Stabilisation of Waste in Shallow Test Cells: focus on biogas

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Submitted in partial fulfillment of the academic requirements for the degree of Master of Science in Water and Environmental Management

In the School of Civil Engineering, Surveying and Construction
Civil Engineering Programme
University of KwaZulu-Natal

Durban
December 2006

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ABSTRACT

Present day society generates large volumes of waste that present an environmental hazard when disposed of in landfills. As our population grows, so does the volume of waste generated and hence the threat to our environment. One method of reducing harmful emissions in landfills is the mechanical-biological pretreatment of waste prior to landfilling. The purpose of this dissertation is to investigate the degree of stabilization of waste in shallow landfills (simulated by test cells) with particular focus on biogas production and quality. Municipal waste was composted in aerobic, open windrows for periods of eight and sixteen weeks. Five test cells, designed and operated according to the PAF model (Pretreatment, Aeration and Flushing) were constructed at the Bisasar Road landfill site. These cells were used to simulate large scale municipal landfill sites. They were filled with fresh and pretreated waste and were used to monitor the dynamics of prolonged aeration and degradation of waste over a period of six months. The cells were monitored on a weekly basis while being aerated. Two flushing events were conducted at the beginning of the passive aeration. Gas emissions were also monitored by recording the methane, carbon dioxide and oxygen volumes per volume of air in probes strategically placed in each cell. These results were then analysed to assess the effect of mechanical-biological pretreatment of municipal solid waste on the emission quality of sanitary landfills and the appropriateness of prolonging the aeration in shallow landfills, as often used in sub-tropical countries.

It was found that the design of the test cells was appropriate for the landfilling and stabilization of waste that was aerobically treated. After six months in the test cells, analysis of the waste from each cell showed that the waste was completely degraded. The PAF model, when applied to shallow landfills, is very effective in stabilising waste and would be appropriate for a sub-tropical climate. Waste that is pretreated, placed in shallow landfills, initially flushed and then aerated over a six month period was fully stabilized. The requirement for such treatment would be relatively small amounts of waste, a wet climate and the availability of open space for shallow landfills. This method, therefore, would be very appropriate in a South African context. The major problem with this method may be the generation of large quantities of leachate which will have to be treated and disposed of in an environmentally safe manner.

PREFACE

I, Nevendra Krishnia Chetty, hereby declare that this research project is my own work, unless where otherwise indicated and has not been submitted to any other University for degree purposes. It was carried out under the supervision of Dr. C Trois of the University of KwaZulu-Natal and in accordance with the requirements of the University for the award of the MSc in Water and Environmental Management.

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ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr. C. Trois, for her dedication and expert guidance during the course of this research. I am also grateful to Mrs. Sheila Arnold who was ever willing to assist and share her wealth of knowledge and experience. To Prof. Ijumba, thank you for the encouragement and your understanding, without which this undertaking would not have been possible. To my family, thank you for your support and patience. I would also like to thank Mark Griffith for his advice and assistance. Thank you also to Santha and Tina for always being there whenever I needed anything.

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CHAPTER 1: Introduction

1.1 Motivation of Work

Humans and animals, in their daily activities, produce material that is no longer needed and that cannot be further utilised. This material is referred to as solid waste and has to be disposed of (Tchobanoglous, 1993). Present day society generates large volumes of waste which poses an environmental hazard when disposed of in landfills. As our population grows, so does the volume of waste generated and hence the threat to our environment.

Throughout the world, solid waste is generally disposed of by landfilling or landspreading because the economical and environment benefits outweigh any other method available (Tchobanoglous, 1993). In South Africa, for example, it is estimated that approximately 95 % of all urban waste is disposed of on land (DEAT). When waste is deposited in a landfill, the organic material in the waste begins to decompose by chemical and biological action producing biochemical breakdown products and gases (Ham, 1998). When rainfall and ground and surface water percolate through the waste mass, a leachate is produced which contains soluble components of the waste, suspended solids and micro-organisms (Ham, 1998).

The gas and leachate produced impact negatively on the environment for decades to come. The biogas produced is explosive, has components that are classified as greenhouse gases and causes odour problems (Griffith & Trois, 2005). The leachate produced has a high organic content and poses a danger to groundwater (Griffith & Trois, 2005). For many years, the leachate produced has to be collected and treated at a great cost before being disposed of and the biogas produced must be flared or used as an energy source (Leikam, 1997).

It must be borne in mind that it is impossible to avoid the production of waste totally and for this reason, attempts are always being made to reduce the emission potential of municipal solid waste (Horing et. al, 1999). Techniques in use today are treatment through incineration and/or mechanical-biological pre-treatment (MBP) of waste (Horing et. al, 1999).

MBP may be defined as "the processing or conversion of municipal solid waste, which contains biologically degradable components, by a combination of mechanical processes (e.g. crushing, sorting screening) with biological processes (aerobic "rotting", anaerobic fermentation)" (Soyez, 2002b). It results in the degradation of organic matter in the waste as well as a reduction of landfill volume and settlement that is brought about by separation and recycling of reusable components (Heerenklage, 1995). This limits the environmental impact that the landfill has by reducing the emission of landfill gas and leachate (Soyez, 2002; Leikam, 1997). Thus, MBP is an extremely valuable technique that can be used to effectively reduce the many harmful effects of landfills.

1.2 Objectives

The purpose of this dissertation is to investigate the degree of stabilization of waste in shallow landfills (simulated by test cells) with particular focus on biogas production and quality. More specifically, the objectives of the study were:

- to study the efficiency of the cellular method applied to mechanically and biologically pretreated waste in the South African context,
- to monitor the long-term behaviour of pretreated waste using landfill cells,
- to improve landfill design and operations of local landfill sites with direct technology transfer via the local authority-partner in the project (Durban Solid Waste, Ethekwini Municipality).

1.3 Overview of Investigation

Municipal solid waste, disposed of at the Bisasar Road Landfill in Durban, was composted in aerobic, open windrows for periods of eight and sixteen weeks as part of a study presented in Simelane (2006). A pilot project at the same landfill site was undertaken, in which five test cells, designed and operated according to the PAF model (Pretreatment, Aeration and Flushing (Cossu, et. al., 2003)) were constructed. These cells were used to simulate large scale shallow, aerobic landfills. They were filled with untreated and pretreated waste and were used to monitor the dynamics of prolonged aeration and degradation of waste over a period of six months. As part of this dissertation, the cells were monitored on a weekly basis while being self-aerated. Two flushing events were conducted at the beginning of the passive aeration. Gas emissions were also monitored by recording the methane, carbon dioxide and oxygen volumes per volume of air in vents and probes strategically placed in each cell. Leachate samples were collected each week and analysed to assess the rate of degradation of waste in the cells. These results were then used to assess the effect of mechanical-biological pretreatment of municipal solid waste on the emission quality of sanitary landfills, the effect of separating the waste into fine and coarse fractions and the appropriateness of prolonging the aeration in shallow landfills.

1.4 Structure of Dissertation

This dissertation consists of 5 chapters. Chapter 2 is the literature survey and presents the current trends of waste management. Chapter 3 is a case study of the MBP of solid waste and the construction of the test cells at the Bisasar Road landfill in Durban. Chapter 4 is a discussion of the materials and methods involved in the monitoring of the test cells and the analysis of leachate and gas production. Chapter 5 is a presentation and discussion of the results obtained and chapter 6 outlines the conclusions that were drawn from the investigation.

CHAPTER 2: Literature Survey

2.1 Introduction

The increase in population density brought about a clear hazard, associated with waste, to humans and the environment. The problem escalated to such an extent that, to prevent the devastating effect of diseases associated with unsanitary discarding of waste, solid waste management was introduced (Tchobanoglous, 1993).

2.2 Solid Waste Management

A definition of solid waste management is "the discipline associated with the control of generation, storage, collection, transfer and transport, processing and disposal of solid wastes in a manner that is in accordance with the best principles of public health, economies, engineering, conservation, aesthetics, and other environmental considerations, and that is also responsive to public attitudes" (Tchobanoglous, 1993). A waste management system must be related to a country's financial position, resources, socio-economic level and its industrial growth and must contribute to sustainable development and improvement in the quality of life (Wiechers, et. al., 2002;DEAT).

Solid waste management may be divided into six different steps (Tchobanoglous, 1993):

(i) waste generation,
(ii) waste handling and separation,
(iii) storage and processing at the source,
(iv) collection, separation, processing and transformation of solid wastes,
(v) transfer and transport,
(vi) disposal.

2.3 Sustainable Waste Management

A definition of sustainable development is "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Robinson, 1996).

To assist in achieving sustainability in waste management, there are many options which are available that can be applied prior to disposal. These options reduce the amount of solid waste to be disposed of and can be ranked into a hierarchy of benefit to the environment (Robinson, 1996):

(i) Waste Reduction (This is of greatest importance and all attempts to reduce waste to a minimum must be made),

(ii) Re-use (The next level of importance is reuse and all material that can still be used should be removed for reuse.),

(iii) waste recovery (The third level of importance in which material must be recycled, composted or used as a source of energy).

2.3.1 Sustainable Waste Management in South Africa

Section 24 of the South African Constitution states the following (adapted from Visser, 2002):

"Everyone has the right –

(a) to an environment that is not harmful to their health or well-being; and

(b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that –

(i) prevent pollution and ecological degradation;

(ii) promote conservation; and

(iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development."

In accordance with the Constitution, South Africa is also developing strategies that will promote sustainable waste management. Government, business, industry and civil society need to work together in providing a solution to the waste management problems in South Africa (Wiechers, et. al., 2002) The National Waste Summit, held in Polokwane in 2001, agreed that there is an urgent need to reduce, reuse and recycle waste for the benefit of the environment (Wiechers, et. al., 2002). At this summit, the Polokwane Declaration was drafted in which Government, business, industry and civil society committed to work together in providing a solution to the waste management problems in South Africa (Wiechers, et. al., 2002). It was agreed to work towards the following goal: "to reduce waste generation and disposal by 50% and 25% respectively by 2012 and to develop a plan for zero waste by 2022" (Wiechers, et. al., 2002).

2.3.2 Landfills

Throughout the world today, solid waste is generally disposed of by landfilling or landspreading because the economical and environment benefits outweigh any other method available (Tchobanoglous, 1993). In South Africa, for example, it is estimated that approximately 95 % of all urban waste is disposed of on land (DEAT).

2.3.2.1 The Sanitary Landfill

"Landfilling is the process by which residual solid waste is placed in a landfill and includes monitoring of the incoming waste stream, placement and compaction of the waste and installation of landfill environmental monitoring and control facilities" (Tchobanoglous, 1993).

Landfill sites are designed and operated in a scientific manner so as to ensure that minimum harm is caused to the environment and society. The necessary steps that are involved in the design and operation of landfills are (Tchobanoglous, 1993):

- Selection of a suitable site,
- Selection of the methods and operations that are suitable to the site chosen,
- Production and management of gases and leachate,
- Design of the landfill

2.3.2.2 The "Flushing Bioreactor"

To a certain extent, all landfills can be regarded as flushing bioreactors if a suitable amount of moisture is allowed to percolate through them. In order to make landfills behave more like flushing bioreactors, two changes from the current operational techniques must be introduced (Robinson, 1996):

- The first is to increase the degradation rates of the organic material within the landfill by distributing moisture more evenly throughout thereby increasing the moisture content to above field capacity,
- The second step is to flush out all the material that the increased reactions produce.

By operating a landfill as a flushing bioreactor, many benefits can be derived (Robinson, 1996):

- The methanogenesis stage is accelerated,
- Gas yields are enhanced,

- Leachate quality is improved,
- Degradation rates are increased and waste stabilization is accelerated,
- The flows and loads of contaminants are balanced,
- The time and cost for the landfill aftercare are reduced.

In order to operate a landfill more as a flushing bioreactor, solutions have to be provided for the following problems (Robinson, 1996):

- Providing a high rate of irrigation,
- Thorough percolation of liquids through the waste mass,
- The collection of large quantities of leachate.

2.3.2.3 The PAF Model

Presently, attempts at reducing landfill emissions employ one of the following methods (Cossu et. al., 2003):

- The pretreatment of waste either by thermal or mechanical-biological means,
- Operation of the landfill in a semi-aerobic mode by aeration of the waste by natural air inflow or forced aeration,
- Operation of the landfill as a flushing bioreactor by in situ flushing of the waste.

Cossu et. al. (2003), in their experiments, tested a combination of these options to attempt to capitalise on all their benefits. Six plexiglass columns, 100 cm high and 18 cm in diameter, were used in laboratory tests carried out at constant temperature of 35 °C (Cossu et. al., 2003). Each column was used to simulate a different landfill concept as shown in Table 2.1 (Cossu et. al., 2003).

Table 2.1: Simulation of Different Landfill Concepts.

COLUMN	MATERIAL	OPERATING CONDITIONS	LANDFILL CONCEPT
A	MSW	Anaerobic	Traditional Landfill
B	MBP	Anaerobic	Pre-treated waste landfill
C	MBP	Anaerobic with high water input	Flushing bioreactor
D	MBP	Aerobic with high air inflow	Aerated landfill
E	MBP	Aerobic with low air inflow	Semiaerobic landfill
F	MBP	Aerobic with low air inflow and high water input	PAF model

The conclusions of their experiments can be summarized as follows (Cossu, et. al., 2003):

- The anaerobic landfill filled with MSW (just like those used in South Africa today) generated the highest level of emissions. The acid phase of decomposition delayed biogas production.
- By disposing mechanically-biologically pretreated waste under anaerobic conditions, it was found that the BOD_5, COD and ammonia in leachate was reduced but still high.
- Columns with MBP waste showed accelerated methanogenesis and the total gas production is higher than that of unprocessed waste.
- Flushing of MBP waste rapidly reduced the level of all emissions produced.
- A rapid oxidation of organics and nitrogen occurs when the waste mass is aerated.
- The combination of pre-treatment, semi-aerobic conditions and flushing, referred to as the PAF model, appears to provide the benefit of each of the different options to achieve a greater and quicker reduction of the concentrations of COD, TKN and ammonia in leachate.

Therefore, one can see that the PAF model has tremendous potential in the landfilling process as it combines the benefits of MBP, continued aeration and flushing.

2.4 Decomposition of Solid Waste in Landfills

When waste is deposited in a landfill, the organic material in the waste begins to decompose by physical, chemical and biological action which produces biochemical breakdown products and gases. When rainfall and ground and surface water percolate through this waste mass, a leachate, which contains soluble components of the waste, suspended solids and micro-organisms, is produced (Ham, 1998).

2.4.1 Physical Decomposition

Physical decomposition is both the physical washing out of material from the waste and the changes in physical characteristics of the waste caused by the decomposition process (Ham, 1988).

2.4.2 Chemical Decomposition

Chemical decomposition includes the dissolution of materials from the refuse into the water that percolates through the waste (Ham, 1988).

2.4.3 Biological Decomposition

The most significant aspect of decomposition is the biological decomposition. Biological decomposition occurs in three major phases: aerobic phase, acid-phase anaerobic phase and methanogenic anaerobic phase (Ham, 1988).

2.4.3.1 Aerobic Decomposition

Aerobic decomposition begins to occur with the consumption of oxygen present in the refuse (Farquhar & Rovers, 1973). This aerobic decomposition is possible because of the infiltration of air into the landfill from near its surface, from oxygen that is dissolved in the precipitation that infiltrates the landfill and the air that is incorporated into the landfill while it is being filled with waste. Aerobic decomposition is generally of short duration and will cease to occur as soon as the oxygen in the waste mass is consumed. Aerobic decomposition also occurs quickly because waste that is recently deposited has more materials that are readily decomposable (Ham, 1988). The aerobic bacteria oxidize the long molecular chains of complex carbohydrates, proteins and lipids into carbon dioxide (Bockreis & Steinberg, 2005). Heat, CO_2,, water and salts are produced, oxygen is consumed and leachate containing partially degraded organic materials is produced (Krogman,1995:Ham, 1988). The temperature during aerobic decomposition increases sharply to temperatures in the region of 50 °C to 70 °C. If leachate is produced during this phase it will be acidic with the pH in the range of 6-7. It will also have a high COD because of the presence of partially degraded organic materials (Ham, 1988). At this early stage of the decomposition process, the refuse has generally not reached field capacity and, therefore, leachate is usually not produced (Ham, 1988).

2.4.3.2 Acid-phase Anaerobic Decomposition

When the available oxygen has been consumed and the aerobic decomposition process is unable to continue, acid-phase anaerobic decomposition begins. At the beginning of this phase, facultative anaerobic organisms, which prefer the presence of oxygen but can utilize other electron acceptors in its absence, prevail. During this transitional period between aerobic and methanogenic decomposition, strictly anaerobic acid producers begin to thrive as the oxygen is depleted. During acid-phase anaerobic decomposition, CO_2 is produced, there is less production of heat as compared to the aerobic process and large amounts of partially degraded organic materials (mostly organic acids) are produced. Because of these organic acids and because of the presence of dissolved CO_2, the leachate produced has an acidic pH level. The pH levels during this phase of decomposition are generally in the range of 5.5 to 6.5. The refuse begins to reach field capacity during the latter part of this decomposition phase and this results in the generation of leachate at the bottom of the landfill. This leachate has a low pH, a high COD (because of the large amounts of partially degraded organic material) and a high amount of dissolved inorganic material. Because of the acidic pH, the leachate is more chemically reactive and therefore has a high inorganic content (Ham, 1988).

2.4.3.3 Methanogenic Anaerobic Decomposition

The last stage of the decomposition of solid waste in a landfill is methanogenic anaerobic decomposition. Organisms, which are unable to tolerate oxygen, convert the partially degraded organics, which are produced by the acid-phase anaerobic organisms and others, to methane and CO_2. The organic acids begin to be consumed, the COD of the leachate is reduced and the pH increases until it becomes close to neutral. As the soluble substrates become depleted, the production of methane relies upon the hydrolysis of cellulose, which is the highest source of carbon for the production of methane. During this phase of decomposition, heat is continued to be produced and temperatures remain at, or possibly slightly more than, the levels obtained in the previous phase. Dissolved organic materials continue to be consumed, methane and CO_2 are produced and the pH increases to close to neutral. Because of this increase in pH, the leachate is no longer as chemically reactive as before and the concentration of inorganic materials (whose solubility is affected by pH) will decrease. This phase of decomposition, in which methane is produced, is an important one because it lasts longer than the other phases and because it is the phase in which most of the decomposable wastes are degraded (Ham, 1988).

2.5 Landfill Emissions

A landfill, in which solid waste is disposed, behaves like a biochemical reactor with the main inputs being solid waste and water and the main outputs being gas and leachate (Tchobanoglous, 1993)

2.5.1 Landfill Gas

Because of the biodegradation of putrescible wastes in a landfill, large volumes of landfill gas are produced and if this landfill gas is not managed correctly, it will have a negative impact on the environment (Lombard, 1998). In order to eliminate the discharge of harmful constituents to the atmosphere, landfill gas which is recovered is generally used to produce energy or it is flared (Tchobanoglous, 1993).

The main landfill gases are ammonia (NH_3), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), hydrogen sulfide (H_2S), methane (CH_4), nitrogen (N_2) and oxygen (O_2) and trace landfill gases are acetone, benzene, chlorobenzene, chloroform, 1,1-dichloroethane, dichloromethane, 1.1-dichloroethene, diethylene chloride, etc. (Tchobanoglous, 1993).
The typical percentage distribution of gases found in a MSW landfill is shown in Table 2.2.

Table 2.2: Major Constituents of Landfill Gas (Griffith, 2005).

Constituent		Volume Range (%)
Methane	CH_4	0 – 85
Carbon Dioxide	CO_2	0 – 88
Carbon Monoxide	CO	0 – 3.0
Hydrogen	H_2	0 – 3.6
Oxygen	O_2	0 - 31.0
Nitrogen	N_2	0 – 82.5
Ammonia	NH_3	0 – 0.35 vol. ppm
Hydrogen Sulphide	H_2S	0 – 70 vol. ppm

Table 2.3 illustrates the typical composition of landfill gas (Lombard, 1998) for a landfill in the methanogenic stage:

Table 2.3: Typical Landfill Gas Composition for a landfill in the Methanogenic Stage (Lombard, 1998).

COMPONENT	% BY VOLUME
CH_4	64 %
CO_2	34 %
N_2	2 %

2.5.2 Landfill Leachate

Liquid from external sources, such as surface drainage, rainfall, groundwater, water from underground springs and the liquid produced from the decomposition of the wastes itself, percolates through the solid waste mass (Tchobanoglous, 1993). This liquid extracts biological materials and chemical constituents from the waste while it is decomposing and is thereafter referred to as leachate (Tchobanoglous, 1993). The characteristics of leachate are shown in Figure 1, for both young and mature landfills. For each phase of decomposition, there is a corresponding, characteristic leachate composition which arises from the products of decomposition, the flow of moisture and the availability of organic matter in the decomposing refuse (Ham, 1998).

Table 2.4: Typical Landfill Leachate Composition (Griffith, 2005)

Value, mg/l[a]			
	New Landfill (less than 2 years)		Mature Landfill (greater than 2 years)
Constituent	Range[b]	Typical[c]	Range[b]
BOD_5 (5-day biochemical oxygen demand)	2000-30000	10000	100-200
TOC (total organic carbon)	1500-20000	6000	80-160
COD (chemical oxygen demand)	3000-60000	18000	100-500
Total suspended solids	200-2000	500	100-400
Organic nitrogen	10-800	200	80-120
Ammonia nitrogen	10-800	200	20-40
Nitrate	5-40	25	5-10
Total phosphorus	5-100	30	5-10
Ortho phosphorus	4-80	20	4-8
Alkalinity as $CaCO_3$	1000-10000	3000	200-1000
pH	4.5-7.5	6.0	6.6-7.5
Total hardness as $CaCo_3$	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
Sulfate	50-1000	300	20-50
Total iron	50-1200	60	20-200

[a] Except pH, which has no units

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

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

2.6 Environmental Impacts of Landfills

Most of the long term environmental problems caused by landfills are associated with leachate and biogas (Griffith & Trois, 2005). The biogas produced is explosive, has components that are classified as greenhouse gases and causes odour problems (Griffith & Trois, 2005). The leachate produced has a high organic content and poses a danger to groundwater (Griffith & Trois, 2005). There are other impacts such as surface run-off, dust, litter and noise which only pose a problem during the operation of the landfill (Christensen et. al., 1995).

The potential environmental impacts of a landfill are shown in Figure 2.1 (Christensen, et. al., 1995).

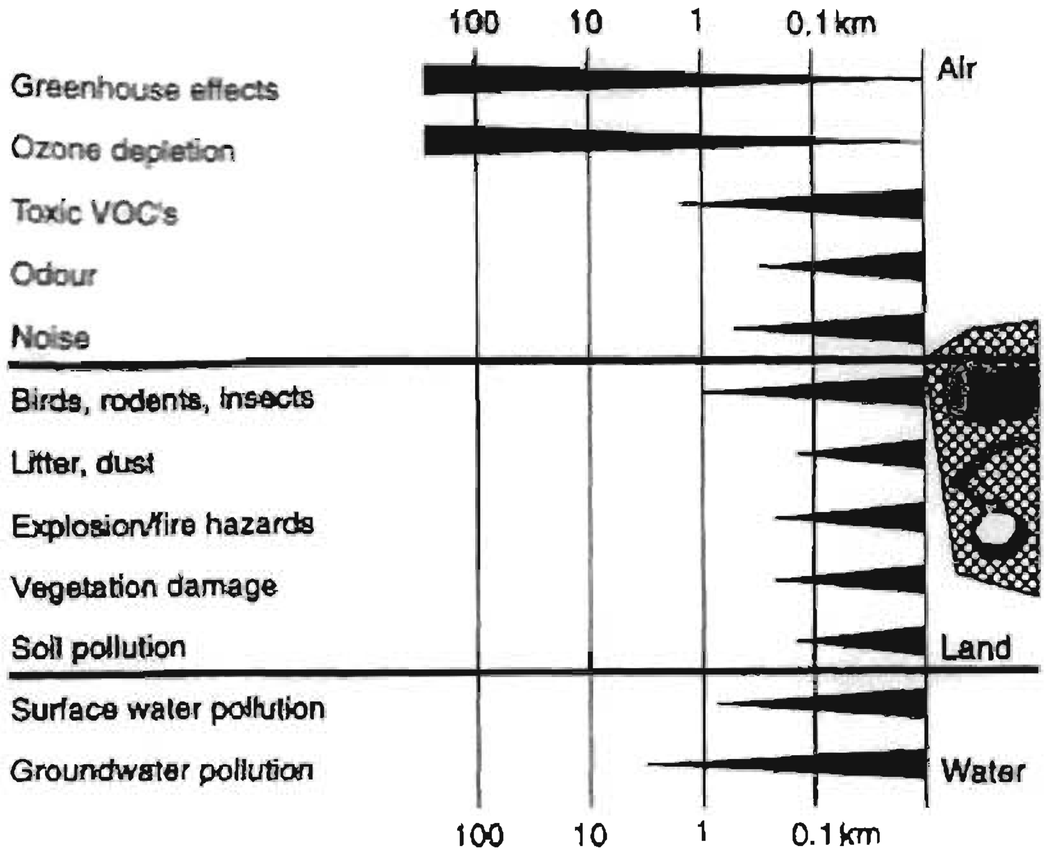

Figure 2.1: Potential Environmental Impacts of Landfills with Estimated Zone of Influence of Each Impact Type (Christensen, et. al., 1995).

The impacts shown and the distances associated with each impact varies according to many factors like, landfill size, type of waste and technology used (Christensen, et. al., 1995).

2.6.1 Fire and Explosion Hazards

Even though landfill gas is rich in methane and can provide a source of energy, it is generally considered a liability because it is flammable, explosive and migrates easily away from the landfill by diffusion and advection (El-Fadel et. al., 1997). This gas penetrates buildings and underground facilities that are built close to landfills, forms pockets of gas, and becomes an explosive hazard (El-Fadel et. al., 1997). Many fires occur below the landfill surface when air penetrates the landfill causing methane and oxygen to mix thereby creating a flammable mixture (El-Fadel et. al., 1997). Another property of landfill gas that makes it dangerous is its ability to displace oxygen from enclosed places, thus making it extremely dangerous to life forms (Lombard, 1998).

2.6.2 Vegetation damage

When landfills are closed, many are rehabilitated by the creation of parks, golf courses, agricultural and commercial developments (El-Fadel et. al., 1997). Landfill gas displaces oxygen from the root zone of the soil on and near the landfill thereby causing vegetation damage in these facilities (El-Fadel et. al., 1997).

2.6.3 Unpleasant odours

Odour problems are caused by the many odourous constituents found in landfill gas, like esters, hydrogen sulphide, organosulphurs, alkylbenzenes, limonene and other hydrocarbons (El-Fadel et. al., 1997). These constituents might be toxic but generally, are considered to be more of a nuisance (El-Fadel et. al., 1997).

2.6.4 Landfill settlement

As refuse decomposes in a landfill, the void ratio increases, which weakens the structural strength of the refuse mass. This causes major settlement which hinders the development of completed landfill sites (El-Fadel et. al., 1997).

2.6.5 Groundwater pollution

Leachate contains high concentrations of organic carbon, ammonia, chloride, iron, sodium, potassium and hydrogen carbonate (Christensen et. al., 1995). When leachate reaches the bottom of a landfill, it either travels laterally until it disharges to the ground's surface or it moves through the bottom of the landfill into the subsurface areas where it poses a major threat to ground water (El-Fadel et. al., 1997). The carbon dioxide found in landfill gas is highly soluble and therefore is able to pollute ground water with ease (El-Fadel et. al., 1997). Trace toxic gases that are emitted in the landfill gas are also a source of pollution to ground water (El-Fadel et. al., 1997).

2.6.6 Air pollution

Even though methane and carbon dioxide are the two major components of the gas emitted from landfills, it also contains numerous other constituents in trace amounts that can cause environmental and health problems (El-Fadel et. al., 1997). The VOCs in landfill gas may have the potential to increase cancer risk in the communities (El-Fadel et. al., 1997). The

CO_2 and VFA components found in landfill gas can cause buildings to weaken as these components are aggressive to concrete, brick, cement and mild steel (Lombard, 1998).

2.6.7 Global warming

Municipal solid waste contains approximately 30% carbon and about two thirds of this carbon is converted to landfill gas (Lombard, 1998).

The methane and carbon dioxide found in landfill gases are major contributors to global warming or the greenhouse effect if released into the atmosphere (El-Fadel et. al., 1997). Methane is very effective at trapping infrared radiation within the atmosphere and tends to remain for a long time and it is estimated that methane contributes about 18 % towards global warming (El-Fadel et. al., 1997). When landfill gas is flared, CH_4 is converted to CO_2 and water thus reducing the contribution to the greenhouse effect (Lombard, 1998). This contribution can be further reduced if CH_4 is used as a source of energy, replacing fossil fuels (Lombard, 1998).

Trace component of CFCs, which are also classified as greenhouse gases, are found in landfill gas which arise from the disposal of aerosol cans, styrene foams, refrigerators and air conditioners (Lombard, 1998).

2.7 Mechanical-Biological Pretreatment

The traditional method of landfilling was to dispose of all MSW into landfills and then to deal with the large quantities of emissions produced (Griffith & Trois, 2006). The trend in recent years is moving away from this and towards reducing the polluting potential of waste before its disposal in a landfill (Griffith & Trois, 2006). When municipal solid waste (MSW) is disposed of in a landfill and, depending on the climate and the composition of the waste, approximately 150 m^3 biogas/Mg MSW and 5 m^3/ha*d leachate emissions are produced during its existence (Leikam, 1997). For decades, the leachate produced has to be collected and treated at great cost before being disposed of and the biogas produced must be flared or used as an energy source (Leikam, 1997).

Over the years, more attempts are being made to reduce the volume of solid waste that is produced (Horing et. al, 1999). It makes sense that waste production has to be avoided as far as possible and non-avoidable waste must be re-used as much as possible (Soyez, 2002). Only the residual waste, which cannot be avoided or re-used, should be deposited in landfills (Soyez, 2002). This results in a tremendous reduction of the amount of waste to be placed in landfills which, in turn, reduces the harmful effects to the environment.

It must be borne in mind that it is impossible to avoid the production of waste totally and for this reason, attempts are always being made to improve the emission behaviour of municipal solid waste (Horing et. al, 1999). One technique that is in use today is waste incineration and another technique is the mechanical-biological pre-treatment (MBP) of waste (Horing et. al, 1999). These techniques, when applied to solid waste before landfilling, reduce the negative effects to the environment to a large extent thus providing benefit for generations to come.

"Mechanical-biological pre-treatment is the processing or conversion of municipal solid waste, which contains biologically degradable components, by a combination of mechanical processes (e.g. crushing, sorting screening) with biological processes (aerobic "rotting", anaerobic fermentation)" (Soyez, 2002b).

The MBP of MSW can be applied to the waste management process as a sole method or may be used in combination with thermal pretreatment (Leikam, 1997).

Mechanical-biological pretreatment results in the degradation of organic matter in the waste as well as a reduction of landfill volume by separation and recycling of reusable components (Heerenklage, 1995). This reduces the environmental impact that the landfill has on the environment by (Soyez, 2002; Leikam, 1997) :

- reducing the emissions of landfill gas and leachate,
- reducing the volume of material to be landfilled by up to 60 %,
- minimizing settlement of the landfill body.

Thus, MBP is an extremely valuable technique that can be used to effectively reduce the many harmful effects of landfills.

During MBP, the decomposition of biodegradable substances contained in the waste occurs which results in the minimization of the biological processes that take place within the landfill (Scheelhaase, 1997). This means that the emission potential in the waste is reduced during pretreatment which results in a substantial reduction in the period over which the processes in a landfill occur (Heerenklage, 1995). The reduced emissions from a landfill with pretreated waste results in less expenditure for their control and treatment (Heerenklage, 1995). Stabilized waste also decomposes very slowly because the amount of degradable organic matter is reduced to a large extent during the pre-treatment process (Horing et. al, 1999).

Approximately 70 % of the organic matter in solid waste is degraded in a conventional landfill and approximately 90 % of the degradation products are emitted as landfill gas and 10 % as leachate (Scheelhaase, 1997). By applying MBP to these solid wastes, it is possible to reduce the organic mass by 60 % - 70 % and, therefore, the gas emissions by approximately 90 % (Scheelhaase, 1997). Studies have proved that the gas production rate for pretreated waste is about 20 l/kg dry matter which is about 90 % lower than that for untreated MSW (Leikam, 1997).

The low emission potential of MBP MSW causes a very slow movement of organics and nitrogen into the leachate which results in low leachate concentrations for a long time. COD and total nitrogen in the leachate will be reduced by about 90% and since no acid phase will occur during the decomposition process, the organic carbon in the leachate can be reduced by up to 95% (Horing et. al, 1999).

There are also further benefits arising from MBP. Dust emissions, odour emissions and paper flow are reduced (Heerenklage, 1995). There is also better compactibility and a reduction in the settling processes due to a reduction in grain size during rotting (Heerenklage, 1995; Scheelhaase, 1997).

2.7.1 Mechanical Pretreatment

Mechanical pretreatment on MSW results is the separation of the waste according to its material properties by means of shredding, screening, sorting and separation (Leikam, 1997). Separation results in the salvage of useful waste components for industrial re-use (such as metals and plastics), as well as refuse derived fuel (RDF) (Soyez, 2002). Shredding results in a reduction of the waste volume and the increase in the specific surface of the waste, thereby facilitating more efficient biological degradation (Heerenklage, 1995).

2.7.2 Biological Pretreatment

MSW contains a significant amount of organic matter and by treating this waste with biological processes, the organic content is degraded and reduced, resulting in the landfilling of waste that has a much lower biological activity, which reduces the environmental impact (Soyez, 2002).

Aerobic rotting, anaerobic fermentation or a combination of the two processes are employed during biological pretreatment with aerobic processes generally being the preferred method (Soyez, 2002). Current aerobic systems treat the MSW biologically for a period of 4 to 8 weeks after which the waste is matured in an open passively aerated windrow. Anaerobic systems also use 2 or 3 step processes, produce methane and also require aerobic maturation (Soyez, 2002b). Aerobic degradation is a three-phase process involving solids, air and water and anaerobic digestion is a two phase process involving solids and water (Krogmann, 1995).

2.7.2.1 Anaerobic waste pretreatment

When MSW is treated anaerobically, the organic fraction of the waste is converted to biogas and a residue. The advantages of anaerobic treatment over aerobic treatment are (Leikam, 1997):

- less space is needed,
- the construction of the system is modular,
- energy can be obtained from the biogas,
- less odours are released into the atmosphere because the system is closed

In the intial stages of the anaerobic treatment, simpler organic compounds like acetic acid, other organic acids, hydrogen and carbon dioxide are produced after which methane, carbon dioxide, salts and humic substances are produced. Anaerobic digestion releases little energy with 1 mole of glucose producing only 405 kJ of energy which results in the need for addition energy for optimal treatment. Different stages of the anaerobic process involve different microorganisms which operate under different conditions which complicates the process further (Krogmann, 1995).

Wastes with a high sugar and carbohaydrate content and compressible and dense wastes, like food wastes, are better suited to anaerobic treatment (Krogman, 1995). Not all organic substances (e.g. substances containing lignin) can be degraded under anaerobic treatment and, therefore, it is necessary to further compost the material after anaerobic treatment (Leikam, 1997).

2.7.2.2 Aerobic waste pretreatment

During complete aerobic degradation of 1 mole glucose to water and carbon dioxide, 2803 kJ of energy is released (Krogmann, 1995).

During aerobic biological treatment, micro-organisms, utilizing oxygen, reduce the organic material in the waste to carbon dioxide, water and biomass along with the production of heat and odours (Leikam, 1995). For the aerobic process to be as effective as possible, the following operating conditions are of the utmost importance (Kiely, 1998):

(i) Temperature: During the composting process, different stages with different temperature profiles occur namely psychrophilic (15–20 °C), mesophilic (25–35 °C) and thermophilic (50–60 °C) stages. Ideally, the thermophilic stage must be attained as soon as possible.

(ii) Moisture content: Water is an important requirement for the activity of micro-organisms. The ideal moisture content is 50 – 60 %. Below this range, microbial activity slows down and above this range water fills the air spaces preventing the circulation of oxygen.

(iii) Oxygen: Oxygen is another important requirement for aerobic decomposition and the optimum oxygen range is 15 – 20 %.

(iv) C/N ratio: The ideal C/N ratio for efficient composting is 30.

(v) pH: The optimum pH range is 6 – 8,

(vi) Biochemical composition: Different types of material degrade at different rates with plants, manure and food wastes being easily degradable and high lignin material like straw, wood and paper being slowly degradable.

(vii) Texture: The texture of the waste is important in providing a substrate for the activity of micro-organism. It also affects its ability to retain moisture.

Aerobic systems that are more commonly used today are (Heerenklage, 1995) :

- Drum composting,
- Bin/container composting,
- Windrow composting,
- Row/tunnel composting and
- Brikollare composting.

Table 2.5 shows the classification of the most common composting systems in use today (Trois, et. al., 2007).

Table 2.5: Classification of composting systems (Trois, et. al., 2007)

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

Aerobic decomposition in open windrows relies on airflow to provide oxygen and to remove heat. It is possible to supply forced aeration but this would require added resources (Mollekopf, et. al., 2002).

2.8 Dome Aeration Technology

As explained earlier in the chapter, there are many methods that may be used in the pretreatment of waste. One such method is the Dome Aeration Technology (DAT) which has been extensively tested by the University of KwaZulu-Natal in partnership with Durban Solid Waste and it was found to be the ideal method for the aerobic treatment of MSW in South Africa due to its low cost, low level of maintenance and no energy requirement during the composting period (Griffith, 2005; Griffith & Trois, 2005).

In order to facilitate the optimal aerobic decomposition of waste, a simple but effective dome aeration system was developed at the Institute of Chemical Engineering and Environmental Engineering of the University of Technology Dresden (Paar, 1999, Mollekopf, 2002). This technology, termed "Dome Aeration Technology" (DAT), used simple structures to allow open rotting windrows to be self-aerated (Mollekopf, 2002). These structures were special devices which were installed in the windrows that capitilised on the thermal buoyancy of the hot gases to enable the circulation of air through the waste thereby providing a sufficient supply of oxygen to the core of the windrow (Mollekopf, 2002).

Open windrows are built outdoors with the cross section having the shape of a triangle or trapezium. To allow for aeration during the aerobic process, forced aeration devices, utilizing either suction or pressure gradients, may be employed, which is an added cost. Even with forced aeration, windrows need to be frequently turned. The oxygen introduced into the waste with one turning action is consumed by the micro-organisms in less than one hour which results in anaerobic processes occurring between the turnings. This causes the production and release of methane and bad odours. A solution to this problem is to make use of diffusion processes and the heat energy emitted by the micro-organisms for the aeration process. These methods are referred to as "passive aeration" or "self aeration" (Mollekopf, 2002).

The advantages of this system are (Paar, 2002):

- It employs a grid design which allows for more effective air exchange ,
- It is physically more stable,
- The grid material is resilient to the effects of the composting material,
- It is easy to manufacture and is reusable,
- It is relatively cheap to implement.

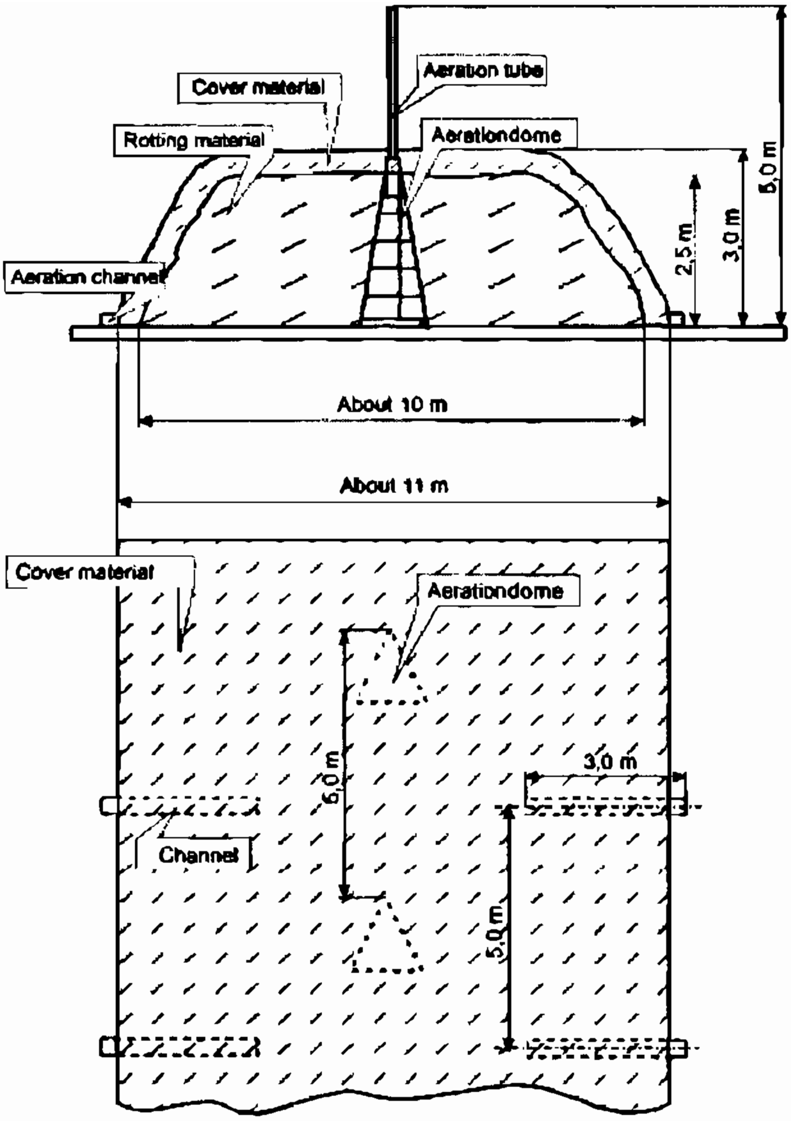

Figure 2.2: DAT Windrow Layout (Mollekopf et. al., 2002).

A DAT windrow is constructed with vertical exhaust domes and horizontal inflow channels manufactured from carbon steel. Both the domes and channels have apertures that are approximately 100 to 150 mm. This allows gases to flow through the domes and channels without allowing the composting material to fall through. Hot gases, generated by the rotting material, collect in the domes creating a column of hot gas. These hot gases are forced to move up the chimney by the buoyancy forces and ambient air is drawn through the channels, and forced through the composting material, thus achieving aeration of the waste (Mollekopf et. al., 2002). A cross section of a windrow depicting the domes and channels is shown in Figure 2.2.

Figure 2.3 shows a cross section with vertical standing exhaust domes and horizontal inflow channels.

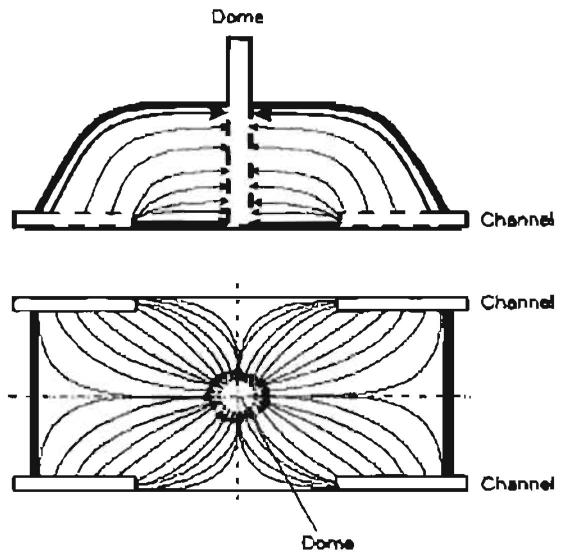

Figure 2.3: Flow pattern of the Dome Aeration Technology (Mollekopf et. al., 2002).

The windrows are generally covered with material that has been previously composted in the same facility for the following reasons (Mollekopf, 2002):

(i) reduction in the release of odours and harmful substances to the atmosphere,
(ii) prevents the blowing away of light materials by wind,
(iii) maintenance of a high temperature within the windrow,
(iv) reduces the effect of climatic conditions,
(v) allows for defined, controllable emission paths through the channels and domes.

The construction of DAT windrows is relatively quick and simple with the following steps being followed (Paar, 1999):

(i) Predefined quantities of bulky waste and/or sewage sludge are added to the material to be composted.
(ii) The mixture is then crushed, mixed and irrigated.
(iii) Aeration is providing by the domes and channels and the decomposition process occurs aerobically.
(iv) The separation of recyclable material like plastics, textiles and metals can then be carried and some of the fine material can be used as surface cover for the windrows.

CHAPTER 3: CASE STUDY

The focus of this study involves the monitoring of test cells that operate according to the PAF model and that are filled with waste that has been mechanically biologically pretreated. Therefore, the pretreatment of the waste and the construction and filling of the test cells are presented as a case study of the work undertaken by Oscar Simelane at the Bisasar Road landfill site (Simelane, 2006).

3.1 Pretreatment of Waste

The municipal solid waste was pretreated using the Dome Aeration Technology (DAT) (Mollekopf, 2002). DAT was found to be a suitable method of composting waste in the South African context and hence was implemented in this study (Griffith et. al., 2005).

The waste was already mixed and shredded to a certain extent while being transported by rotopress trucks to the landfill site. Structural material, consisting mainly of dry wood and garden refuse, was then added to the waste in a ratio of two parts MSW to one part structural material. The reason for adding structural material was to provide air spaces within the waste mixture, thereby allowing air and water to permeate the waste mass. This is necessary for DAT to be effective (Mollekopf, 2002).

Microbial activity is most pronounced when the moisture content of the material is between 50% and 60% (Kiely, 1998). Thus, after being well mixed, the waste was spread on the ground and sprayed with water from a water tanker. The amount of water that was added was calculated so as to achieve a moisture content of 55 %. By assuming a Loose Bulk Density of 0.5 ton/m^3, 20 kl of water was added to every 80 m^3.

3.1.1 Construction and Operation of Windrows

Three windrows were constructed at the Bisasar Road landfill in which municipal solid waste (MSW) and pine bark were decomposed separately. The waste was aerobically decomposed in the windrows for periods of 8 and 16 weeks. The domes and channels were set up on the site prepared for the windrow construction and the wet waste was placed over this. Table 3.6 shows the input material per dome of the three windrows. The windrows were then covered with a 0.5m thick layer of pine bark.

Table 3.6: Input Material per Dome of the Three Windrows (Simelane, 2006).

WINDROW NO.	MATERIAL	MIXING RATIO (MSW:SM)	MATERIAL VOLUME (m^3)	WATER (m^3)
1	MSW + Structural Material (SM)	2:1	120	30
2	MSW + Structural Material (SM)	2:1	120	30
3(a)	MSW + Structural Material (SM)	2:1	120	30
3(b)	Pine Bark		120	30

Figure 3.5 shows a cross sectional view of a typical windrow at the Bisasar Road Landfill site.

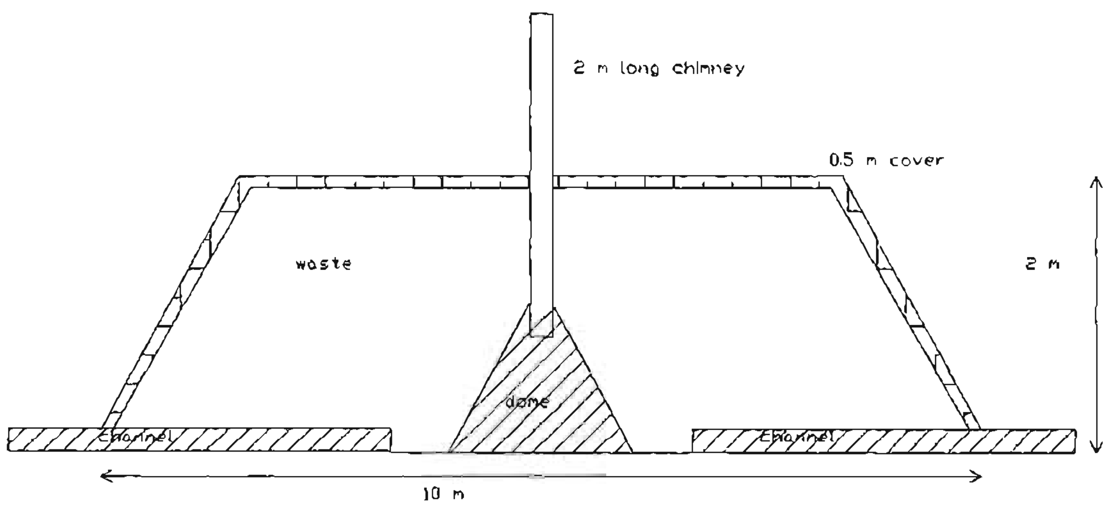

Figure 3.5: Cross sectional view of typical windrow (Simelane, 2006)

The temperature, gas flow and gas composition were monitored regularly. During the first week, data was collected daily and thereafter on a weekly basis. A thermocouple was used to monitor the temperature of the windrows from the chimneys and between the domes. The positions at which decomposition temperatures was checked within the chimney, was at the brim, at 1m and 2m depths and at the centre of the bulk material. Gas flow and gas composition were checked at a depth of 1m within chimneys using an anemometer and a gas analyzer respectively. Carbon dioxide, oxygen and methane percent compositions were also monitored. The results of this case study (pretreatment of waste with DAT) are well documented in Trois et. al. (2006). The main findings can be summarized as:

- The aerobic degradation process is enhanced by provision of oxygen throughout the waste mass,
- Removal of material that is slowly or non-biodegradable before the rotting process improves the efficiency of the process,
- The material must be well mixed and shredded to ensure even moisture distribution and to improve aeration,
- Standard landfilling equipment can be employed in this process,
- The process depends on the addition of suitable structural material.

3.2 Construction of Cells

A total of five test cells were constructed each with a dimension of 12.5m X 12.5m wide X 1m high containing an average of 35 m^3 of waste as part of Simelane, 2006 study. The site was cleared of all vegetation and the dimensions of each cell were marked. The cell walls were then constructed using Berea Red sand, as shown in Figure 3.6.

Figure 3.6: Construction of Cell Walls.

The bottom of each cell was covered with a geosynthetic clay liner (GCL) over which was placed a protective layer of geofabric liner. The leachate pipe was placed in position on the geofabric liner and a layer of 53mm stone was laid over this. The leachate pipe allowed for the collection and drainage of leachate into the leachate tank. A 1000 l plastic tank was installed on the edge of each test cell to collect the leachate to which the leachate pipe was attached. From this tank, leachate samples could be drawn and volumes measured. A drainage system was built around the edge of each cell to collect rainwater runoff. A second 1000 l plastic tank was installed on the edge of each test cell to collect the runoff. The runoff was measured and the tank drained each week. The runoff that was measured could then be compared to the amount of water that is supplied to the cells. This gives an indication whether the amount of water estimated to simulate natural rainfall is correct or not. Figure 3.7 shows the leachate and runoff collection tanks on a cell.

Figure 3.7: Leachate and runoff collection tanks.

Gas vents were constructed of 50 mm pipes that were placed in each corner of the cell, along the slope of the bottom of the cell, for a total of approximately 2 m each. The test cells were filled with waste as depicted in Table 3.7. The fines were obtained by sieving global waste through a 50mm sieve. Global waste is waste taken directly from the windrows after pretreatment. All material that did not pass through the sieve was removed. The reason for sieving is that the fine material that was separated has a larger content of easily biodegradable material. Also, in MBP plants throughout the world, after pretreatment, only the fine fractions are available for landfilling. Therefore, by sieving the waste, the particle size is in accordance with that found in real landfills.

Table 3.7: Filling of test cells.

Cell Number	Type of waste
1	8 weeks treated fines
2	16 weeks treated fines
3	8 weeks treated MSW
4	Control-untreated MSW
5	16 weeks treated MSW

The waste was then covered by a layer of 53mm diameter stone. A drip irrigation system, consisting of a lateral pipe network system with a nozzle spacing of 1m X 1m was installed on top of the stone layer. The amount of irrigation was calculated so as to simulate 50 years of typical landfill processes in 1 year. Weather data for the Durban area, collected over the last 30 years, was used in the calculation. The cells were then covered by a plastic polymer, soil and vegetation to prevent the influence of ambient atmospheric conditions. Five probes were constructed out of 25 mm diameter plastic pipes that were inserted approximately 0.5 m vertically into the waste. The pipes have slots cut into them every 100 mm to allow the gas to enter the pipe throughout its entire length. The position of the probes are shown in Figure 4.12. The layout of the partially constructed cells are shown in Figure 3.8.

Figure 3.8: Partially Completed Cells.

A cross sectional view of each test cell is shown in Figure 3.9.

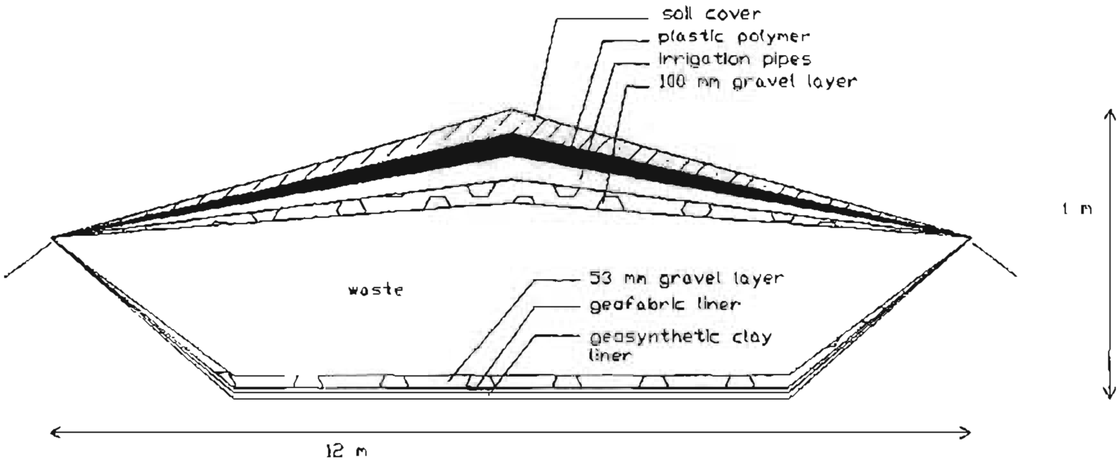

Figure 3.9: Cross-sectional view of test cells (Simelane, 2006)

The cells were allowed to be in a semi-aerobic state for six months after inception, that is, natural advective airflow was allowed to permeate the cells through the leachate pipe.

3.3 Characterisation of Pretreated Waste

Samples of waste were obtained and characterized in the laboratory by various students. Tests were performed on dry matter and eluate to assess the efficiency of pretreatment. Eluates from the input materials to the cells were prepared by mixing the waste and distilled water at a solid:liquid ratio of 1:10. The solid/liquid mixtures were shaken for periods of 24 hours, 36 hours and 72 hours. Comparisons of eluates obtained from different leaching periods were performed. The tests carried out on the eluates were COD, BOD_5, pH, conductivity, NH_3, NO_x, total solids and volatile solids. All results presented in this section are extracted from Tatho (2006) and Ramgunn (2005).

The composition of the pretreated waste is shown in Table 3.8.

Table 3.8: Composition of Pretreated Waste (Ramgunn, 2005).

Material	8 weeks/16 weeks fines (%)	8 weeks/16 weeks global (%)
Plastic	2.5	26.7
Glass	7.7	0.7
Wood	0.3	7.4
Metal	0.8	4.7
Paper	6.3	19.8
Rubber	-	3.5
Fabrics	1.2	25.9
Plant	15.1	-
Stone	11.5	3.9
Fines	54.5	7.5
TOTAL	100	100

The moisture content of the solid matter that was deposited in the cells is tabulated in Table 3.9.

Table 3.9: Moisture Content of Solid Matter (Ramgunn, 2005; Tatho, 2006)

	Cell 1 8 wks fines	Cell 2 16 wks fines	Cell 3 8 wks global	Cell 4 untreated	Cell 5 16 wks global
Moisture Content (%)	11.9	13.6	28.2	42.0	4.9

The characterization of the eluates of the MBP waste that were deposited in the test cells are shown in Figure 3.10.

Table 3.10: Eluate Tests (Ramgunn, 2005; Tatho, 2006)

	Cell 1 (8 wks fines)	Cell 2 (16 wks fines)	Cell 3 (8 wks global)	Cell 4 (untreated)	Cell 5 (16 wks global)
TS (g/l)	2.08	3.76	8.14	2.53	0.57
VS (g/gDM)	0.40	1.33	0.66	1.32	0.33
COD (mg/l)	1489.49	1874.33	1750	2269.33	2269
Conductivity (mS/cm)	1.54	1.41	1.16	1.91	1.37
pH	7.34	7.52	7.13	6.37	7.14

Table 3.11 Respiration Index (Ramgunn, 2005; Tatho, 2006)

	Cell 1 (8 wks fines)	Cell 2 (16 wks fines)	Cell 3 (8 wks global)	Cell 4 (untreated)	Cell 5 (16 wks global)
RI_4 (mgO_2/gDM)	1.34	3.45	4.48	2.07	3.54

Conclusion

To accomplish the objectives of the study, it was necessary to conduct a case study into the construction of the test cells and the characterization of the input material to the cells as outlined in this chapter. Comparison of the rate of degradation could then be made to samples removed from the cells after six moths. Comparison of biogas production between the different types of petreated waste could also be made.

CHAPTER 4: Materials and Methods

The aim of this research is to investigate the effect of Mechanical Biological Pretreatement (MBP) on the emissions produced by a landfill that is in a semi-aerobic state (with natural advective airflow).

To be able to assess the effect of MBP, gas and temperature readings as well as leachate sample collection were carried out each Saturday of the week between 06h00 and 10h00 for a period of approximately six months.

Figure 4.10 shows a view of the five test cells. Figure 4.11 shows the structure of a single cell and Figures 4.12 and 4.13 show the placement of the vents and probes on a cell.

Figure 4.10: View of Test Cells

Figure 4.11: Picture of a single Cell with Runoff and Leachate Tanks.

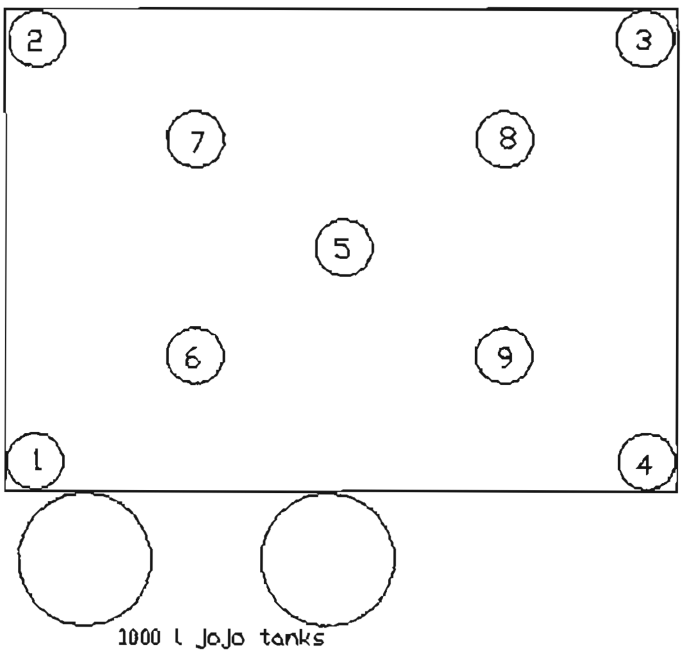

Figure 4.12: Plan view of test cell and location of vents and probes.

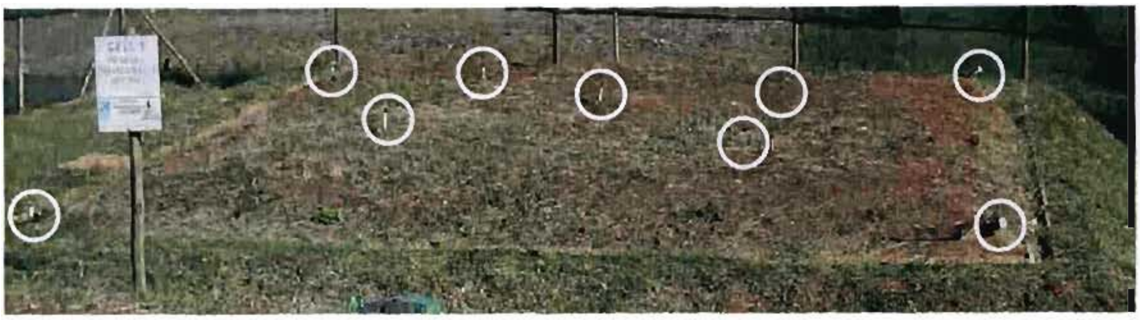

Figure 4.13: Placement of probes (within white circles).

The temperature, as well as the percentage of CH_4, CO_2 and O_2 in the air emitted from each probe, were measured and recorded. The apparatus used to measure gas percentage and temperature were a gas analyzer (GA2000) and a digital thermometer (Major Tech MT-630 with K-type thermocouple) respectively. The composition of methane, carbon dioxide and oxygen, as a vol/vol of air, as well as the temperature in °C were plotted for each vent and probe for each test cell (see Results chapter).

The cells were flushed initially and the inception date (when cells were covered) and flushing events are recorded in Table 4.12. During irrigation, problems with the irrigation unit resulted in irregular irrigation intervals and high volumes of water (between 200 l and 670 l per week) being introduced to the cells. This gave rise to the flushing events indicated in Table 4.12.

Table 4.12: Flushing Events Applied to the Cells

CELL NO.	INCEPTION DATE	FLUSHING EVENT
1	18 December 2005	23 February 2006 – 11 March 2006
2	31 August 2005	8 November 2005 – 28 November 2005
		10 January 2006 – 17 January 2006
		14 February 2006 – 11 March 2006
3	18 December 2005	10 January 2006 – 17 January 2006
		14 February 2006 – 11 March 2006
4	24 August 2005	8 November 2005 – 28 November 2005
		10 January 2006 – 17 January 2006
		14 February 2006 – 11 March 2006
5	18 August 2005	8 November 2005 – 28 November 2005
		10 January 2006 – 17 January 2006
		14 February 2006 – 11 March 2006

The quantity and quality of the leachate produced by the cells were measured and recorded. A two litre leachate sample was obtained from each cell for analysis in the laboratory. These samples were analysed in the Environmental Laboratory at the School of Civil Engineering. The characteristics of the leachate (COD, BOD_5, NH_3, NO_x, TS, VS, pH and conductivity) were then plotted against time (in days).

The level of leachate and rainwater runoff was measured on a weekly basis. A dipstick, made of a 2 m length of 25 mm plastic pipe, marked at 100 mm intervals was used to measure the level. Each 100 mm interval corresponded to a level of 100 l of liquid. The volume obtained from the leachate tank could then be compared to the required volume of water provided by the irrigation system. The volume obtained from the runoff tank gives an indication of the amount of actual rainfall that has fallen onto the cells minus evaporation and transpiration.

4.1 Gas Analysis

A total of four vents (located on each corner of the cell) and five probes (placed in the interior of the cells), were used to monitor temperature and gas composition. Vents 1 to 4 and probes 5 to 9 were monitored each week. Probes 5, 6, 7, 8 and 9 were constructed out of 25 mm diameter plastic pipes that were inserted approximately 0.5 m vertically into the waste. The pipes have slots cut into them every 100 mm to allow the gas to enter the pipe throughout its entire length. Gas vents 1, 2, 3 and 4 are 50 mm pipes that are placed in each corner of the cell, along the slope of the bottom of the cell for a total of approximately 2 m.

To obtain the gas composition on probes 5 to 9, a simple apparatus was constructed out of a rubber bung through which a rigid plastic tube was inserted. The bung was then pushed into the opening of the probe ensuring that a tight seal was formed. The readings obtained when the values on the gas analyzer stabilised were then recorded. On probes 1 to 4, the gas analyzer pipe was attached to the end of a 2 m long pipe with a rubber band and inserted approximately 1.5 m into the probe.

Figure 4.14: Gas data collection.

In probes 5 to 9, temperature is obtained by placing the thermocouple directly in each probe until the reading on the thermometer stabilized. Temperature on vents 1 to 4 were obtained in a similar fashion as the gas reading by attaching the thermocouple to a 2 m long pipe and inserting it approximately 1.5 m into the probe.

4.2 Leachate Characterisation

A two litre sample of leachate was collected from the leachate tank of each cell and analysed weekly. The laboratory tests conducted were: TS, VS, COD, conductivity, pH, BOD_5, NH_3, NO_x.

Figure 4.15: Measuring of leachate and runoff levels.

The characteristics of the leachate and the methods used to analyse them are presented and discussed below.

4.2.1 Solids (TS and VS)

Solids refer to particulate matter suspended or dissolved in water. Standard method used to determine TS was number ASTM 2540 B (Clesceri, 1997). Total solids (TS) is the residue left in a crucible after evaporation of a 50 ml sample in an oven at 105 °C. Total solids include total suspended solids (SS) (the component of total solids that does not pass through a filter of 20 μm) and total dissolved solids (TDS) (the component that passes through a filter paper) (Clesceri, 1997). Solids incenerated in a muffle furnace at a temperature of 550 °C are called volatile solids (VS) (Kiely, 1998). Standard method used to determine VS was number 2540 E (Clesceri, 1997).Samples are analysed in duplicate and the averages used. The volatile solids test offers a rough approximation of the amount of organic matter present in the waste.

4.2.2 Nitrogen

Nitrogen is one of the basic components of proteins and is used by the primary producers in cell production (Kiely, 1998). Ammonia and ammonia compounds are converted into nitrates or nitrites by bacterial action in a process called nitrification (Ramgunn, 2005). This bacterial action uses oxygen and thus depletes oxygen content (Ramgunn, 2005). As nitrification is aerobic, the presence of nitrates or nitrites is an indication of aerobic conditions (Ramgunn, 2005).

Standard method used to determine nitrogen was number ASTM 4500-NH_3 (Clesceri, 1997). The procedure is described as follows. A 50 ml sample was buffered with NaOH. It was then distilled into a solution of Boric Acid. The ammonia in the distillate was then determined titrimetrically with 0.25N HCl and a mixed indicator. The residue from the previous distillation was then used to determine the nitrite and nitrate (Majosi, 2005). After the removal of ammoniacal nitrogen by distillation under alkaline conditions, the nitrate and nitrite were reduced with Devardas Alloy, resulting in quantitative conversion to ammonia. This was distilled again into a solution of boric acid (Majosi, 2005). The Nitrogen was then calculated using the equation $P=14N_{HCl}V_{HCl}$, where P is mg of Nitrogen, N_{HCl} is the normality of HCl (0.1 in this case) and V_{HCl} is the volume of HCl (Clesceri, 1997).

Figure 4.16: Equipment used to for ammonia test.

4.2.3 pH

Most ecological life forms are sensitive to pH. The pH of a leachate is an indicator of the state of its biological activity (Majosi, 2005). Each type of bacteria operates within its unique pH range e.g. the methanogenic bacteria operate within a range of pH of 6 to 8 (Majosi, 2005). The PH provides an indication to the state of the sample e.g. acidic PH ranges indicate that the sample maybe in the early phases of degradation i.e. acetogenic or acidogenic (Ramgunn, 2005). pH is defined as the negative log (base 10) of the hydrogen ion concentration and is unitless. It was measured using a pH meter.

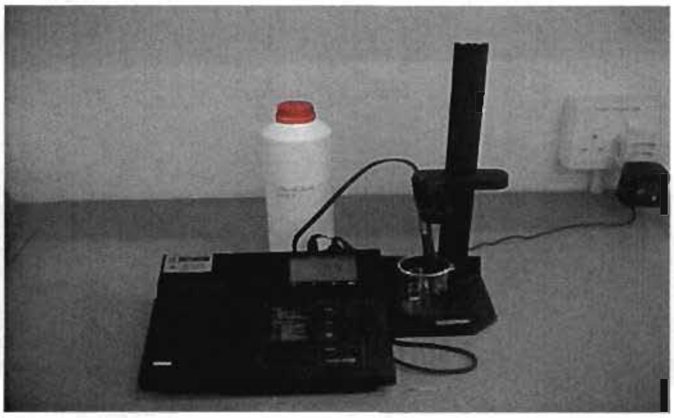

Figure 4.17: pH meter

4.2.4 Conductivity

Conductivity is a measure of the ability of an aqueous solution to carry an electric current. The conductivity of a sample solution gives an indication of the amount of dissolved ionic compounds and the total dissolved solids. Solutions of most organic compounds are relatively good conductors. Conductivity was measured with a conductivity meter. The unit of conductivity is mS/m (Clesceri, 1997).

4.2.5 BOD (biochemical oxygen demand)

The biochemical oxygen demand is a parameter used to indicate the oxygen requirements of a mixed population of micro-organisms, for the aerobic degradation of biodegradable fractions (Ramgunn, 2005). It is a measure of the readily biodegradable organic carbon. Low BOD values indicate little pollution, whereas a high BOD indicates increased activity of heterotrophic microorganisms and therefore, heavy pollution (Majosi, 2005).

Standard method used to determine BOD_5 was number ASTM 5210 B (Clesceri, 1997). The respirometric method provides a direct measurement of the oxygen consumed by micro-organisms from an air-enriched environment in a closed vessel under conditions of constant temperature and agitation (Clesceri, 1997). The BOD_5 is the amount of dissolved oxygen used up from the sample by micro-organisms as they break down organic material at 20 °C over a 5-day period.

Figure 4.18: Apparatus used to determine BOD_5.

4.2.6 COD (chemical oxygen demand)

COD is a measure of the oxygen required for the oxidation of the organic matter by micro-organisms, into carbon dioxide and water (Ramgunn, 2005). It is an indication of the biodegradable organic matter (Ramgunn, 2005).

The standard method used to determine COD was number ASTM 5220 C (Clesceri, 1997). The test measures the amount of oxygen needed to chemically oxidize the organics in a sample. A strong chemical oxidizing agent, potassium dichromate, was used to oxidize the organics in an acid solution. Because of its unique chemical properties, the dichromate ion ($CR_2O_7^{2-}$) is the specified oxidant. It is reduced to the chromic ion (Cr^{3+}) in these tests. In a COD analysis, hazardous wastes of mercury, hexavalent chromium, sulfuric acid, silver and acids are generated. There are two methods that are commonly used, the open reflux method and the closed reflux method. The open reflux method is suitable for a wide range of wastes where a large sample size is preferred. The closed reflux methods are more economical in the use of metallic salt reagents and generate smaller quantities of hazardous waste but require homogenization of samples containing suspended solids to obtain reproducible results (Clesceri, 1997).

Figure 4.19: Apparatus used to determine COD.

4.3 Characterisation of Eluates

For the preparation of the eluate, water was added to the solid sample in a solid:liquid ratio of 1:10 and the mixture was agitated for 24 hours. Tests carried out on the eluates include TS, VS, COD, Conductivity, pH, BOD_5, NH_3, NO_x.

4.4 Characterisation of Solid Matter

4.4.1 Moisture Content

Moisture content refers to the percentage of water contained in a solid sample. Standard method used to determine moisture content was ASTM 2540 B (Clesceri, 1997). Solid samples of known mass were dried in an oven for a 24 hour period at a temperature of 105 °C, after which the sample was reweighed. Moisture content was then calculated using the following equation:

$$W(\%) = \frac{(A-B)}{A}.100$$

where A = mass of wet sample and B = mass of dry sample.

4.4.2 Field Capacity

The field capacity of a sample is defined as the maximum amount of water that the sample can retain after excess water from saturated conditions had been drained by the force of gravity. The apparatus used were a beaker, funnel, wire mesh and cotton wool. A wad of cotton wool was placed into the neck of the funnel to trap any fine material washed out of the sample. The sample to be tested was placed on a fine wire mesh in the funnel. This prevented contact between sample and cotton wool which prevented the latter from drawing water out of the sample. The apparatus and sample were weighed. The stem of the funnel was blocked by means of a finger and water was added to the sample until it was completely covered. The funnel was placed in a beaker and allowed to stand until water ceased to drain out of the funnel. The apparatus and sample was reweighed. The difference between the masses is a measure of the amount of water that the sample retained at field capacity.

4.4.3 Respiration Index

This test provides a measure of the amount of oxygen consumed by biological activity in a sample per unit time at 20 °C and indirectly represents the biodegradability of the sample itself. The sample of known mass with water added to field capacity, is placed into 1500ml BOD vessel with sensor. The vessel is placed into an incubator for four to seven days. In the vessel, O_2 is consumed by the microorganisms during decomposition the waste sample. Carbon dioxide (CO_2) is produced as a by product and is removed by potassium hydroxide (KOH). The negative pressure, caused by the consumption of oxygen, is then recorded and used to calculate the respiration index (Leikam et. al., 1995).

4.5 Measuring Biogas Production with the Liquid Displacement Method

The biogas quality and production were measured using the liquid displacement method. Some of the results reported in this dissertation were derived from Tatho (2006) and Sebonego (2006). A known mass of sample was tested at field capacity. The experiment is normally carried out under anaerobic conditions. The sample was placed in a 1 litre fixed volume vessel which served as a reactor at a constant temperature of approximately 25 °C. The bottle was connected to a gas burette by means of a tube and the gas burette was connected to a reservoir. Gas burette and reservoir were filled with a solution of sodium chloride (NaCl), and sulphuric acid (H_2S0_4) which does not absorb the biogas components. All the connections were sealed thoroughly in order to avoid any leakage. When reading the volume of gas produced, the levels in the reservoir and gas collection vessel were equated to ensure atmospheric pressure within the gas collection vessel. The % volume of CH_4, CO_2 and O_2 were recorded with a gas analyzer.

4.6 Accuracy of Results

Accuracy of the results of laboratory experiments is of the utmost importance in enabling one to establish reliable conclusions. This section explains the steps that are taken for each experiment to ensure a high standard of accuracy.

4.6.1 COD

(i) Accuracy and consistency is checked by adding a set of standards and a set of blanks to each batch of samples to be tested. The standard that is used is Potassium Hydrogen Phthalate (KHP) and the solution has a theoretical COD of

500 μg/ml. The results of these standard samples must test to within 2 % of the expected value. A set of blanks is also included in each batch of tests. The blanks are merely a COD test on a sample of distilled water. The test gives an indication of any COD content of the water and the reagents.

(ii) Samples are tested in triplicate and the results must be within ± 5 % of the average.

(iii) The pipettes used to measure samples and reagents are tested and if necessary, calibrated on a regular basis.

4.6.2 Nitrogen

(i) Approximately every two to three weeks (after about 50 samples tested) or whenever a new solution of titrant (HCl) is used, the accuracy of the apparatus is tested against a known sample of Ferrous Ammonium Sulfate. The apparatus must be steamed out before samples are tested. This ensures that all traces of the previous sample are removed from the apparatus. Sometimes the sample starts to foam and is forced back into the apparatus. This can affect future results. When this happens, the apparatus should be steamed out again before the next experiment. Also, the amount of 200 – 250 ml of distillate that should be collected allows for all traces of the sample to be removed from the apparatus. Therefore, future samples are not affected.

(ii) The accuracy of the pipettes used (50 ml) are within ± 0.14 %. This is a very satisfactory level of accuracy.

4.6.3 TS and VS

(i) Errors could occur if the crucibles are contaminated. Thus, they are fired at 550 °C before use to gasify all contaminants. The crucibles are handled with tongs at all times and are cooled in a desiccator. This prevents contaminants and moisture from adhering to the crucibles.

(ii) The crucibles are all weighed using a balance that provides accuracy to within 4 decimal places or 0.1 mg.

(iii) When measuring out the required amount of sample, the sample must be stirred properly to prevent the sediment from settling.

4.6.4 BOD

(i) All heads that are used are electronic and are programmed and calibrated at the factory. They, therefore, provide a high level of accuracy.

(ii) Each sample is done in duplicate to ensure that the procedure, as well as the equipment, is at an acceptable level of accuracy.

(iii) Errors in measuring out the samples could also occur. There is inaccuracy of the measuring cylinder and, thus, it is important to use a measuring cylinder of the correct range. The accuracy of the person carrying out the experiment is also important. The person carrying out the experiment, therefore, must be able to carry out consistent measurements. The resultant errors are reduced by analyzing each sample in duplicate.

4.6.5 pH

(i) The pH meter is regularly calibrated with buffer solutions. It is set calibrate mode and two solutions with a known, standard pH are tested. The pH meter adjusts itself to these two known solutions.

(ii) The electrode is made of fine glass, which is actually a semi-permeable membrane. The pores of this glass periodically become clogged after regular use. The electrodes are therefore cleaned often with a descaling chemical, EDTA.

(iii) A high accuracy can therefore be achieved.

4.6.6 Conductivity

The conductivity meter, like the pH meter, is calibrated regularly using two solutions of known conductivity, one with a conductivity of 1413 μS/m and the other 12.88 mS/m. This ensures accurate results.

4.6.7 Gas analyzer

(i) The gas analyzer is regularly tested against a known, standard gas mixture to ensure accuracy of the instrument.

(ii) A filter in the instrument that filters out contaminants from the air before sampling is replaced on a regular basis.

4.6.8 Thermometer

(i) The thermometer and thermocouple are regularly tested by measuring the temperature of a bath of boiling water and comparing to the expected result.

(ii) The instrument is also regularly compared to a high quality mercury and glass thermometer.

(iii) Thus, measurements obtained with the electronic thermometer have an accuracy of ± 0.1 °C.

CHAPTER 5: RESULTS AND DISCUSSION

This chapter presents the characterization and comparison of the waste that was deposited in the cells and the waste samples that were collected from the cells after in-situ flushing and aeration. Eluate tests were conducted in a solid:liquid ratio of 1:10. All results reported in this chapter are averages and the detailed results and accuracy checks, wherever available, are found in appendix 1 and appendix 2.

5.1 Characterisation of Waste After Six Months Aeration in Cells

The characterization of the solid samples is tabulated in Table 5.13. Part of this research was presented in Sebonego (2006).

Table 5.13: Characterisation of Solid Matter

	Cell 1 8 wks fines	Cell 2 16 wks fines	Cell 3 8 wks global	Cell 4 untreated	Cell 5 16 wks global
Moisture Content (%)	25.55	22.71	39.14	38.85	32.33
Field Capacity	17.56	16.99	7.99	11.94	7.42

The results of the eluate tests of the samples from the cells are depicted in table 5.14.

Table 5.14: Eluate Tests

	Cell 1 8 wks fines	Cell 2 16 wks fines	Cell 3 8 wks global	Cell 4 untreated	Cell 5 16 wks global
TS (g/l)	4.09	10.83	2.98	5.43	3.79
VS (g/gDM)	3.29	7.08	1.89	2.16	2.29
COD (mg/l)	2018.03	2517.27	1320.73	2876.24	2368.74
Conductivity (mS/cm)	11.11	5.18	6.84	10.81	3.26
pH	7.53	7.57	7.54	7.38	7.62

5.2 Comparison of Characteristics

This section shows a comparison of the characteristics of the input material to the cells and material that was removed after six months of treatment in the cells.

5.2.1 Comparison of Tests on Solid Matter

Table 5.15: Comparison of Tests on Solid Matter

Characteristic	Cell 1 8 wks fines		Cell 2 16 wks fines		Cell 3 8 wks global		Cell 4 untreated		Cell 5 16 wks global	
	Bef	Aft	Bef	Aft	Bef	Aft	Bef	Aft	Bef	Aft
Moisture Cont. (%)	11.90	25.55	13.6	22.71	8.2	39.14	42.0	38.85	4.9	32.33

5.2.2 Comparison of Tests on Eluates

Table 5.16: Comparison of Tests on Eluates

Characteristic	Cell 1 8 wks fines		Cell 2 16 wks fines		Cell 3 8 wks global		Cell 4 untreated		Cell 5 16 wks global	
	Bef	Aft	Bef	Aft	Bef	Aft	Bef	Aft	Bef	Aft
TS (g/l)	2.08	4.09	3.76	10.83	8.14	2.98	2.53	5.43	0.57	3.79
VS (g/gDM)	0.40	3.29	1.33	7.08	0.66	1.89	1.32	2.16	0.33	2.29
COD (mg/l)	1489.33	2018.03	1874.33	2517.27	1750.00	1320.73	2269.33	2876.24	2269.00	2368.74
Conductivity (mS/cm)	1.54	11.11	1.41	5.18	1.16	6.84	1.91	10.81	1.37	3.26
pH	7.34	7.53	7.52	7.57	7.13	7.54	6.37	7.38	7.14	7.62

The TS values in the eluate show a marked increase in the leachate for all samples except the 8 weeks global sample. Since the cells are continuously being aerated, an increase is expected.

All samples show an increase in the VS values, which is expected due to the continued aerobic activity.

There is an increase in the pH level of approximately 1 in the untreated sample after 6 months of aerobic stabilization and only a slight increase in the other samples.

The conductivity of the eluate after 6 months of stabilization in the cells shows a marked increase.

For all samples, there is an increase in COD concentrations after 6 months. There should be a decrease in COD as the waste has been further stabilized. This, therefore, shows a limitation of the eluate test adopted which does not seem to be representative for the analysis of the organics. A more accurate and sophisticated method should be employed, such as RI_7, volatile fatty acids (VFA) or total organic carbon (TOC).

5.3 Initial Flushing Events: Leachate Analysis

As explained in Chapters 3 and 4, flushing events were conducted immediately after commissioning of the cells. The amount of irrigation was calculated so as to simulate 50 years of typical landfill processes in 1 year. Weather data for the Durban area, collected over the last 30 years, was used in the irrigation set up to provide 250 l of water per week. During irrigation, problems with the irrigation unit resulted in irregular irrigation intervals and high volumes of water (between 200 l and 670 l per week) being introduced to the cells. This resulted in the flushing events.

The flushing events are shown on the leachate analysis graphs. The key below each graph identifies the events.

Figure 5.20 is a graphical representation of the evolution of BOD in the leachate during the flushing.

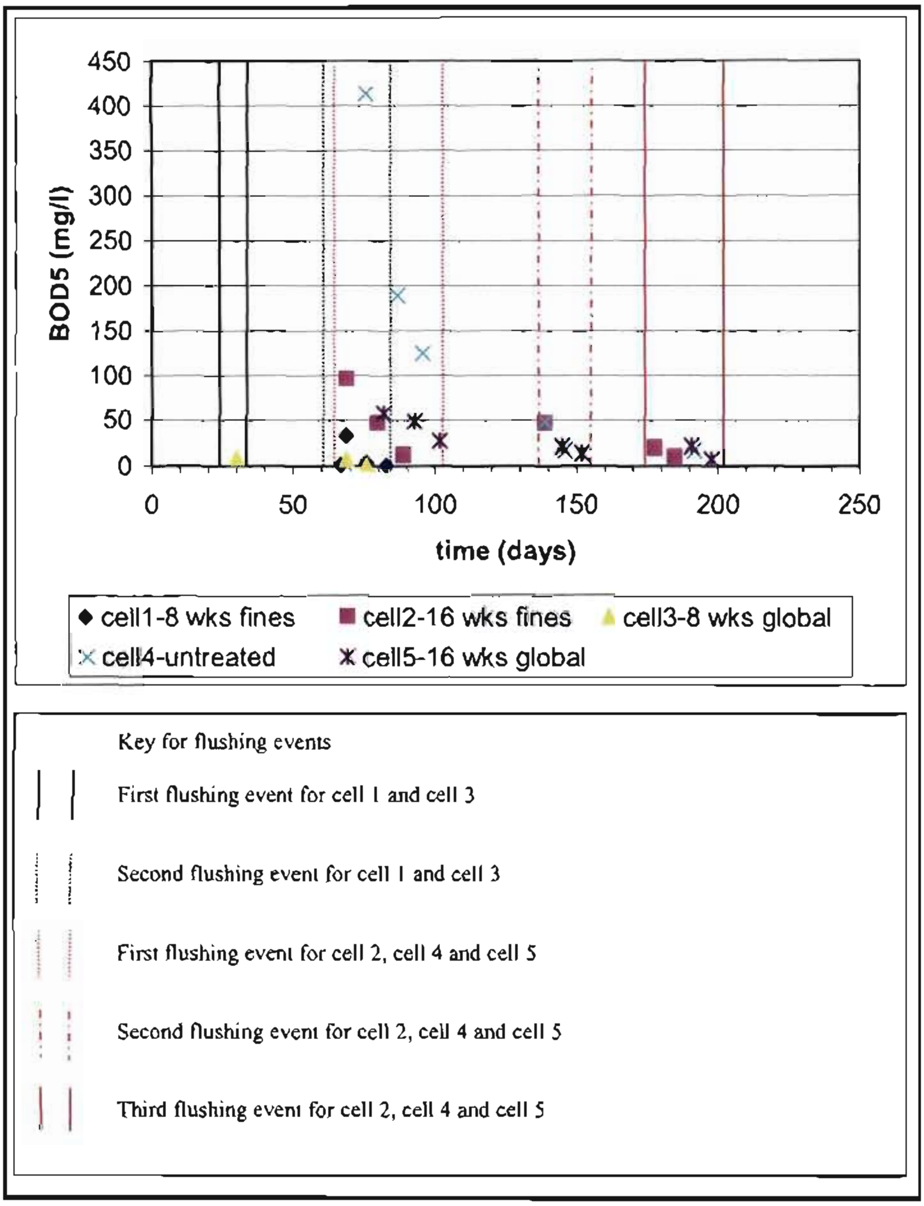

Figure 5.20: Evolution of BOD in Leachate.

BOD concentrations give an indication of the biodegradable fractions that are leached out of the cells during irrigation. Initially, the control cell (cell 4) with untreated waste has a much higher BOD concentration than the other cells. Both 8 weeks pretreated cells (cells 1 and 3) have a lower BOD concentration than the 16 weeks pretreated cells (cells 2 and 5). This should not be the case as the waste has been treated for a longer time and it should, theoretically, contain less biodegradable fractions. Also, the evident drop in BOD concentration in the control cell (cell 4) is due to the heavy flushing.

Figure 5.21 is a graphical representation of the evolution of NH_3 in leachate.

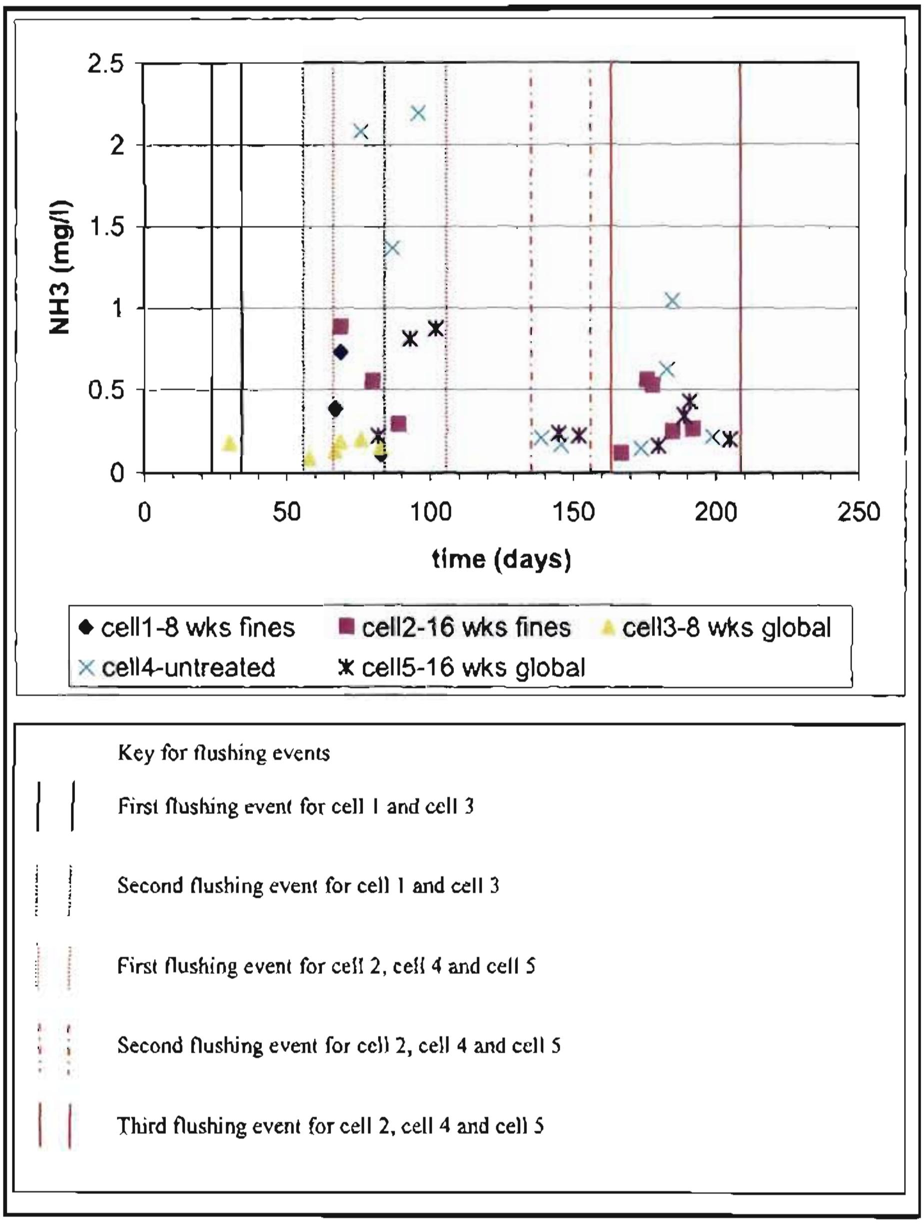

Figure 5.21: Evolution of NH_3 in Leachate.

The cell with the highest concentration of NH_3 is the control cell with untreated waste (cell 4). This is expected. It also shows that pretreated waste has lower concentrations of NH_3. However, the 16 week pretreated waste (cells 2 and 5) has a higher level of concentration of NH_3 than the 8 weeks pretreated waste (cells 1 and 3). This is not expected. The ammonical nitrogen decreases over time. This is expected as the cells did not reach anaerobic conditions. Further, the drastic decrease can be attributed to the flushing event which causes ammonical nitrogen to be washed out. During anaerobic conditions, ammonical nitrogen increases as ammonical nitrogen is not degraded.

Figure 5.22 is a graphical representation of the evolution of NO_x in leachate.

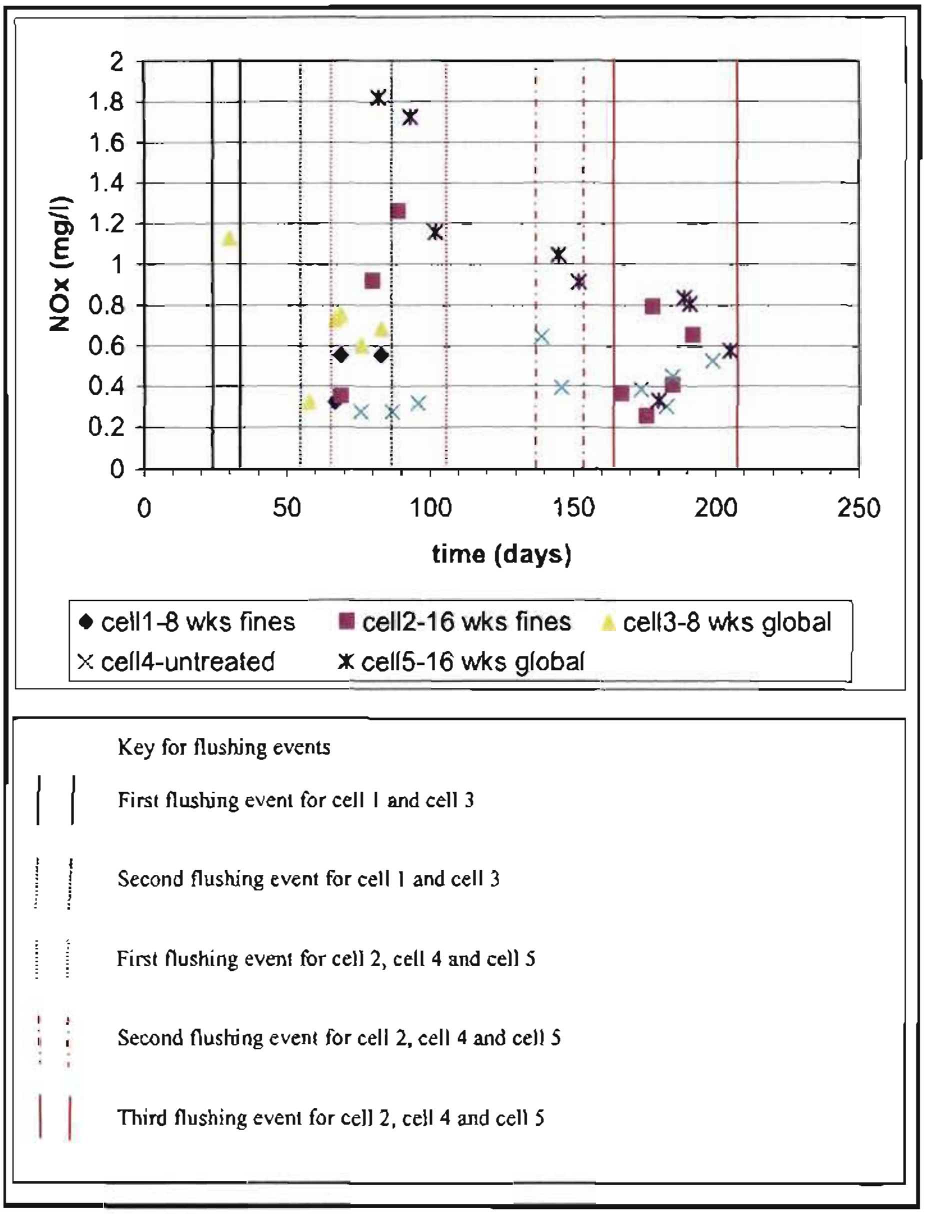

Figure 5.22: Evolution of NO_x in Leachate.

The concentration of Nitrates in the 16 week pretreated waste (cells 2 and 5) is much higher than the other cells. Higher levels of Nitrates are expected as the cells are still in semi-aerobic conditions. Ammonia and ammonia compounds are converted into nitrates or nitrites by bacterial action in a process called nitrification. As nitrification is aerobic, the presence of nitrates or nitrites is an indication of aerobic conditions (Ramgunn, 2005).

Figure 5.23 is a graphical representation of the evolution of COD in leachate.

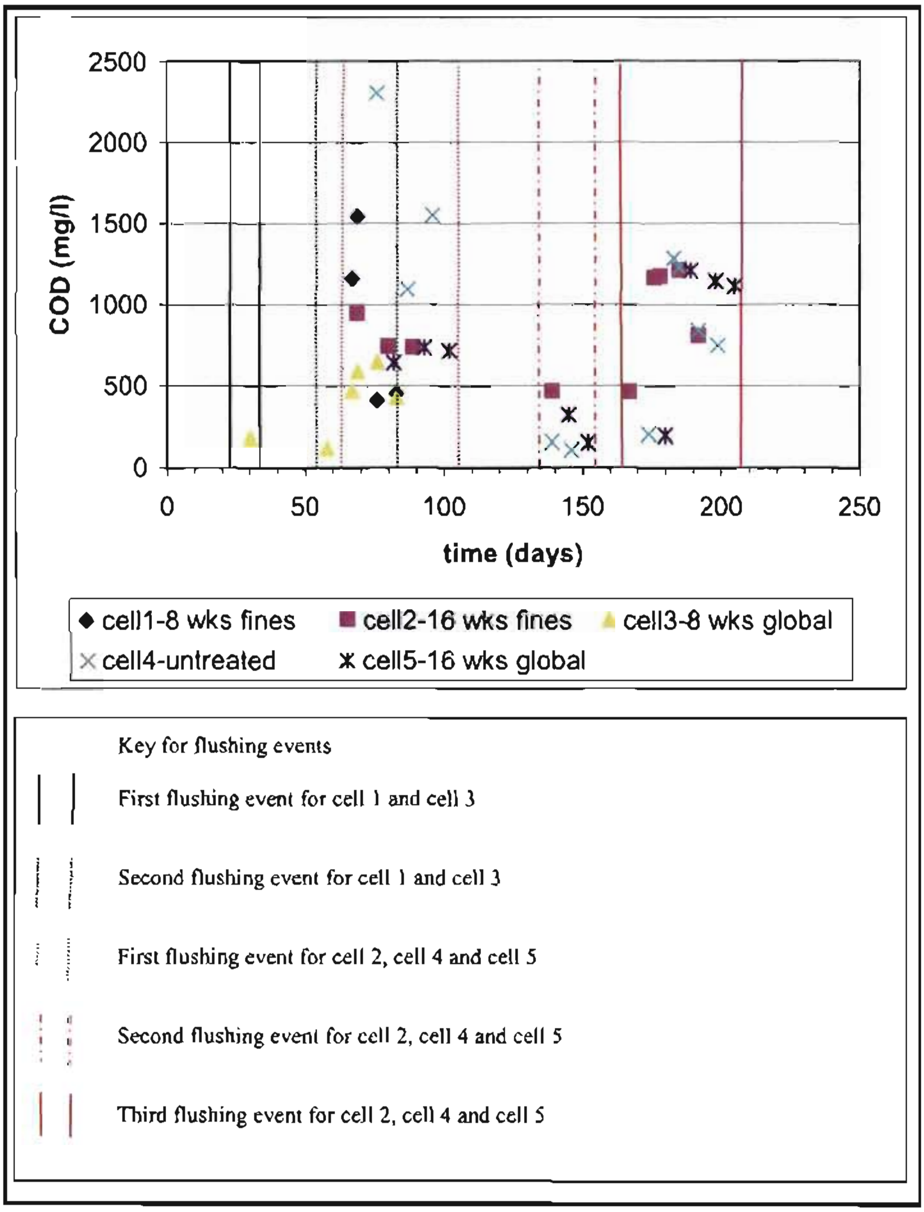

Figure 5.23: Evolution of COD in Leachate.

The initial concentration of COD in the control cell (cell 4) was high, which is expected. The drastic decrease in COD levels and then the subsequent increase after 150 days are attributed to the fact the cells were initially being flushed with a high volume of water, which caused the drastic decrease and then the lag between the next flushing event allowed COD levels to rise.

Figure 5.24 is a graphical representation of the evolution of TS in leachate.

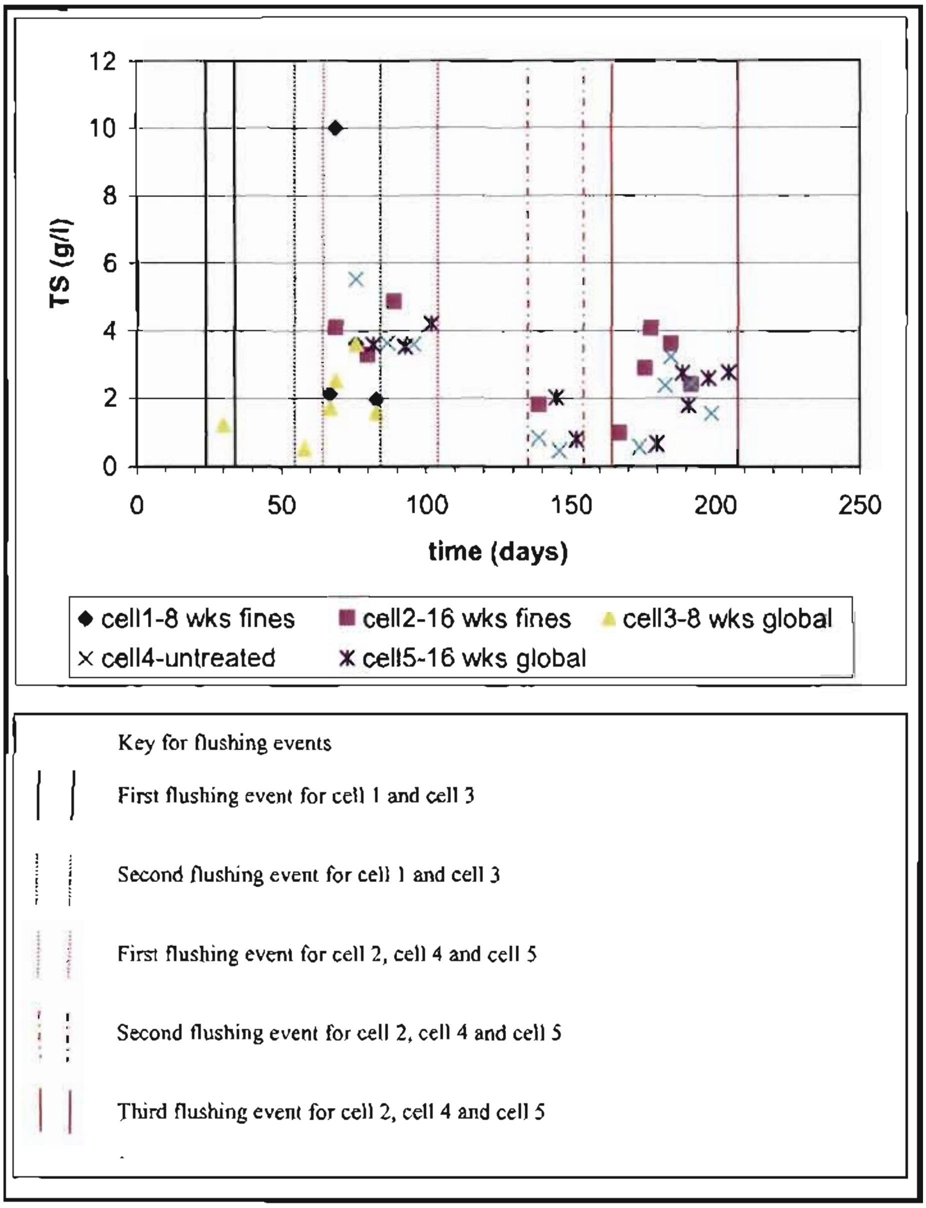

Figure 5.24: Evolution of TS in Leachate.

Figure 5.25 is a graphical representation of the evolution of VS in leachate.

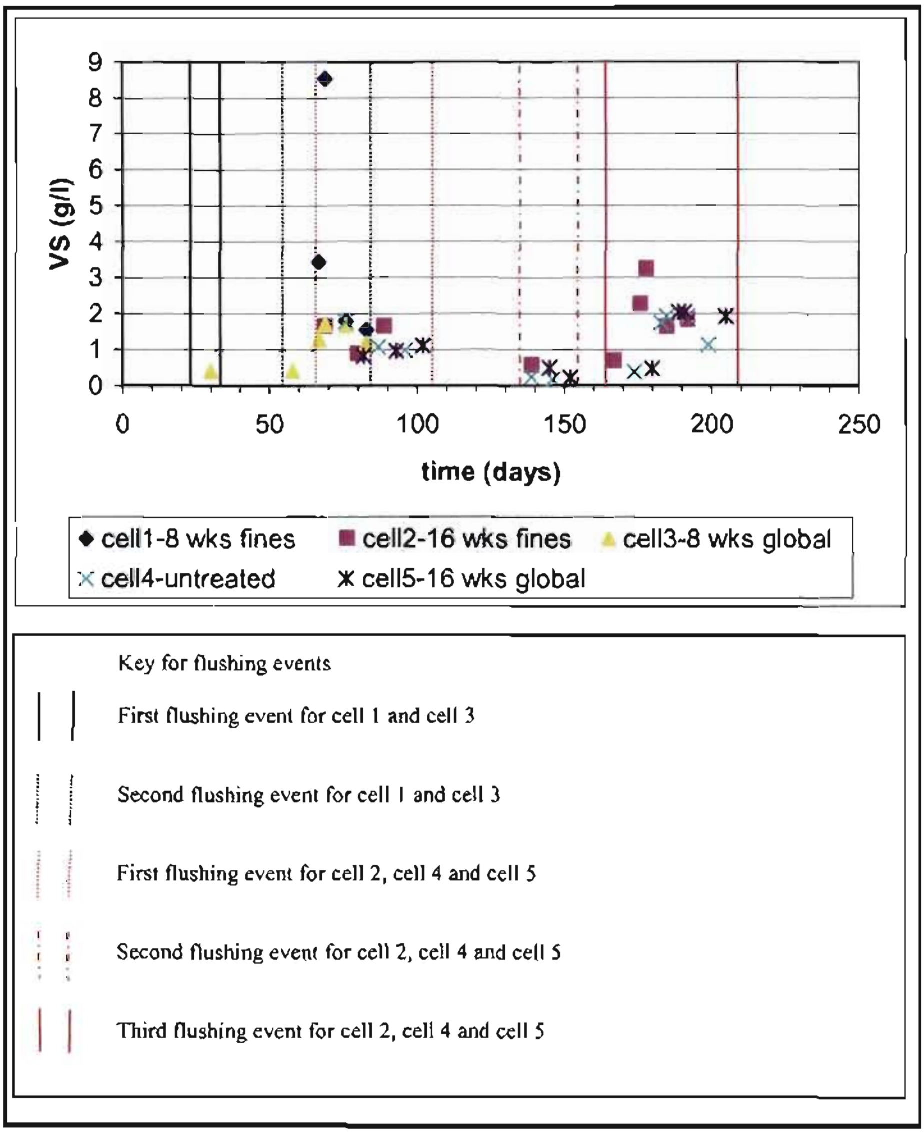

Figure 5.25: Evolution of VS in Leachate.

Much higher concentrations of TS and VS were observed at the beginning when the cells were being flushed. This is a result of the physical removal of the solids by the flushing.

Figure 5.26 is a graphical representation of the evolution of pH in leachate.

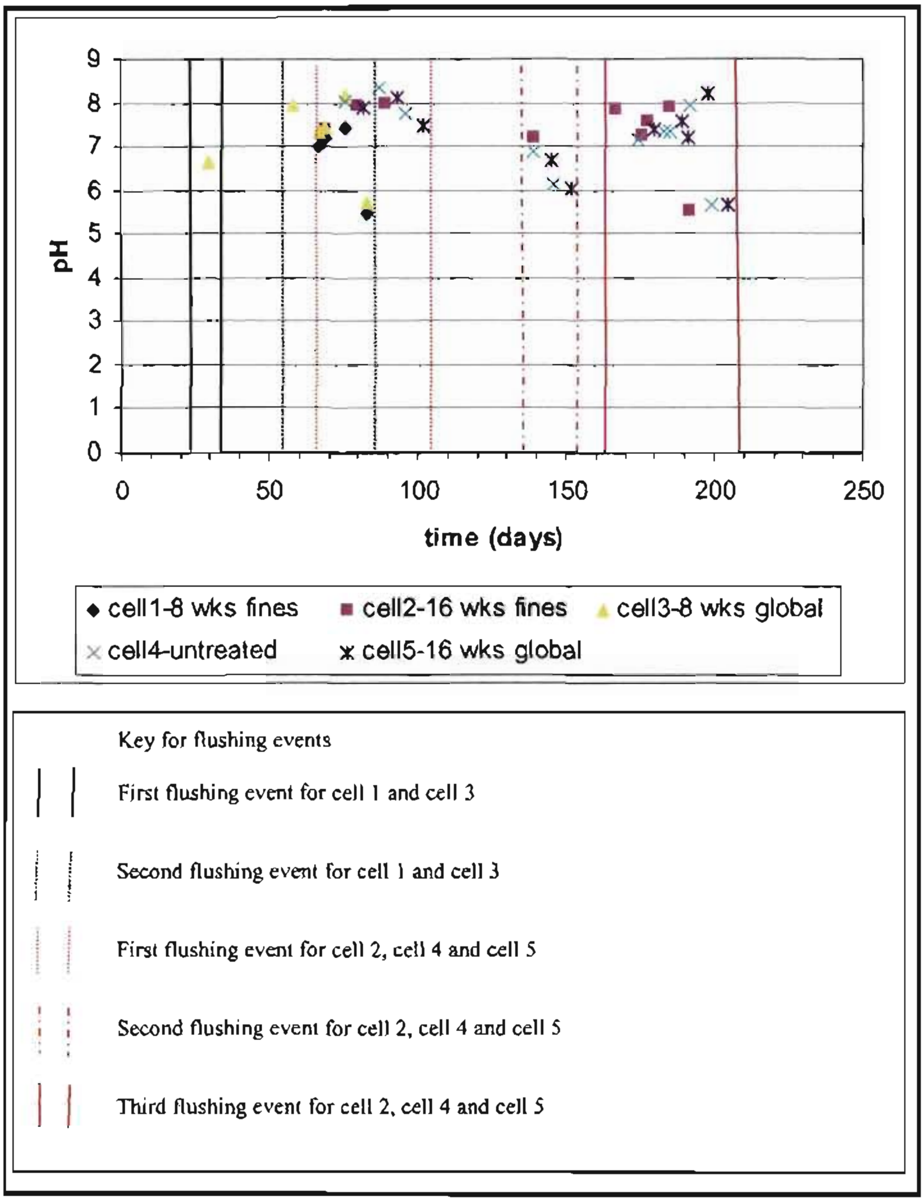

Figure 5.26: Evolution of pH in Leachate.

The pH generally decreases with time showing a slightly acidic characteristic. This could be due to the increased CO_2 production over time, as can be observed in the biogas production graphs in Section 5.4, which dissolves in the leachate and increases the acidity.

Figure 5.27 is a graphical representation of the evolution of conductivity in leachate.

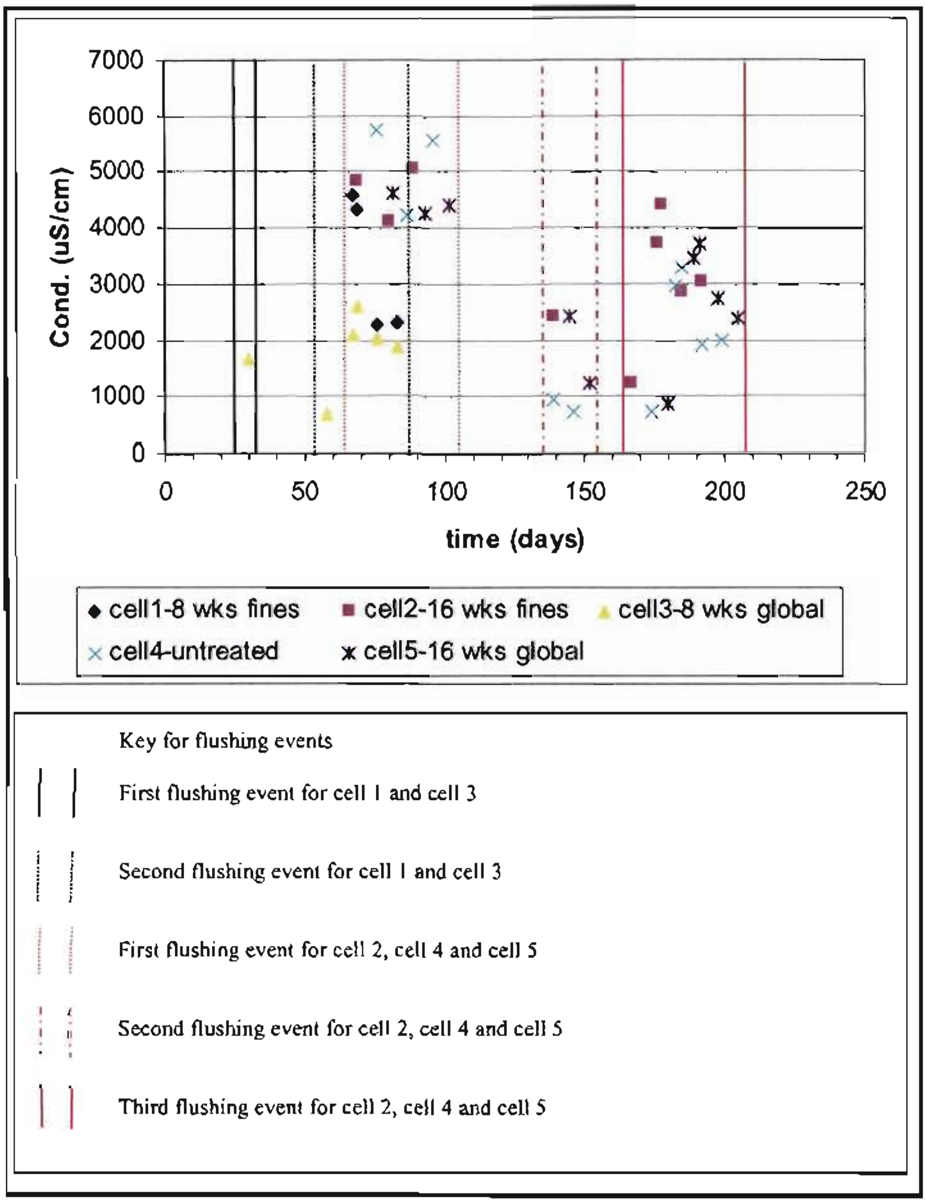

Figure 5.27: Evolution of Conductivity in Leachate.

The conductivity of the leachate decreases with time which is attributed to the initial consumption of oxygen and the decrease in the total solids being leached out.

Discussion

1. A single flushing event is not enough to reduce the contaminants concentration within the discharge limits.
2. Regardless of the length of the dry periods between flushing, the concentration of contaminants returns to high values, displaying a peak when flushing is resumed.

3. The comparison between untreated and treated waste shows that there is a definite benefit in the pretreatment.

5.4 Biogas Production

The production of biogas from the vents and probes are presented in this section graphically. Aeration was stopped after approximately six months in an attempt to provoke methanogenic conditions by putting an airtight rubber seal over the opening of the leachate pipe. This proved to be impossible, possibly due to the movement and tearing of the plastic lining covering the cells during routine maintenance, thereby allowing air to infiltrate the waste mass.

5.4.1 Diagrammatic representation of biogas production in Cell 1

Figure 5.28 represents the biogas production from the vents of cell 1.

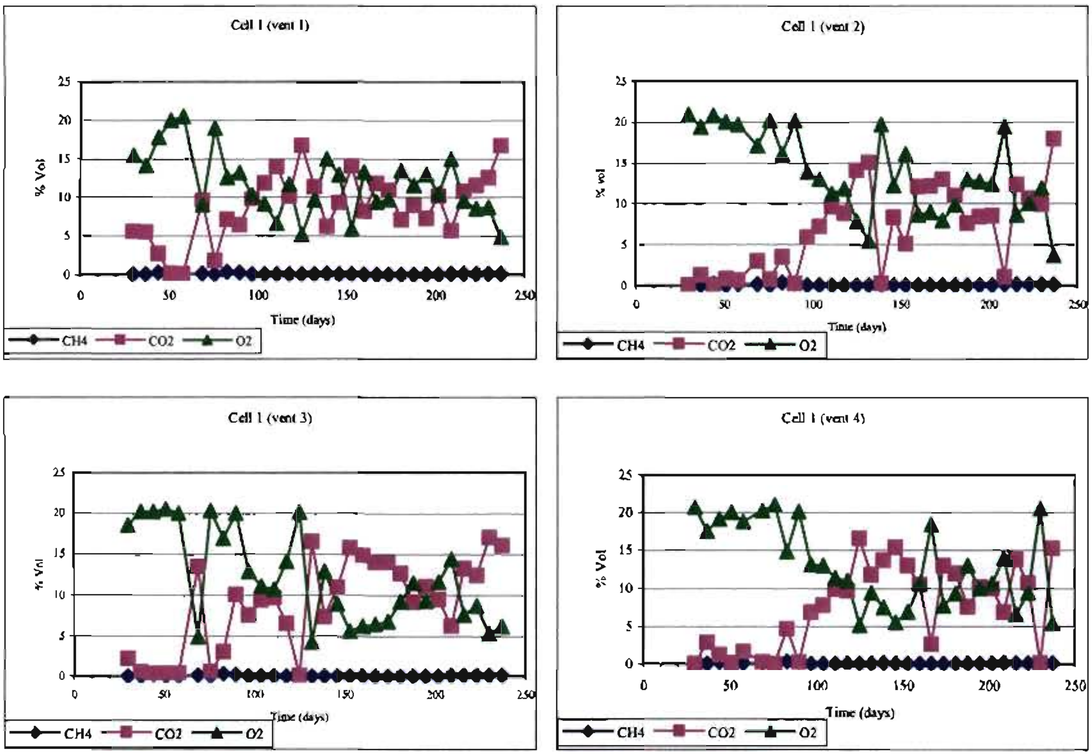

Figure 5.28: Evolution of CO_2, O_2 and CH_4 on Vents of Cell 1.

In the vents of cell 1, O_2 decreases and CO_2 increases as the initial oxygen trapped in the cells is consumed. They reach equilibrium at a concentration of about 10 % after approximately 100 to 120 days. Negligible amounts of methane were produced.

Figure 5.29 represents the biogas production from the probes of cell 1.

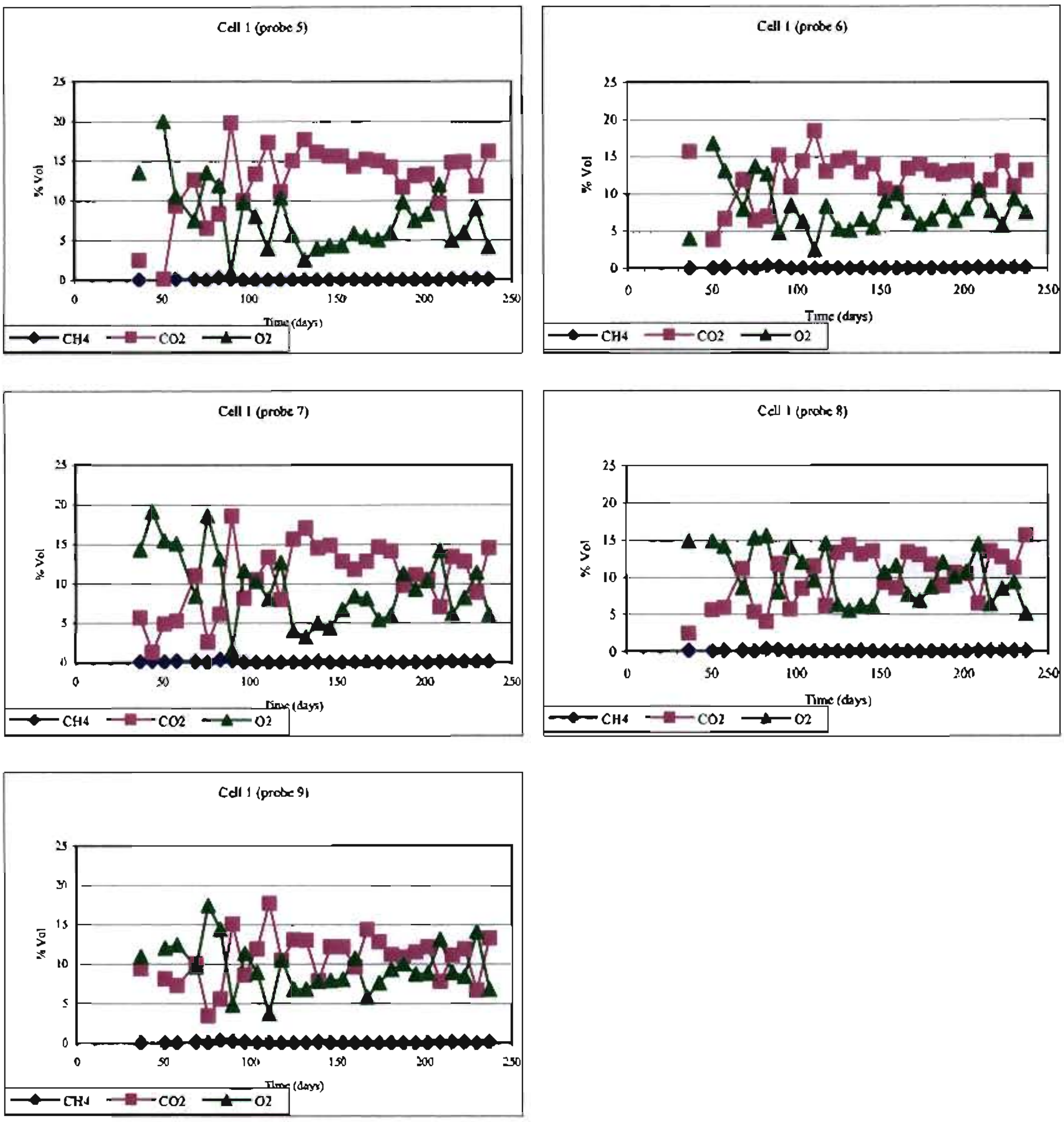

Figure 5.29: Evolution of CO_2, O_2 and CH_4 on Probes of Cell 1.

In the probes of cell 1, O_2 decreases and CO_2 increases as the initial oxygen trapped in the cells is consumed. They reach equilibrium at a concentration of about 10 % after approximately 50 to 70 days. Negligible amounts of methane were produced.

5.4.2 Diagrammatic representation of biogas production in Cell 2

Figure 5.30 represents the biogas production from the vents of cell 2.

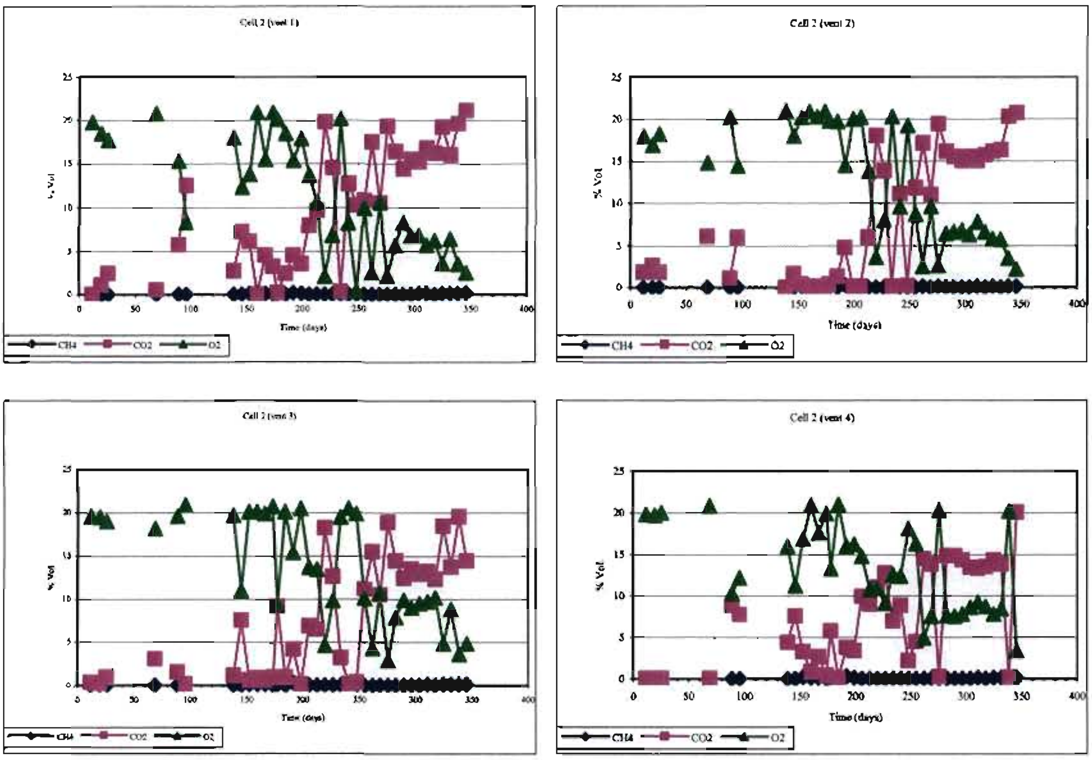

Figure 5.30: Evolution of CO_2, O_2 and CH_4 on Vents of Cell 2.

In the vents of cell 2, O_2 decreases and CO_2 increases as the initial oxygen trapped in the cells is consumed. They reach equilibrium at a concentration of about 10 % after approximately 210 days and after 260 days, CO_2 levels are greater than O_2 levels. Aeration was stopped at 223 days. Negligible amounts of methane were detected thereafter.

Figure 5.31 represents the biogas production from the probes of cell 2.

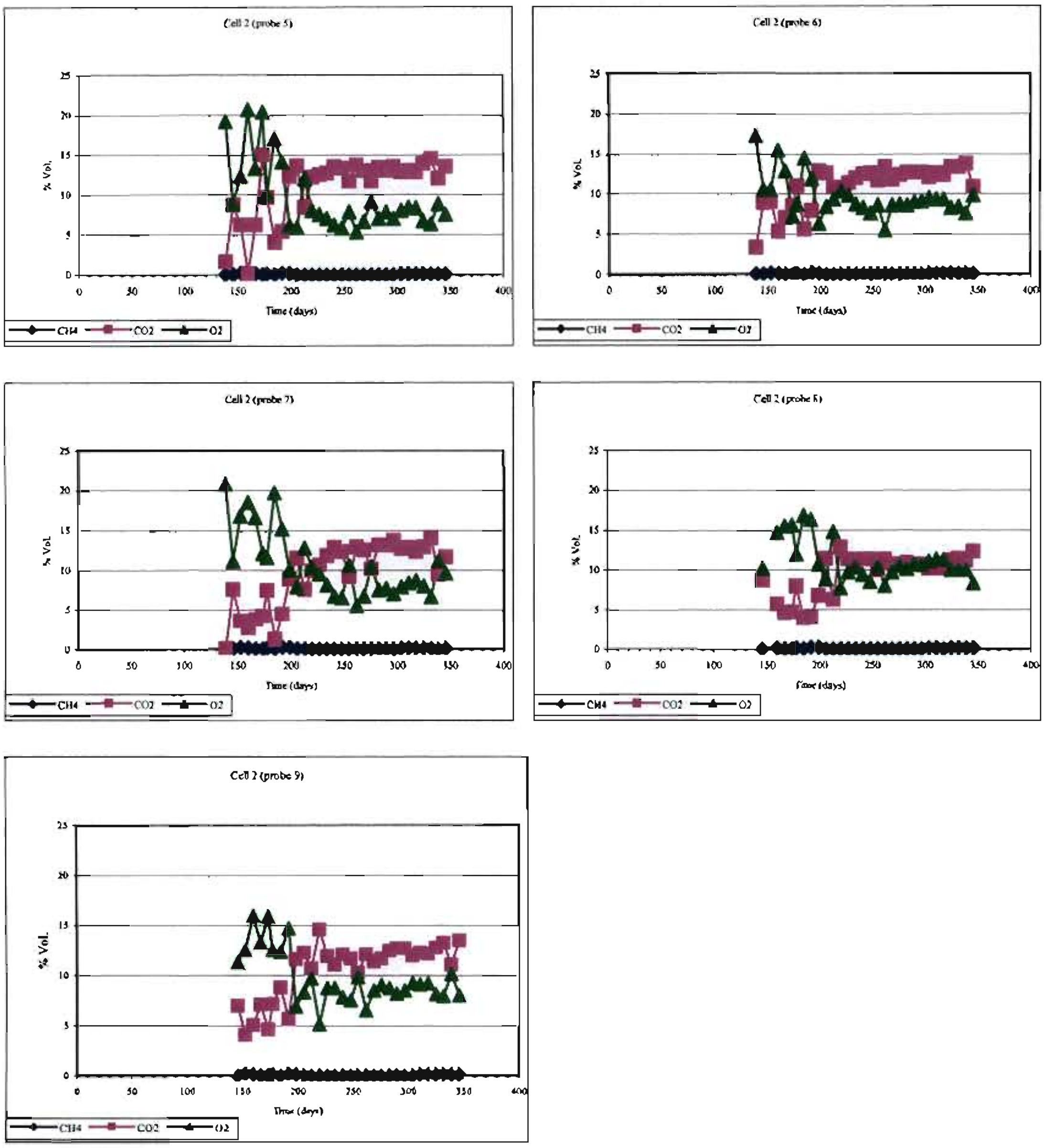

Figure 5.31: Evolution of CO_2, O_2 and CH_4 on Probes of Cell 2.

In the probes of cell 2, O_2 decreases and CO_2 increases as the initial oxygen trapped in the cells is consumed. They reach equilibrium at a concentration of about 10 % after approximately 200 days. Thereafter the CO_2 concentrations are slightly greater than the O_2 concentrations. Aeration was stopped at 223 days. Negligible amounts of methane were produced thereafter.

5.4.3 Diagrammatic representation of biogas production in Cell 3

Figure 5.32 represents the biogas production from the vents of cell 3.

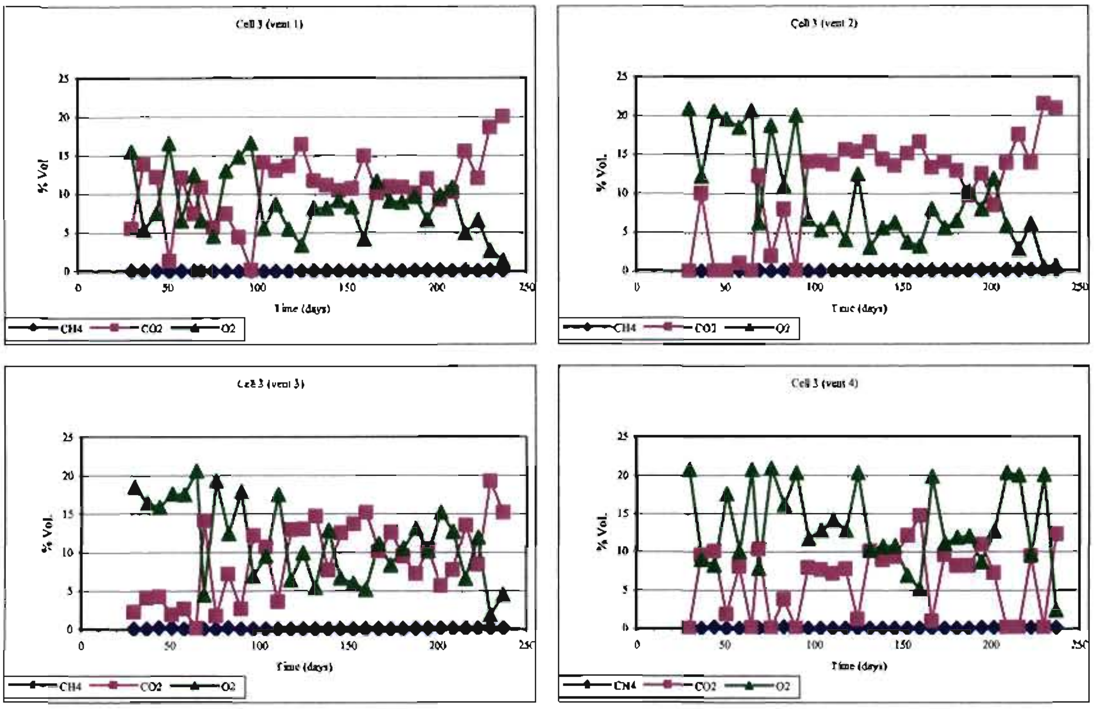

Figure 5.32: Evolution of CO_2, O_2 and CH_4 on Vents of Cell 3.

In the vents of cell 3, O_2 decreases and CO_2 increases as the initial oxygen trapped in the cells is consumed. They reach equilibrium at a concentration of about 10 % after approximately 70 days. After 100 days, CO_2 levels are greater than O_2 levels in vents 1 and 2. Aeration was stopped at 221 days after which CO_2 concentrations are greater than O_2 concentrations. Negligible amounts of methane were produced during entire sampling.

Figure 5.33 represents the biogas production from the probes of cell 3.

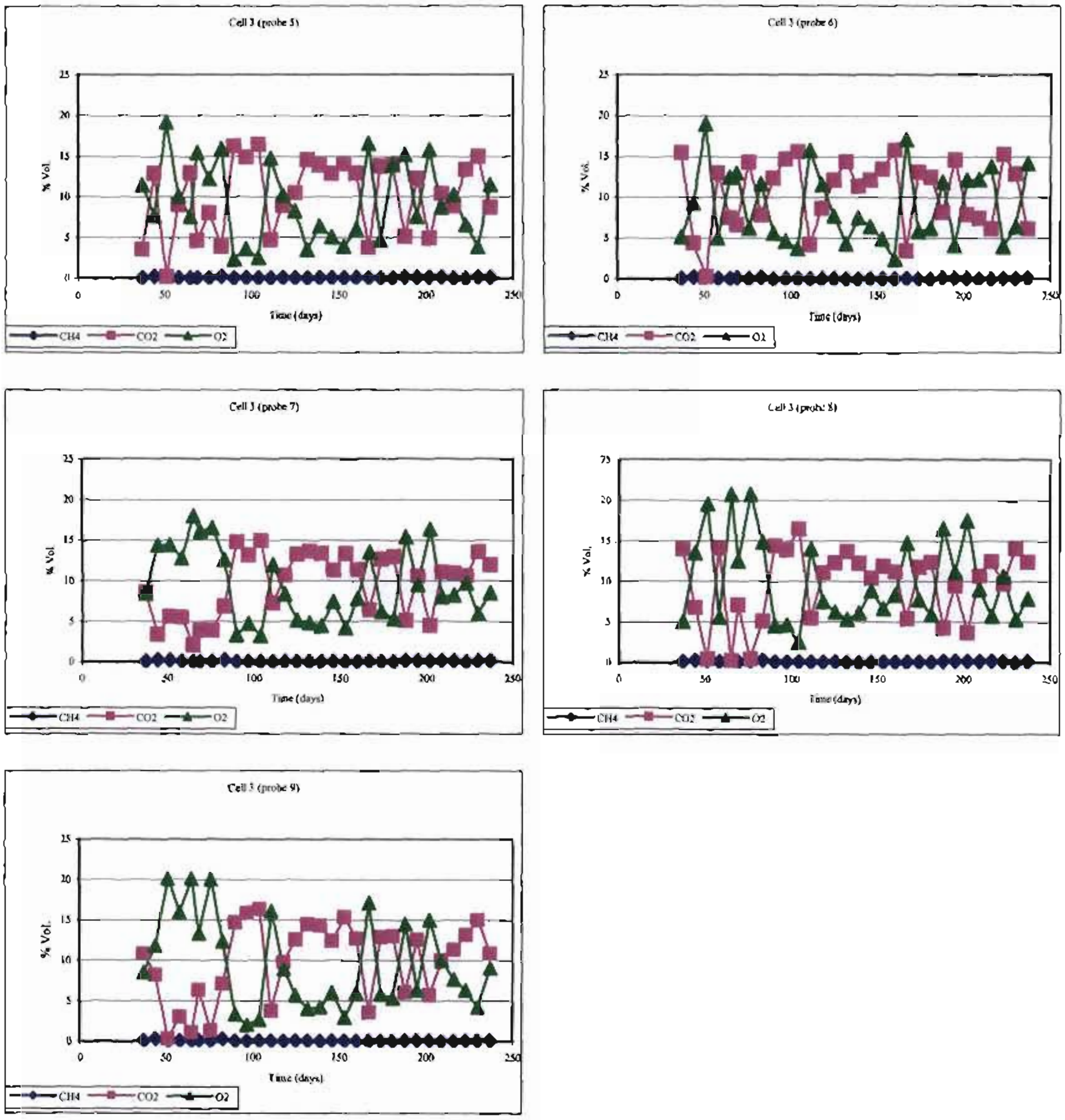

Figure 5.33: Evolution of CO_2, O_2 and CH_4 on Probes of Cell 3.

The concentrations of CO_2 and O_2 fluctuate greatly but it appears that CO_2 levels are generally greater after about 80 days. Aeration was stopped at 221. Negligible amounts of methane were produced thereafter.

5.4.4 Diagrammatic representation of biogas production in Cell 4

Figure 5.34 represents the biogas production from the vents of cell 4.

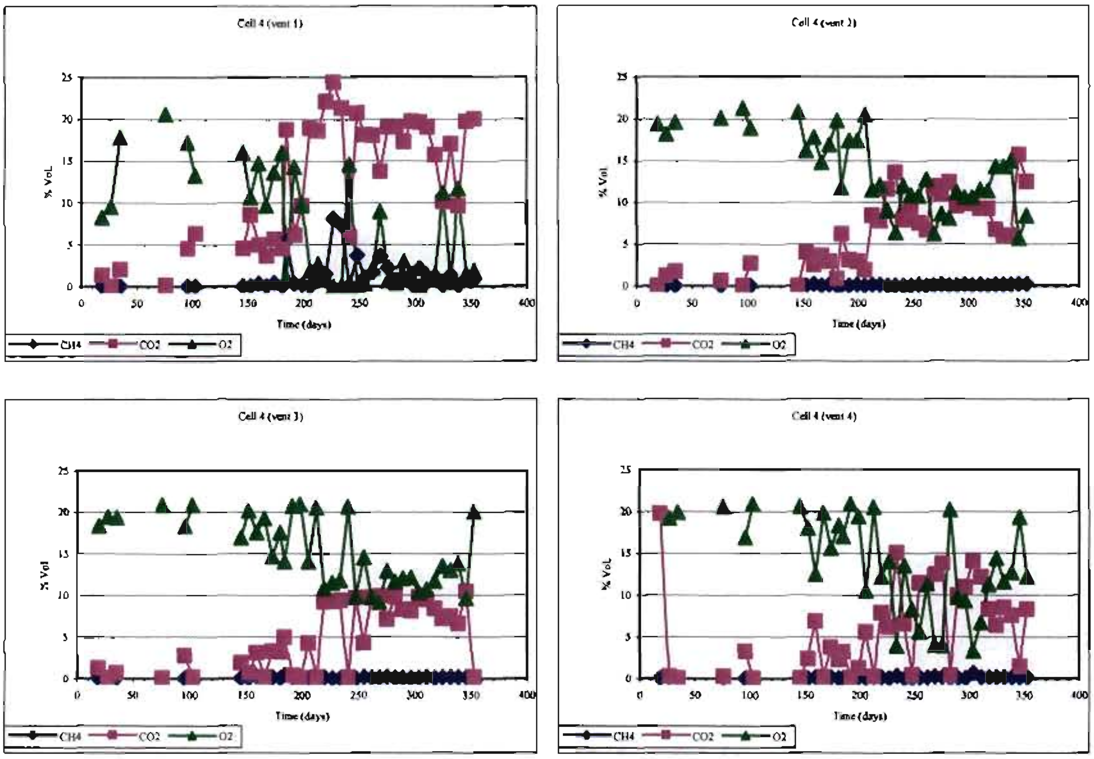

Figure 5.34: Evolution of CO_2, O_2 and CH_4 on Vents of Cell 4.

In the vents of cell 4, O_2 decreases and CO_2 increases as the initial oxygen trapped in the cells is consumed. They reach equilibrium at a concentration of about 10 % after approximately 200 to 220 days. Vent 1 displays a different behaviour to the others. Small amounts of methane are produced and equilibrium between O_2 and CO_2 is not achieved. This could be because the waste mass is very inhomogenous and large pieces of plastic material might be preventing oxygen from entering this section. Aeration was stopped at 206 days after which CO_2 concentrations are greater than O_2 concentrations. Negligible amounts of methane were produced thereafter.

Figure 5.35 represents the biogas production from the probes of cell 4.

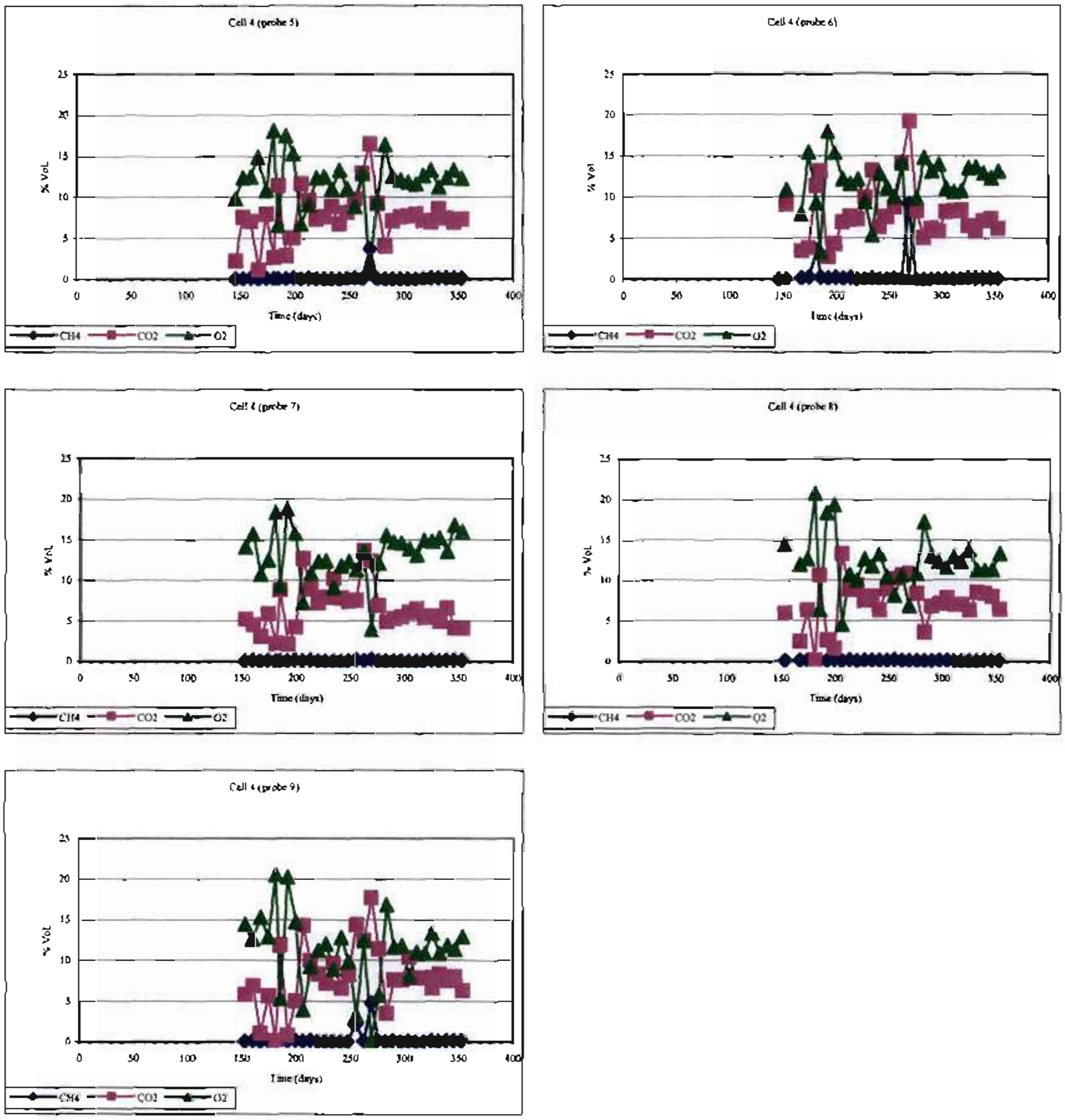

Figure 5.35: Evolution of CO_2, O_2 and CH_4 on Probes of Cell 4.

In the vents of cell 4, O_2 decreases and CO_2 increases as the initial oxygen trapped in the cells is consumed. They reach equilibrium at a concentration of about 10 % after approximately 180 days. After 270 days O_2 concentrations are greater. Aeration was stopped at 206. Negligible amounts of methane are produced thereafter.

5.4.5 Diagrammatic representation of biogas production in Cell 5

Figure 5.36 represents the biogas production from the vents of cell 5.

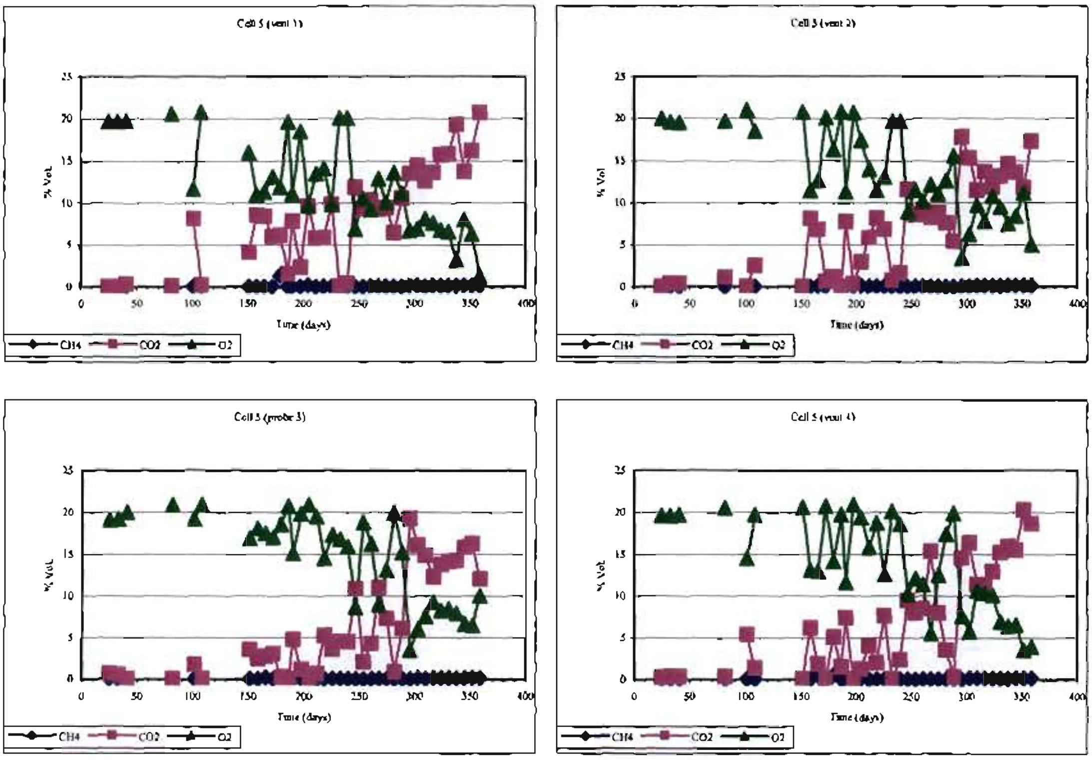

Figure 5.36: Evolution of CO_2, O_2 and CH_4 on Vents of Cell 5.

In the vents of cell 5, O_2 decreases and CO_2 increases as the initial oxygen trapped in the cells is consumed. They reach equilibrium at a concentration of about 10 % after approximately 240 days. After 280 days CO_2 levels become grater than O_2 levels. Aeration was stopped at 286 days after which CO_2 concentrations are greater than O_2 concentrations. Negligible amounts of methane were produced thereafter.

Figure 5.37 represents the biogas production from the probes of cell 5.

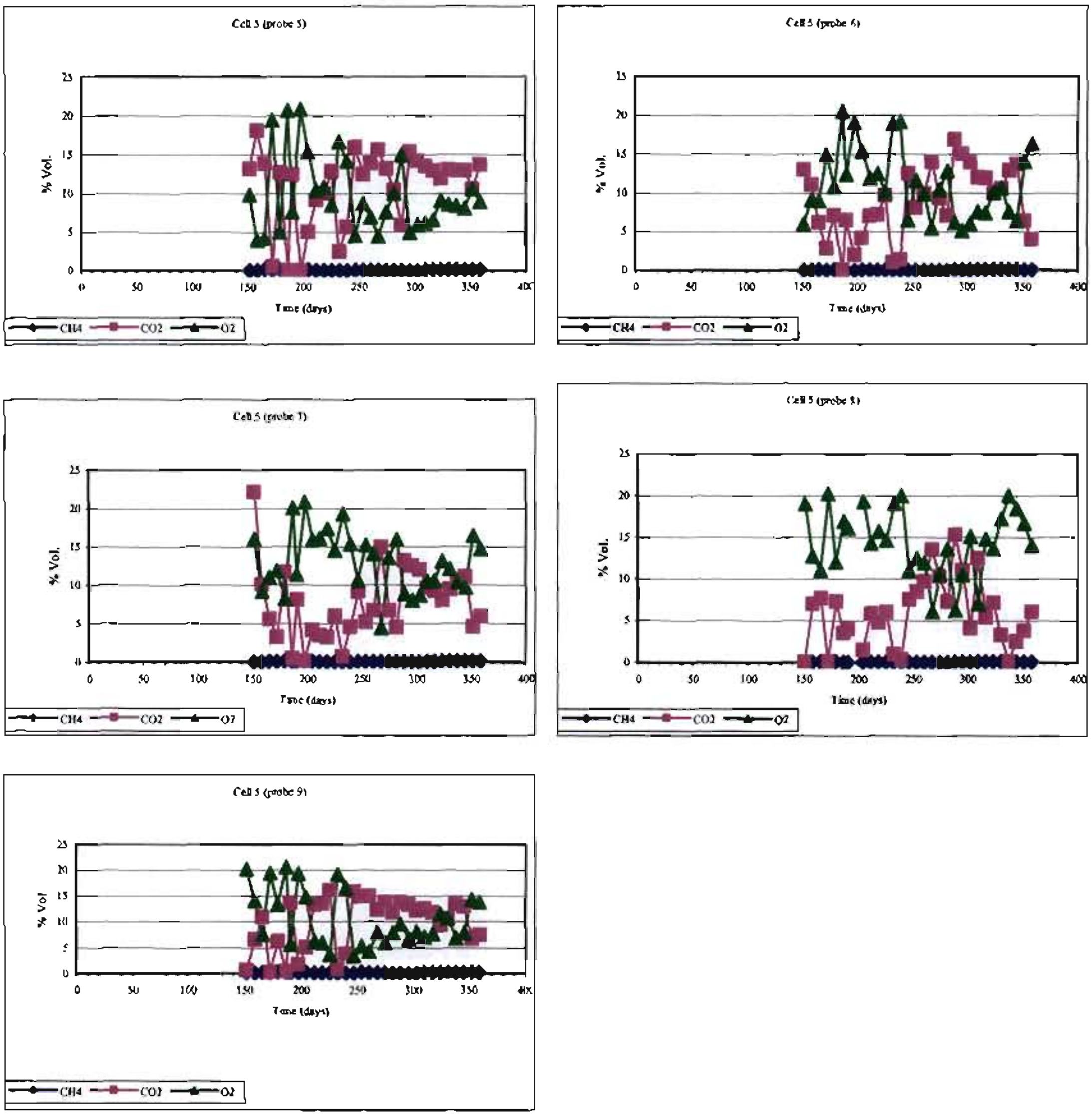

Figure 5.37: Evolution of CO_2, O_2 and CH_4 on Probes of Cell 5.

In the probes of cell 5, O_2 decreases and CO_2 increases as the initial oxygen trapped in the cells is consumed. They reach equilibrium at a concentration of about 10 % after approximately 240 to 260 days. After 280 days CO_2 levels become grater than O_2 levels . Aeration was stopped at 286 days after which CO_2 concentrations are greater than O_2 concentrations. Negligible amounts of methane were produced thereafter.

Discussion

1. Passive aeration was successful, allowing the cells to reach equilibrium between CO_2 and O_2 production in a timeframe of about 200 days.
2. The efficiency of the prolonged treatment in the shallow landfills, regardless of the nature and degree of the pretreatment of the input waste, is comparable.

5.5 Biogas Comparison with Liquid Displacement Experiment

This section presents the evolution of CO_2, O_2 and CH_4 of samples of MBP waste that were deposited into the cells which were analysed using anaerobic reactors in the form of the liquid displacement method. Part of this research was presented in Tatho (2006).

Figure 5.38 represents the evolution of CO_2, O_2 and CH_4 with 8 weeks fine sample (cell 1).

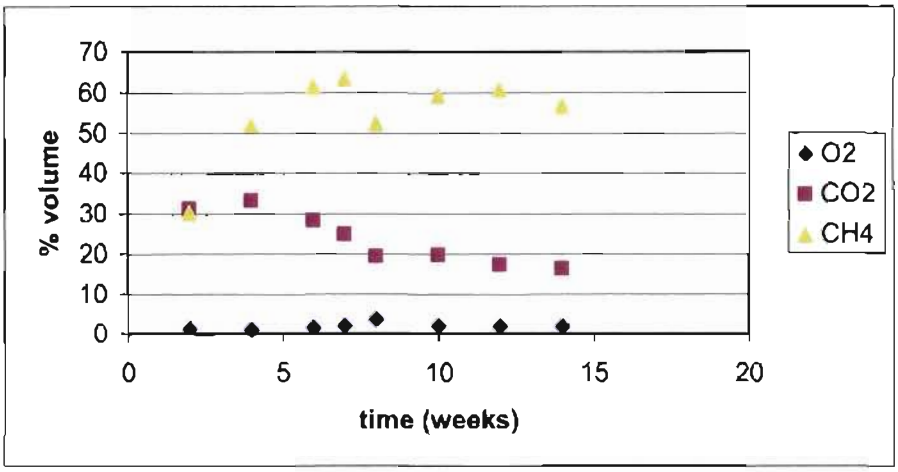

Figure 5.38: Evolution of CO_2, O_2 and CH_4 with 8 weeks fines (Cell 1).

Figure 5.39 represents the evolution of CO_2, O_2 and CH_4 with 16 weeks fine sample (cell 2).

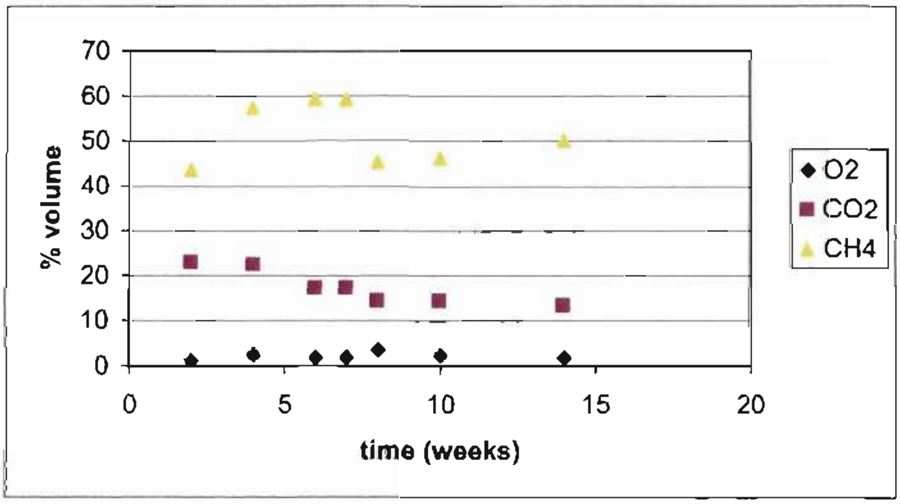

Figure 5.39: Evolution of CO_2, O_2 and CH_4 with 16 weeks fines (Cell 2).

Figure 5.40 represents the evolution of CO_2, O_2 and CH_4 with 8 weeks global sample (cell 3).

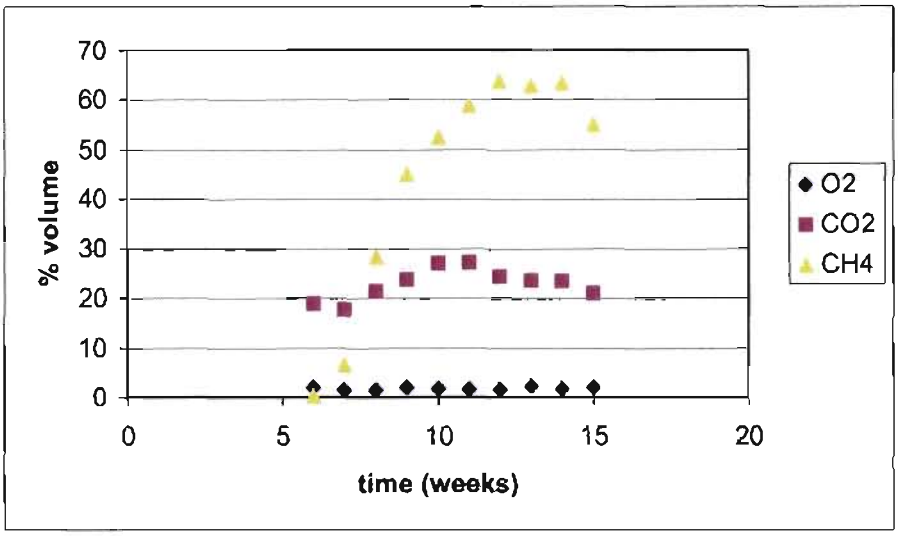

Figure 5.40: Evolution of CO_2, O_2 and CH_4 with 8 weeks global (Cell 3).

Figure 5.41 represents the evolution of CO_2, O_2 and CH_4 with 16 weeks global sample (cell 5).

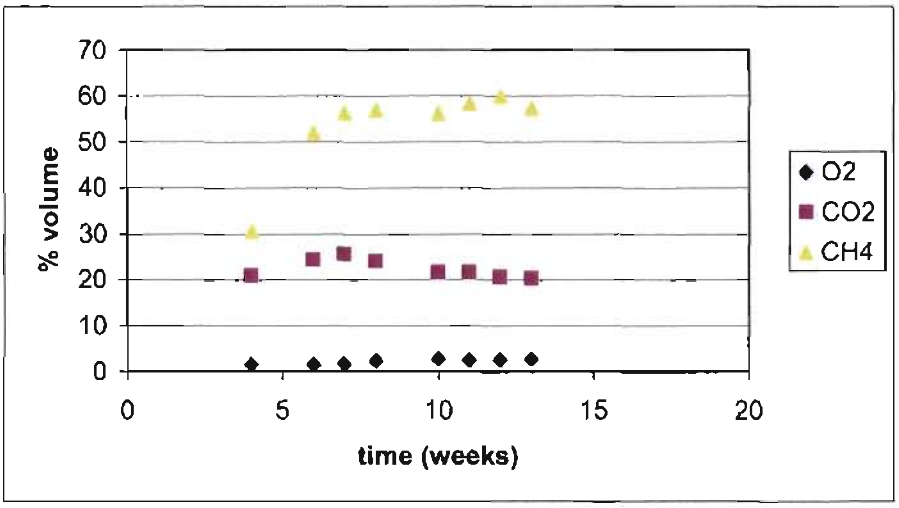

Figure 5.41: Evolution of CO_2, O_2 and CH_4 with 16 weeks global (Cell 5).

In the liquid displacement experiment, oxygen is consumed rapidly and the waste reaches methanogenic stage within about 5 weeks. The cells on the other hand, do not produce methane, which reaffirms the efficiency of passive aeration. The results of this experiment show that the percent volume of gas produced for 8 weeks and 16 weeks pretreated waste is very similar, suggesting that it is not necessary to prolong aerobic treatment longer than 8 weeks.

5.6 Biogas Production After 6 Months Aeration (Liquid Displacement Method)

Samples of waste that were treated to in-situ flushing and aeration in the cells for six months, were analysed in anaerobic reactors using the liquid displacement method. Part of this research was presented in Sebonego (2006). This section is a summary of the volumes and percent of CO_2, O_2 and CH_4 that were produced.

Figure 5.17 and figure 5.18 tabulate the gas composition and volume that were recorded at two different periods during the liquid displacement experiment.

Table 5.17: Biogas production: reading 1

	Parameter	Untreated		8 week global		8 week fines		16 week global		16 week fines	
Start Day		15-Aug-06		15-Aug-06		15-Aug-06		15-Aug-06		15-Aug-06	
Test Day		10-Oct-06		10-Oct-06		10-Oct-06		10-Oct-06		10-Oct-06	
		%	ml	%	ml	%	ml	%	ml	%	ml
	CH_4	0	0	0	0	0	0	2.43	0.073	20	18.2
	CO_2	0	0	0	0	0	0	3.25	0.096	10.8	9.72
	O_2	0	0	0	0	0	0	2.74	0.081	1.3	1.17

Table 5.18: Biogas production: reading 2

	Parameter	Untreated		8 week global		8 week fines		16 week global		16 week fines	
Start Day		15-Aug-06		15-Aug-06		15-Aug-06		15-Aug-06		15-Aug-06	
Test Day		26-Oct-06		26-Oct-06		26-Oct-06		26-Oct-06		26-Oct-06	
		%	ml	%	ml	%	ml	%	ml	%	ml
	CH_4	0	0	0	0	5.2	0.572	3.5	76	0	0
	CO_2	0	0	0	0	2.4	0.264	5.4	31.9	0	0
	O_2	0	0	0	0	13.4	1.474	7.8	3.2	0	0

This experiment shows that there is a drastic reduction in methane production after 6 months of prolonged treatment in the shallow landfills. There is very little gasifiable carbon left as most of it has been converted to CO_2 and O_2 during the previous stage.

CHAPTER 6: CONCLUSIONS

To assist in implementing the ever growing need to preserve our environment, the pretreatment of waste before disposal has been found to be an effective method of reducing the organic fractions of waste, thereby causing a reduction of the gaseous and leachate emissions produced by landfills. Despite this fact, South Africa does not employ this technique in its waste disposal facilities. This research is part of a broader project, in partnership with Durban Solid Waste, a waste management services provider within the eThekwini Municipality, to assess the effectiveness of pretreatment in a subtropical climate and to attempt to introduce this concept in the waste disposal strategies of South Africa.

The following observations and conclusions were drawn from this study:

1. After 6 months of prolonged treatment in passively aerated, shallow landfills, with multiple flushing events, almost all of the gasifiable carbon is converted to CO_2 and $O_{2,}$ which results in low levels of gaseous emissions.

2. The results of the monitoring of the passively aerated shallow landfills show that the quality of the gaseous emissions is similar, regardless of the degree of pretreatment. It can therefore be concluded that it is not necessary to pretreat waste in aerobic windrows if passively aerated, shallow landfills are to be employed.

3. The analysis of biogas production in anaerobic reactors suggests that the waste treated for 8 weeks and 16 weeks displayed a similar behaviour. After eight weeks, the waste is prone to desiccation which drastically slows down degradation, making an additional eight weeks of treatment unnecessary.

4. Aeration is not the only contributing factor to waste degradation. Multiple flushing events are also important as they contribute to a drastic reduction in the organic compounds.

5. A minimum of 200 days is required to reach equilibrium between O_2 consumption and CO_2 production but passive aeration is easy to eastablish and maintain with the use of a single, centralized large pipe (leachate collection) that served as an oversize gas vent.

In conclusion, the operation of passively aerated, shallow landfills is not trivial. In fact, even after aeration was suppressed, methanogenic conditions were unable to be established.

REFERENCES

Bockreis, A. & Steinberg, I., 2005. Influence of Mechanical-biological Waste Pre-treatment Methods on the Gas Formation in Landfills, Waste Management, 25 (2005), pp.. 337-343.

Christensen, T. H., Kjeldsen, P., 1995. Landfill Emissions and Environmental Impact: An Introduction, Proceedings Sardinia 95, Fifth International Landfill Symposium, S. Margherita di Pua, Cagliari, Italy, pp. 4-11.

Clesceri, L. S., Greenberg, A. E., Eaton, A. D.,1997. Standard Methods for the Examination of Water and Wastewater, 20th edition.

Cossu, R., Raga, R., Rossetti, D., 2003, The PAF Model: in Integrated Approach for Landfill Sustainability, Waste Management, 23 (2003) 37-44.

Department of Environmental Affairs and Tourism, Waste Management in South Africa, Memorandum to the Portfolio Committee: Private Members Legislation Proposals (National Assembly).

El-Fadel, M., Findikakis, A. N., Leckie, J. O., Environmental Impacts of Solid Waste Landfilling, Journal of Environmental Management, 1997, Vol. 50, pp. 1-25.

Farquhar, G. J. & Rovers, F. A., Gas Production During Refuse Decomposition, Water, Air and Soil Pollution, Vol. 2, 1973.

Griffith, M., 2005. An Investigation of Mechanical Biological Pretreatment of Waste and its Effect on landfill Emissions in South Africa, MSc Eng. Civil Engineering Dissertation, University of KwaZulu- Natal, Durban, South Africa (pending).

Griffith, M. & Trois, C., 2005, Applications of Waste Pre-treatment to Landfill Operations in South Africa, Landfill Symposium, S. Margherita di Pua, Cagliari, Italy, October, 2005.

Griffith, M. & Trois, C., 2006, Mechanical Biological Pretreatment of Waste and its Effect on Landfill Emissions, Wastecon 2006, Vol. 1, Somerset West, September 2006, Ham, R. K. & Bookter, T. J., 1997. Decomposition of Solid Waste in Test Lysimeters, Proceedings Sardinia 97, Sixth International Landfill Symposium, S. Margherita di Pua, Cagliari, Italy, pp. 13-36.

Ham, R. K., 1988. Landfill Gas, Leachate and Related Problems, Institute of Waste Management of Southern Africa Biennial Congress, Durban, South Africa

Heerenklage, J. & Stegman, R., 1995. Overview on mechanical-biological pretreatment of residual MSW, Proceedings Sardinia 95, Fifth International Landfill Symposium, S. Margherita di Pua, Cagliari, Italy, pp. 913-925

Horing, K., Kruempelbeck, I., Ehrig, H. J., 1999, Long-term Emission Behaviour of Mechanical-Biological Pre-treated Municipal Solid Waste, Proceedings Sardinia 1999, Seventh International Waste Management and Landfill Symposium, S. Margherita di Pua, Cagliari, Italy, October 1999.

Kiely, G., 1998. Environmental Engineering, McGraw-Hill Inc., Singapore

Krogman, U., 1995, Anaerobic digestion or composting for Waste Pretreatment, Proceedings Sardinia 95, Fifth International Landfill Symposium, S. Margherita di Pua, Cagliari, Italy, October 1995

Laine-Ylijoki, J., Syrja, J., Wahlstrom, M., 2004, Biodegradability Testing of the Municipal Solid Waste Reject, NT Technical Report 560, Nordic Innovation Centre, Norway

Leikam, K. & Stegman, R., 1995. Mechanical and Biological Treatment of residual waste before landfilling, Proceedings Sardinia 95, Fifth International Landfill Symposium, S. Margherita di Pua, Cagliari, Italy, pp. 947-955

Leikam, K. & Stegmann, R., Mechanical-Biological Pretreatment of residual Municipal Solid Waste and the Landfill Behaviour of Pretreated Waste, Proceedings, Sardinia 97, Sixth International Landfill Symposium, S. Margherita di Pua, Cagliari, Italy, October 1997

Lombard, R. & de Mattos, G. W. P, 1998, Landfill Gas Management, International Communications for Management: Waste Management and Recycling, Midrand, South Africa

Majozi, N. I., 2005. An Investigation into the Efficiency of the Cellular Method Applied to Mechanical Biological Pretreatment of Waste and Leachate Modelling in the South African Context. MSc Civil Engineering Dissertation, University of KwaZulu-Natal, Durban, South Africa

Mollekopf, N., Brummack, J., Paar, S., Vorster, K., 2002. Use of the Dome Aeration Technology for Biochemical Stabilisation of Waste Prior to Landfilling, Wastecon, Durban, October, 2002

Ramgunn, S., 2005. An Investigation into the Mechanical Biological Pretreatment of Waste in South Africa. Final Year Dissertation, BSc Civil Engineering, University of KwaZulu-Natal, Durban, South Africa

Robinson, H. D., Sustainable Waste Management: Is there a future for Landfills? Proceedings of WasteCon '96, Institute of Waste Management, Durban, 17-21 September 1996

Scheelhaase, T. & Bidlingmaier, W, 1997, Effects of Mechanical-Biological Pre-treatment on Residual Waste and Landfilling, Proceedings Sardinia 97, Sixth International Landfill Symposium, S. Margherita di Pua, Cagliari, Italy, October 1997

Sebonego, 2006, Kinetics of Biodegradation of Pretreated of Pretreated Waste: Biogas Production using the Oxitop Method, Final Year Dissertation, BSc Civil Engineering, University of KwaZulu-Natal, Durban, South Africa, 2006

Simelane, O. T., 2006, The study of Long-term Emissions from Mechanical-biological Pretreated Waste Using Test Cells, MSc. Eng. Civil Engineering Dissertation, University of KwaZulu-Natal, Durban, South Africa, 2006 (pending)

Soyez, K., Plickert, S., 2002. Mechanical-Biological Pre-Treatment of Waste – State of the Art and Potentials of Biotechnology, Acta Biotechnologica, Volume 22, Issue 3-4, pp. 271-284

Soyez, K., Plickert, S., (b) 2002, Mechanical-biological Treatment of Waste (MBP) – integration into Waste Management Concepts, Wastecon, Durban, October, 2002

Tatho, 2006, Kinetics of Biodegradation of Pretreated Waste: Biogas Production, Final Year Dissertation, BSc Civil Engineering, University of KwaZulu-Natal, Durban, South Africa, 2006

Teplitzky, A. L., 1995, Municipal Landfill Regulations in the U.S.: Overview and Update, Proceedings Sardinia 1995, Fifth International Landfill Symposium, S. Margherita di Pua, Cagliari, Italy, October 1995

Tchobanoglous, G., Theisen, H, Vigil, S., 1993. Integrated Solid Waste Managemet: Engineering Principles and Management Issues,McGraw-Hill Inc., Singapore.

Trois, C. and Polster, A., 2007, Effective Pine Bark Composting using the Dome Aeration Technology. Waste Management, Volume 27, Issue 1, 2007, Pages 96-105.

Visser, G. A. V., 2002, Waste Management in South Africa – the Role of Government, Wastecon, Durban, 2002, pp. 321-325.

Wiechers, H. N. S., Borland, J., Matsabu, M., 2002, Polokwane to Practice, Wastecon, Durban, 2002, pp. 336-343.

Appendix 1

Characterisation of Waste Into Cells

TS(g/l)

	cell 1	cell 2	cell 3	cell 4	cell 5
1	2.06	3.71	8.04	2.56	0.57
2	2.1	3.72	8.28	2.52	0.57
3	2.09	3.84	8.1	2.512	
Mean	2.083333	3.756667	8.14	2.530667	0.57
Std. Dev.	0.020817	0.072342	0.1249	0.025716	0
Max.	2.1	3.84	8.28	2.56	0.57
Min.	2.06	3.71	8.04	2.512	0.57
Median	2.09	3.72	8.1	2.52	0.57
Variance	0.000433	0.005233	0.0156	0.000661	0

VS(g/gDM)

	cell 1	cell 2	cell 3	cell 4	cell 5
1	0.429	1.296	1	1.288	0.325
2	0.376	1.332	0.492	1.324	0.327
3	0.4	1.376	0.48	1.352	
Mean	0.401667	1.334667	0.657333	1.321333	0.326
Std. Dev.	0.026539	0.040067	0.296819	0.032083	0.001414
Max.	0.429	1.376	1	1.352	0.327
Min.	0.376	1.296	0.48	1.288	0.325
Median	0.4	1.332	0.492	1.324	0.326
Variance	0.000704	0.001605	0.088101	0.001029	0.000002

COD
(mgO2/l)

	cell 1	cell 2	cell 3	cell 4	cell 5
1	1832	1882	1750	2263	2171
2	1147	1859	1750	2210	2367
3	1489	1882	1750	2335	
Mean	1489.333	1874.333	1750	2269.333	2269
Std. Dev.	342.5001	13.27906	0	62.74021	138.5929
Max.	1832	1882	1750	2335	2367
Min.	1147	1859	1750	2210	2171
Median	1489	1882	1750	2263	2269
Variance	117306.3	176.3333	0	3936.333	19208

pH

	cell 1	cell2	cell 3	cell 4	cell 5
1	7.34	7.52	7.13	6.37	7.14

conductivity

	cell 1	cell 2	cell 3	cell 4	cell 5
1	1.54	1.41	1.16	1.91	1.37

Moisture Content

	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5
MC (%)	11.9	13.6	28.2	42	4.9

RI4 (20mg)

	cell 1	cell 2	cell 3	cell 4	cell 5
1	1.53	4.06	4.89	1.8	3.15
2	1.11	3.56	4.23	2.09	4.97
3	1.39	2.73	4.31	2.31	2.49
Mean	1.343333	3.45	4.476667	2.066667	3.536667
Std. Dev.	0.213854	0.671789	0.360185	0.255799	1.286934
Max.	1.53	4.06	4.89	2.31	4.97
Min.	1.11	2.73	4.23	1.8	2.49
Median	1.39	3.56	4.31	2.09	3.15
Variance	0.045733	0.4513	0.129733	0.065433	1.649733

Appendix 2

Characterisation of Waste After 6 Months Aeration in Cells

TS(g/l)

	cell 1	cell 2	cell 3	cell 4	cell 5
1	4.124	12.084	3.036	5.344	3.712
2	4.072	8.396	2.936	5.184	3.844
3	4.06	11.996	2.96	5.752	3.828
Mean	4.085333	10.82533	2.977333	5.426667	3.794667
Std. Dev.	0.03402	2.104324	0.052205	0.292885	0.072037
Max.	4.124	12.084	3.036	5.752	3.844
Min.	4.06	8.396	2.936	5.184	3.712
Median	4.072	11.996	2.96	5.344	3.828
Variance	0.001157	4.428181	0.002725	0.085781	0.005189

VS(g/l)

	cell 1	cell 2	cell 3	cell 4	cell 5
1	2.928	7.932	1.924	2.144	2.28
2	2.88	5.436	1.884	2.152	2.284
3	2.87	7.872	1.872	2.184	2.308
Mean	2.892667	7.08	1.893333	2.16	2.290667
Std. Dev.	0.031005	1.424062	0.027227	0.021166	0.015144
Max.	2.928	7.932	1.924	2.184	2.308
Min.	2.87	5.436	1.872	2.144	2.28
Median	2.88	7.872	1.884	2.152	2.284
Variance	0.000961	2.027952	0.000741	0.000448	0.000229

COD (mgO2/l)

	cell 1	cell 2	cell 3	cell 4	cell 5
1	0.156	0.2	0.112	0.219	0.197
2	0.155	0.209	0.105	0.275	0.183
3	0.177	0.202	0.104	0.204	0.195
Mean	0.162667	0.203667	0.107	0.232667	0.191667
Std. Dev.	0.012423	0.004726	0.004359	0.037421	0.007572
Max.	0.177	0.209	0.112	0.275	0.197
Min.	0.155	0.2	0.104	0.204	0.183
Median	0.156	0.202	0.105	0.219	0.195
Variance	0.000154	2.23E-05	0.000019	0.0014	5.73E-05
Result	2018.03	2517.27	1320.73	2876.24	2368.74

pH

	cell 1	cell2	cell 3	cell 4	cell 5
1	7.53	7.57	7.54	7.38	7.62

conductivity

	cell 1	cell 2	cell 3	cell 4	cell 5
1	11.11	5.18	6.84	10.81	3.26

Moisture content on solid samples

	cell 1	cell 2	cell 3	cell 4	cell 5
1	17.17	19.32	37.5	43.37	33.77
2	24.05	26.1	40.77	34.32	30.88
3	35.42				
Mean	25.54667	22.71	39.135	38.845	32.325
Std. Dev.	9.216596	4.794184	2.312239	6.399316	2.043539
Max.	35.42	26.1	40.77	43.37	33.77
Min.	17.17	19.32	37.5	34.32	30.88
Median	24.05	22.71	39.135	38.845	32.325
Variance	84.94563	22.9842	5.34645	40.95125	4.17605

Field capacity

	cell 1	cell 2	cell 3	cell 4	cell 5
1	20.179	26.19	3.15	8.01	9.89
2	14.944	7.78	12.82	15.86	4.94
3					
Mean	17.5615	16.985	7.985	11.935	7.415
Std. Dev.	3.701704	13.01784	6.837723	5.550788	3.500179
Max.	20.179	26.19	12.82	15.86	9.89
Min.	14.944	7.78	3.15	8.01	4.94
Median	17.5615	16.985	7.985	11.935	7.415
Variance	13.70261	169.4641	46.75445	30.81125	12.25125

Appendix 3 – Biogas Data

1.1 Biogas Data for Cell 1 (Inception of Cell 1: 18 December 2006)

Date	Cell No.	Gas Probe I.D	Gas Concentration % Vol			Pressure (mBar)	Temp. ^{0}C	Leachate (Litres)	Runoff (Litres)
			CH_4	CO_2	O_2				
17-Jan-06	1	1	0	5.5	15.5	1004	32.6	260	100
		2	0	0	20.9	1004	30.5		
		3	0	2.2	18.5	1004	36.5		
		4	0	0	20.7	1004	31		
		5				1004			
		6				1004			
		7				1004			
		8				1004			
		9				1004			
24-Jan-06	1	1	0	5.4	14.1	1009	35.2	0	200
		2	0	1.2	19.4	1009	34.6		
		3	0	0.6	20.2	1009	38.9		
		4	0	2.8	17.5	1009	36.2		
		5	0	2.5	13.5	1009	49.2		
		6	0	15.7	4	1009	41.6		
		7	0	5.6	14.3	1009	43.3		
		8	0	2.3	14.9	1009	48.7		
		9	0	9.3	10.9	1009	43.6		
31-Jan-06	1	1	0.2	2.6	17.8		35.6	0	0
		2	0.2	0	20.8		33		
		3	0.2	0.4	20.2		37.9		
		4	0.2	1.2	19.1		35.1		
		5					46.5		
		6					39.2		
		7	0.1	1.2	19.1		41.1		
		8					43.5		
		9					40.3		
7-Feb-06	1	1	0	0.1	20	1006	31.2	0	0
		2	0	0.8	20	1006	34.3		
		3	0	0.4	20.5	1006	38.3		
		4	0	0.1	20	1006			
		5	0	0.1	20	1006	45.3		
		6	0	3.8	16.8	1006	38.2		
		7	0	4.8	15.5	1006	41.2		
		8	0	5.5	14.9	1006	43.6		
		9	0	8	12	1006	40.4		

14-Feb-06	1	1	0	0	20.5	1004	33.7	0	
		2	0.1	0.6	19.7	1004	30.7		
		3	0	0.4	20	1004	34.7		
		4	0.1	1.6	18.8	1004	33.3		
		5	0.1	9.3	10.5	1004	41.3		
		6	0.1	6.6	13.1	1004	34.6		
		7	0.1	5.2	15.1	1004	37.2		
		8	0.1	5.8	14.2	1004	40.2		
		9	0	7.2	12.4	1004	36.8		
25-Feb-06	1	1	0.1	9.5	9	1001	32.5	20	720
		2	0.1	2.9	17.1	1001	31.8		
		3	0.1	13.4	4.9	1001	36.6		
		4	0.1	0.2	20.2	1001	30.5		
		5	0.1	12.6	7.5	1001	39.6		
		6	0.1	11.9	7.9	1001	35		
		7	0.1	11	8.4	1001	40.8		
		8	0.1	11.1	8.6	1001	41.4		
		9	0.1	9.9	9.6	1001	39.5		
4-Mar-06	1	1	0	1.7	19	1021	32.7	250	0
		2	0	0.7	20.2	1021	33.1		
		3	0	0.6	20.3	1021	37.6		
		4	0	0	21	1021	23		
		5	0	6.5	13.5	1021	31.9		
		6	0	6.4	13.7	1021	31.1		
		7	0	2.5	18.6	1021	35		
		8	0	5.2	15.3	1021	38.4		
		9	0	3.4	17.4	1021	38		
11-Mar-06	1	1	0.3	7	12.6	1003	30.8	250	0
		2	0.3	3.4	16.1	1003	31.6		
		3	0.3	3	16.9	1003	37.1		
		4	0.3	4.6	14.8	1003	31.8		
		5	0.3	8.3	11.9	1003	37.7		
		6	0.3	6.9	12.7	1003	33.5		
		7	0.3	6.1	13.2	1003	39.9		
		8	0.3	3.9	15.6	1003	40.5		
		9	0.3	5.5	14.4	1003	36.6		
18-Mar-06	1	1	0.2	6.3	13.2	1010	28.5	80	0
		2	0.2	0.2	20.2	1010	29.3		
		3	0.2	10	20	1010	30.5		
		4	0.2	0.2	20.1	1010	29		
		5	0.2	10.8	1	1010	33.5		
		6	0.2	15.2	4.8	1010	28.4		
		7	0.2	18.5	1.6	1010	31.7		
		8	0.2	11.8	8	1010	34.3		
		9	0.2	15	4.8	1010	33.4		

25-Mar-06	1	1	0	9.7	10.3	1010	28.2	0	0
		2	0	5.8	13.9	1010	28.6		
		3	0	7.5	12.9	1010	37.2		
		4	0	6.8	13.1	1010	29.2		
		5	0	10	9.7	1010	34.2		
		6	0	11	8.4	1010	30.8		
		7	0	8.1	11.7	1010	34.9		
		8	0	5.6	14.1	1010	36		
		9	0.1	8.5	11.3	1010	33.5		
1-Apr-06	1	1	0	11.8	9.1	1009	27.5	0	0
		2	0	7.1	13	1009	29.3		
		3	0	9.3	11.1	1009	31.5		
		4	0	7.7	13	1009	28.6		
		5	0	13.3	8	1009	34.3		
		6	0	14.4	6.3	1009	31.9		
		7	0	10.5	10.3	1009	33.6		
		8	0	8.4	12.1	1009	35.3		
		9	0	11.8	8.9	1009	34.5		
8-Apr-06	1	1	0	13.9	6.6	1010	31.6	0	0
		2	0	9.5	11.2	1010	30.7		
		3	0	9.6	10.7	1010	34.1		
		4	0	9.8	11.4	1010	25.9		
		5	0	17.3	4	1010	32.6		
		6	0	18.5	2.5	1010	32.6		
		7	0	13.3	8.1	1010	34.7		
		8	0	11.5	9.6	1010	35.9		
		9	0	17.6	3.7	1010	35.4		
15-Apr-06	1	1	0	10	11.7	1018	28.4	0	0
		2	0	8.7	11.8	1018	31.3		
		3	0	6.5	14.1	1018	32.5		
		4	0	9.6	11	1018	30.6		
		5	0	11.1	10.3	1018	32.4		
		6	0	13	8.3	1018	30.5		
		7	0	7.9	12.7	1018	32.8		
		8	0	6.1	14.6	1018	34.3		
		9	0	10.4	10.6	1018	33.3		
22-Apr-06	1	1	0	16.7	5.1	998	27.2	0	0
		2	0	14	7.8	998	27.8		
		3	0	0.1	20.1	998	29.6		
		4	0	16.5	5.1	998	27.4		
		5	0	15	5.7	998	29.6		
		6	0	14.4	5.3	998	27.5		
		7	0	15.6	4	998	30.1		
		8	0	13.3	6.3	998	31.7		
		9	0	13	6.8	998	30.4		

29-Apr-06	1	1	0	11.3	9.6	1007	24.5	0	0
		2	0	15	5.4	1007	24		
		3	0	16.5	4.2	1007	24.4		
		4	0	11.7	9.4	1007	26		
		5	0	17.7	2.6	1007	28		
		6	0	14.8	5.1	1007	26.8		
		7	0	17	3.2	1007	28.6		
		8	0	14.3	5.5	1007	30		
		9	0	12.9	6.8	1007	29		
6-May-06	1	1	0.1	6.1	15		22	0	0
		2	0	0.2	19.7		22.3		
		3	0	7.3	12.9		25.7		
		4	0.1	13.6	7.5		24.5		
		5	0	16.1	4		25.5		
		6	0	12.9	6.6		24.1		
		7	0.1	14.5	5		26		
		8	0.1	13.1	6.2		27		
		9	0.1	7.8	7.8		26.5		
13-May-06	1	1	0	9.2	12.9	1008	21	0	0
		2	0	8.2	12.2	1008	22.7		
		3	0	10.9	8.9	1008	24		
		4	0	15.3	5.5	1008	22.3		
		5	0	15.6	4.4	1008	24.5		
		6	0	14	5.5	1008	22.9		
		7	0	14.8	4.4	1008	25.7		
		8	0	13.5	6.1	1008	26.4		
		9	0	12.1	7.9	1008	24.7		
20-May-06	1	1	0	14	5.8	995	23.5	0	0
		2	0	5	16.1	995	25.1		
		3	0	15.7	5.6	995	27.6		
		4	0	12.9	6.9	995	24.1		
		5	0	15.6	4.4	995	26.2		
		6	0	10.6	9	995	23.8		
		7	0	12.8	6.7	995	27		
		8	0	9.2	10.7	995	28.5		
		9	0	12.1	8	995	26.3		
27-May-06	1	1	0	8.1	13.3	1003	21.9	100	0
		2	0	12	8.6	1003	21.3		
		3	0	14.8	6.2	1003	23.5		
		4	0	10.4	10.6	1003	22.8		
		5	0	14.3	5.9	1003	23.7		
		6	0	10.1	10	1003	21.8		
		7	0	11.8	8.4	1003	23.4		
		8	0	8.5	11.6	1003	24.7		
		9	0	9.5	10.7	1003	23		

3-Jun-06	1	1	0	11.8	9.4	1020	22.5	0	0
		2	0	12.1	8.9	1020	22.1		
		3	0	14	6.5	1020	24.4		
		4	0	2.6	18.4	1020	22.1		
		5	0	16.2	5.5	1020	23		
		6	0	13.4	7.5	1020	21.5		
		7	0	12.8	8.1	1020	24.5		
		8	0	13.4	7.7	1020	25.5		
		9	0	14.3	5.8	1020	23.3		
10-Jun-06	1	1	0	10.9	9.7	1010	19.8	0	0
		2	0	12.9	7.9	1010	21.2		
		3	0	14	6.8	1010	24		
		4	0	12.9	7.7	1010	21.2		
		5	0	15	5.1	1010	21.8		
		6	0	14	5.9	1010	19.7		
		7	0	14.6	5.4	1010	23.2		
		8	0	13	6.9	1010	24.7		
		9	0	12.7	7.6	1010	23		
17-Jun-06	1	1	0	7	13.5	1016	22.7	0	0
		2	0	10.9	9.8	1016	22.4		
		3	0	12.6	9.2	1016	24.4		
		4	0	11.9	9.3	1016	22.7		
		5	0	14.2	6	1016	23.8		
		6	0	13.1	6.6	1016	22.8		
		7	0	14.1	6	1016	25.2		
		8	0	11.7	8.7	1016	26.4		
		9	0	11.1	9.3	1016	24.8		
24-Jun-06	1	1	0	8.9	11.6	1018	21.7	0	0
		2	0	7.5	13	1018	20		
		3	0	9.1	11.5	1018	23.8		
		4	0	7.5	13	1018	21.5		
		5	0	11.7	9.8	1018	23		
		6	0	12.6	8.3	1018	20.4		
		7	0	9.7	11.3	1018	23.8		
		8	0	8.8	12.1	1018	25.2		
		9	0	10.8	10	1018	22.7		
1-Jul-06	1	1	0	7.2	13	1021	22.3	0	0
		2	0	8.3	12.7	1021	21.6		
		3	0	11	9.3	1021	21.9		
		4	0	10.1	10	1021	20.2		
		5	0	13.1	7.5	1021	23.1		
		6	0	13	6.4	1021	21		
		7	0	11.1	9.3	1021	23.6		
		8	0	10.6	10.1	1021	25.4		
		9	0	11.4	8.7	1021	22.2		

8-Jul-06	1	1	0	10.1	10.5	1021	22.6	0	0
		2	0	8.4	12.4	1021	22.3		
		3	0	9.4	11.6	1021	23.5		
		4	0	9.9	10.6	1021	22		
		5	0	13.3	8.3	1021	25.2		
		6	0	13.1	8	1021	23.4		
		7	0	10.5	10.4	1021	25.3		
		8	0	10.4	10.8	1021	27.6		
		9	0	12.1	8.8	1021	24.7		
15-Jul-06	1	1	0.1	5.6	15	1021	17	0	0
		2	0.1	1	19.5	1021	17.2		
		3	0.1	6.2	14.4	1021	19.4		
		4	0.1	6.8	14	1021	16.5		
		5	0	9.6	12	1021	19.1		
		6	0.1	10.3	10.6	1021	16.7		
		7	0.1	7	14.2	1021	18.9		
		8	0.1	6.4	14.5	1021	21.7		
		9	0.1	7.7	13.1	1021	18.5		
22-Jul-06	1	1	0.1	10.7	9.5	1005	19.6	0	0
		2	0.1	12.3	8.6	1005	19.2		
		3	0.1	13.2	7.6	1005	20.2		
		4	0.1	13.7	6.6	1005	18.8		
		5	0.1	14.8	5	1005	22.8		
		6	0.1	11.8	7.7	1005	20.7		
		7	0.1	13.4	6.2	1005	22.2		
		8	0.1	13.5	6.4	1005	24.6		
		9	0.1	11	8.9	1005	21.6		
29-Jul-06	1	1	0.1	11.5	8.5	1014	20.4	0	0
		2	0.1	10.6	10.0	1014	21.3		
		3	0.1	12.4	8.7	1014	21.4		
		4	0.1	10.6	9.4	1014	19.3		
		5	0.1	14.9	6.0	1014	23.3		
		6	0.1	14.4	5.8	1014	20.5		
		7	0.1	12.8	8.2	1014	22.7		
		8	0.1	12.7	8.5	1014	26.4		
		9	0.1	11.8	8.4	1014	22.3		
5-aug-06	1	1	0.1	12.5	8.7	1012		0	0
		2	0.1	9.8	11.9	1012			
		3	0.1	17.0	5.3	1012			
		4	0.1	0.1	20.5	1012			
		5	0.1	11.8	9.0	1012			
		6	0.1	11.0	9.3	1012			
		7	0.1	8.8	11.4	1012			
		8	0.1	11.3	9.4	1012			
		9	0.0	6.6	14.1	1012			

12-Aug-06	1	1	0.1	16.7	4.8	1003	26.8	0	0
		2	0.0	17.9	3.7	1003	26.1		
		3	0.0	16.0	6.2	1003	26.5		
		4	0.0	15.2	5.4	1003	25.4		
		5	0.0	16.2	4.2	1003	26.1		
		6	0.0	13.1	7.5	1003	24.6		
		7	0.0	14.5	6.1	1003	27.7		
		8	0.0	15.6	5.1	1003	29.4		
		9	0.0	13.2	6.8	1008	27.5		

1.2 Biogas Data for Cell 2 (Inception of Cell 2: 31 August 2005)

Date	Cell No.	Gas Probe I.D	Gas Concentration % Vol			Pressure (mBar)	Temp. °C	Leachate (Litres)	Runoff (Litres)
			CH_4	CO_2	O_2				
12-Sep-05	2	1	0	0	19.8	1008	23.7	0	120
		2	0	1.8	18	1008	27.4		
		3	0	0.3	19.6	1008	28.6		
		4	0	0	19.8	1008	25.4		
20-Sep-05	2	1	0	1.1	18.5	1010	27.5	0	100
		2	0	2.6	16.9	1010	28.4		
		3	0	0.2	19.5	1010	26.7		
		4	0	0	19.7	1010	24.3		
26-Sep-05	2	1	0	2.4	17.7	1007	27.2	0	0
		2	0	1.8	18.2	1007	28.9		
		3	0	0.9	19	1007	29.8		
		4	0	0	20	1007	20.6		
10-Oct-05	2	1					28.5	0	115
		2					24.8		
		3					30.2		
		4					24.4		
31-Oct-05	2	1						0	105
		2							
		3							
		4							
8-Nov-05	2	1	0	0.5	20.8	1012	26.7	500	415
		2	0	6.1	14.8	1012	26.2		
		3	0	3	18.2	1012	25.1		
		4	0	0	20.8	1012	25.4		
19-Nov-05	2	1						670	340
		2							
		3							
		4							
28-Nov-05	2	1	0	5.7	15.3	1011	35	200	400
		2	0	1.1	20.3	1011	29.9		
		3	0	1.5	19.6	1011	39.2		
		4	0	8.8	10.3	1011	32.3		
5-Dec-05	2	1	0	12.5	8.3	1002	36.2	0	0
		2	0	6	14.4	1002	38		
		3	0	0.1	20.9	1002	31.8		
		4	0	7.7	12.2	1002	32.7		
10-Jan-06	2	1						0	0
		2							
		3							
		4							
17-Jan-06	2	1	0	2.7	18	1004	34.2	350	0

		2	0	0	21	1004	31.9		
		3	0	1.1	19.7	1004	38		
		4	0	4.3	16	1004	35.7		
		5	0	1.6	19.2	1004	33.9		
		6	0	3.3	17.3	1004	42		
		7	0	0	20.8	1004	38.3		
		8				1004	43.7		
		9				1004	45		
24-Jan-06	2	1	0	7.2	12.3	1009	39.1	0	245
		2	0	1.6	18	1009	29.6		
		3	0	7.5	11	1009	30.5		
		4	0	7.5	11.2	1009	29.8		
		5	0	8.7	8.9	1009	37		
		6	0	8.8	10.5	1009	39.6		
		7	0	7.5	11.1	1009	32.2		
		8	0	8.6	10.2	1009	36.6		
		9	0	6.9	11.3	1009	35.6		
31-Jan-06	2	1	0.1	6.1	13.8		36.1	0	0
		2	0.2	0.4	20.2		33.3		
		3	0.1	0.6	20.1		38.8		
		4	0.2	3.2	16.9		36.3		
		5	0.2	6.2	12.4		37.7		
		6	0.1	9	10.5		38.9		
		7	0.2	3.5	16.8		35		
		8					41.2		
		9	0.2	4	12.5		41.8		
7-Feb-06	2	1	0.1	0	20.9	1006	30.7	0	0
		2	0.1	0	20.9	1006	29.2		
		3	0.1	0.8	20.1	1006	38		
		4	0.1	0.8	20.9	1006	34.2		
		5	0.1	0.1	20.7	1006	33.4		
		6	0.1	5.3	15.5	1006	38.3		
		7	0.1	2.6	18.5	1006	35.3		
		8	0.1	5.6	14.7	1006	41.3		
		9	0.1	5	16	1006	43.7		
14-Feb-06	2	1	0.1	4.5	15.5	1004	34.3	370	
		2	0.1	0.1	20.3	1004	27.4		
		3	0.1	0.6	19.9	1004	36.2		
		4	0.1	2.6	17.6	1004	34.1		
		5	0.1	6.2	13.3	1004	37.3		
		6	0	7	12.9	1004	39.3		
		7	0	3.7	16.6	1004	34.7		
		8	0	4.5	15.5	1004	40.6		
		9	0	7	13.3	1004	41.9		

21-Feb-06	2	1	0	3.2	20.9	1007	36.3		
		2	0	0.1	20.9	1007	34.4		
		3	0	0.9	20.717.4	1007	37.4		
		4	0	0.4	19.9	1007	29.3		
		5	0	15	20.4	1007	31.3		
		6	0	8.5	7.2	1007	41.6		
		7	0	4.1	12.1	1007	38.1		
		8	0	4.6	15.6	1007	43.3		
		9	0	4.6	15.9	1007	43.6		
25-Feb-06	2	1	0.1	0.2	20.1	1001	31.1	90	775
		2	0.1	0.4	19.8	1001	30.8		
		3	0.1	9.1	9.4	1001	36.5		
		4	0.1	5.7	13.3	1001	32.1		
		5	0.1	9.6	10	1001	36.6		
		6	0.1	11	8.7	1001	38.6		
		7	0.1	7.4	11.6	1001	33.7		
		8	0.1	7.9	12	1001	39.4		
		9	0.1	7.1	12.5	1001	42.4		
4-Mar-06	2	1	0	2.4	18.5	1021	34.4	20	0
		2	0	1.3	19.7	1021	31.4		
		3	0	0.9	20.1	1021	36.5		
		4	0	0	21	1021	21.3		
		5	0	4	17.1	1021	34.8		
		6	0	5.6	14.5	1021	35		
		7	0	1.2	19.7	1021	30.6		
		8	0	3.9	16.8	1021	37.2		
		9	0	8.7	12.3	1021	40.1		
11-Mar-06	2	1	0.2	4.5	16.4	1003	30.5	220	50
		2	0.3	4.7	14.5	1003	30.4		
		3	0.3	4.1	15.4	1003	34.8		
		4	0.3	3.7	16	1003	31.7		
		5	0.2	5.4	14.1	1003	34.3		
		6	0.2	7.9	11.9	1003	35.3		
		7	0.2	4.4	15.2	1003	31.8		
		8	0.2	4	16.3	1003	36.4		
		9	0.2	5.6	14.7	1003	38.1		
18-Mar-06	2	1	0.1	3.5	17.9	1010	29	0	60
		2	0.1	0.1	20	1010	29.5		
		3	0.1	0.1	20.6	1010	30.1		
		4	0.1	3.3	16.2	1010	29.2		
		5	0.2	12.3	6.1	1010	34.4		
		6	0.1	12.9	6.3	1010	34.8		
		7	0.2	8.8	10	1010	30.2		
		8	0.2	6.7	10.7	1010	33.4		
		9	0.1	11.5	6.9	1010	35.3		

25-Mar-06	2	1	0	7.9	13.7	1010	28.4	0	10
		2	0	0.1	20.2	1010	26.9		
		3	0	6.8	13.7	1010	28.3		
		4	0	9.9	14.8	1010	28.3		
		5	0	13.6	5.9	1010	31.1		
		6	0	12.6	8.4	1010	31.2		
		7	0	11.5	7.9	1010	29.4		
		8	0	11.4	8.8	1010	32.1		
		9	0	12.2	8.3	1010	33.3		
1-Apr-06	2	1	0	9.6	10.6	1009	29.6	0	0
		2	0	6	13.8	1009	30.7		
		3	0	6.4	13.5	1009	31.4		
		4	0	8.9	10.8	1009	29.3		
		5	0	8.4	12	1009	32.5		
		6	0	10.8	9.3	1009	31.4		
		7	0	7.5	12.8	1009	31.7		
		8	0	6.2	14.8	1009	33.8		
		9	0	10.6	9.7	1009	34.7		
8-Apr-06	2	1	0	19.8	2.1	1010	30.4	0	0
		2	0	18	3.6	1010	30.7		
		3	0	18.2	4.6	1010	29.6		
		4	0	11	10.9	1010	34.9		
		5	0	12.2	8	1010	33.9		
		6	0	10.6	10.3	1010	35.1		
		7	0	9.9	10.4	1010	33.4		
		8	0	12.8	7.7	1010	35		
		9	0	14.5	5.1	1010	36.7		
15-Apr-06	2	1	0	14.5	6.8	1018	29.9	0	0
		2	0	13.8	8	1018	30.6		
		3	0	12.6	9.8	1018	30.2		
		4	0	12.7	9.1	1018	29		
		5	0	12.5	7.5	1018	31.5		
		6	0	11.4	9.8	1018	32.9		
		7	0	10.6	9.5	1018	30.4		
		8	0	11.3	9.7	1018	32.4		
		9	0	11.8	8.7	1018	34.1		
22-Apr-06	2	1	0	0.3	20.2	998	27.3	0	50
		2	0	0.1	20.3	998	27.6		
		3	0	3.1	19.6	998	27.5		
		4	0	6.9	12.6	998	27.2		
		5	0	12.7	7	998	30.1		
		6	0	12	8.7	998	31		
		7	0	11.8	8.1	998	31		
		8	0	10.7	10.3	998	30.1		
		9	0	11	8.7	998	30.6		

29-Apr-06	2	1	0	12.7	8.2	1007	25.4	0	40
		2	0	11.1	9.6	1007	24.8		
		3	0	0.1	20.6	1007	24.5		
		4	0	8.8	12.4	1007	24.1		
		5	0	13.5	6.2	1007	26.8		
		6	0	12.5	8.3	1007	28.4		
		7	0	12.8	6.7	1007	25.1		
		8	0	11.3	9.4	1007	25.9		
		9	0	12	7.8	1007	28.6		
6-May-06	2	1	0	10.2	10.4		25.4	0	25
		2	0	0.2	19.2		25.4		
		3	0	0.3	19.9		25.9		
		4	0	2.1	18.1		25.6		
		5	0	13.3	5.8		26.4		
		6	0	12.6	7.6		26.8		
		7	0	12.3	6.5		24.4		
		8	0	11.3	8.5		21.8		
		9	0	11.6	7.5		27.1		
13 May 206	2	1	0	10.8	9.9	1008	24.7	0	80
		2	0	11.8	8.7	1008	24.6		
		3	0	11.1	10.1	1008	24.5		
		4	0	4.4	16.3	1008	23.6		
		5	0	11.7	7.8	1008	25.3		
		6	0	11.7	8.6	1008	25.9		
		7	0	9.1	10.6	1008	22.8		
		8	0	9.9	10.4	1008	24.2		
		9	0	10.2	9.8	1008	25.5		
20-May-06	2	1	0	17.5	2.6	995	27.1	0	200
		2	0.1	17.1	2.5	995	26		
		3	0	15.5	4.3	995	25.2		
		4	0	14.4	4.9	995	25.1		
		5	0	13.7	5.3	995	26.6		
		6	0	13.4	5.5	995	27.7		
		7	0	12.9	5.5	995	25.5		
		8	0	11.3	8	995	26.4		
		9	0	12	6.5	995	27.4		
27-May-06	2	1	0	10.5	10.6	1003	22.4	0	10
		2	0	11	9.6	1003	21.9		
		3	0	10.5	10.8	1003	22		
		4	0	13.8	7.5	1003	20.4		
		5	0	13	6.6	1003	20.2		
		6	0	11.8	8.6	1003	20.3		
		7	0	12.5	6.7	1003	20.2		
		8	0	10.7	9.7	1003	22.2		
		9	0	11.3	8.5	1003	23.1		

3-Jun-06	2	1	0	19.3	2.2	1020	24.8	0	0
		2	0.1	19.4	2.6	1020	23.8		
		3	0	18.8	2.9	1020	23.1		
		4	0	0.2	20.3	1020	21.2		
		5	0	11.7	9.1	1020	22.6		
		6	0	12.4	8.7	1020	23.8		
		7	0	10.1	10.5	1020	21.4		
		8	0	10.7	10.5	1020	22.3		
		9	0	11.6	9	1020	23.1		
10-Jun-06	2	1	0	16.4	5.7	1010	21.3	0	0
		2	0	16.1	6.4	1010	20.3		
		3	0	14.4	7.9	1010	20.1		
		4	0	14.8	7.6	1010	21.4		
		5	0	13.4	7	1010	20		
		6	0	12.7	8.6	1010	21.2		
		7	0	13.1	7.5	1010	19.5		
		8	0	10.9	10.1	1010	20.8		
		9	0	12.6	8.2	1010	22		
17-Jun-06	2	1	0	14.4	8.3	1016	23.1	0	0
		2	0	15.5	6.6	1016	22.6		
		3	0	12.4	9.9	1016	22.5		
		4	0	14.8	7.5	1016	22.3		
		5	0	13	7.8	1016	23.3		
		6	0	12.7	9	1016	24.7		
		7	0	13.1	7.7	1016	22.8		
		8	0	10.6	10.7	1016	23.1		
		9	0	12.4	8.7	1016	23.9		
24-Jun-06	2	1	0	15.5	6.8	1018	21.3	0	0
		2	0	15	6.8	1018	20.6		
		3	0	13.5	9	1018	20.8		
		4	0	14.3	7.8	1018	21.4		
		5	0	13.5	7	1018	22.4		
		6	0	12.7	9.1	1018	23.1		
		7	0	13.7	7	1018	19.9		
		8	0	10.7	0.6	1018	20.2		
		9	0	12.6	8.5	1018	2.4		
1-Jul-06	2	1	0.1	15.2	6.8	1021	21.1	0	0
		2	0	15.5	6.3	1021	21		
		3	0	12.9	9.5	1021	20.1		
		4	0	13.4	8.6	1021	19.8		
		5	0.1	12.8	8	1021	21.6		
		6	0.1	12.1	9.5	1021	22.3		
		7	0.1	12.7	7.9	1021	20.6		
		8	0.1	10.1	11.1	1021	21		
		9	0	11.9	9.2	1021	21.9		

8-Jul-06	2	1	0.1	16.8	5.7	1021	22.2	0	0
		2	0.1	15	7.8	1021	21.8		
		3	0.1	13.2	9.7	1021	21.3		
		4	0.1	13.3	9.2	1021	21.7		
		5	0.1	13	8.4	1021	23.9		
		6	0.1	12.6	9.3	1021	25.2		
		7	0.1	12.8	8.4	1021	23.4		
		8	0.1	10.1	11.4	1021	23.7		
		9	0.1	12.2	9.1	1021	23.7		
15-Jul-06	2	1	0	16.2	6.2	1021	17.4	0	0
		2	0	15.7	6.6	1021	16.9		
		3	0	12.3	10.2	1021	16.6		
		4	0	13.5	8.7	1021	16.3		
		5	0.1	12.8	8.3	1021	18.3		
		6	0.1	12.4	9.3	1021	19		
		7	0.1	12.3	8.7	1021	16.9		
		8	0	10.2	11.3	1021	17.2		
		9	0.1	12.1	9.2	1021	18		
22-Jul-06	2	1	0.1	19.2	3.6	1005	19.1	0	0
		2	0.1	16.1	5.8	1005	19.3		
		3	0.1	18.4	4.8	1005	19.5		
		4	0.1	14.3	7.8	1005	18.6		
		5	0.1	13.9	6.7	1005	20.5		
		6	0.1	13.4	8.3	1005	20.4		
		7	0.1	12.9	8	1005	18		
		8	0.1	11.2	10	1005	18.6		
		9	0.1	12.7	8.1	1005	19.8		
29-Jul-06	2	1	0.1	16.0	6.4	1014	19.3		
		2	0.0	16.3	5.7	1014	20.0		
		3	0.1	13.7	8.8	1014	19.9		
		4	0.1	13.8	8.4	1014	18.9		
		5	0.1	14.5	6.3	1014	21.9		
		6	0.1	13.4	8.4	1014	22.4		
		7	0.1	14.0	6.6	1014	20.4		
		8	0.1	11.4	10.8	1014	20.9		
		9	0.1	13.2	7.9	1014	20.4		
5-aug-06	2	1	0.1	19.6	3.5	1012	25.8		
		2	0.1	20.3	3.6	1012	24.9		
		3	0.1	19.5	3.6	1012	25.4		
		4	0.1	0.1	20.2	1012	23.6		
		5	0.1	12.0	8.8	1012	24.9		
		6	0.1	13.8	7.6	1012	25.3		
		7	0.0	9.4	11.2	1012	25.7		
		8	0.1	11.1	10.0	1012	26.6		
		9	0.1	11.0	10.1	1012	27.4		

12-Aug-06	2	1	0.2	21.1	2.5	1003	25.8		
		2	0.1	20.7	2.2	1003	26.0		
		3	0.0	14.4	4.8	1003	25.8		
		4	0.0	20.0	3.4	1003	26.0		
		5	0.0	13.5	7.5	1003	26.1		
		6	0.0	10.9	9.8	1003	27.5		
		7	0.0	11.6	9.6	1003	25.7		
		8	0.0	12.3	8.3	1003	26.1		
		9	0.0	13.4	8.0	1003	26.4		

1.3 Biogas Data for Cell 3 (Inception of Cell 3: 18 December 2005)

Date	Cell No.	Gas Probe I.D	Gas Concentration % Vol			Pressure (mBar)	Temp. °C	Leachate (Litres)	Runoff (Litres)
			CH_4	CO_2	O_2				
17-Jan-06	3	1	0	5.5	15.5	1004	32.6	260	100
		2	0	0	20.9	1004	30.5		
		3	0	2.2	18.5	1004	36.5		
		4	0	0	20.7	1004	31		
		5				1004			
		6				1004			
		7				1004			
		8				1004			
		9				1004			
24-Jan-06	3	1	0	13.8	5.3	1009	32.7	0	250
		2	0	10	12.2	1009	28.5		
		3	0	4	16.4	1009	36.3		
		4	0	9.5	9	1009	30.9		
		5	0	3.5	11.5	1009	53		
		6	0	15.5	5.1	1009	36.7		
		7	0	8.5	8.4	1009	32.1		
		8	0	13.9	5	1009	48.2		
		9	0	10.7	8.5	1009	34.9		
31-Jan-06	3	1	0.1	12.2	7.5		33.8	0	0
		2	0.1	0	20.6		29.6		
		3	0.2	4.2	15.8		36.2		
		4	0.2	10	8.3		30.3		
		5	0.2	12.9	7.7		49.5		
		6	0.2	4.4	9.3		35.1		
		7	0.2	3.3	14.4		32.1		
		8	0.2	6.7	13.5		42.6		
		9	0.2	8.1	11.8		34.8		
7-Feb-06	3	1	0	1.3	16.6	1006	32.6	0	0
		2	0	0	19.6	1006	29.2		
		3	0.2	1.8	17.6	1006	34.4		
		4	0	1.8	17.6	1006	29.7		
		5	0	0.1	19.2	1006	36.5		
		6	0.1	0.2	19	1006	36.4		
		7	0.1	5.5	14.4	1006	32.9		
		8	0.1	0.3	19.5	1006	32.9		
		9	0	0.2	20.1	1006	33.5		

14-Feb-06	3	1	0.1	12.1	6.6		32.6	370	0
		2	0.1	1	18.6		29.8		
		3	0	2.6	17.5		35.4		
		4	0	8	10		31.3		
		5	0	9	10.1		46.3		
		6	0	13	5		41.4		
		7	0	5.4	12.8		46.5		
		8	0	14	5.5		47.5		
		9	0	2.9	15.9		42.7		
21-Feb-06	3	1	0	7.4	12.5	1006	32.8	0	0
		2	0	0	20.7	1006	38.1		
		3	0	0.1	20.6	1006	35.9		
		4	0	0.1	20.7	1006	27.8		
		5	0	13	7.6	1006	46.3		
		6	0	7.5	12.5	1006	43.5		
		7	0	2	18	1006	47		
		8	0	0.1	20.7	1006	46.7		
		9	0	1	20.1	1006	43.8		
25-Feb-06	3	1	0	10.8	6.6	1001	31.9	310	0
		2	0.1	12.2	6.2	1001	31.8		
		3	0	14	4.5	1001	32.8		
		4	0	10.3	7.9	1001	30.3		
		5	0	4.6	15.5	1001	39.3		
		6	0.1	6.6	13	1001	38.8		
		7	0	3.8	16.1	1001	40.2		
		8	0	7	12.5	1001	40.4		
		9	0.1	6.2	13.3	1001	38.8		
4-Mar-06	3	1	0	5.7	14.6	1021	32.2	100	0
		2	0	1.9	18.8	1021	34.9		
		3	0	1.7	19.3	1021	33.8		
		4	0	0	20.9	1021	23.4		
		5	0	8	12.3	1021	37.9		
		6	0	14.3	6.2	1021	40.7		
		7	0	3.8	16.5	1021	34.7		
		8	0	0.3	20.7	1021	34.5		
		9	0	1.2	20	1021	39.5		
11-Mar-06	3	1	0.1	7.4	13	1003	31.1	220	80
		2	0.1	7.9	11	1003	31.6		
		3	0.2	7.1	12.4	1003	31.9		
		4	0.2	3.8	16.1	1003	30.6		
		5	0.2	3.9	16	1003	30.9		
		6	0.2	7.8	11.7	1003	40		
		7	0.2	6.8	12.6	1003	40.6		
		8	0.2	5	14.8	1003	40.6		
		9	0.2	7	12.3	1003	38.8		

18-Mar-06	3	1	0	4.4	14.8	1010	30.7	0	100
		2	0	0.1	20.1	1010	29.7		
		3	0	2.6	17.9	1010	27.8		
		4	0	0	20.3	1010	27.2		
		5	0	16.3	2.3	1010	34.9		
		6	0	12.4	5.6	1010	36.4		
		7	0	14.8	3.3	1010	33.8		
		8	0	14.3	4.5	1010	34.7		
		9	0	14.6	3.3	1010	34.9		
25-Mar-06	3	1	0	0.2	16.7	1010	28.5	0	25
		2	0	14	6.7	1010	28.7		
		3	0	12.1	6.9	1010	28.3		
		4	0	7.9	11.7	1010	26.3		
		5	0	14.9	3.6	1010	32.9		
		6	0	14.7	4.6	1010	34.3		
		7	0	13.1	4.7	1010	33.5		
		8	0	13.8	4.6	1010	34.7		
		9	0	15.8	2	1010	33.6		
1-Apr-06	3	1	0	14.1	5.6	1009	30.2	0	0
		2	0	14.1	5.3	1009	29.9		
		3	0	10.6	9.5	1009	29		
		4	0	7.6	12.8	1009	29		
		5	0	16.5	2.5	1009	32.8		
		6	0	15.6	3.7	1009	35		
		7	0	14.9	3.2	1009	32.5		
		8	0	16.4	2.5	1009	32.5		
		9	0	16.2	2.6	1009	33.3		
8-Apr-06	3	1	0	13	8.7	1010	31.5	0	0
		2	0	13.7	6.8	1010	32		
		3	0	3.5	17.5	1010	29		
		4	0	7.1	14.1	1010	28		
		5	0	4.7	14.8	1010	34.8		
		6	0	4.2	15.8	1010	38.5		
		7	0	7.2	12	1010	35		
		8	0	5.4	14	1010	36		
		9	0	3.7	16.1	1010	36.2		
15-Apr-06	3	1	0	13.6	5.5	1018	31.5	0	0
		2	0	15.6	4.1	1018	31.7		
		3	0	12.8	6.4	1018	28.2		
		4	0	7.7	12.8	1018	26.2		
		5	0	8.9	10.2	1018	33.5		
		6	0	8.6	11.6	1018	37.2		
		7	0	10.6	8.3	1018	33.8		
		8	0	11	7.5	1018	34.5		
		9	0	9.7	8.9	1018	34.4		

22-Apr-06	3	1	0	16.4	3.4	998	27.5	0	60
		2	0	15.4	12.5	998	28.1		
		3	0	12.9	9.9	998	26.4		
		4	0	1.2	20.3	998	26.4		
		5	0	10.5	8.3	998	29.7		
		6	0	12.1	7.7	998	32.3		
		7	0	13.2	5.1	998	29.4		
		8	0	12.2	6.2	998	30.9		
		9	0	12.5	5.6	998	30.6		
29-Apr-06	3	1	0	11.7	8.2	1007	24.5	0	100
		2	0	16.6	3.1	1007	25.8		
		3	0	14.6	5.4	1007	26		
		4	0	10	10.3	1007	24.5		
		5	0	14.6	3.5	1007	28.2		
		6	0	14.4	4.3	1007	30.8		
		7	0	13.6	4.8	1007	28.3		
		8	0	13.6	5.3	1007	29.4		
		9	0	14.4	4	1007	28.5		
6-May-06	3	1	0	11.1	8.2		24.5	0	400
		2	0	14.4	5.6		25.9		
		3	0	7.6	12.8		24.6		
		4	0	8.9	10.7		23.2		
		5	0	13.9	6.4		26		
		6	0	11.4	7.5		29.3		
		7	0	13.3	4.4		25.6		
		8	0	12.2	6.1		7.7		
		9	0	14.2	4.2		27.4		
13-May-06	3	1	0	10.4	9.2	1008	25.2	0	80
		2	0	13.5	6.2	1008	25.9		
		3	0	12.4	6.7	1008	24		
		4	0	9.3	10.8	1008	22.5		
		5	0	12.9	5.1	1008	26.5		
		6	0	12.1	6.4	1008	30.4		
		7	0	11.2	7.4	1008	27.2		
		8	0	10.3	8.8	1008	28.3		
		9	0	12.3	6	1008	27.8		
20-May-06	3	1	0	10.7	8.3	995	26.6	0	250
		2	0	15.1	3.7	995	26.1		
		3	0	13.6	6	995	25.3		
		4	0	12	6.9	995	23.3		
		5	0	14.1	3.9	995	28.5		
		6	0	13.5	4.9	995	32.6		
		7	0	13.3	4.2	995	29.2		
		8	0	11.8	6.6	995	30.3		
		9	0	15.2	2.9	995	29.8		

27-May-06	3	1	0	14.9	4.2	1003	23	0	0
		2	0	16.6	3.2	1003	21.9		
		3	0	15.1	5.2	1003	22.2		
		4	0	14.6	5.2	1003	20.9		
		5	0	12.9	6	1003	24.1		
		6	0	15.8	2.4	1003	26.8		
		7	0	11.3	7.8	1003	24.5		
		8	0	11.1	8.3	1003	26.2		
		9	0	12.6	6	1003	24.8		
3-Jun-06	3	1	0	10.1	11.7	1020	24.9	0	0
		2	0	13.3	8	1020	25.2		
		3	0	10.1	11.1	1020	22.1		
		4	0	0.9	19.8	1020	20.4		
		5	0	3.7	16.6	1020	24.6		
		6	0	3.4	17.1	1020	28.7		
		7	0	6.3	13.5	1020	25.8		
		8	0	5.3	14.7	1020	26.8		
		9	0	3.5	17.1	1020	26.5		
10-Jun-06	3	1	0	10.9	9.1	1010	23.4	0	0
		2	0	14	5.6	1010	23.3		
		3	0	12.5	8.3	1010	21.3		
		4	0	9.5	11.1	1010	21.5		
		5	0	13.8	4.7	1010	24.7		
		6	0	13.1	5.8	1010	27.6		
		7	0	12.6	6.2	1010	25.8		
		8	0	11.7	7.7	1010	26.5		
		9	0	12.8	5.8	1010	26		
17-Jun-06	3	1	0	10.8	8.9	1016	23.5	0	0
		2	0	12.9	6.5	1016	24.8		
		3	0	9.4	10.5	1016	22.5		
		4	0	8.1	11.9	1016	22.3		
		5	0	13.9	14	1016	27.4		
		6	0	12.5	6.2	1016	30.6		
		7	0	12.9	5.3	1016	27.8		
		8	0	12.3	5.9	1016	27.5		
		9	0	12.9	5.3	1016	28.3		
24-Jun-06	3	1	0.1	10.1	9.7	1018	22.8	0	0
		2	0	9.6	10.2	1018	23.5		
		3	0.1	7.2	13.1	1018	21		
		4	0	8.1	12	1018	20.6		
		5	0.1	5.1	15.2	1018	27		
		6	0.1	8.1	11.9	1018	30.5		
		7	0.1	5	15.4	1018	26.8		
		8	0.1	4.2	16.5	1018	27.8		
		9	0.1	5.9	14.5	1018	27.3		

1-Jul-06	3	1	0.1	11.9	6.7	1021	22	0	0
		2	0.1	12.5	8	1021	23.1		
		3	0.1	10.3	10.2	1021	19.9		
		4	0.1	10.9	8.7	1021	19.6		
		5	0.1	12.3	7.6	1021	29		
		6	0.1	14.6	4.1	1021	31.1		
		7	0.1	10.5	9.5	1021	29		
		8	0.1	9.4	11.1	1021	28.1		
		9	0.1	12.5	6.3	1021	29		
8-Jul-06	3	1	0.1	9.2	9.8	1021	23.8	0	0
		2	0.1	8.4	11.9	1021	23.2		
		3	0.1	5.6	15.2	1021	21		
		4	0.1	7.2	12.7	1021	21.5		
		5	0.1	4.9	15.8	1021	29.6		
		6	0.1	7.9	12.2	1021	32.8		
		7	0.1	4.4	16.4	1021	29.9		
		8	0.1	3.6	17.5	1021	29.7		
		9	0.1	5.6	15	1021	30.3		
15-Jul-06	3	1	0	10.2	10.8	1021	18.6	0	0
		2	0.1	13.9	5.8	1021	18.7		
		3	0.1	7.7	12.7	1021	16.1		
		4	0.1	0.1	20.3	1021	15.9		
		5	0.1	10.4	8.7	1021	24.2		
		6	0	7.4	12.2	1021	25.1		
		7	0.1	11	8	1021	24		
		8	0.1	10.6	9	1021	22.9		
		9	0	9.9	9.9	1021	23.1		
22-Jul-06	3	1	0.1	15.5	4.9	1005	20.3	0	0
		2	0.1	17.5	2.8	1005	19.8		
		3	0.1	13.4	6.6	1005	18		
		4	0.1	0.1	20	1005	17.6		
		5	0	8.9	10.3	1005	25.8		
		6	0	6.1	13.8	1005	27.9		
		7	0.1	10.9	8.2	1005	25.9		
		8	0.1	12.4	5.7	1005	25.8		
		9	0	11.2	7.6	1005	27		
29-Jul-06	3	1	0.0	12.0	6.6	1014	21.8	0	0
		2	0.1	13.9	6.1	1014	20.9		
		3	0.1	8.3	11.9	1014	19.5		
		4	0.1	9.4	9.7	1014	19.1		
		5	0.0	13.4	6.6	1014	27.7		
		6	0.1	15.3	4.0	1014	29.2		
		7	0.0	10.6	9.7	1014	27.3		
		8	0.1	9.6	10.6	1014	26.8		
		9	0.1	13.1	6.3	1014	27.6		

5-Aug-06	3	1	0.1	18.6	2.7	1012	25.4		
		2	0.1	21.5	0.5	1012	24.3		
		3	0.1	19.2	1.8	1012	23.6		
		4	0.1	0.1	20.1	1012	22.5		
		5	0.1	15.0	3.8	1012	29.2		
		6	0.1	12.9	6.4	1012	30.4		
		7	0.1	13.5	5.9	1012	29.7		
		8	0.0	14.0	5.3	1012	29.9		
		9	0.1	14.9	4.2	1012	30.0		
12-Aug-06	3	1	0.0	20.0	1.4	1003	26.7		
		2	0.0	20.9	0.7	1003	27.1		
		3	0.0	15.1	4.5	1003	25.1		
		4	0.0	12.2	2.4	1003	23.7		
		5	0.1	8.7	11.5	1003	28.2		
		6	0.0	6.1	14.2	1003	29.7		
		7	0.0	11.9	8.5	1003	28.5		
		8	0.0	12.3	7.8	1003	29.2		
		9	0.0	10.8	9.0	1003	29.1		

1.4 Biogas Data for Cell 4 (Inception of Cell 4: 24 August 2005)

Date	Cell No.	Gas Probe I.D	Gas Concentration % Vol			Pressure (mBar)	Temp. °C	Leachate (Litres)	Runoff (Litres)
			CH_4	CO_2	O_2				
12-Sep-05	4	1	0	1.3	18.2	1008	34.3	0	100
		2	0	0	19.4	1008	27.9		
		3	0	1.2	18.3	1008	28.1		
		4	0	19.7		1008	27.2		
20-Sep-05	4	1	0	0	19.5	1010	36.1	0	60
		2	0	1.2	18.2	1010	34.5		
		3	0	0	19.4	1010	27.1		
		4	0	0.2	19.2	1010	26.2		
28-Sep-05	4	1	0	2	17.8	1007	27.5	0	0
		2	0	1.7	19.6	1007	29		
		3	0	0.6	19.3	1007	29.3		
		4	0	0	19.9	1007	20.4		
10-Oct-05	4	1					33	0	100
		2					23		
		3					28.7		
		4					23.8		
31-Oct-05	4	1						0	105
		2							
		3							
		4							
8-Nov-05	4	1	0	0.1	20.6	1012	27.8	100	330
		2	0	0.6	20.1	1012	33.6		
		3	0	0	20.8	1012	24.8		
		4	0	0.2	20.6	1012	23.9		
19-Nov-05	4	1						350	730
		2							
		3							
		4							
28-Nov-05	4	1	0	4.5	17.2	1011	35.4	660	400
		2	0	0	21.3	1011	28.1		
		3	0	2.7	18.3	1011	29.3		
		4	0	3.2	16.9	1011	27.8		
5-Dec-05	4	1	0	6.3	13.3	1002	38.4	0	0
		2	0	2.7	18.9	1002	35.5		
		3	0	0.1	20.8	1002	27.2		
		4	0	0	20.9	1002	28.2		
10-Jan-06	4	1						498	0
		2							
		3							
		4							

17-Jan-06	4	1	0	4.5	16	1004	39.8	625	150
		2	0	0	20.8	1004	28.2		
		3	0	1.8	16.9	1004	31.2		
		4	0	0	20.6	1004	33		
		5	0	2.2	9.8	1004	42		
		6	0			1004	39		
		7	0			1004	29.1		
		8	0			1004	38.3		
		9	0			1004	38.3		
24-Jan-06	4	1	0	8.5	10.6	1009	32.5	0	0
		2	0	4	16.2	1009	31.2		
		3	0	0.6	20.1	1009	37.1		
		4	0	2.3	18	1009	34.6		
		5	0	7.5	12.4	1009	38.5		
		6	0	9	10.8	1009	40.7		
		7	0	5.1	14.1	1009	35.3		
		8	0	5.8	14.5	1009	43.3		
		9	0	5.7	14.4	1009	45.1		
31-Jan-06	4	1	0.3	4.9	14.7		38.3	0	0
		2	0.2	2.5	17.8		27.9		
		3	0.2	3	17.5		29.5		
		4	0.1	6.8	12.5		31.2		
		5	0.1	7	12.1		36.2		
		6					38.6		
		7	0.1	4.4	15.7		33.9		
		8					36.7		
		9	0.1	6.8	12.6		35.9		
7-Feb-06	4	1	0	3.6	9.6	1006	39.4	0	0
		2	0	3.6	14.8	1006	32.6		
		3	0	0.1	19.2	1006	32.7		
		4	0	0.1	19.8	1006	39.3		
		5	0	1.1	14.9	1006	38.6		
		6	0	3.3	7.9	1006	38.9		
		7	0	3	10.7	1006	38.9		
		8	0	2.3	11.9	1006	39		
		9	0	1	15.3	1006	38.8		
14-Feb-06	4	1	0.4	5.6	13.6	1005	38.9	450	0
		2	0.1	2.9	16.9	1005	29.6		
		3	0.1	3.2	14.6	1005	29.8		
		4	0.1	3.7	15.6	1005	29.9		
		5	0.1	7.9	10.8	1005	37.2		
		6	0.1	3.7	15.4	1005	38.8		
		7	0.1	5.8	12.5	1005	30.1		
		8	0	6.2	12.6	1005	36.9		
		9	0.1	5.6	12.9	1005	36.1		

21-Feb-06	4	1	0	4.5	16	1007	40.8	0	0
		2	0	0.8	19.8	1007	33.2		
		3	0	3.1	17.5	1007	27.5		
		4	0	2.2	18.3	1007	28.7		
		5	0	2.6	18.1	1007	41.3		
		6	3.4	11.3	9.2	1007	41.3		
		7	0	2.1	18.4	1007	35.1		
		8	0	0	20.7	1007			
		9	0	0.1	20.5	1007	39.8		
25-Feb-06	4	1	5.4	18.7	1	1001	36.2	300	0
		2	0	6.2	11.8	1001	30.7		
		3	0.4	4.9	14	1001	30		
		4	0	3.1	17	1001	29.5		
		5	0	11.4	6.5	1001	34.8		
		6	0.1	13.1	3.2	1001	36.9		
		7	0	8.7	9.3	1001	30.7		
		8	0	10.5	6.3	1001	34.8		
		9	0	11.8	5.3	1001	34.5		
4-Mar-06	4	1	0.3	6.1	14.3	1021	39.4	190	0
		2	0	3.1	17.4	1021	28.3		
		3	0	0.3	20.7	1021	26.1		
		4	0	0	20.9	1021	22.6		
		5	0	2.8	17.5	1021	33.2		
		6	0	2.6	18	1021	27.9		
		7	0	2	18.8	1021	26.2		
		8	0	2.5	18.3	1021	28.1		
		9	0	0.7	20.2	1021	27.3		
11-Mar-06	4	1	0.2	9.6	9.7	1003	35.3	400	50
		2	0.1	2.9	17.4	1003	29.7		
		3	0.1	0	20.9	1003	30.3		
		4	0.1	1.2	19.4	1003	30.3		
		5	0.1	5	15.3	1003	36.3		
		6	0.1	4.2	15.4	1003	36.3		
		7	0.1	4.1	15.8	1003	29.4		
		8	0.1	1.5	19.3	1003	32.9		
		9	0.1	4.9	14.7	1003	33.6		
18-Mar-06	4	1	0	18.9	1.9	1010	33.8	0	75
		2	0	1.9	20.5	1010	28.2		
		3	0	4.2	14	1010	28.7		
		4	0	5.5	10.5	1010	28.5		
		5	0	11.6	6.7	1010	34.2		
		6	0	6.9	12.2	1010	35.5		
		7	0	12.6	7.2	1010	30.9		
		8	0	13.2	4.5	1010	32.5		
		9	0	14.2	3.9	1010	32.4		

25-Mar-06	4	1	0.7	18.6	2.7	1010	31.4	0	0
		2	0.1	8.4	11.5	1010	27.6		
		3	0.1	0.1	20.5	1010	26.9		
		4	0.1	0.2	20.5	1010	26.2		
		5	0.1	9.6	9.1	1010	32.1		
		6	0.1	7.6	11.6	1010	32.2		
		7	0.1	8.8	10.8	1010	30.1		
		8	0.1	8.8	10.7	1010	30.1		
		9	0.1	9.9	9.2	1010	30.2		
1-Apr-06	4	1	1.5	22.1	1	1009	31.6	0	0
		2	0.1	7.8	12.1	1009	28.9		
		3	0.1	9.1	10.8	1009	28.5		
		4	0.1	7.8	12.2	1009	28.3		
		5	0	7.3	12.4	1009	32.7		
		6	0	7.2	12.1	1009	33.6		
		7	0	7.1	12.3	1009	31.2		
		8	0	9.3	10	1009	31.6		
		9	0	8.2	11.2	1009	32.1		
8-Apr-06	4	1	8.1	21.4	0	1010	33.3	0	0
		2	0	11.6	9	1010	29.5		
		3	0	9.2	11.5	1010	28.2		
		4	0	6.1	14	1010	29.2		
		5	0	7.6	12.5	1010	35.2		
		6	0	9.9	9.3	1010	34.2		
		7	0	7.8	12.4	1010	33.1		
		8	0	7.4	12.6	1010	34		
		9	0	7.1	12	1010	34.2		
15-Apr-06	4	1	7.3	21.3	0.1	1018	32.9	0	0
		2	0	13.6	6.4	1018	28.8		
		3	0	9.3	11.8	1018	28.1		
		4	0.3	15	3.9	1018	28.7		
		5	0	8.8	11	1018	31.5		
		6	0.1	13.2	5.3	1018	32.1		
		7	0	10.1	9.1	1018	30.7		
		8	0	7.9	11.7	1018	31.2		
		9	0	9.5	8.9	1018	30.9		
22-Apr-06	4	1	0.1	5.9	14.6	998	29.4	0	20
		2	0	7.9	12	998	26.9		
		3	0	0.1	20.6	998	25.8		
		4	0	6.5	13.5	998	25.7		
		5	0	6.7	13.3	998	29		
		6	0	6.3	12.8	998	30.3		
		7	0	7.7	11.8	998	28.5		
		8	0	6.2	13.2	998	28		
		9	0	6.5	12.8	998	28.4		

29-Apr-06	4	1	3.7	20.7	0.1	1007	25	0	90
		2	0	9.1	10.9	1007	24		
		3	0	9.6	9.9	1007	22.8		
		4	0	10.4	8.3	1007	25		
		5	0	8.1	11	1007	27		
		6	0	7.5	11.1	1007	28.9		
		7	0	7.3	12.3	1007	26.1		
		8	0	8.8	10.4	1007	26.8		
		9	0	8.1	9.8	1007	26.3		
6-May-06	4	1	1	18.1	0.3		27.1	0	700
		2	0.1	7.5	10.8		24.3		
		3	0.1	4.2	14.5		23.2		
		4	0.1	11.4	5.6		23.2		
		5	0.1	9.7	8.8		23.7		
		6	0.1	8.7	10		25.6		
		7	0.1	7.4	11.2		24.2		
		8	0.1	10.1	8.1		23.8		
		9	2.1	14.3	3.2		24.2		
13-May-06	4	1	1.7	18	2.2	1008	25.2	0	80
		2	0	6.7	12.8	1008	21.8		
		3	0	9.6	9.7	1008	22.7		
		4	0.1	11.3	11.3	1008	22		
		5	0	12.9	12.9	1008	23.1		
		6	0	14.1	14.1	1008	25.7		
		7	0	13.6	13.6	1008	23.9		
		8	0	10.6	10.6	1008	23.7		
		9	0	12.4	12.4	1008	22.9		
20-May-06	4	1	3.6	13.7	8.9	995	28.5	0	350
		2	0	11.9	6.2	995	25.1		
		3	0	9.8	9.1	995	23.8		
		4	0.2	12.4	4	995	24.4		
		5	3.7	16.5	1.1	995	24.3		
		6	9.1	19.2	0	995	26		
		7	0.2	12.3	3.9	995	24.4		
		8	0	10.8	6.8	995	25.2		
		9	4.7	17.6	0.1	995	25.3		
27-May-06	4	1	2.2	19	0.7	1003	26.1	0	0
		2	0.1	10.9	8.6	1003	23.4		
		3	0.1	7	12.9	1003	23.3		
		4	0.1	13.7	3.9	1003	22.4		
		5	0	9.2	9.4	1003	21.3		
		6	0	8.3	9.8	1003	23.1		
		7	0	6.8	12.1	1003	21.4		
		8	0	8.3	10.8	1003	21		
		9	0.2	11.3	5.7	1003	21.8		

3-Jun-06	4	1	0.7	19	0.4	1020	26.7	0	0
		2	0	12.4	8.1	1020	22.7		
		3	0	9.7	11.6	1020	20		
		4	0	0.3	20.2	1020	20.8		
		5	0	4	16.4	1020	23.3		
		6	0	5	14.8	1020	24.2		
		7	0	4.8	15.5	1020	22.2		
		8	0	3.5	17.2	1020	22.2		
		9	0	3.4	16.8	1020	22.9		
10-Jun-06	4	1	1	17.3	3	1010	22.3	0	0
		2	0	9.5	11.2	1010	19.3		
		3	0	8.2	12	1010	20		
		4	0	9.9	9.7	1010	20.4		
		5	0	7.1	12.6	1010	22.4		
		6	0	6.1	13.1	1010	22.9		
		7	0	5.2	14.7	1010	20.7		
		8	0	6.7	13.1	1010	20.4		
		9	0.1	7.5	11.6	1010	20.7		
17-Jun-06	4	1	0.3	19.7	1.2	1016	23.9	0	0
		2	0.1	10	10.6	1016	22		
		3	0	8	12.1	1016	20.8		
		4	0	10.9	9.3	1016	21.5		
		5	0	7.6	12.1	1016	25.3		
		6	0	5.7	13.9	1016	26.3		
		7	0	5.4	14.6	1016	23.5		
		8	0	7	12.4	1016	23.6		
		9	0	7.5	11.8	1016	24.3		
24-Jun-06	4	1	2.1	19.6	0	1018	24.5	0	0
		2	0	9.8	10.6	1018	20.7		
		3	0	9.7	10.3	1018	19.3		
		4	0.6	14	3.3	1018	20.6		
		5	0	7.7	11.9	1018	20.9		
		6	0	8.1	11	1018	24.4		
		7	0	6	13.9	1018	21.8		
		8	0	7.7	11.6	1018	21.9		
		9	0.1	10.3	8.1	1018	21.8		
1-Jul-06	4	1	0.5	19	1.4	1021	24.2	0	0
		2	0.1	9.2	11.5	1021	20.7		
		3	0.1	9.4	10.5	1021	18.2		
		4	0.1	12.1	6.7	1021	19		
		5	0	7.9	11.6	1021	23.2		
		6	0	8.2	10.6	1021	23.7		
		7	0	6.4	13.1	1021	21.4		
		8	0	6.9	13	1021	21.7		
		9	0	7.8	11	1021	23		

8-Jul-06	4	1	1.2	15.7	1.5	1021	24.2	0	0
		2	0	9.2	11.4	1021	21.9		
		3	0	8.3	11.7	1021	20.9		
		4	0.1	8.2	11.2	1021	21.6		
		5	0	7.1	12.6	1021	23.3		
		6	0	8.3	10.7	1021	23.5		
		7	0	5.3	14.9	1021	22.3		
		8	0	6.9	12.4	1021	23		
		9	0	7.8	10.8	1021	23.7		
15-Jul-06	4	1	0.1	10.1	11.2	1021	17.8	0	0
		2	0.1	6.7	14.3	1021	16.2		
		3	0.1	7.1	13.5	1021	15.2		
		4	0.1	6.3	14.4	1021	15.5		
		5	0.1	6.9	13.3	1021	20.4		
		6	0.1	6.4	13.5	1021	20.3		
		7	0.1	5.5	14.8	1021	18		
		8	0	6.2	13.8	1021	19		
		9	0.1	6.5	13.3	1021	19		
22-Jul-06	4	1	1.4	17	0.5	1005	20.5	0	0
		2	0.1	6	14.3	1005	18		
		3	0.1	7.4	13	1005	17		
		4	0.1	8.4	11.6	1005	17.4		
		5	0.1	8.5	11.2	1005	22.1		
		6	0.1	5.7	13.6	1005	22		
		7	0	4.8	15.2	1005	19.9		
		8	0	8.4	11.2	1005	21.7		
		9	0	8.2	10.8	1005	21.5		
29-Jul-06	4	1	0.1	9.6	11.7	1014	21.4		
		2	0.1	6.0	15.0	1014	19.3		
		3	0.1	6.5	13.8	1014	18.0		
		4	0.1	7.5	12.7	1014	17.9		
		5	0.1	7.4	12.4	1014	23.3		
		6	0.1	7.0	12.9	1014	22.8		
		7	0.1	6.5	13.5	1014	21.3		
		8	0.1	8.3	11.2	1014	23.2		
		9	0.1	7.4	11.8	1014	22.4		
5-Aug-06	4	1	0.8	19.7	1.5	1012	26.7		
		2	0.2	15.7	5.7	1012	23.0		
		3	0.1	10.4	9.6	1012	22.3		
		4	0.1	1.4	19.3	1012	22.8		
		5	0.1	6.9	13.3	1012	25.9		
		6	0.1	7.3	12.3	1012	22.5		
		7	0.1	4.0	16.8	1012	25.1		
		8	0.1	8.2	11.0	1012	23.7		
		9	0.1	7.9	11.3	1012	26.4		

12-Aug-06	4	1	0.8	20.0	1.9	1003	26.1		
		2	0.2	12.5	8.4	1003	23.6		
		3	0.1	0.1	20.0	1003	23.6		
		4	0.1	8.2	12.2	1003	23.5		
		5	0.1	7.3	12.3	1003	27.8		
		6	0.1	6.1	13.1	1003	27.4		
		7	0.1	4.0	16.0	1003	25.6		
		8	0.1	6.3	13.3	1003	27.3		
		9	0.1	6.2	12.9	1003	26.1		

1.5 Biogas Data for Cell 5 (Inception of Cell 5: 18 August 2005)

Date	Cell No.	Gas Probe I.D	Gas Concentration % Vol			Pressure (mBar)	Temp. ^0C	Leachate (Litres)	Runoff (Litres)
			CH_4	CO_2	O_2				
12-Sep-05	5	1	0	0	19.7	1008	26.6	0	60
		2	0	0	20	1008	24.6		
		3	0	0.6	19.1	1008	32.2		
		4	0	0.2	19.6	1008	27.4		
20-Sep-05	5	1	0	0	19.7	1010	29.9	0	80
		2	0	0.4	19.6	1010	27.1		
		3	0	0.5	19.2	1010	28.5		
		4	0	0.3	19.6	1010	26.7		
28-Sep-05	5	1	0	0.3	19.8	1007	29.4	0	0
		2	0	0.4	19.5	1007	27.6		
		3	0	0	20	1007	26		
		4	0	0.3	19.7	1007	23.8		
10-Oct-05	5	1						0	60
		2							
		3							
		4							
31-Oct-05	5	1						0	100
		2							
		3							
		4							
8-Nov-05	5	1	0	0.1	20.6	1012	28.3	375	355
		2	0	1.1	19.7	1012	29.4		
		3	0	0	20.9	1012	27.7		
		4	0	0.3	20.5	1012	27.2		
19-Nov-05	5	1						350	340
		2							
		3							
		4							
28-Nov-05	5	1	0	8.1	11.7	1011	30.5	200	200
		2	0	0	21	1011	30.7		
		3	0	1.7	19.2	1011	40		
		4	0	5.3	14.5	1011			
5-Dec-05	5	1	0	0.2	20.8	1002	27.5	0	0
		2	0	2.5	18.5	1002	36		
		3	0	0	20.9	1002	29.9		
		4	0	1.3	19.7	1002	32.4		
10-Jan-06	5	1						180	0
		2							
		3							
		4							
17-Jan-06	5	1	0	4.1	16	1005	32.4	625	150
		2	0	0	20.8	1005	30.8		

		3	0	3.5	16.9	1005	37.9		
		4	0	0	20.6	1005	32.2		
		5	0	13.2	9.8	1005	43		
		6	0	13	6	1005	39.8		
		7	0	22.1	16	1005	41.9		
		8	0	0	19	1005	39.9		
		9	0	0.5	20.2	1005	45.4		
24-Jan-06	5	1	0	8.5	11	1009	30	0	245
		2	0	8.1	11.5	1009	31.6		
		3	0	2.4	18.1	1009	38.5		
		4	0	6.1	13.1	1009	32.1		
		5	0	18.1	3.9	1009	40.6		
		6	0	11.1	9.1	1009	36.8		
		7	0	10	9.2	1009	39.7		
		8	0	6.9	12.7	1009	34.3		
		9	0	6.4	14	1009	43.4		
31-Jan-06	5	1	0	8.4	11.3	1008	31	0	0
		2	0.1	6.8	12.7	1008	31.2		
		3	0.2	2.7	17.5	1008	37.7		
		4	0.5	1.8	13	1008	32.3		
		5	0.2	13.8	4.2	1008	37.4		
		6	0.1	6.2	9	1008	33.5		
		7	0.1	5.5	11	1008	36.9		
		8	0.1	7.6	11	1008	34		
		9	0.1	10.8	7.5	1008	40.4		
7-Feb-06	5	1	0	6	13.1	1006	30.4	0	0
		2	0	0.6	20.1	1006	30.2		
		3	0	3	17	1006	36.5		
		4	0	0	20.7	1006	28.2		
		5	0	0.5	19.4	1006	40		
		6	0	2.8	14.9	1006	35.5		
		7	0	3.2	11.8	1006	38.4		
		8	0	0.1	20.2	1006	32.9		
		9	0	0.1	19.4	1006	41.9		
14-Feb-06	5	1	1.3	6.1	11.9	1005	32.3	350	0
		2		1.1	16.3	1005	29.1		
		3	0.2	0.2	18.5	1005	36.9		
		4	0.5	5	14.1	1005	29.9		
		5	0.1	12.7	5	1005	42.1		
		6	0.1	7.1	10.8	1005	34.9		
		7	0.1	11.6	8.2	1005	39.6		
		8	0.1	7.2	12	1005	36		
		9	0.1	6.1	13.2	1005	43.4		

21-Feb-06	5	1	0	1.5	19.6	1007	31.2	0	0
		2	0	0	20.8	1007	32.3		
		3	0	0	20.7	1007	35.8		
		4	0	1.4	19.7	1007	32.1		
		5	0	0	20.7	1007	42.6		
		6	0	0.1	20.5	1007	38.8		
		7	0	0.4	20.1	1007	41.1		
		8	0	3.5	16.9	1007	39		
		9	0	0.2	20.6	1007	44		
25-Feb-06	5	1	0	7.8	11.1	1001	31.7	90	1250
		2	0	7.7	11.3	1001	31.8		
		3	0	4.7	15.1	1001	36.9		
		4	0	7.3	11.6	1001	31.2		
		5	0	12.4	7.6	1001	40.4		
		6	0	6.5	12.4	1001	35.4		
		7	0	8	11.3	1001	38.3		
		8	0	3.9	16.1	1001	33.8		
		9	0	13.5	5.6	1001	41		
4-Mar-06	5	1	0	2.3	18.5	1021	32.5	50	25
		2	0	0.3	20.7	1021	25.5		
		3	0	1.1	19.8	1021	39		
		4	0	0	20.9	1021	21.6		
		5	0	0	20.8	1021	38.4		
		6	0	2	19.1	1021	31.1		
		7	0	0.1	20.8	1021	36.5		
		8	water	logged		1021	29.6		
		9	0	1.6	19.3	1021	35.3		
11-Mar-06	5	1	0.2	9.6	9.7	1003	35.3	400	50
		2	0.1	2.9	17.4	1003	29.7		
		3	0.1	0	20.9	1003	30.3		
		4	0.1	1.2	19.4	1003	30.3		
		5	0.1	5	15.3	1003	36.3		
		6	0.1	4.2	15.4	1003	36.3		
		7	0.1	4.1	15.8	1003	29.4		
		8	0.1	1.5	19.3	1003	32.9		
		9	0.1	4.9	14.7	1003	33.6		
18-Mar-06	5	1	0	5.8	13.5	1010	27.1	0	100
		2	0	5.8	14	1010	32.4		
		3	0	0.6	19.5	1010	37.7		
		4	0	4	15.8	1010	31.5		
		5	0	9.2	10.4	1010	38		
		6	0	7	11.9	1010	33.7		
		7	0	3.4	16.1	1010	36.8		
		8	0	5.8	14.2	1010	31.4		
		9	0	13.1	6.2	1010	39.5		

25-Mar-06	5	1	0	5.8	14.1	1010	27.5	0	25
		2	0	8.1	11.5	1010	31.5		
		3	0	5.2	14.5	1010	33.7		
		4	0	1.9	18.7	1010	31.5		
		5	0	10	10.8	1010	37.9		
		6	0	7.2	12.5	1010	34.2		
		7	0	3.2	17.3	1010	36.2		
		8	0	4.7	15.7	1010	32.8		
		9	0	13.4	6	1010	38		
1-Apr-06	5	1	0	9.8	9.8	1009	29.1	0	0
		2	0	6.8	13.1	1009	32.1		
		3	0	3.5	17.3	1009	33.8		
		4	0	7.5	12.6	1009	31.1		
		5	0	12.8	8.5	1009	38.4		
		6	0	9.7	10.2	1009	35.1		
		7	0	5.9	14.5	1009	37		
		8	0	5.9	14.6	1009	34.2		
		9	0	16	3.6	1009	39.4		
8-Apr-06	5	1	0	0	20.1	1010	28.5	0	20
		2	0	0.7	19.7	1010	29		
		3	0	4.4	16.8	1010	32		
		4	0	0	20.1	1010	23.5		
		5	0	2.8	16.7	1010	39.8		
		6	0	1	18.9	1010	37		
		7	0	0.7	19.3	1010	37.4		
		8	0	0.9	19.1	1010	34.4		
		9	0	0.8	19.2	1010	40.6		
15-Apr-06	5	1	0	0.4	20.1	1018	27.3	0	0
		2	0	1.6	19.7	1018	29.7		
		3	0	4.4	15.9	1018	30.7		
		4	0	2.3	18.6	1018	31.2		
		5	0	5.7	14.2	1018	38.6		
		6	0	1.3	19.2	1018	34.8		
		7	0	4.5	15.3	1018	36.2		
		8	0	0.3	20	1018	32.4		
		9	0	3.7	16.6	1018	40.6		
22-Apr-06	5	1	0	11.9	6.9	998	26.9	0	40
		2	0	11.6	8.9	998	30.5		
		3	0	10.8	8.6	998	31		
		4	0	9.4	10.2	998	28.9		
		5	0	15.9	4.5	998	35.9		
		6	0	12.5	6.5	998	32.4		
		7	0	9.1	10.6	998	34.2		
		8	0	7.5	11	998	30.3		
		9	0	15.7	3.4	998	38.4		

29-Apr-06	5	1	0	9.3	10.6	1007	28.8	0	20
		2	0	8.5	11.5	1007	30.7		
		3	0	2	18.8	1007	34.7		
		4	0	7.9	12.1	1007	30.2		
		5	0	12.4	8.7	1007	34.3		
		6	0	8.1	11.7	1007	30.4		
		7	0	5.1	15.2	1007	31.9		
		8	0	8.4	12.5	1007	28.2		
		9	0.1	14.7	5.2	1007	25.9		
6-May-06	5	1	0	10.3	9.2		25.2	0	30
		2	0	9.1	10.2		28.2		
		3	0	4.2	16.2		29.8		
		4	0	8.4	11.4		28.7		
		5	0	13.8	6.9		33.6		
		6	0	9.9	9.9		29		
		7	0	6.6	14		30.6		
		8	0	9.6	11.9		27.1		
		9	0	14.8	4.2		34.6		
13-May-06	5	1	0	9.2	12.9	1008	21	0	0
		2	0	8.2	12.2	1008	22.7		
		3	0	10.9	8.9	1008	24		
		4	0	15.3	5.5	1008	22.3		
		5	0	15.6	4.4	1008	24.5		
		6	0	14	5.5	1008	22.9		
		7	0	14.8	4.4	1008	25.7		
		8	0	13.5	6.1	1008	26.4		
		9	0	12.1	7.9	1008	24.7		
20-May-06	5	1	0	9.4	10.1	995	27.5	0	300
		2	0	8.8	11.1	995	29.3		
		3	0	7.2	13.1	995	29.1		
		4	0	7.9	12.5	995	27.1		
		5	0	13.2	7.6	995	32.4		
		6	0	9.3	10.5	995	29.5		
		7	0	6.6	13.5	995	31		
		8	0	10.2	10.6	995	26.6		
		9	0	13.6	5.9	995	33.7		
27-May-06	5	1	0	6.4	13.6	1003	26.8	0	25
		2	0	7.6	12.7	1003	27.6		
		3	0	0.8	20	1003	29.7		
		4	0	3.5	17.4	1003	27.4		
		5	0	10.4	10	1003	27.8		
		6	0	7.1	12.8	1003	25.9		
		7	0	4.4	15.9	1003	27.3		
		8	0	7.2	13.6	1003	23.7		
		9	0	11.6	7.8	1003	32		

3-Jun-06	5	1	0	10.6	11.2	1020	24.8	0	0
		2	0	5.4	15.6	1020	25.6		
		3	0	6	15.2	1020	25.5		
		4	0	0.3	19.9	1020	24.9		
		5	0	5.8	14.9	1020	27.4		
		6	0	16.8	6.2	1020	25.4		
		7	0	13.1	8.8	1020	26.5		
		8	0	15.2	6.2	1020	23.5		
		9	0	13.6	9.5	1020	29.4		
10-Jun-06	5	1	0.1	13.5	6.7	1010	24.1	0	0
		2	0	17.8	3.4	1010	24.5		
		3	0	19.2	3.5	1010	24.6		
		4	0	14.5	7.6	1010	24.7		
		5	0	15.3	4.9	1010	27.5		
		6	0	15	5.1	1010	26.2		
		7	0	12.4	8	1010	26.7		
		8	0	10.9	10.5	1010	23.6		
		9	0	13.1	6.7	1010	28.7		
17-Jun-06	5	1	0.1	14.4	6.9	1016	25.8	0	0
		2	0	15.3	6.2	1016	25.7		
		3	0.1	16	6	1016	25.3		
		4	0.1	16.3	5.7	1016	25.7		
		5	0	14.2	5.9	1016	28.6		
		6	0	13.9	6	1016	27.5		
		7	0	11.9	8.7	1016	28.1		
		8	0	4	15.1	1016	24.9		
		9	0	12	8.1	1016	29.8		
24-Jun-06	5	1	0	12.6	8.1	1018	25.7	0	0
		2	0.1	11.5	9.7	1018	25.3		
		3	0	14.8	7.5	1018	25.4		
		4	0.1	11.3	10.6	1018	25.6		
		5	0.1	13.5	6.2	1018	26.9		
		6	0.1	12	7.6	1018	25.7		
		7	0.1	9.6	10.5	1018	26.6		
		8	0.1	2	18.7	1018	22		
		9	0.1	12.4	7	1018	28.5		
1-Jul-06	5	1	0.1	13.6	7.6	1021	25.6	0	0
		2	0.1	13.7	7.8	1021	25.7		
		3	0.1	12.2	9.2	1021	24.6		
		4	0.1	11.1	10.3	1021	25.2		
		5	0.1	12.9	6.6	1021	27		
		6	0.1	11.9	7.4	1021	25.4		
		7	0.1	9.2	10.6	1021	25.6		
		8	0.1	5.3	14.8	1021	23.3		
		9	0.1	11.6	7.7	1021	28.6		

8-Jul-06	5	1	0.1	15.7	6.8	1021	28.3	0	0
		2	0.1	11.9	10.8	1021	27.5		
		3	0.1	13.7	8.2	1021	26.5		
		4	0.1	12.9	10.1	1021	26.5		
		5	0.1	11.9	9.1	1021	28.6		
		6	0.1	9.9	10.2	1021	27.3		
		7	0.1	7.9	13.1	1021	27.4		
		8	0.1	7.1	13.6	1021	24.7		
		9	0.1	9.1	11.6	1021	29		
15-Jul-06	5	1	0.1	15.8	6.6	1021	20.8	0	0
		2	0.1	13.2	9.5	1021	20.9		
		3	0.1	14.1	8.4	1021	20.5		
		4	0.1	15.2	6.9	1021	20		
		5	0.1	13	8.6	1021	22.9		
		6	0.1	10.6	10.7	1021	21.3		
		7	0.1	9.3	12.1	1021	21.7		
		8	0.1	3.2	17.2	1021	18		
		9	0.1	10.4	10.7	1021	20.7		
22-Jul-06	5	1	0.1	19.3	3.2	1005	22.2	0	0
		2	0.1	14.6	7.5	1005	21.1		
		3	0	14.2	7.9	1005	20.8		
		4	0.1	15.9	6.4	1005	20.3		
		5	0.1	12.9	8.4	1005	24		
		6	0.1	12.9	7.6	1005	22.8		
		7	0.1	10.6	10.3	1005	23.1		
		8	0.1	0.1	20	1005	19.7		
		9	0.1	13.3	6.8	1005	24.7		
29-Jul-06	5	1	0.1	13.7	8.0	1014	22.0		
		2	0.1	13.6	8.4	1014	21.2		
		3	0.1	15.8	6.6	1014	20.3		
		4	0.1	15.4	6.5	1014	16.6		
		5	0.1	12.9	8.1	1014	25.1		
		6	0.1	13.7	6.4	1014	23.5		
		7	0.1	11.0	9.7	1014	23.8		
		8	0.1	2.5	18.5	1014	22.0		
		9	0.1	12.7	7.8	1014	26.1		
5-Aug-06	5	1	0.1	16.2	6.3	1012	26.6		
		2	0.1	11.8	11.2	1012	25.2		
		3	0.1	16.2	6.4	1012	26.7		
		4	0.1	20.2	3.5	1012	26.2		
		5	0.1	10.5	10.6	1012	24.5		
		6	0.1	6.4	14.1	1012	24.5		
		7	0.1	4.5	16.4	1012	28.6		
		8	0.1	3.8	16.7	1012	25.4		
		9	0.1	6.6	14.2	1012	28.3		

12-Aug-06	5	1	0.1	20.7	1.3	1003	26.7		
		2	0.0	17.3	5.0	1003	26.6		
		3	0.0	12.0	10.0	1003	26.9		
		4	0.0	18.6	3.9	1003	26.1		
		5	0.0	13.7	8.9	1003	30.1		
		6	0.0	4.0	16.3	1003	28.2		
		7	0.0	5.8	14.7	1003	29.1		
		8	0.0	6.0	14.0	1003	26.4		
		9	0.0	7.3	13.7	1003	31.3		

Appendix 4 - Leachate Data

Date	DAYS	Cell No5 16 Weeks Treated MSW (global) from leachate							
		BOD5	NH3	Nox	C.O.D (mg/L)	T.S (g/L)	V.S (g/L)	pH	Cond. (mS/cm)
8-Nov-05	82	57.1	0.224	1.82	639.9	3.5693	0.8227	7.9	4630
19-Nov-05	93	48.2	0.812	1.724	732.3	3.5160	0.9547	8.11	4270
28-Nov-05	102	26.4	0.875	1.155	714.0	4.2000	1.0980	7.45	4410
10-Jan-06	145	21	0.238	1.043	318.2	2.0050	0.4830	6.68	2420
17-Jan-06	152	13.5	0.224	0.91	148.6	0.7720	0.2160	6.05	1223
14-Feb-06	180		0.161	0.329	190.5	0.6480	0.4700	7.37	883
23-Feb-06	189		0.343	0.833	1207.3	2.7340	2.034	7.54	3460
25-Feb-06	191	21	0.427	0.805		1.766	2.04	7.2	3720
4-Mar-06	198	7.1			1143.116	2.592		8.2	2750
11-Mar-06	205		0.203	0.574	1113.147	2.7580	1.922	5.66	2370

Date	DAYS	Cell No4 Control Leachate							
		BOD5	NH3	Nox	C.O.D (mg/L)	T.S (g/L)	V.S (g/L)	pH	Cond. (mS/cm)
8-Nov-05	76	413.0	2.079	0.273	2302.8	5.5107	1.7787	8.03	5730
19-Nov-05	87	188.5	1.365	0.273	1091.1	3.6293	1.0693	8.34	4230
28-Nov-05	96	124.7	2.191	0.315	1549.8	3.5920	0.9700	7.75	5560
10-Jan-06	139	47	0.21	0.644	152.3	0.8170	0.2310	6.87	942
17-Jan-06	146	17	0.168	0.392	107	0.4667	0.1720	6.14	719
14-Feb-06	174		0.147	0.385	199.1	0.5580	0.3860	7.13	713
23-Feb-06	183		0.623	0.301	1282.3	2.3700	1.7420	7.34	2970
25-Feb-06	185		1.043	0.448	1222.3	3.214	1.922	7.35	3270
4-Mar-06	192	16.2			837	2.41	1.922	7.91	1920
11-Mar-06	199		0.217	0.525	747.093	1.5320	1.1300	5.67	1997

Date	DAYS	Cell No3 8 Weeks Treated MSW (global) Leachate							
		BOD5	NH3	Nox	C.O.D (mg/L)	T.S (g/L)	V.S (g/L)	pH	Cond. (mS/cm)
8-Nov-05									
19-Nov-05									
28-Nov-05									
10-Jan-06									
17-Jan-06	30	9	0.182	1.127	178.3	1.1960	0.4107	6.64	1666
14-Feb-06	58		0.091	0.322	117.737	0.5320	0.412	7.94	693
23-Feb-06	67		0.133	0.728	464.525	1.7000	1.274	7.33	2080
25-Feb-06	69	7.4	0.189	0.749	586.543	2.5340	1.6880	7.40	2580
4-Mar-06	76	1.2	0.203	0.602	644.341	3.604	1.688	8.18	2010
11-Mar-06	83		0.154	0.686	423.852	1.5540	1.174	5.7	1889

Date	DAYS	Cell No2 16 Weeks Treated Fines Leachate							
		BOD5	NH3	Nox	C.O.D (mg/L)	T.S (g/L)	V.S (g/L)	pH	Cond. (mS/cm)
8-Nov-05	69	96.2	0.882	0.35	943.4	4.0907	1.6530	7.36	4850
19-Nov-05	80	46.8	0.553	0.917	740.2	3.2747	0.8840	7.93	4120
28-Nov-05	89	11.7	0.294	1.26	735.0	4.8580	1.6500	7.98	5050
10-Jan-06	132								
17-Jan-06	139	46.4			463.9	1.7960	0.5667	7.21	2400
14-Feb-06	167		0.119	0.364	460.243	0.9500	0.6980	7.84	1241
23-Feb-06	176		0.56	0.252	1162.382	2.8800	2.2660	7.22	3730
25-Feb-06	178	19.5	0.525	0.791	1170.945	4.0680	3.2540	7.55	4400
4-Mar-06	185	9.2	0.252	0.406	1209.477	3.604	1.638	7.9	2850
11-Mar-06	192		0.266	0.651	805.548	2.3980	1.8320	5.54	3020

Date	DAYS	Cell 1							
		BOD5	NH3	Nox	C.O.D (mg/L)	T.S (g/L)	V.S (g/L)	pH	Cond. (mS/cm)
14-Feb-06									
23-Feb-06	67	1.2	0.385	0.322	1158.101	2.1270	3.436	7.01	4570
25-Feb-06	69	32.75	0.728	0.553	1545.561	10.0020	8.53	7.17	4330
4-Mar-06	76	3.1			409.966	3.604	1.782	7.41	2280
11-Mar-06	83	0	0.112	0.553	451.681	1.954	1.542	5.46	2300