1	23	0.1	2.1	18	26.5	23	0.1	1.9	18.1	27	23	18.2	0.1	1.5	28-June-07
63	26.1	23	0.1	1.4	19.3	26.4	23	0.1	1.2	19.7	26.1	23	19.7	0.1	1.2	29-June-07
65	26.8	24	0.1	1.2	19.5	26.2	24	0.1	1.2	19.5	26.6	24	19.6	0.1	1.1	31-June-07
69	27.3	27	0.1	1.6	18.9	28.6	27	0.1	1.7	18.5	29.2	27	18.6	0.1	1.7	4-July-07
72	24.7	23	0.1	0.9	19.8	26	23	0.1	1.1	19.5	25.9	23	19.2	0.1	1.2	6-July-07
77	30	25.5	0.1	2.4	18.1	30	25.5	0.1	2.4	18.1	30	25.5	18	0.1	2.5	12-July-07
79	30	26.5				30	26.5				30	26.5				20-July-07
81	30	26.5				30	26.5				31	26.5				22-July-07
84	30	26				30	26				30	26				25-July-07
87	31	26.5				31	26.5				30	26.5				28-July-07
99	30	27				30	27				31	27				29-July-07
102	30	27				31	27				30	27				30-July-07
105	31	28				30	28				30	28				31-Jul-07

Point C							Point F							Point I		
Day	T/oC	AmT/oC	%CH4	%CO2	%O2	T/oC	AmT/oC	%CH4	%CO2	%O2	T/oC	AmT/oC	%O2	%CH4	%CO2	Date
1	33.7	25	0.1	0.6	19.9	31.9	25	0.1	0.9	19.8	39.6	25	19.9	0.1	0.6	28-March-07
2	38	25	0.1	2.1	19	41	25	0.1	1.2	19.3	37	25	16.6	0.1	3.9	29-March-07
3	61	26	0.1	3.5	16.9	55	26	0.1	0.2	20.3	60	26	13.9	0.1	7.3	30-March-07
4	54	26	0	2.6	17.7	47	26	0	2.5	17.7	55	26	18.7	0	1.7	31-March-07
7	59	33	0.1	6	17	57	33	0.1	1.6	19.1	64	33	17.3	0.1	3	3-April-07
8	59.8	30	0	2.1	18.7	48	30	0	1.6	19	59.8	30	18.6	0	2.4	4-April-07
9	62	30	0.1	0.8	18.9	50	30	0.1	0.8	19.3	58.4	30	18	0.1	2.8	5-April-07
14	60	28				55	28				59.8	28				10-April-07
15	58	28				60	28				60	28				11-April-07
18	60	30				61	30				66	30				14-April-07
19	66	30	0.1	6.8	13.7	61	30	0.1	8.9	12	66	30	11.4	0.1	8.5	15-April-07
20	70	30	0.1	6.2	13.7	60	30				60	30	17.5	0.5	2.6	16-April-07
21	71	30	0.3	3.5	16.7	66	30				61	30	16	0.9	4.1	17-April-07
22	66	30	1	4.6	15.1	68	30				60	30	18.7	0	0.8	18-April-07
23	64.5	30	1.1	2.2	18.3	66	30	0.1	0.6	19.3	52.1	30	17.9	1.8	0.8	19-April-07
24	62.5	30	1	4.2	15.9	66	30	0.5	3.5	15.8	52	30	16.9	1.5	2.5	20-April-07
27	48.7	31	0.7	0.7	18.8	60	31	0.1	0.2	18.8	49.2	31	18.4	0	0.3	23-April-07
28	50.1	30	1.8	0.3	9.6	55	30	1.4	0.6	18.9	46.9	30	18.4	1.4	0.8	24-April-07
29	46.5	31	0.4	3.4	17.5	53	31	1.1	3.2	17.9	49.1	31	17.3	1.1	3.5	25-April-07
30	43.3	30	0.3	1.1	19.8	50	30	0.8	1.8	18.9	42.6	30	19.9	0.9	0.2	26-April-07
36	34.5	30	0.2	1.1	19.5	45	30	0.5	1.5	19.2	35.1	30	19.5	0.3	0.5	2-May-07
41	34.2	30	0.1	1.7	18.9	37.7	30	0	0.9	19.5	37.9	30	17.8	0.2	2.4	7-May-07
43	35.5	30	0.1	0.9	19.8	33.5	30	0.2	2.3	18.4	33.4	30	18.3	0.2	2.4	9-May-07
44	36.4	30	0.3	1.1	19.6	34.2	30	0.3	3.1	17.7	32.3	30	16.1	0.3	3.9	10-May-07
45	37.2	30	0	1.2	19	34	30	0.1	0.7	19.3	33	30	18	0.1	1.9	11-May-07
48	34.4	31.2	0.1	0.7	19.7	32.9	31.2	0.1	0.2	20.3	33.4	31.2	19.1	0.1	1.4	14-June-07
50	31.9	30	0	0.6	19.9	33	30	0	1	19	32	30	18.7	0.1	1.2	16-June-07

Point C							Point F							Point I		
Day	T/oC	AmT/ oC	%CH 4	%CO 2	%O2	T/oC	AmT/ oC	%CH 4	%CO 2	%O2	T/oC	AmT/ oC	%O2	%CH 4	%CO 2	Date
51	31.3	28	0.1	1.9	18.8	30	28	0.1	1	19	30	28	19	0.1	1	17-June-07
52	30.7	27.5	0.1	1	19.8	30	27.5	0.1	0.8	19.7	30.6	27.5	19.8	0.1	1	18-June-07
55	28.7	27.2	0.1	0.9	19.6	30	27.2	0.1	0.9	19	30	27.2	19.5	0.1	1.2	21-June-07
57	27.3	27	0.1	0.7	19.3	30	27	0.1	0.9	19	30	27	19	0.1	1	23-June-07
62	27	23	0.1	2.5	17.4	26.8	23	0.1	1.9	18.1	26.8	23	18	0.1	2	28-June-07
63	26.9	23	0.1	1.7	19.1	26.4	23	0.1	1.5	19.2	25.4	23	19.1	0.1	1.7	29-June-07
65	27.1	24	0.1	1.7	19	26.1	24	0.1	1.5	19.2	26.8	24	19.4	0.1	1.3	31-June-07
69	27.2	25.5	0.1	2.1	18	28.3	27	0.1	2	18	29.1	27	18.1	0.1	2.1	4-July-07
72	25.6	23	0.1	1.7	18.9	24.8	23	0.1	1.3	19.1	25.9	23	19	0.1	1.5	6-July-07
	27	25.5	0.1	2.2	18.4	30	25.5	0.1	3.4	17.1	28	25.5	17.5	0.1	3	12-July-07
	29	26.5				30	27				30	26.5				20-July-07
	30	26.5				31	26.5				31	26.5				22-July-07
	30	26				31	26				31	26				25-July-07
	30	26.5				30	26.5				30	26.5				28-July-07
	30	27				31	27				31	27				29-July-07
	30	27				31	27				30	27				30-July-07
	30	28				30	28				31	28				31-July-07

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Durban Marianhill Landfill site Statistic

DATE :	LD CLEAR (KG)	LD COLOUR (KG)	SCRAP BOXES (KG)	PET (KG)	HD (KG)	HL 1 (KG)	CANS (KG)	CMW (KG)	IMW (KG)	PP BAGS (KGS)	POLYSTYRENE (KGS)	PP ICE-CREAM (KGS)	SCRAP COMPUTERS (KGS)	SUB-GRADE	25L CONTAINER	SCRAP PLASTIC (KG)	GLASS (KG)	TOTAL (KG)	TONNAGE	% RECYCLABLES
DEC '06	645	62	10611	688	491	1541	642	4005	0	0	0	0	0	0	0	3228	2809	26276	92700	28
JAN '07	1270	1113	8784.5	881	533	1373	579	2669	0	0	0	115	0	0	0	2256	2095	21668	90860	24
FEB '07	1575	143	6629	1047	541	820	462	2584	326	34	0	47	0	0	0	1753	1222.5	17184	99880	17
MARCH '07	511	190	6847.5	643	441	1003	669	1764.5	0	0	0	23.5	0	0	0	2000	1591.5	15682	127200	12
APRIL '07	390	278	5121	787	375	653	593	3049	0	74.5	0	0	0	0	0	1721	1700.5	14740	84040	18
MAY '07	1209	81.5	7216.5	714	548	2062	628	2454	0	143	0	0	0	1550	74	1993	1911.5	20584	135560	15
TOTALS	**5599**	**1867**	**45210**	**4760**	**2928**	**7451**	**3572**	**16526**	**326**	**251.5**	**0**	**186**	**0**	**1550**	**74**	**12950**	**11330**	**116132**	**630240**	**18**
% Against Total	4.8	1.6	38.9	4.1	2.5	6.4	3.1	14.2	0.3	0.22	0.0	0.2	0.0	1.3	0.1	11.2	9.8			
% Against Tonnage	0.89	0.3	7.2	0.8	0.5	1.2	0.6	2.6	0.1	0.040	0.00	0.03	0.00	0.25	0.01	2.1	1.8			

APPENDIX 1-ANAALYSIS ON SOLID MATTER

	Moisture content						
Date	Sample	weight	weight full	weight full 105'	MC	Moisture content	Day
29/03/2007	RawMSW	956	2617	1713	54%	**54%**	2
4/18/2007	2Wk Pret	955	1184	1046	60%	**60%**	22
2-May	4WkPret	444	540	484	58%	**58%**	36
14-May	6WkPret	468	556	504	59%	**59%**	48
28-May	8WkPret	955	1363.9	1135.9	56%	**56%**	62
12-Jun	10WkPret	464	668	554	56%	**56%**	77
24-Jun	12WkPret	444	584	514	50%	**50%**	97
12-Jul	14WkPret	444	532	492	45%	**45%**	105
25-Jul	16WkPret	466	562	520	44%	**44%**	120

BIOGAS BY DISPLACEMENT TEST									
Sample	**Date**	**O2/%**	**CO2/%**	**CH4/%**	**Vol**	**CumVol(ml)**		**Day**	**Made**
Raw MSW		0	0	0	0	0	0	0	
	28-May	2.1	39	0	175	175	1750	4	24-May
	12- June	2.9	51.4	0.1	30	205	2050	15	
	15-June				0	205	2050	25	
	21-June				7	212	2120	25	
	22-June				2	214	2140	26	
	25-June				3	217	2170	29	
	5-July				0	217	2170	48	rising
	16-July				0	217	2170	52	
	19-July				0	217	2170	55	
	24-July				0	217	2170	57	
	26-July				0	217	2170	59	
	30-July				0	217	2170	63	
	3-August				0	217	2170	67	
	20August				0	217	2170	84	
	27August				0	217	2170	91	

Sample	Date	O2/%	CO2/%	CH4/%	vol	CumVol/ml	CumVol(ml)	Day	Made
2Week Pret		0	0	0		0	0	0	
	28-May	5.1	15.3	1.2	173	173	1730	4	24-May
	15-June	12.4	12.1	18.9	15	188	1880	15	
	15-June				2	190	1900	18	
	18-June				35	225	2250	21	
	19-June				13	238	2380	22	
	20-June	4	15.9	48.1	18	256	2560	23	
	21-June				73	329	3290	24	
	22-June	4.7	21.4	53.2	74	403	4030	25	
	25-June				0	403	4030	29	
	2-July				19	422	4220	36	
	5-July				7	429	4290	39	
	9-July				17	446	4460	42	
	12-July				-30	416	4160	45	
	16-July				-12	404	4040	47	
	19-July	4.4	15.1	69.6	0	404	4040	51	
	24-July				30	434	4340	56	
	26-July				0	434	4340	58	
	30-July				3	437	4370	62	
	1-August				0	437	4370	63	
	3-August	4.3	13.2	69.8	0	437	4370	67	
	20August				1	438	4380	79	
	27August				1	439	4390	86	

Sample	Date	O2/%	CO2/%	CH4/%	vol	CumVol/ml	CumVol(ml)	Day	Made
4WkPret		0	0	0		0	0	0	
	7-May-07	2.8	27.5	10.8	155	155	1550	4	3-May
	9-May-07	3.5	35	10.5	170	325	3250	6	
	14-May-07	2.5	33.6	43.6	183	508	5080	11	
	21-May-07	1.1	32.6	61.5	155	663	6630	18	
	28-May- 07	0.8	32.1	65	265	928	9280	25	
	15-June-07	1.1	26.1	71.3	85	1013	10130	40	
	15-Jun-07				80	1093	10930	43	
	18-June-07				90	1183	11830	46	
	19-June-07				19	1202	12020	47	
	20-June-07	1.3	27.1	69.2	24	1226	12260	48	
	21-June-07				24	1250	12500	49	
	22-June-07				19	1269	12690	50	
	25-June-07	1.4	27.1	66.6	66	1335	13350	53	
	2-July-07				44	1379	13790	60	
	5-July-07				23	1402	14020	63	
	9-July-07	1.1	25	69.2	60	1462	14620	66	
	12-July-07				30	1492	14920	69	
	16-July-07				34	1526	15260	73	
	19-July-07	1.2	21.9	70	5	1531	15310	77	
	24-July-07				55	1586	15860	82	
	26-July-07				10	1596	15960	84	
	30-July-07				15	1611	16110	88	
	1-Aug-07				9	1620	16200	90	
	3-Aug-07	1.2	18.1	70.5	9	1629	16290	92	
	20Aug-07				15	1644	16440	109	
	27Aug-07				0	1644	16440	126	
	4-Sept -07	0.9	10.2	71.2	30	1674	16740	157	

Sample	Date	O2/%	CO2/%	CH4/%	vol	CumVol/ml	CumVol(ml)	Day	Made
6WkPret		0	0	0		0	0	0	
	30-May -07	5.9	15.9	5.1	150	150	1500	20	24-May
	10-June-07	4.5	25.2	7.5	43	193	1930	28	
	15-June-07				29	222	2220	31	
	18-June-07				21	243	2430	34	
	19-June-07				8	251	2510	35	
	20-June-07	1.2	11.9	22.5	10	261	2610	36	
	21-June-07				30	291	2910	37	
	22-June-07				9	300	3000	38	
	25-June-07				29	329	3290	41	
	2-July-07				28	357	3570	48	
	5-July-07				7	364	3640	51	
	9-July-07				1	365	3650	54	
	12-July-07				0	365	3650	57	
	16-July-07				0	365	3650	61	
	20-July-07	1.7	17.3	52.1	0	365	3650	64	
	24-July-07				0	365	3650	71	
	26-July-07				0	365	3650	73	
	30-July-07				0	365	3650	77	
	1-Aug-07				0	365	3650	79	
	3-Aug-07				0	365	3650	81	
	20-Aug-07				0	365	3650	99	
	27-Aug-07				0	365	3650	105	

Sample	Date	O2/%	CO2/%	CH4/%	vol/ml	CumVol/ml	CumVol(ml)	Day	Made
8WkPrret		0	0	0		0	0	0	
	15-June-07				8	8	80	20	25-May
	18-June-07				0	8	80	23	
	19-June-07				1	9	90	24	
	20-June-07				3	12	120	25	
	21-June-07				10	22	220	26	
	22-Jun-07				2	24	240	27	
	25-June-07				7	31	310	30	
	2-July-07				13	44	440	37	
	5-July-07				3	47	470	40	
	9-July-07				4	51	510	43	
	12-July-07				5	56	560	46	
	16-July-07				1	57	570	50	
	19-July-07	1.8	7.3	19.3	0	57	570	53	
	24-July-07				3	60	600	58	
	26-July-07				2	62	620	60	
	30-July-07				0	62	620	64	
	1-Aug-07				0	62	620	66	
	3-Aug-07				4	66	660	68	
	20-Aug-07				0	66	660	85	
	27-Aug-07				0	66	660	92	

Sample	Date	O2/%	CO2/%	CH4/%	vol/ml	CumVol/cm	CumVol(ml)	Day	Made
16WkPret					0	0	0	0	
	20-Aug-07				5	5	50	24	27-July
	27-Aug-07				2	7	70	31	

Sample	Date	O2/%	CO2/%	CH4/%	vol/ml	CumVol/cm	CumVol(ml)	Day	Made
10WkPret		0	0	0		0	0	0	
	15-June-07				4	4	40	20	12-June
	18-June-07				0	4	40	23	
	19-June-07				0	4	40	24	
	20-June-07				0	4	40	25	
	21-June-07				1	5	50	26	
	22-June-07				3	8	80	27	
	25-June-07				20	28	280	30	
	2-July-07				70	98	980	37	
	5-July-07				10	108	1080	40	
	9-July-07				24	132	1320	44	
	12-July-07	1.9	11.7	25.4	21	153	1530	47	
	16-July-07				12	165	1650	51	
	19-July-07	2.7	12	32.9	5	170	1700	54	
	24-July-07				6	176	1760	59	
	26-July-07				4	180	1800	61	
	30-July-07				0	180	1800	65	
	1-Aug-07				2	182	1820	67	
	3-Aug-07	2.7	10.2	35.6	5	187	1870	69	
	20Aug-07				0	187	1870	86	
	27Aug-07				0	187	1870	93	

VS AND TS ON SOLID MATTER						
Date/Sample	**Container**	**weight**	**weight full**	**weight full 600'**	**VS/%**	**Av.VS/%**
29March-07/Raw MSW	w	41.231	43.21	41.511	86%	
	p	40.762	41.832	40.94	83%	
	9	54.473	56.483	54.905	79%	
	8	55.162	57.902	55.933	72%	
	25	57.171	61.86	59.202	57%	
	29	56.242	58.842	56.587	87%	
	22	56.912	62.786	59.41	57%	
	32	62.266	65.409	63.328	66%	
	28	61.576	67.069	63.507	65%	72%
9-April-07/2WkPret	32	62.2685	65.7392	63.6991	59%	
	15	47.1056	51.6883	48.9557	60%	
	8	55.1661	59.6894	56.1534	78%	66%
25-April-07/4WkPret	p	40.767	45.201	42.654	57%	
	8	55.1667	63.7272	59.7036	47%	
	23	53.8404	60.1512	57.1754	47%	
	c	43.385	49.4516	46.4908	49%	
	16	52.8945	58.096	55.4893	50%	
	blank	44.4242	48.167	46.0655	56%	51%
14-May-07/6WkPret	m	45.5418	50.233	47.7434	53%	
	9	54.5762	57.8613	56.3775	45%	
	p	40.7656	43.3952	42.377	39%	46%
28-May-07/8WkPret	m	45.541	49.4104	47.2217	57%	
	8	55.1869	58.7915	57.4036	39%	
	b	43.8707	49.2516	47.964	24%	40%
12-June-07/10WkPret	23	53.8398	56.5192	55.1336	52%	
	19	49.3444	51.4746	50.4698	47%	
	1	53.9084	56.1893	55.3766	36%	40%
25-June-07/12WkPret	W	41.2258	43.6426	42.5934	43%	
	6	54.2572	56.5785	55.7567	35%	

VS AND TS ON SOLID MATTER CONT

Date/Sample	Container	weight	weight full	weight full 600'	VS/%	Av.VS/%
	15	47.1642	49.8851	48.8236	39%	39%
12-July-07/14WkPret	20	54.4785	55.6346	55.1039	46%	
	23	53.8378	55.3408	54.767	38%	
	25	57.172	59.2069	58.4972	35%	40%
25-July07/16WkPret	blank	44.3982	46.6987	46.0483	46%	
	M	53.8378	55.3408	54.767	38%	
	Z	51.172	59.2069	58.4972	9%	31.1%

RESULTS OF C/N TEST

Sample	Week	Day	N	C	C/N
Raw	Raw	0	%	%	
2Wk Pret	0	22	1.27	23.53	18.52756
4WkPret	2	36	1.55	19.3	12.45161
6WkPret	4	48	1.71	16.02	9.368421
8WkPret	6	62	1.91	16.99	8.895288
10WkPret	8	77	1.85	18.97	10.25405
12WkPret	10	91	1.82	17.84	9.802198
14WkPret	12	105	1.75	14.9	8.514286
16WkPret	14	122	1.7	14.2	8.352941

APPENDIX 2 -ELUATE ANALYSIS

Sample	Week	Day	TOC	TKN
Raw MSW	0	0	431	75.3
2Wk Pret	2	22	600	134
4WkPret	4	36	720	60
6WkPret	6	48	181	52
8WkPret	8	62	379	60
10WkPret	10	77	196	22
12WkPret	12	91	177	38
14WkPret	14	105	162	31
16WkPret	16	122	165	29

RESULTS OF THE COD TEST

				Reading					Ave	Std D	Var	Result
Sample	Date	Vol	Blank Av	1	2	3	4	5				
RAW	4-April 07	0.1	0.0010	0.114	0.123	0.111			0.116	0.0062	4E-05	7117.35
		0.1	0.0010	0.108	0.112	0.112			0.1107	0.0023	5E-06	6787.27
		0.1	0.0010	0.122	0.126	0.22			0.156	0.0555	0.0031	9592.95
Std		1.5	0.0010	0.133	0.137	0.132			0.134	0.0026	7E-06	548.76
		0.1	0.0010	0.12	0.118	0.122			0.12	0.002	4E-06	7364.91
2WkPret	24April07	0.15	0.0010	0.17	0.169	0.172			0.1703	0.0015	2E-06	6986.69
		0.05	0.0010	0.06	0.061	0.062			0.061	0.001	1E-06	7426.80
Std		1.5	0.0010	0.116	0.127	0.123			0.122	0.0056	3E-05	499.25
4WkPret	5-May 07	0.13	0.0010	0.036	0.03	0.029	0.033	0.032	0.032	0.0027	7E-06	1475.84
		0.18	0.0010	0.05	0.049	0.051	0.052	0.047	0.0498	0.0019	4E-06	1677.91
		0.24	0.0010	0.068	0.068	0.063	0.064	0.061	0.0648	0.0031	1E-05	1645.24
Std		1.5	0.0010	0.114	0.114	0.125	0.118	0.109	0.116	0.006	4E-05	474.49
6WkPret	20 May 07	0.57	0.0010	0.07	0.062	0.068	0.068	0.068	0.0672	0.003	9E-06	718.79
		0.76	0.0010	0.091	0.093	0.094			0.0927	0.0015	2E-06	746.48
		0.43	0.0010	0.055	0.057	0.054			0.0553	0.0015	2E-06	782.02
Std		1.5	0.0010	0.1480	0.146	0.149			0.1477	0.0015	2E-06	605.15

RESULTS OF THE COD TEST												
				Reading					Ave			
Sample	**Date**	**Vol**	**Blank Av**	**1**	**2**	**3**	**4**	**5**		**Sample**	**Date**	**Vol**
8WkPret	06 June 2007	0.55	0.0010	0.097	0.098	0.102			0.099	0.0026	7E-06	1102.77
		0.55	0.0010	0.105	0.097	0.104			0.102	0.0044	2E-05	1136.53
		0.75	0.0010	0.135	0.133	0.128			0.132	0.0036	1E-05	1081.01
Std		1.5	0.0010	0.123	0.122	0.124			0.123	0.001	1E-06	503.37
10WkPret	20 June 07	0.8	0.0000	0.118	0.119	0.119			0.1187	0.0006	3E-07	918.04
		0.9	0.0010	0.129	0.129	0.126			0.128	0.0017	3E-06	873.34
Std		1.5	0.0010	0.118	0.121	0.12			0.1197	0.0015	2E-06	489.62
12WkPret	6 July 07	0.5	0.0010	0.072	0.076	0.08			0.076	0.004	2E-05	928.35
	.	0.8	0.0010	0.114	0.12	0.114			0.116	0.0035	1E-05	889.67
Std		1.5	0.0010	0.124	0.122	0.122			0.1227	0.0012	1E-06	502.00
		0.15	0.0010	0.038	0.039	0.038			0.0383	0.0006	3E-07	1540.37
		0.2	0.0010	0.341	0.387	0.264			0.3307	0.0621	0.0039	10201.54
14WkPret	14 July 07	0.5	0.0010	0.06	0.061	0.06			0.0603	0.0006	3E-07	734.43
		0.8	0.0010	0.094	0.093	0.094			0.0937	0.0006	3E-07	716.89
		0.9	0.0010	0.109	0.104	0.107			0.1067	0.0025	6E-06	726.63
Std		1.5	0.0010	0.121	0.122	0.124			0.1223	0.0015	2E-06	500.62
16WkPret	26 july 07	0.5	0.0001	0.06	0.06	0.058			0.0593	0.0012	1E-06	733.19
		0.8	0.0001	0.086	0.082	0.08			0.0827	0.0031	9E-06	638.76
		0.3	0.0001	0.036	0.037	0.038			0.037	0.001	1E-06	761.25
std		1.5	0.0001	0.117	0.117	0.118			0.1173	0.0006	3E-07	483.70

RESULTS OF THE BOD			
Date	**Sample**	**BOD(mg/l)**	**Av.BOD**
5-Apr	Raw	951	
		1079	**1015**
19-Apr	2WkPret	1496	
		1571	**1533.5**
5/7/2007	4WkPret	1197	
		1186	
		1571	
		1315	1317.25
14-May	6WkPret	1270	
		1250	
		1310	
		1250	1270
28-May	8WkPret	1165	
		1775	1470
16-Jun	10WkPret	1154	
		1124	
		1243	1173.667
26-Jun	12WkPret	748	
		663	705.5
13-Jul	14WkPret	395	
		716	555.5
24-Jul	16WkPret	353	
		352.54	
		354	353.18

RESULTS ON THE NH/NOx TEST

Nitrogen Analysis			NH3						NOx					
			Repeat			Ave	Result	Std Dev					Result	Std Dev
Date	Sample	Vol	1	2	3				1	2	3	Average		
4-Apr	Raw	50	3.34	3.73	3.42	3.496667	**48.95333**	2.883909	0.71	0.47	0.61	0.596667	**8.353333**	1.68776
		50	2.418	2.43	2.44	2.429333	**34.01067**	0.154212	0.45	0.42	0.39	0.42	**5.88**	0.42
		50	2.84	2.86	2.81	2.836667	**39.71333**	0.352326	0.74	0.76	0.72	0.74	**10.36**	0.28
23-Apr	2Wk Pret	50	3.56	3.53	3.66	3.583333	**50.16667**	0.95296	0.37	0.39	0.38	0.38	**5.32**	0.14
7-May	4WkPret	50	3.41	3.45	3.47	3.443333	**48.20667**	0.427707	0.29	0.28	0.25	0.273333	**3.826667**	0.291433
16-May	6WkPret	50	2.14	2.19	2.17	2.166667	**30.33333**	0.352326	0.26	0.27	0.3	0.276667	**3.873333**	0.291433
30-May	8WkPret	50	0.72	0.74	0.68	0.713333	**9.986667**	0.427707	0.27	0.42	0.44	0.376667	**5.273333**	1.30082
14-Jun	10WkPret	50	0.55	0.61	0.64	0.6	**8.4**	0.641561	0.45	0.46	0.48	0.463333	**6.486667**	0.213854
26-Jun	12WkPret	50	0.15	0.18		0.165	**2.31**	0.296985	0.25	0.27		0.26	**3.64**	0.19799
13-Jul	14WkPret	50	0.15	0.14	0.12	0.136667	**1.913333**	0.213854	0.27	0.28	0.27	0.273333	**3.826667**	0.080829
26-Jul	16WkPret	50	0.13	0.15	0.14	0.14	**1.96**	0.14	0.2	0.23	0.24	0.223333	**3.126667**	0.291433

RESULTS OF TS-SOLID MATTER

Date	Sample	Cruc No	DRY INITIAL	After drying	After firing	TS g/l	VS g/l	Cruc No	DRY INITIAL	After drying
4-April-07	Raw							vs	TS	
		M	45.5410	45.9130	45.6520	14.880	4.440			
		25	57.1703	57.5360	57.2799	14.628	4.384			
		blank	43.8803	44.2519	43.9915	14.864	4.448	4.424	14.788	0
20 April-07	2WkPret	32	62.2685	65.7392	63.6991	138.828	57.224			
		15	47.1056	51.6883	48.9557	183.308	74.004			
		8	55.1661	59.6894	56.1534	180.932	39.492	56.9066667	167.689	2
5-May-07	4WkPret	M	45.5410	45.9130	45.6520	14.880	4.440			
		25	57.1703	57.5360	57.2799	14.628	4.384			
		blank	43.8803	44.2519	43.9915	14.864	4.448	4.4240	14.79	4.0000

RESULTS OF TS-SOLID MATTER

Date	Sample	Cruc No	DRY INITIAL	After drying	After firing	TS g/l	VS g/l	Cruc No	DRY INITIAL	After drying
20-May-07	6WkPret	c	43.3856	44.514	44.4504	45.136	42.592			
		blank	43.4247	44.514	44.4504	43.572	41.028			
		25	57.1728	57.2601	57.1980	3.492	1.008	28.2093333	30.7333	6.0000
2- June-07	8WkPret	22	57.9133	58.5747	58.1532	26.456	9.596			
		15	47.1647	47.8147	47.3995	26.000	9.392			
		c	43.3827	44.0311	43.6183	25.936	9.424	9.47066667	26.1307	8.0000
20-June- 07	10WkPret	M	44.5422	45.1606	45.7952	24.736	50.120			
		P	40.7668	41.3078	40.9839	21.640	8.684			
		32	62.2666	62.8163	62.4908	21.988	8.968	22.5906667	22.7880	10.0000
2-July-07	12WkPret	32	62.2657	62.6675	62.4196	16.072	6.156	5.968	16.1893	12.0000

		8	55.1644	55.5728	55.3080	16.336	5.744			
		z	40.5660	40.9700	40.7161	16.160	6.004			
17-July-07	14WkPret	p	40.7558	41.0540	40.8746	11.928	4.752			
		1	53.8958	54.1931	54.0136	11.892	4.712			
		z	40.5628	40.8573	40.6763	11.780	4.540	14.004	4.6000	14.0000
30-July-07	12WkPret	b	43.8680	44.1836	43.9990	12.624	5.240			
		16	52.8937	53.2133	53.6226	12.784	29.156			
		32	62.2661	62.5872	62.3957	12.844	5.184	39.5800	12.7507	16.0000