GARDEN REFUSE COMPOSTING AS PART OF AN INTEGRATED ZERO WASTE STARTEGY FOR SOUTH AFRICAN MUNICIPALITIES

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Submitted in fulfillment of the requirements for a research Masters of Science in Engineering in the Civil Engineering Programme, University of Kwa-Zulu Natal, Durban, South Africa.

December 2010 **Supervisor: Prof. Cristina Trois**

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As the candidate's Supervisor I agree/do not agree to the submission of this dissertation.

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PREFACE

The research presented in this dissertation was carried out under the supervision of Prof. Cristina Trois of the School of Civil Engineering, Surveying and Construction, University of Kwa-Zulu Natal, Durban, South Africa. This dissertation has been complied in accordance with *The Style Guide for Dissertations,* prepared by the Faculty of Engineering of the University of Kwa-Zulu Natal, Durban and represents work written by Loganathan Moodley, unless otherwise stated in the text.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Prof. Cristina Trois, for her continuous encouragement and professional guidance during the period of this masters research dissertation. Cristina is truly a supportive and dedicated individual whom has been patient and understanding throughout this research. Cristina, Grazie Millie!

To the team at the UKZN Civil Engineering Department a special thank you for their assistance with characterisation of the compost.

To my colleagues at DSW and my family, thank you for your loyal support during this period and allowing me the time to complete this dissertation.

Finally, I dedicate this work to my late dad, Jeffrey Moodley, dad you are not here but this is for you.

ABSTRACT

Garden refuse has been seen to constitute a significant proportion of the total waste stream received at landfills in the eThekwini Municipal Area (EMA). With the growing demand for conserving "precious landfill airspace" as a result of limited availability of land for new landfill development, there is a shift in the mindsets of landfill operators to adopt alternative methods of treatment other than the traditional way of landfilling. As a result composting of green waste stream was seen as the most appropriate treatment solution as not only would there be a direct landfill airspace saving but the added environmental, economical and social sustainable benefits to the city. The first South African Waste Summit saw the signing of the Polokwane Declaration i.e. "Reduce waste generation and disposal by 50% and 25% respectively by 2012 and develop a plan for ZERO WASTE by 2022". Hence, the push for composting to try and achieve waste reduction to landfills.

The Dome Aeration Technology (DAT) is an advanced treatment option for aerobic biological degradation of garden refuse (Mollekopf et al, 2002, Trois and Polster, 2006). The originality of the DAT system is the use of passive aeration brought about by thermal driven advection through open windrows which is induced by thermal differences between the composting material and the ambient atmosphere (Polster, 2003). Previous work on organic waste composting using the DAT on a small scale showed that good quality compost was attainable within 6 weeks of composting (Moodley 2005). This study offers comparative performances between DAT system and Traditional Turned Windrows (TTW) in composting garden refuse and recommending the most appropriate system for integration into existing landfill operations. Full scale windrows were constructed for each system at the Bisasar Road Landfill Site in Durban, Kwa-Zulu Natal to evaluate the influence of climate, quality of compost, operational requirements and feasibility.

The process monitoring for the DAT windrow showed that temperatures reached thermophilic ranges within a week of composting which confirms that of the German studies. Waste characterisation of both input and output materials are discussed for both systems with recommendations on the most practical and appropriate system applicable to that of an operational landfill are drawn. The study further concludes with potential uses of the composted garden refuse within landfill sites and its contribution to "closed loop" landfilling yet within an integrated waste management plan.

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LIST OF ABBREVIATIONS

Ammonia	NH_3
Articulated Dump Truck	ADT
Biochemical Oxygen Demand	BOD
Biological Treatment Process	BTP
Carbon Dioxide	CO_2
Carbon to Nitrogen Ratio	C:N
Chemical Oxygen Demand	COD
Commercial Garden Refuse	CGR
Dome Aeration Technology	DAT
Et cetra	etc
Front End Loader	FEL
Mechanical Biological Treatment	MBT
Mechanical Treatment Process	MTP
Methane	CH_4
Moisture Content	w
Nitrate	NO_3
Oxygen	O_2
Respiration Index	RI_7
Total Solids	TS
Traditional Turned Windrow	TTW
Volatile Solids	VS

CHAPTER 1
INTRODUCTION

Garden refuse or better termed "green waste" constitutes a large proportion of the total waste stream received at landfills in the eThekwini Metropolis and the City of Durban. The limited availability of suitable land within the eThekwini Municipal Area (EMA) for the development of new landfills has recently necessitated a shift in philosophy in line with developed countries to reduce the amount of waste destined to landfills. In particular, EMA has two landfills situated in close proximity to urban centres (Mariannhill and Bisasar Road Landfills) and this has contributed to high costs of waste disposal. A growing urban population is resulting in ever increasing volumes of waste and is significantly reducing the lifespan of these existing landfills.

1.1 MOTIVATION

The eThekwini area is situated in a sub-tropical climate with a multi seasonal vegetation growth zone that allows for green waste production to be seen as a resource rather than waste sent directly to landfill. A high volume of garden refuse is disposed at the Mariannhill and Bisasar Road landfills (13 000 tons/annum and 37 000 tons/annum respectively), which is currently being landfilled along with all other general waste types. The reduction of these volumes and the 're-use' of this waste type are seen as the first step towards sustained diversion of waste from landfill. Further to this, there is no proper waste separation of recyclable material at source within the eThekwini municipality and as a result it poses a difficult task to separate such mixed waste streams at landfills. Therefore the garden refuse waste stream was seen as an easy target to separate and treat. This allowed for an opportunity that the landfill operator could use to study and develop an integrated waste management solution applicable for landfill end use. The emphasis placed on this research was to formulate a modern waste management strategy that satisfies the eThekwini municipality's needs within an existing operational landfill.

The Department of Cleansing and Solid Waste, DSW, which is responsible for the waste management in the EMA is renowned both locally and internationally for an innovative approach to landfill management where waste disposal operations are integrated with landfill rehabilitation during the operational life of the landfill site. DSW uniquely rehabilitates its landfill sites by rescuing indigenous vegetation within the buffer zone and the waste footprint of the landfill property. A holding nursery was therefore created to store rescued indigenous vegetation from within the landfill footprint prior to lining works and consequent landfilling operations. The rescued vegetation has led to the creation of the Plant Rescue Unit (PRUNIT) which has proven to be both environmentally and economically successful (Parkin, 2006). This study was yet another motivation to innovate a green waste management strategy that could be linked into the PRUNIT concept for use of the composted green waste on rehabilitated cells of landfills and for propagating plants within the nursery.

Composting has been and is still being used to decompose or stabilise organic waste to produce carbon dioxide (CO_2), water (H_2O) and a useful less active product (Haug, 1993). Composting is used in households and solid waste management in order to convert ‘’green’’ organic waste into useful agricultural products such as compost, soil amendments or bulking agents. There have been numerous methods of composting and one of the first documented composting methodology dates back as far as the 1930’s (Golueke, 1972). Numerous methods from the primitive to the recent high technology systems of composting have actually shown the evolution and growth within composting industry. Recently, composting has attracted a lot of interest, for example in Europe, where, according to the Directive 99/31/EC, biodegradable components should be gradually diverted from landfills, necessitating the use of alternative Municipal Solid Waste (MSW) treatment techniques (Komilis, 2005). South Africa has recently opted to follow a similar path to achieve the requirements of the Polokwane Declaration i.e. “Reduce waste generation and disposal by 50% and 25% respectively by 2012 and develop a plan for ZERO WASTE by 2022”. Most areas are now adopting garden refuse composting as the first step towards the Polokwane’s targets. Compost plays an important role in agriculture whereby if prepared correctly; it is an environmental friendly product that can be used to reduce the cost and input of chemical fertilizers. When food crops are produced organically the use and role of compost becomes more important.

South Africa has a diverse use of composting systems from traditional static piles to turned windrows. The composting methods varies with the level of technology since higher level of technology requires higher capital investment but result in better control of the process and higher processing rates. Various types of waste pre-treatment techniques have been reviewed with particular focus on passive aeration in aerobic windrows. The Dome Aeration Technology (DAT) (Mollekopf et al. 2002, Trois & Polster, 2006, Trois et al, 2007) was identified as an appropriate technology for waste stabilsation in passively aerated windrows. This technique ensures full composting, complying with European standards, of municipal solid waste and garden refuse in three months with no turning. Mechanical biological treatment of solid waste reduces the environmental impact and potential for long term emissions. Aerobic treatment in passively aerated windrows applied to garden refuse composting has great potentials for resource recovery and high quality composts with reduced efforts. A comparative research on available waste treatment systems has highlighted that the DAT is appropriate for South Africa in terms of low costs, low energy inputs and potential for labour intensive operations. Previous research has proven the technology to be effective also for pine bark and garden refuse composting (Trois and Polster, 2006). However there is still the need to optimize this technology as part of full scale operations.

1.2 OBJECTIVES

The main objective of this study was to optimise full scale green waste composting as part of an established waste minimisation system in municipal landfills. The Bisasar Road landfill site was targeted as a suitable location for a pilot project to study the efficiency of various composting systems. The DAT and traditional turned windrows (TTW) treatment systems were chosen for comparative research. The aims in terms of achieving the objective of the pilot project are as follows:

- To establish a mechanical treatment operation for garden refuse at the landfill. Volume reduction particle size preparation of the garden refuse was seen as essential prior to biological treatment in windrows.
- To construct a DAT and TTW using the mechanically treated garden refuse for biological treatment.
- To carry out process monitoring of the each windrow to evaluate the operation of each windrow system.
- To carry out waste characterization evaluations on the composted product of each system at regular intervals in order to assess the quality of the compost.
- To evaluate and report on the operational costing of each composting system.

The second objective entailed determining the efficiency between the DAT and TTW and recommending the most applicable technology that could be integrated into current landfill operations. A further objective of the study was to recommend potential markets and re-utilisation of the composted garden refuse within landfill sites.

1.3 METHODOLOGY

A full scale test windrows of garden refuse was set up at the Bisasar Road Landfill Site, which is a site operated within close proximity to neighbouring communities and offered an appropriate case study for the use of the composted material. A mechanical treatment drop off facility was established for garden refuse. Full scale DAT and TTW windrows were constructed using the shredded garden refuse. Process monitoring such windrow temperatures and gas concentrations were monitored over the composting period to evaluate each windrow performance. Input and output material was characterized over the composting process inorder to determine the compost quality of each system. In particular output material was sampled at 6, 10 and 16 weeks respectively in order to fully evaluate the quality of the compost over the composting period.

1.4 EXPECTED OUTCOMES

The outcomes of this pilot study were to evaluate the efficiency of the DAT composting system compared to the efficiency of the TTW composting system and make informed recommendation for the most appropriate system for landfill applications. The implementation of the most appropriated system would enable the Department of Cleansing and Solid Waste, DSW to ensure cost effective and environmental sustainable waste management solution for garden resource other than landfilling. This dissertation comprises of a literature review chapter that details the fundamental background research and knowledge relevant to this research topic. The next chapter 3 describes the case study at the Bisasar Road landfill site which is followed by chapter 4 that being the materials and methods approach to the research. Chapter 5 presents the results and discussion chapter of the process monitoring, waste characterization and comparisons between the two composting systems. Chapter 6 is then followed with the conclusions and recommendations.

CHAPTER 2
LITERATURE REVIEW

2.1 OBJECTIVE OF COMPOSTING

The common objective of composting is to biologically convert organic waste i.e. garden refuse, putrescible (kitchen waste) and other similar "green" waste into a less active form and destroying pathogenic bacteria, weed seeds and plant causing diseases through sterilization (Haug, 1993). Therefore, general organic waste that is currently being landfilled together with all other waste streams can be utilised as a precious resource.

2.1.1 Waste Reduction to Landfill

Natural systems rely on plant matter "wastage" to ensure nutrients are returned to the soil profile through biological breakdown mechanisms in an unending cycle (Golueke, 1972). Composting therefore becomes an ideal process for converting such organics into an usable product and is now seen as a strategy to be used not only for reduction of waste to landfill but also as a solution to developing countries like South Africa in terms of sustainable development which includes job creation, poverty alleviation and ongoing education (Trois and Polster, 2006, Simelane, 2007).

Composting is a biological process and is affected by basic environmental conditions that influence the microbial activity (Golueke 1972, Palmisano 1996). This principle has to be combined with the current economic status of the country, community or municipality in order to choose the most appropriate technology for composting. The most common method of composting to on landfills is aerobic treatment (Morkel, 2006).

2.1.2 Emission Reduction through Composting

The present degradation of organic waste or biomass does significantly add to the production of Landfill Gas (LFG), which typically comprises a high percentage of methane (CH_4) which is a gas of significance in terms of Green House Gas (GHG) emission (Strachan, 2003). Clean Development Mechanism (CDM) is used as to combat climate change through projects that implement cleaner technology. A project carried out through aerobic treatment by composting would meet these requirements and be beneficial in qualifying for emission reductions from landfills (Parkin, 2006).

The objective of the project would be to set up a pilot composting facility to treat garden refuse and selected organic waste. In the context of the Clean Development Mechanism (CDM), the results quantify the certified emission reduction (CER) in terms of carbon credits that are based on the difference in greenhouse gas (GHG) emissions between the most likely future practices and proposed practice due to project activities (ISWA, 2009). By avoiding methane production (a GHG 21 times more potent than CO_2) through composting of organic wastes, and producing CO_2 (the less potent GHG), the project will contribute to a reduction in the impact on climate change and is therefore eligible for CDM registration. The application of composting to treated organic waste can contribute to avoided GHG emissions by approximately 60kg of CO_2 equivalent per tonne of biodegradable waste, (ISWA, 2009). On this basis, the proposed project would form part of the existing eThekwini CDM “gas to electricity” project since there is an expectancy to generate GHG emission reductions (ER) while complying with requirements of the CDM of the Kyoto Protocol (Strachan, 2010).

2.2 THE FUNDAMENTAL TYPES OF COMPOSTING

Composting can occur under two fundamental types either *aerobically (*in the presence of oxygen) or *anaerobically* (in the absence of oxygen). It is vital to understand the types of decomposition that can occur within a composting process.

2.2.1 Aerobic Composting

Aerobic composting is the degradation or decomposition of organic wastes in the presence of oxygen (O_2) and resulting in by-products such as carbon dioxide (CO_2), water and heat (Cekmecelioglu, 2005). Effective composting can be achieved through providing the optimum conditions for the bacterial population. These include moisture content, pH and carbon to nitrogen ratio to name a few and any change in the optimum conditions would significantly inhibit the decomposition process. There has to be an adequate supply of oxygen throughout the composting pile to ensure proper ventilation and this can be achieved by periodic turning of the pile, forced aeration e.g. pumping compressed air or passive aeration (Haug, 1993, Ekelund, 2007).

2.2.2 Anaerobic Composting

Anaerobic composting is the degradation or decomposition of organic wastes in the absence of oxygen (O_2) and resulting in by-products such as methane (CH_4), carbon dioxide (CO_2), other trace elements and organic acids (Cekmecelioglu, 2005). This method was traditionally used with animal manure and sludge composting. This particular type of composting process is relatively slow and can give off unpleasant odours and more importantly methane (CH_4), which is a potent greenhouse gas (GHG) (Das, 2002). It would follow from this that the use of this particular method would arouse concern by interested and affected parties.

The above two types of composting do achieve similar results but an evaluation the boundary conditions in terms of applicability, quality of the final product, available area, target market for the end use product and public perception. Nevertheless, effective composting can be achieved if the process is well managed and operated. For purposes of achieving a quick composting turn around rate and sterilisation through heat, an aerobic treatment would be most appropriate (Gray, 1971, Rasapoor, 2009).

2.3 COMPOSTING SYSTEMS

Composting systems are classified either as *reactor (closed)* or *non – reactor* (*open*) processes. Reactor processes or otherwise called “in – vessel” or “enclosed systems” revolve around process control and containment (Haug, 1993). On the other hand, static piles and windrows are typical examples of non-reactor systems and these are further classed according to their aeration principles i.e. natural or forced aeration. Figure 2.1 below illustrates the classification of the two composting systems.

The choice of the type of system to be adopted should be based not only on technical capabilities but also consideration should be given within the cultural, social and economic context with the aim of optimising the requirements of a modern waste management strategy (Cossu, 2009.) The selection of a type of system must be done within practical and financially viable limits i.e. a system should be designed or implemented to serve the purpose of the end compost market.

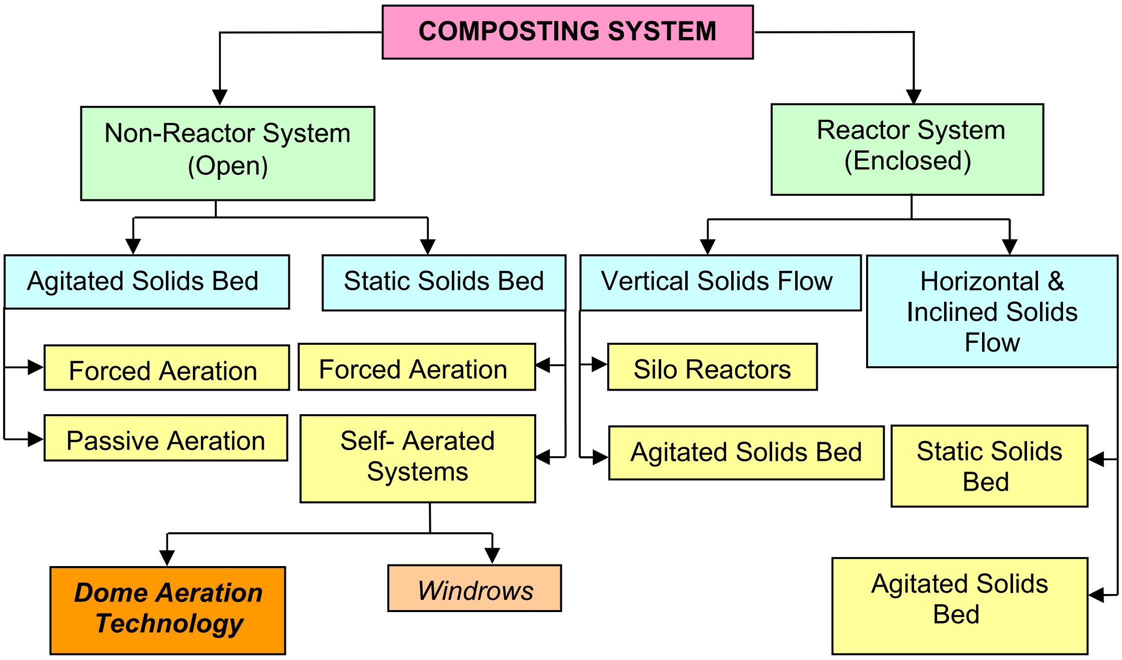

Figure 2.1: Schematic representation of the Composting Systems (Haug, 1993, Polster, 2003)

Modern technology and equipment will continue to enter the market in response to a growing interest in composting however they all in some way cover the basis fundamental concepts of composting (Haug, 1993). For ease of description, systems that consist of reactors are more commonly referred to as mechanical, enclosed or in-vessel and systems that consist of non reactors are called open systems.

2.3.1 Non – Reactor System

As depicted above in figure 1, non-reactor systems are divided into agitated solids beds and static solids bed. The term “agitation” refers to the infeed material being disturbed or distributed throughout the compost pile by either turning by hand or machinery. The description “open” refers to the fact that these piles are not housed inside a reactor or vessel specifically designed for composting. These types of systems are the traditional methods applied and are typically elongated piles or other known as windrows stacked after the input material has undergone particle size volume reduction (Elkind, 2000). The dimensions and geometry is often a function of the method of aeration (Golueke, 1972) as there are limitations of turning equipment and forced aeration. The follow are examples of typical “open” systems:

- Turned Windrow: This type of system is physically broken down and re-constructed which in an attempt to naturally aerate (supply oxygen) to the entire cross section of the windrow. Turning is commonly done using mechanical plant such as front end loaders, excavators, etc and is a function of the aeration requirements of the material being composted (Trois and Polster, 2006)

- Static Pile: This type of windrow is not physically broken and reconstructed as the method of aeration to the pile is in the form of forced aeration. Aerobic composting is still achieved by either by mechanical supply of passive aeration (Haug, 1993). Mechanical supply of oxygen is typically where piles are built on a grid network of perforated pipes or vented floor beds (concrete, asphalt, finished compost etc) (Defra, 2007). The grid network is in turn connected to a positive pressure device typically a fan/blower that forces air through the pipework and into the pile. Alternatively another common method of oxygen supply is through applying a negative pressure on the blower which effectively creates a suction effect of the ambient air around the pile thereby pulling air into the pile (Torr, 2009). The choice of such a system is dependent on the user and nature of the material. The passive aeration system is also a windrow that does not require demolish and rebuilt as oxygen supply is achieved through thermal gradients that induce a natural suction of ambient air from the surrounding environment into the pile i.e. the Dome Aeration Technology (DAT) (Polster, 2003).

2.3.2 Reactor System

The term “reactor” refers to the compost material being placed inside a vessel or container specifically designed for composting. This type of system is constantly being modified to suit optimum composting conditions but is nonetheless an advance in technology to compost using a modern approach (Haug, 1993). The emphasis on such techniques is placed on quality control of composting conditions i.e. temperature, moisture content, oxygen requirements, pH etc (Defra, 2007). This is typically a sophisticated expensive system which is commonly operated by computer control and ensures shorter duration of active composting followed by maturation on hardstands in the open environment (Recycled Organics, 2002). The application of such techniques is more used in commercial large scale composting facilities were emphasis is placed on productivity for economic return.

A typical example of such a system is the “in – vessel” method which is effectively an Advanced Biological Treatment (ABT) (Defra, 2007, Elkind, 2000). Modern in-vessel units are large scale rectangular divisions equipped with forced aeration equipment which either blows air or sucks air into the system. These structures can are designed as permanent or mobile units that are masonry structures. Vessels are either single or double ended for loading and unloading and the system works in batches i.e. all in and all out (Cekmecelioglu, 2005). Both oxygen and temperature are controlled by varying the amount of cool ambient air entering the system and any odours emanating through the process is passed through an exhaust gas scrubber or biofilter prior to release into the environment (Defra, 2007, Recycled Organics 2002).

2.4 BIOLOGICAL DEGRADATION

Composting has been seen to be a primitive technique that is defined as decomposition of heterogeneous organic matter by a mixed microbial population in a moist, warm and aerobic environment, (Van Ginkel, 2002). Indigenous Micro-organisms in the substrate use organic matter, minerals, water and oxygen for their growth and metabolic activity stabilising it to a humus type product, (Haug, 1993).

2.4.1 Types of Microorganisms

Most composting organisms fall into two general groups, namely:

- Microorganisms, and
- Invertebrates

Amongst the microorganisms, aerobic bacteria are most important in terms of initiating decomposition and heat generation (Gray, 1971). Bacteria can be best described as colorless organisms that cannot make their own food via photosynthesis and therefore they reproduce billions of offspring in a short space of time (Keeling, 1995). However they die within 20 to 30 minutes but within that short space of time, they are able to break down any type of organic matter (Palmisano, 1996, Das, 2002).

Typical types of bacteria are psychrophilic bacteria, which are energetic when a compost heap is first constructed (Polster, 2003). Most favorable activity occurs between 0 to 20 degrees celsius. This bacterial activity generates heat as a by-product and creates the phase for the most efficient decomposers namely the mesophilic bacteria (Maggs, 1984).

Mesophilic bacteria are most active in the pile when the temperature is between 20 to 40 degrees. Heat is then created when there is a fast decomposition of the material by these bacteria. When the temperature of the pile starts to increase, thermophilic bacteria start to take control at temperatures between 40 and 75 degrees and upper. Due to the intense heat during this phase, weed seed and pathogens die (Stutzenberger, 1991, Haug, 1993). The temperature profile of composting usually rises to thermophilc conditions and thereafter gradually decreased to mesophilic conditions resulting in changes in the bacterial population.

Other vital microorganisms in the composting process include actinomycetes and fungi (Golueke, 1972). Actinomycetes are tolerant of lower moisture conditions than other bacteria and are responsible for the release of geosmin, a chemical associated with the typically musty, earthy smell of compost. Fungi form their individual cells into long filaments called hyphae. Fungal hyphae are larger than actinomycetes and may be more easily seen with the naked eye (Das, 2002). They are famous in the advanced stages of the process and they become plentiful. Fungi are vital in the decomposition of cellulose, which is a more defiant part of the organic matter. Fungal hyphae physically stabilise the compost into small aggregates, providing the compost with improved aeration and drainage. Temperature is an important consideration as the fungi will die when temperatures approach 55 to 60 degrees (Stutzenberger, 1991). Fungi play a vital ecological role in the degradation of dead plant matter. The bodies of microorganisms, both living and dead form an important part of the compost product (Palmisano, 2000).

Figure 2.2 from Palmisano, 2000 below, clearly illustrates the three general categories populations of microorganisms that dominate the composting process.

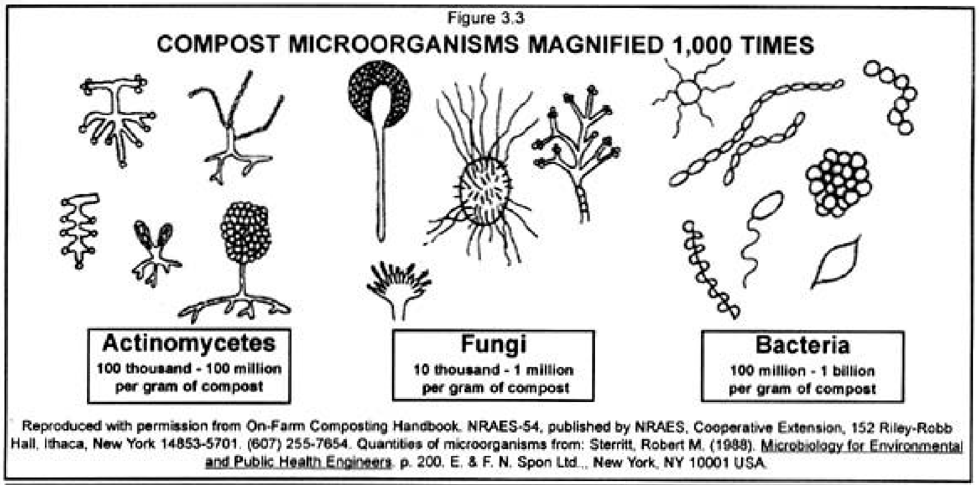

Table 3.6

MICROORGANISMS IN COMPOST

Actinomycetes	Fungi	Bacteria
Actinobifida chromogena	*Aspergillus fumigatus*	*Alcaligenes faecalis*
Microbispora bispora	*Humicola grisea*	*Bacillus brevis*
Micropolyspora faeni	*H. insolens*	*B. circulans* complex
Nocardia sp.	*H. lanuginosa*	*B. coagulans* type A
Pseudocardia thermophilia	*Malbranchea pulchella*	*B. coagulans* type B
Streptomyces rectus	*Myriococcum themophilum*	*B. licheniformis*
S. thermofuscus	*Paecilomyces variotti*	*B. megaterium*
S. thermoviolaceus	*Papulaspora thermophila*	*B. pumilus*
S. thermovulgaris	*Scytalidium thermophilim*	*B. sphaericus*
S. violaceus-ruber	*Sporotrichum thermophile*	*B. stearothermophilus*
Thermoactinomyces sacchari		*B. subtilis*
T. vulgaris		*Clostridium thermocellum*
Thermomonospora curvata		*Escherichia coli*
T. viridis		*Flavobacterium* sp.
		Pseudomonas sp.
		Serratia sp.
		Thermus sp.

Source: Palmisano, Anna C. and Barlaz, Morton A. (Eds.) (1996). Microbiology of Solid Waste. Pp. 125-127. CRC Press, Inc., 2000 Corporate Blvd., N.W. Boca Raton, FL 33431 USA.

Figure 2.2: Types of Microorganisms dominant during composting (Palmisano, 2000)

2.4.2 Composting Stages

The composting process occurs in different stages whereby temperatures and nutrient availabilities vary and this directly effects the microorganism development. Each stage follows from the next as "evolution stages" (following stage) are brought about the preceding stage being the substrate for the next (Cekmecelioglu, 2005). As discussed above, the process is bacteria indicated and can be best expressed by the following equation:

$$OrganicCompounds\left(OC \xrightarrow{O_2} CO_2 + heat + H_2O \right) \quad \text{Eq (1)}$$

Organic compounds are broken down in the presence of oxygen to form carbon dioxide (CO_2), heat and water (H_2O). Attention is drawn to the by-product heat in the above respiration equation as it is the thermophiles that degrade the organic matter.

According to Stutzenberger, 1991 and Haug, 1993, the stages of composting can be linked directly to the temperature regimes of the compost windrows.

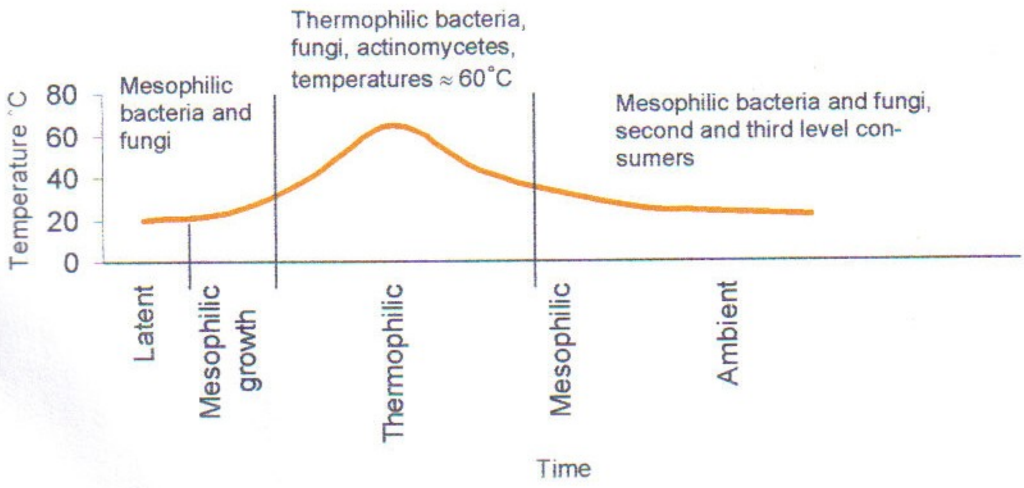

Figure 2.3: Stages of composting and microbial evolution (Polster 2003)

- **Latent Phase:** This is the first phase in process where the microbial population forms colonies in preparation of degradation. Temperature experienced is typical less tan 20^{o}C and dominated by mespohilic bacteria and fungi (Polster, 2003)

- **Mesophilic Growth Phase:** This phase continues with the accumulation of mesophilic bacteria for the degradation of readily biodegradable substances such as fatty acids, sugars and carbohydrates. Temperatures are typically in the range of 20^{o}C to 30^{o}C (Golueke, 1972).

- **Thermophilic Phase:** This particular phase allows for all first level consumers such as thermophilic bacteria, fungi, and actinomycetes break down higher-level substances such as cellulose and lignin, which are more resistant substances decompose. All pathogenic bacteria and disease causing viruses are sanitised as a result of extremely high temperatures reached i.e. in excess of 60^{o}C. This phase is known for its increased rate of degradation or high biological activity and ideally is the most suited range to hold for composting (Keeling, 1995). However, the key to prolonging this phase is to ensure that the windrow does not become too hot and desiccates i.e. excessive loss of moisture through transpiration which inhibits the biological activity (Stutzenberger, 1991).

- **Maturation Phase:** This is theoretically the last phase in the composting process as there is a decrease in the biological activity as a result to a drop in temperatures to that of the mesophilic conditions. Second and third level consumers can be found during this stage other than mesophilic bacteria that result in humification (Polster 2003). Nitrification reactions convert the materials in humus like substance that yields good compost (Keeling, 1995).

2.4.3 Composting Environmental Variables

Since composting is a biological process brought about by microbial action, an environment with optimum conditions is required for effective biological degradation. More importantly a conducive atmosphere needs to be set such that bacteria can easily thrive in and grow throughout the composting process. Environmental variables/parameters that are required to be controlled during the composting process are aeration, temperature, moisture content, Carbon to Nitrogen Ratio (i.e. nutrient balance), pH and the nature of the substrate. The following section highlights a brief overview of the contributions of the above mentioned variables:

- **Aeration** (Haug, 1993): Air is required for composting to satisfy three purposes. The first purpose is to balance the stoichiometric demand which is governed by the demand for oxygen through the decomposition of the organic matter. The second purpose is to satisfy the drying demand. This is utterly important in composting wet substrates as air is picks up moisture during composting and as a result dries the surrounding material. The third purpose is linked to the cooling process whereby hot exhaust air formed as a result of the composting process must be removed (Das, 2002).

  Air is constantly required to ensure aerobic conditions and avoid anaerobic areas that could lead to odour concerns. Aeration can be seen as a function of the composting technique or process applied i.e. oxygen supply varies from mechanical forced aeration to traditional turning of windrows. The amount of aeration required also varies with the physical and molecular nature of the input material (Golueke, 1972). In order to maintain aerobic conditions from a practical point of view, structural material is required to ensure varied particle size of material thereby allowing for voids/airpockets (Trois and Polster, 2006, Mollekopf, 2002). The added benefit to having structural (mix of particle sizes) is that it prevents collapse of the windrows and voids over time thereby maintaining aerobic conditions.

- **Temperature**: Amongst all variables, temperature can be view as one of the most critical parameter of composting. According to Das (2002) not only is microbial metabolism highly temperature dependent, but also the population dynamics (composition and density) of microbes are drastically influenced by temperature. As it can be seen from Figure 2.3 above, biological activity is a function of temperature. Seeing that the goal is to produce a high quality compost in the quickest way possible, temperature must be well managed. Previous studies have shown that temperatures below 20^{o}C have demonstrated slow composting as well as temperatures above 60^{o}C have also shown a reduction in biological activity and excessive temperatures above this show to impede the composting process. Previous work by Maggs, 1984 and Torr, 2009 show that the optimum range for composting is between 45^{o}C to 60^{o}C.

  Further to maintaining a balance in the optimum temperature regimes, is to ensure that all weed seeds and pathogens are destroyed. Elevated temperatures in the thermophilic range guarantee sanitisation of windrows. Local experiences by (Giffith, 2005, Moodley, 2006, Trois and Polster, 2006) showed that sweep out conditions were attained early on in the composting process i.e. windrow cooled quickly. One way of negating this problem is to ensure an adequate insulating layer over the composting material. This can be material such as pine bark or even finished compost.

- **Moisture Content**: Moisture content affects microbial activity and including the physical structure of the windrows in the composting process and therefore has a major influence on the biodegradation of organic materials (Ahn, 2007). Moisture within a compost windrow allows for dissolved nutrients required for the metabolic and physiological activities for microorganisms to be transported (Liang, 2002). Research has shown that there is no universally ideal optimum moisture content range that one can rely as materials vary in chemical and physical properties. Too much moisture within a windrow will hinder the aerobic composting process as air pockets amongst particles become saturated leading to anaerobic conditions. On the opposite end, very low moisture content will lead to early dehydration of the composting process thereby inhibiting the degradation. The general findings of previous local research have reported an optimum moisture content range of 40% to 55% as being suitable for efficient composting (Palmisano, 1996, Elkind, 2000, Das, 2002).

The aeration potential of a windrow can also affect the moisture content. An excess supply of oxygen into a compost windrow can lead to moisture loss that may negatively affect biological activity (Rasapoor, 2009). Therefore it is important to maintain optimum moisture content to achieve maximum biological degradation.

It should be noted that moisture content and aeration are to some extent interrelated. The rationale behind this can be best explained as during aeration whereby excessive aeration leads to air displacing the available moisture within the windrow i.e. too much oxygen can dilute the biological activity leading to sweep out conditions. Therefore it becomes of utmost importance to maintain recommended optimum moisture content ranges inorder to achieve maximum biological degradation.

- **Carbon to Nitrogen: Nutrient Balance:** The availability and amount of nutrients is a limiting factor in the composting process. The two critical elements are carbon and nitrogen for the supply of nutrients (Haug, 1993, Keeling, 1995, Anh, 2007). The microorganisms require carbon for their growth and nitrogen for protein synthesis of microbial cell matter. Substrates with rich or high nitrogen levels e.g. grass and food waste, nitrogen would be sufficiently available for the composting process without any supplementation (Haug, 1993). On the other hand, nitrogen poor or low levels e.g. branches and hardy organic species will hinder the synthesis process resulting in overall decomposition rates to decrease to that of the available nutrient balance, In such a case, nitrogen that is naturally available in lush green organic matter can be added to the composting blend to achieve maximum decomposition of the green waste at hand. The rate of decomposition is dependent on the balance of carbon to nitrogen ratio in the composting input raw materials (Moodley 2005).

  The ideal carbon to nitrogen ratio is 30 – 35:1(30-35 to 1) that represents 30 parts carbon to 1 part nitrogen (Recycled Organics, 2002). The rate of decomposition would reduce if the C: N ratio move away from the optimum ratio resulting in an increased duration of composting. According to Polster, 2003, the German composting standard classifies a good quality garden refuse compost with an average C:N ratio of 19 to 21. Ratios lower than this indicates that the compost is mature.

- **pH:** Is the measure of the concentration of hygrogen ions within a solution. A low pH is consider to be acidic as opposed to a high pH considered to be basic. During the composting process, the material will become slightly acidic and then return to near neutral conditions as stability is approached. Decomposition is most efficient between a pH of 6.0 and 8.0. If the pH is too high, nitrogen is driven off as ammonia. If the pH drops below 6.0, the microorganisms begin to die off and the decomposition process slows (Golueke, 1972). A high pH typically in excess of 8.5 will favour the conversion of nitrogen compounds into ammonia gas and thereby resulting in a nitrogen poor compost. This loss of nitrogen can result in odours but more importantly effects the C:N ratio and would be required to be adjusted by supplementing acid into the composting mix, Recycled Organics Unit, 2002). Figure 2.4 below can be used to describe the pH trend over time of a typical composting process.

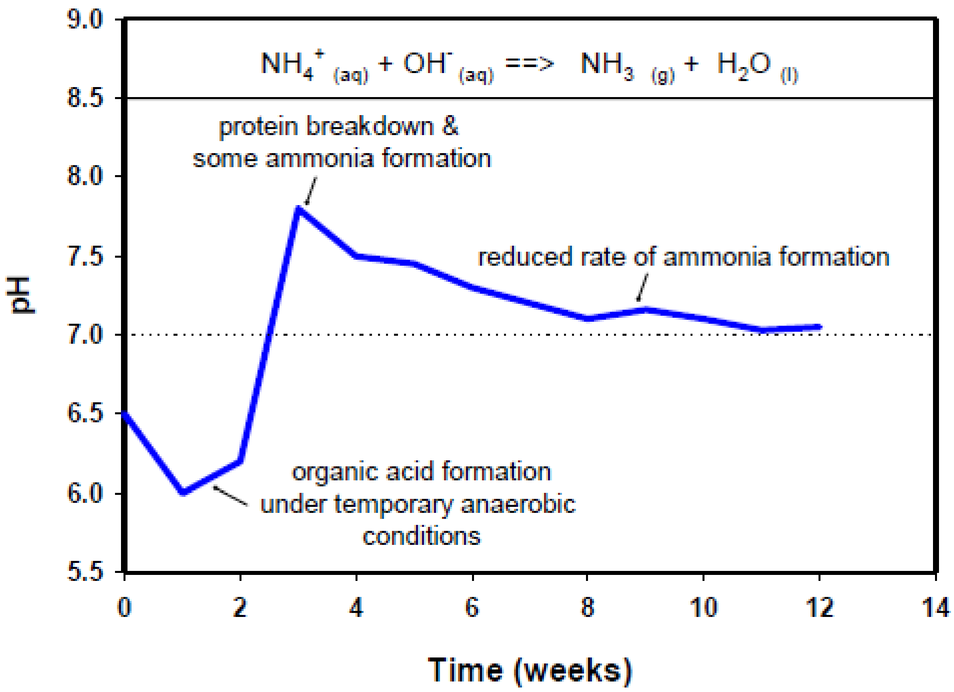

Figure 2.4: Typical changes in pH during the composting process (Gray, 1971)

In the initial stages of the composting process, the pH drops as a result of organic acids being released from the degradation of the green matter. Thereafter the pH gradually rises as the organic acids are being broken down and eventually reached a level that is neutral i.e. pH ~ 7 for the final maturation phase.

- **Particle Size**: The particle size required for composting is dependent on two criteria. The first criterion is the end compost market which would dictate the quality of the product and secondly type mechanical treatment required for a particular nature of input material. Once again an optimum particle size needs to be used just as having an optimum value for all other factors affecting the composting process. Relatively small particle size of organic waste allow for smaller surface area for the microorganisms to attack in – order to decompose the raw material. However, very small particle size would cause the organic waste particles to closely pack together thereby reducing the air pockets which would lead to anaerobic conditions. On the other hand, particle sizes that are too big would create a larger surface for the microorganisms to attack on and therefore the organic decomposition will occur at a very slow rate. On this regard an optimum range should be between 10mm to 50mm (Moodley, 2005). On a practical note, a heterogeneous or varied mix of particle sizes are required within a windrow to achieve structural integrity which will thereby ensure aerobic conditions are maintained and further negate the need to place efforts in reducing particle sizes to small as possible.

Table 2.1 below gives a summary of the optimum ranges for factors/environmental variables that effect green waste composting.

Table 2.1: Summary of Optimum Range of Factors Affecting Garden Refuse Composting (Haug, 1993, Moodley, 2005, Trois and Polster, 2006).

Influencing Factor	Optimum Range
Moisture Content	55% – 65%
Aeration	> 10%
Temperature	40ºC – 65ºC
Particle Size	10 mm – 50 mm
Nutrients: C: N	19-21: 1
pH	6 - 8

2.4.4 Aerobic Digestion

Understanding the biological process amongst the above discussion of the environmental variables is key in gaining an insight into the composting process, its process control and operation. Aerobic digestion merely refers to the biological degradation of green waste whereby naturally occurring bacteria use oxygen to convert the waste in carbon dioxide (CO_2), water (H_2O), heat, energy and more bacteria.

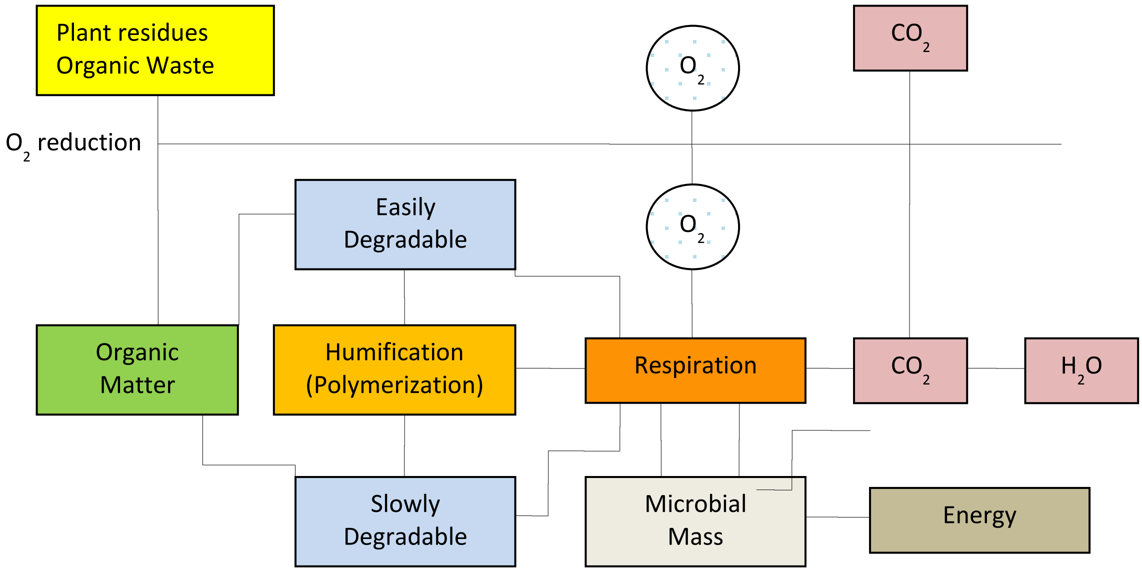

Figure 2.5: Aerobic Digestion Pathway (Ginkel, 2001).

Figure 2.5 above illustrates a typical respiration/digestion pathway of organic matter. Micro-organism consumes oxygen, nutrients and water to degrade a substrate. The products of this digeston are carbon dioxide, water vapour and heat energy (Keeling, 1995). Firstly, easily biodegradable matter is degraded and thereafter slowly degradable organic matter degraded.

The resulting CO_2 from the respiration indicated the kinematic of the respiration (Ginkel, 2001). The Micro-organisms culture changes with time, i.e. cultures die and form a substrate for the evolution of new cultures and throughout this development and nutrients are absorbed in the solution state through the cell membrane (Gray, 1971).

2.5 OVERVIEW OF MECHANICAL BIOLOGICAL TREATMENT (MBT)

One of the guiding principles in waste management has been the concept of a hierarchy of waste management options. These options range from the "most desirable" which is waste prevention i.e. not to produce unnecessary waste to the "least desirable" which is disposal of waste at landfill sites with no recovery of recyclable materials and energy (Defra, 2007). Waste managers are nowadays left to decide which treatment options are best suited for implementation between these two (2) ranges. It is out of this concept that waste strategies are developed to serve the ever changing markets e.g. Material Recycling Facilities (MRF's), composting plants, Construction and Demolition Waste Recycling, tyre recycling etc (ISWA, 2009). Other strategies may include for energy recovery from waste such as the local South African example of the Durban Landfill Gas to Electricity Project.

South Africa has seen the signing of the Polokwane Declaration in 2001, i.e. "Reduce waste generation and disposal by 50% and 25% respectively by 2012 and develop a plan for ZERO WASTE by 2022" (Griffith, 2005). It follows from this declaration that developing countries such as South Africa have realized the need the for alternative waste management strategies for dealing with waste inorder to conserve landfill airspace and prevent long term negative environmental effects. An efficient waste reduction mechanism can be realized through the introduction of Mechanical Biological Treatment (MBT) prior to disposal (Weichers, 2002), where the mechanical processing stage follows for materials recovery, while aerobic stabilization of organic waste has the potential for reuse as a compost. The MBT technologies adopted globally are merely pre-treatment options which allow for diversion of waste from landfill. This may form a link or part of an integrated waste management plan which might allow for further treatment (Defra, 2007).

MBT is a waste treatment process that is made up of numerous sub processes such as Materials Recovery Facilities, Composting, Aerobic/Anaerobic Digestion etc. As the terminology indicates, the first process is *mechanical* and the second is *biological*. Seeing that there are limited treatment and recovery of waste on South African landfill sites where waste is concentrated and contained results in long term environmental impacts (Bowers, 2002). There MBT plants can be used to pre-treat residual waste which reduces the negative environmental impact of landfilling. However, not all MBT plants may be applicable in the South African context due to high capital and operating costs resulting in the option being uneconomical. With the growing demand for environmental protection, MBT can be used locally as an opportunity not only to satisfy the environment but also to create job creation and provide skills development which is vital in making any project sustainable.

As waste management practices have evolved and awareness of the scarcity of natural resources has grown, there has been a major shift from a waste management to a resource management philosophy. Through material and energy recovery, waste is increasingly considered as a resource to be exploited. It would ten follow that MBT would be applicable to address this change in philosophy.

2.5.1 Objective of Mechanical Biological Treatment Processes

As mentioned above, the processes involved are mechanical and biological and it is through these options that benefits can be gained to an organization. The main objective to reduce the environmental impact and thereafter other related objectives (listed below) are gained through an integrated waste management system (Defra, 2007). The process is unique in the sense that it can be arranged or set up to serve an organization objectives and markets. These include the following:

- Pre-Treatment of landfill emission prior to disposal. Landfill emissions in question are biogas which is extremely explosive as well as having a climate change impact in the form of greenhouse gases and leachate which is a liquid emission that has the potential to contaminate the groundwater.
- Conserving precious landfill airspace through mechanical extraction of recyclable materials for re-use and energy recovery as a Refuse Derived Fuel (RDF).
- Conserving precious landfill airspace through composting of all biodegradable waste destined for landfill.
- Use of composted product after biological treatment for re-use on landfills or even put back into the commercial market.
- Production of high calorific value materials through drying for RDF’s.
- Combating climate change through aerobic composting which will ensure methane (CH_4) avoidance.
- Job creation of local unemployed community for poverty alleviation and skills development. Note this satisfy’s the social objective of the process which ensure sustainability.

The MBT plants can be designed to achieve any of the above objectives in any sequence required. The process can either separate the waste followed by biological treatment or alternatively biologically treat the waste (for emission stabilization) and then separate the waste for recovery which can be done by post screening. The integrated waste management plan will inform the MBT process as the process is highly sensitive output markets. Figure 5 below highlight a typical MBT process that can be adopted.

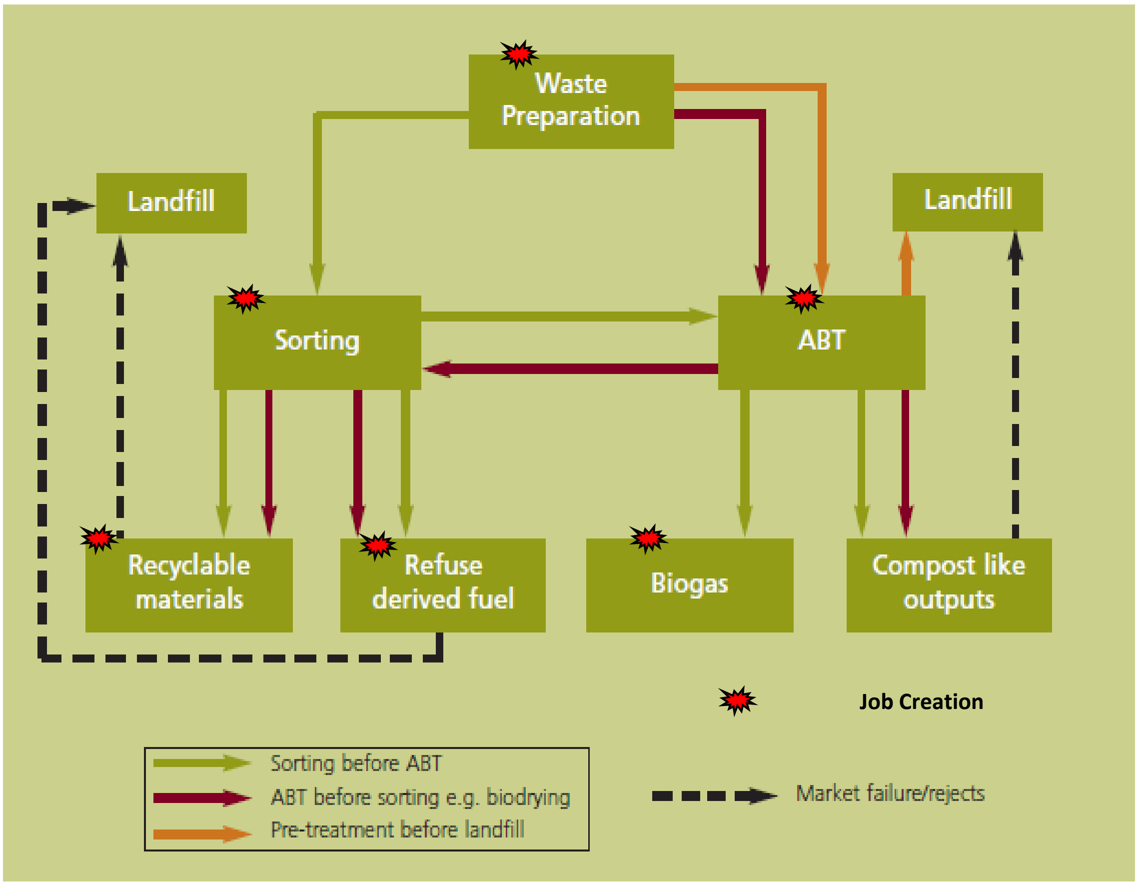

Figure 2.6: A Typical Mechanical Biological Treatment System (Defra, 2007)

2.5.2 Mechanical Treatment Processes - MTP

Since the operation is a two staged process, the first step is the mechanical preparation of the waste (Griffith, 2005). As depicted in Figure 2.6 above, the operations entails sorting of the materials for removal of useful fractions for end use and is the preparation for the second staged process which is the biological treatment. Typical waste preparation may involve bag breaking to expose waste within bags to assist downstream sorting. The waste preparations options can be adopted as part of the MTP are (Griffth, 2009, Defra, 2007, Strachan, 2010):

- Bag Breaker: A rotary drum system equipped with teeth to expose waste within bags whilst conserving the condition of the waste within.
- Rotating Drum or Trommel: Waste is fed through a spinning cylinder designed with openings suited to sort material by size and gravity. As material is passed, it is homogenized by tumbling and heavier items assist in breaking softer materials.
- Shredder: A machine equipped with hooks that turn at a slow speed and by the action of shearing manages to slice and rip materials apart
- Hammer Mill: Equipment that is designed to force material through a screen inorder to reduce particle size.

Following waste preparation leads to <u>waste separation</u> which involves the physical sorting of the homogenized material before biological treatment (Griffith, 2009). The sorting/extraction are highly dependent on the demand markets. In some cases there might not be any extraction as the process may directly be followed by biological treatment and thereafter disposal by landfill of treated product. Typical benefits of sorting allows for ease of material recovery, energy recovery and organic fraction separation for composting (Strachan, 2010). The <u>waste separation options</u> can be adopted as part of the MTP are (Simelane, 2007):

- Manual Separation: Labour intensive methods which would be ideal for South African markets. These are done by visual identification and extraction of materials according to market needs.
- Air Density Separation: Property of separation is based on mass of materials e.g. light such as paper, plastic, etc and heavy, glass bottles, high density plastics etc
- Magnetic Separation: Based on attracting ferrous metals onto a band magnets and discharges at a collection point.
- Screens and Trommels: Materials are sorted by particle sizes and fed onto conveyor belt network destined for extraction.
- Optical Separation: Materials are separated by diffraction such as polymers

2.5.3 Biological Treatment Processes - BTP

BTP allows for waste to be treated inorder to stabiles emissions prior to disposal or re-use as a compost like product. Typical types of biological treatment processes may include the following:

- Aerobic Composting: Is treatment of waste in open windrows with the supplementation of oxygen (turned windrows, forced aeration etc). Output material can either be disposed of at a landfill site or used as compost product.
- Anaerobic Digestion: Digestion in the absence of oxygen for e.g. energy recovery Aerobic In – Vessel Composting: Closed composting units with high technology to monitor and control optimum conditions for composting. This is a typical type of Advanced Biological Treatment as shown in figure 2.6 above.

The most commonly implemented biological treatment stage is the thermophillic aerobic composting whereby the degradable organic material is broken down in the presence of oxygen to form carbon dioxide and water vapour at high temperatures in the excess of 60°C (Paar 1999, Mollekoph, 2002). The quality of the treated product will depend on the type of treatment option, the waste preparation and separation (Oelofse, 2008). Often a low quality material may be attainable but markets can be secured such as use on landfill rehabilitated areas, nitrate removal from leachate, mulching agent for moisture retention in landscapes etc. Further to this, reference is made to figure 2.6 where the entire MBT process can be used as an opportunity for job creation. MBT plants in general can be used to accomplish environmental, financial and social sustainability (Simelane, 2007, Trois and Polster 2006).

An applicable MBT technique that has proven to be adopted in South Africa is the use of the Dome Aeration Technology (DAT) (Trois and Polster, 2006). The next section will review the use DAT in composting processes.

2.6 OVERVIEW OF THE DOME AERATION TECHNOLOGY – DAT

The Dome Aeration Technology is German engineered since 1993 and is based on open rotting windrow, which is applied outdoors. The main concept behind the principle relies on self-aeration i.e. a natural supply of oxygen throughout the compost heap. The self-aeration is achieved by installing specially developed devices in the windrow during construction that induces airflow throughout the internal cross section of the windrow (Mollekopf et al, 2002). An investigation into various waste pre-treatment and composting techniques has indicated that the DAT is appropriate for South Africa in terms of low capital costs, low energy inputs, limited plant requirements and potential for labour intensive operations (Simelane, 2007, Griffith, 2005). This method of composting is based on an open rotting system where the degrading material once constructed into a static windrow does not require periodic turning. As sighted in Paar, 1999, this open rotting windrow system is perfectly applicable to cases where longer composting times may be required. Seeing that the garden refuse received at most landfills are of a varied substrate nature i.e. wood species, organic rich species etc, would not necessarily compost quickly but rather require a longer duration. The originality of the DAT system similar to that of a *chimney principle* whereby a large void is created inside the inside the windrow which allows for accumulation of hot gases from the biological degradation process. Steel mesh structures termed domes and channels are used to allow for self aeration (Mollekopf et al, 2002, Polster, 2003). Figure 2.7 below illustrates a typical cross section of a DAT windrow.

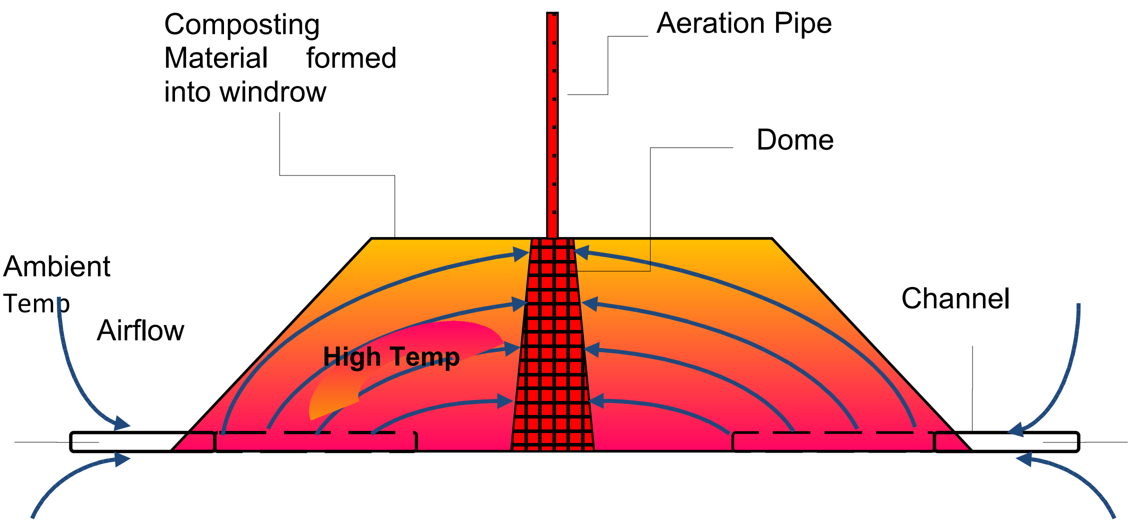

Figure 2.7: Typical Thermal flow of a Dome Aeration Windrow

The above cross section in Figure 2.7 shows the dome which is a steel mesh structure placed in the centre of the windrow along the entire length of the windrow. Two (2) channels also made up of steel and mesh structure are placed horizontally on each side of the dome and extends throughout the windrow length. Each dome is equipped with a PVC or HDPE (typically a 110 to160mmOD size) exhaust pipe which has a sampling point for process monitoring purposes (Paar, 1999, Polster, 2003). These open rotting windrows are typically covered by an insulating material such as matured compost, pine bark etc to prevent excessive heat loss and moisture retention.

Heat energy being one of the by-products of the biological reaction is dissipated within the windrow and as a result temperatures can be reached in excess of 65°C. The hot gases therefore accumulate in the domes and seeing that the temperature exterior to the windrow is ambient, this results in a temperature gradient between in the exterior and interior of the windrow. This change is temperature induces a change in pressure as the density of air is a function of temperature (Mollekopf et al, 2002) results in the self aeration of the windrow. One of the main advantages of this type of system is that works on a simple MBT process which using *low – cost technology* (Paar, 1999, Griffth, 2005, Griffith, 2009).

The German experiences show that DAT windrows are easily applicable for landfill use as available landfill plant such as front end loaders, excavators etc can be used for preparation and placement of input material into windrows whilst the initial stages of domes and channels placement can be done by local labour. Local experience by Polster, 2003 and Moodley 2005 showed that the preparation of the input material prior to composting is vital. A typical reason attributed to this is that once the windrow is constructed, it proves difficult to control moisture as no turning is required during the composting period and therefore material preparation prior to placement is essential.

It is important to note that the material porosity, particle sizes in terms of structural mass, and moisture content form links as factors affecting the biological exothermic reaction in conjunction with the principles of the DAT self aeration system. However, the application of the DAT through its self aeration can be used to satisfy a variety of markets. Such markets can be merely to compost and achieve a useful product which could be returned back into the environment or for pre-treatment of waste in general i.e. aerobic treatment whereby emissions are stabilized and then landfilled thereby reducing the risks related to landfilling (Simelane, 2007). This technology can definitely be integrated into an existing waste management practice for developing countries as not only does it have low energy input and equipment requirements but created opportunities for job creation through labour intensive construction of windrows.

2.7 GARDEN REFUSE COMPOSTING IN SOUTH AFRICA

Organic waste internationally such as food waste, bio-waste and garden refuse comprises approximately 30% to 70% of the total waste received at landfills (ISWA, 2009). South African metropolitan municipalities such as City of Cape Town, City of Tshwane, Nelson Mandela Municipality, Johannesburg Municipality, Ekurhuleni Municipality and eThekwini Municipality were estimated to have disposed some 8.9 million tones of municipal waste (Von Blottnitz, 2006). However, organic waste received at these landfills comprises some 40% (Greben, 2009). Generally landfilling this waste is seen as the most practical solution rather than diverting for treatment as there is a lack of funds to substantiate such project development let alone meeting basic service delivery such as waste collection and supply of clean portable water. On the contrary, limited availability of land for siting of new landfills as well as exiting landfills diminishing in airspace has recently forced municipal waste management philosophy's to that of working towards the principles of the Polokwane Declaration.

Since the main objective of the research was to optimise full scale green waste composting as part of an established waste minimisation system in municipal landfills, similar municipalities to that of eThekwini was research in terms of green waste treatment projects. Examples that were uses are the City of Cape Town and the Johannesburg Municipality as these are fairly large in terms service delivery areas.

2.7.1 Overview of the City of Cape Town Municipality

The City of Cape Town known to many as the "Mother City" of South Africa is estimated to have a population of some 3.1 million people with a approximate annual growth rate of some 1.6%. The city comprises of 81% formal sector and 19% informal from which it serves some 2.16 million tonnes per annum of which 86% is landfilled and 14% is reported to be recycled (Morkel, 2006).

The city experiences Mediterranean climate with hot dry summers and mild winters. The valleys and coastal plains experience an annual rainfall of 500mm whilst the mountain area receives some 150mm per annum. This type of climate is favourable for composting all year round however ho summer places demand on moisture supply for composting (Ekelund, 2007).

The overall landfill capacity for Cape Town as it currently stands (not including any extensions and designs for new landfills in the near future) is estimated to be some 8 years (Morkel, 2006). In view of the tremendous volumes of waste generated the operational cost to collect and landfill the waste and the limited available airspace, it has become essential to develop strategies aimed at waste reduction (City of Cape Town, 2004). As reported by Morkel 2006, Cape Town's total organic waste stream equates to approximately 40% of which majority is garden refuse. This waste stream was seen as ideal for forming part of a waste minimization initiative such as composting. The author undertook a technical visit to the city inorder to understand and learn from the city green waste management practices that could be used as a case study for recommendations to the eThekwini strategy. Interviews were conducted with municipal officials and composting plant operators and findings from the research visit is detailed in the next section.

2.7.1.1 Composting Project Overview

Lessons learnt from the Cape Town experience were that the organization is well trained in waste collection and disposal thereafter. However they lack the skill and resources to implement composting internally (Haida, 2006). On this basis, a decision was taken implement composting of green waste using a public private partnership whereby the municipality appointed different contractors to separate, chip and compost green waste. Three contractors were appointed through an open tender process to cover the city's service area.

Various garden refuse services are offered by the City such as acquiring and additional container at a cost, using a drop off facility or employing private contractors. Generally households rather bring their garden refuse to the garden refuse drop sites free of charge (Morkel, 2006). It is at these sites that the appointed private contractor separates chips and transports chipped green material for offsite treatment. These contractors are paid on a production basis i.e. tarrif charge bases on production of chipped green material. Site personnel at the chipping operations commented that there is often difficulty in sorting the green waste prior to mechanical treatment. Since the mechanical treatment operational costs are relatively high of some R280 – R480 per tonne, a third of the incoming material is send back to landfill for disposal (Ekelund, 2007). The implementation of the project realizes a landfill airspace saving of 705 $000m^3$ i.e. diversion of garden refuse waste from landfill (Morkel, 2006). Should one factor in a conservative approach of $R150/m^3$ equivalent airspace saving, then the city effectively saved some R8 million from diverting green waste for composting. Another interesting observation made was that the mechanical treatment reduces the volume of the green waste by a factor of 4. Plates 2.1-2.4 below illustrate the operation at the Wynberg Garden Refuse Drop off Facility.

Plate 2.1: Garden Refuse Drop Area where the public can utilise

Plate 2.2: Mechanical Treatment of Garden Refuse using a Tub Grinder

Plate 2.3: Manual Sorting of contamination

Plate 2.4: Typical offsite Composting

2.7.1.2 Reliance Composting Operation

Reliance is one of the appointed commercial enterprises appointed by the City of Cape Town for the mechanical treatment of garden refuse at four of the city's garden refuse drop off facilities. These include Gordons Bay, Killarney, Morningstar in Durbanville and the Wynberg site that was visited by the author. All volume reduced green material is transported to the Karwyderskraal landfill for biological treatment in open rotting windrows. Reliance is well known for grape farming for the international market and started marketing their produce as organic through composting of garden refuse (Ekelund, 2007).

- **Biological Treatment**

Chipped garden refuse delivered from above mentioned garden drop off facilities equate to some 500 000m^3 of green waste received annually for treatment (Kotze, 2006). There are times when fruit and vegetable waste from local agricultural farmers are added to the process. Although Reliance claim to produce organic compost as sighted in review by Ekelund, 2007, inoculums i.e. microbes are added to the chipped green material. The material is then wetted, homogenized and placed into 1.8m high traditional open rotting windrow. The biological treatment undertaken is aerobic as windrows are regularly monitored and process monitoring parameters such as temperature provide guidance to the operator in the turning intervals. Turning of windrow and wetting are done mechanically using a straddle turner driven by a tractor (Ekelund, 2007). Discussions with the general manager of the composting operation showed that biological treatment in windrows is typically 8 weeks followed by screening of composted material into different market sizes. Mechanical treatment of garden refuse is limited by the type of machine used as the nature of the material are not always suited for volume reduction i.e. fibrous materials and this in turn has an effect on the biological treatment (Kotze, 2006). Optimum conditions prove a challenge to control as windrows typically dry out too quickly in summer or become saturated in rainy season (Moodley, 2006). A nearby dam is the main source of wetting for biological treatment and sample batch testing is undertaken at onsite laboratory for ease of management of the windrows and quality control.

- **Established End Use Markets**

Seeing that there is no local legislated guidance on the quality standards for compost, Reliance therefore markets their products in terms of Plant an Soil Feed (Kotze, 2006). Other market niches include lawn dressing that is typically supplied in bulk to landscapers, soli conditioners for nutrient depleted soils, potting soil for growing mediums and mulch for landscaping and moisture retention. Products are sold in bulk per cubic metre and prices range from R50/m^3 for mulch to R145/m^3 for compost potting soil.

2.7.1.3 Earth to Earth Composting Operation

Another one of the contractors appointed by the City of Cape Town for chipping and composting of garden refuse is Earth to Earth. This is one of the umbrella companies under the international Interwaste Group. The enterprise is responsible for mechanical treatment of two garden refuse drop off facilities whereby chipped garden refuse either sent for offsite composting or alternatively sold to commercial composters for composting. All incoming fine green particle size material is diverted from chipping and added directly to compost piles (Ekelund, 2007).

- **Biological Treatment**

Following mechanical treatment, chipped green waste is mixed with urea and allowed to compost in open rotting windrows. An approximate chipped volume of 72 000m^3 is produced annually from the two sites. Windrows are constructed using a front end loader and only turned and water after some 3 weeks of composting. The operators do not use any process monitoring to assist with decisions required for composting. Reasons attributed to this are due to limited space, equipment and personnel in managing the operation (Ekelund, 2007). The maximum duration allowed for composting on this site is 15weeks and product is sold in bulk to the public but mainly landscapers.

- **Established End Use Markets**

The composted product is believed to be low in nutrients and on this basis is not registered as a fertilizer. Products are sold relatively fast as the selling price is lower than that of other commercial compost producers (Ekelund, 2007). Prices range from R90/m^3 for compost to R120/m^3 for mulch. As noted above, chipped garden refuse also has a market and is sold directly to other large scale composting facilities. This is often the case as composters realize that operational costs of mechanical treatment are usually high such as fuel, wearing parts, downtime etc and on this basis rather purchase feed material and concentrate efforts on favouring optimum composting conditions i.e. moisture supply, aeration, temperature control etc. As this will ensure better quality compost and hence increased profits from the sale of the product (Moodley, 2006).

2.7.2 Overview of the Johannesburg Municipality

The municipal city's land area of 1,645 km2 is one of the largest when compared to other cities, has houses some 3 million people (Pikitup, 2007). Johannesburg is the economic hub of both South Africa and neighboring Africa countries. Temperatures in Johannesburg are usually fairly mild due to the city's high altitude and annual average rainfall is 713 mm which is mostly concentrated in the summer months.

The Johannesburg municipality waste management is operated by Pikitup Johannesburg (Pty) Ltd whom has been involved with treating garden refuse and selected organic waste into compost with the full scale launch of the Panorama Composting Plant in Roodepoort. The operation was commissioned during September 2005 and has recently expanded their composting operations to other garden sites. Pikitup claims to firstly “recycle” green waste and secondly preventing the common practice of disposing of green waste at Pikitup’s landfill sites. Amongst the composting operation underway, Pikitup has 12 waste management depots strategically located throughout the city, 33 garden refuse sites, four landfill sites and one incinerator.

- **Biological Treatment**

The author visited the Pikitup operation in December 2006 to investigate the Johannesburg green waste treatment strategies. It was learnt that Pikitup enforced a “Zero Greens to Landfill” campaign whereby garden refuse was accepted free of charge only at garden drop off sites. Emphasis was placed on volume reduction of green material before transferable to satellite composting site (Venter, 2006). A typical garden refuse site was visited and all incoming garden refuse from the public was stockpile and fed into a low speed shredder using a TLB machine.

The shredded material was discharged directly in to open containers which are operated on a dolley system i.e. a container management system that allows at all times to have a container ready to be filled. The shredder is procured on a supply and operate tender with Plant Africa and this type of mechanical treatment yields a volume reduction from 40~60% (Venter, 2006). Plates 2.5 and 2.6 below illustrate the mechanical treatment at Pikitup’s garden drop off sites.

Plate 2.5: Shredding of Garden Refuse

Plate 2.6: Dolley Container System

All mechanically treated material is transported by Pikitup operation to the Panaroma Composting Facility for biological treatment. The facility also receives bulk garden refuse (no volume reduction) from public and garden cleaning contractors. All untreated material is diverted to a designated area onsite for mechanically treatment. Pikitup had purchased two large high speed shredders through an open tender process (Llyod, 2006). The shredders are fed using a front end loader and shredded material is thereafter homogenized, wetted and placed into open rotting windrows 4m wide by 1.5m high. These windrows turned regularly turned with a windrow turner that caters for water input as well as the addition of microbes. These turners are 4 meters wide by 1.8 m high fitted with 102w Diesel with all hydraulic drives (Moodley, 2006).

The windrows constructed were dry and in need of additional moisture, irrigation systems were installed in an attempt to deliver a trickling moisture supply but it was discovered that the plant has been experiencing problems with maintaining optimum moisture conditions for composting (Shoemaker, 2006). The self-propelled turner can cover a distance of 300m per hour. The purpose-designed rotor lifts fluffs and turns the compostable material as it is driven along. This ensures for aerobic composting and also cools down the microbial activity to an optimum level. Another point to note is that all the components are manufactured in South Africa and there would be availability of spares for maintenance. After the composting time which is typical 16 weeks, the product is put through drum screen to filter out material that has not composted, and deposited into a stockpile where it is taken for bagging and bulk (Moodley, 2006). The compost has been registered with the Department of Agriculture as a Group 2 fertiliser and is screened into different particle sizes for sale to the public. The compost was branded and marketed as Pikitip – Compost either sold in bags or in bulk. Plates 2.7, 2.8 and 2.9 below illustrate the turning, screening and bagging process respectively.

Plate 2.7: Turning & Wetting of Windrows

Plate 2.8: Screening of Compost

Plate 2.9: Bagging Machine of Compost Final Product

- **Established End Use Markets**

As mentioned above that the compost is registered by the Department of Agriculture as a Group 2 fertiliser. According to Shoemaker, 2006, there is an increased demand for compost and mulch in industry and the Panaroma Composting Site is trying to keep up with demand. Prices range from R100/m^3 for compost to R120/m^3 for mulch. Majority of the products are sold in bulk for use in sport fields, landscaping, and commercial developments etc (Moodley, 2006). It was noted that there was a higher demand for the mulch category product and the reason for this is due to the dry climatic conditions where the application of mulch assist in the vegetation moisture pretension. The Pikitup composting team did stress the challenges faced with maintaining optimum conditions for composting and were in progress of looking at alternative options for easy of controlling these conditions. There are future plans of adding other organic waste streams to garden refuse composting such as vegetable waste to the windrows and results from this research may affect end markets (Shoemaker, 2006).

2.8 LEGISLATION ON WASTE MANAGEMENT IN SOUTH AFRICA

2.8.1 Environmental Regulations and Acts

Waste has grown to become one of the most talked about issues globally as the boom in economic development has resulted in different waste sectors i.e. industrial, commercial, hazardous, energy generation etc contributing to such growth. Waste needs to be managed according to the following principles (Fiehn, 2005):

- Accountability
- Affordability
- Cradle to Grave Management
- Polluters Pay
- Sustainable Development
- Integration
- Waste Minimisation
- Co-Operative Governance and
- Environmental Protection

In the South African context, the above principles are regulated and managed under the National Environmental Management Act (NEMA), the Environmental Conservation Act (ECA), the National Water Act (NWA), the Minimum Requirements for Waste Disposal by Landfill and the Waste Bill. These acts all consider the term waste as an unwanted superfluous item that by nature has a polluting potential to the receiving environment (Oelofse, 2008). In particular, the Minimum Requirements for Disposal (DWAF, 1998) stipulates that waste is highly toxic until proven otherwise. This often restricts the recovery of resource material as there are long winded administrative delays in delisting wastes with the relevant authorities. According to Oelofse, 2008, whilst the ECA allows and promotes for resource recovery, re-use etc, permit applications still have to be made with the DEAT which often can be a lengthy and bureaucratic process. On the contrary, this lengthy process can be avoided as recycling, composting etc can be uniquely implemented at permitted landfill sites since the operating permits would make allowance for including such projects within the footprint of the site (Moolman, 2010).

There can be much debate on the governance of the above mentioned environmental regulations and acts but the main objective is to have reasonable legislation to have a protected environment. Moreover, emphasis is placed on pollution prevention, ecological degradation prevention, conservation promotion, secure ecological sustainable development and conserves natural resources (Torr, 2009).

2.8.2 Composting Legislation on Green Waste

Composting activities can have the potential to have negative impacts on the receiving environment if not carefully managed and operated. It would follow then that there should be specific environmental guidelines or legislative framework written around composting of green waste by authorities. Unfortunately there is no specific environmental legislation pertaining to treatment of such waste streams (Moolman, 2010).

2.8.2.1 Adverse Impact on the Environment

A typical open rotting windrow process can threaten the environment in the following three ways (Ekelund, 2007):

- **Groundwater contamination**: The liquid emission from the composting process is termed leachate which is toxic by nature, (Robinson, 1993). The characteristics of the green waste leachate contain for e.g. a high Biological Oxygen Demand (BOD) which if discharged into a natural water course will deplete the receptor of dissolved oxygen leading to destruction of aquatic life. A further common leaching characteristic of green waste is nitrate which has adverse effects to the users of groundwater.

- **Atmospheric pollution**: Should the composting process turn anaerobic, then the gaeous emissions emitted from the process will adversely affect the atmosphere, (Strachan, 2003). The resulting methane (CH_4) is a greenhouse gas (GHG) that is 21~25 times potent to that of carbon dioxide (CO_2) and proven to effect climate change. Apart from the CH_4 emission are the dust and odour issues resulting from lack of management on the process. There is also indirect emission pollution from the plant used in the processes of the compost.

- **Soil Pollution:** There is also risk of contamination of soils through metals and Persistent Pollutants, such as polychlorinated biphenyls (PCB's), pesticides and polycyclic aromatic hydro carbons (PAHs). The compost could contain PCBs if the waste material included treated wood. If the waste includes foliage that has grown close to heavily trafficked roads the produced compost may contain PAH's. These contaminants are relatively harmless in small amounts however the long-term application of these composts could cause an accumulation of metals and Persistent Organic Pollutants that could degrade the quality of soil.

Seeing that there is no legislation on composting, the above adverse impacts can be managed through an Environmental Impact Assessment (EIA) which is detailed in the next section.

2.8.2.2 Overview of Environmental Impact Assessments (EIA's)

South Africa has compiled a strong legal framework to ensure that all development is biophysically, socially and economically sustainable (Diederichs, 2009). A legislative management tool in achieving this is the national Environmental Impact Assessment Regulations which lists a range of activities that are known to have a detrimental effect on the environment if not managed properly. The role of the EIA is to access if the activity can avoid against such detrimental impacts.

The EIA is also used to satisfy the constitutional rights as all South African citizens have a right to live in protected environment which is free from harm to human health (DWAF, 2005). The process evaluates both positive and negative impacts which are presented to environmental decision makers regarding the developments sustainability and resulting acceptability or not. EIA's pertinent to composting activities mainly take into account the environmental impacts and more detailed focus on construction and monitoring (Ekelund, 2007). Relevant mitigation measure to the potential adverse impacts i.e. windrows to be constructed on hardstands with catchment controlled areas for managing contaminated runoff or anaerobic conditions can be avoided through forced aeration etc. It should be noted that it is a legal requirement to comply with the EIA regulations as perpetrators are liable for fines or imprisonment (Diederichs, 2009). The regulation also considers factors such as job creation by implementation on an activity as it assists in avoiding negative economic impacts. In effect through composting activities, social upliftment can be achieved which makes it sustainable for developing countries like South Africa (Moodley, 2006). In general, the EIA Regulations is a holistic assessment of the impacts on the environment affected by the activity and even used to integrate information and knowledge.

2.8.2.3 Compost Standards

It is a proven fact that different types of composting methods will affect the quality of the compost product. Ideally the quality of composts is set aside by a set of guidelines or standard. Once again South Africa does not have a standard for composting of green waste (Moolman, 2010). Standards are vital in environmental and consumer protection and international experiences shown that the different classes of compost and its corresponding standard legislative standards and quality assurance tests (Fiehn, 2005). Previous research by Moodley, 2005 has shown that most local composting operations rely on international standards for guidelines or alternatively large scale composters register and get compost products classed as a “fertilizer” through the Fertilizer, Farm Feeds, Agricultural Remedies and Stock Remedies Act.

At this stage the relevant authorities state that although there is no specific guideline or compost standard for green waste compost, one can refer to the Guidelines for Utilisation and Disposal for Waste Water Sludge (Moolman, 2010). The guidelines cover criteria such as safety, health risks and minimum acceptable concentration for parameters. There is still much work required in the industry from a scientific biological point of view in setting local standards for green waste composting and in blessing the push for alternative waste treatment in South Africa would lead the industry in setting such specific trends in the near future.

2.9 TYPES OF MECHANICAL TREATMENT

Particle size reduction can be achieved by different types of mechanical treatment which are characterised by the modus of mechanical operation. The term “shredding” is most commonly used in size reduction of refuse (Trois and Polster, 2006). The following are examples of the volume reduction equipment used in the industry for green waste:

- **Wood Chippers**: Are designed to feed garden refuse into a feed-chute manually. Additions can be used place mechanical grab which will in essence pick the garden refuse and then feed it into a the chute. Chip sizes range from 5mm-35mm particle sizes. A large model is recommended in terms of a composting operation at a landfill that takes in excess of 70tons/day. These units can be self propelled or towed and the principle behind the volume reduction works on a fly wheel equipped with wearing knives that chip or slice the garden refuse. The application of this plant is predominately used for creating a mulch type product or fuel feeding into a process e.g. wood chip for boilers etc (Kotze, 2006). In general the wearing costs of the plant can be high is not managed adequately as care is required in what types of material and how it is fed through. The operations can be very labour intensive.

- **Shredders**: This particular machinery is more commonly used in composting operations globally. There are two basic types namely slow and high speed shredders. Shredders are ideal for handling contaminated material and more so capable of reducing oversized material (Llyod, 2006). The units can be configured to suit any type of operation but in general has either a vertical or horizontal chute that leads to a hammer mill set up that forces material through a set screen size. Screen sizes can be changed to accommodate the type of output particle size distribution but this directly effects the production of the shredder i.e. a smaller screen will ensure a lower production with a higher wearing cost. Units can be operated remotely and installed with sensors that automatically adjust feed to suit hammering process (Morkel , 2006). Units can either be installed with tyres or on tracks which is more suited for use on landfills due to the risk of punctures and agility on wet platforms.

- **Tub Grinders**: A tub grinder is similar to the shredder's hammer mill operation but instead has a rotary in-feed hopper. The principle behind this operation is that the hammers located in-between the rotary hopper and shaft whereby material is grinded by action of the hammers into a screen (Venter, 2006). This is one of the most commonly used equipment in the garden refuse composting industry (Polster, 2003) due to its high production rates. However, it can be limiting as foreign objects can jam the feed resulting in downtime and safety issues (Kotze, 2006). On the other hand, operating costs are extremely high as steel parts, conveyors belts, hydraulic components etc need constant maintenance. Therefore, waste sorting is vital prior to feeding a tub grinder as it will not only reduce maintenance costs but also allow for a much cleaner garden refuse product to biologically treat. Units are operated remotely and has automatic cut off sensors for safety concerns. Similar to the shredder, tub grinders can also be equipped with tyres or tracks.

CHAPTER 3
THE BISASAR ROAD LANDFILL SITE – A CASE STUDY

3.1 INTRODUCTION

Garden refuse constitutes a large volume of the total waste received at landfills in the eThekwini municipality. Recent airspace calculations show that the Bisasar Road Landfill Site is drastically running out of airspace. It is anticipated that March 2013 is the approximate timeframe for the site to reach full design capacity and this in turn places extreme pressure on the city from a waste management point of view. As a result there has been a shift in the philosophy of thinking to that of reducing waste to landfill in an attempt to conserve landfill airspace thereby winning time to allow for strategic waste management planning.

The reduction of volume and "re-use" of garden refuse was seen as the first step in reducing the amount of waste to landfill. Following from this, the resulting use of the mechanically treated green waste after biological treatment was seen as an internal benefit for the city. Further to this, there is a significant shortage of high quality cover soil that could be utilized for promulgating vegetation growth whether it is for short time-spans or for final landfill rehabilitation. Hence a further motivation was to provide a viable, low cost and sustained source of organic medium that could offer compost-quality like material for Durban's landfill operations.

The research focuses on setting up a full scale mechanical biological treatment (MBT) i.e. mechanical treatment followed by biological treatment and implementing it into daily landfill operations that become part of an integrated waste management plan. Preliminary investigations carried out on the eThekwini landfill sites reveal the significant increase in "green waste" production is brought about by the city expanding its service boundaries as well as the related increase in the standards of living (Moodley, 2006). Nonetheless, landfill sites being the end of the 'waste life cycle' are posed with the problem in treating the green waste which would have related benefits such as environmental, financial and social (Parkin, 2006). Comparative research on different techniques of aerobic composting was used to deduce the optimum technique. Full scale test windrows between DAT windrows and traditional turned windrows (TTW) was constructed and monitored at the Bisasar Road Landfill Site. Parameters such as windrow gas composition (oxygen, carbon dioxide and methane), temperature and waste eluate characteristics were analysed to evaluate each windrow performance. Figure 3.1 below illustrates the research process adopted.

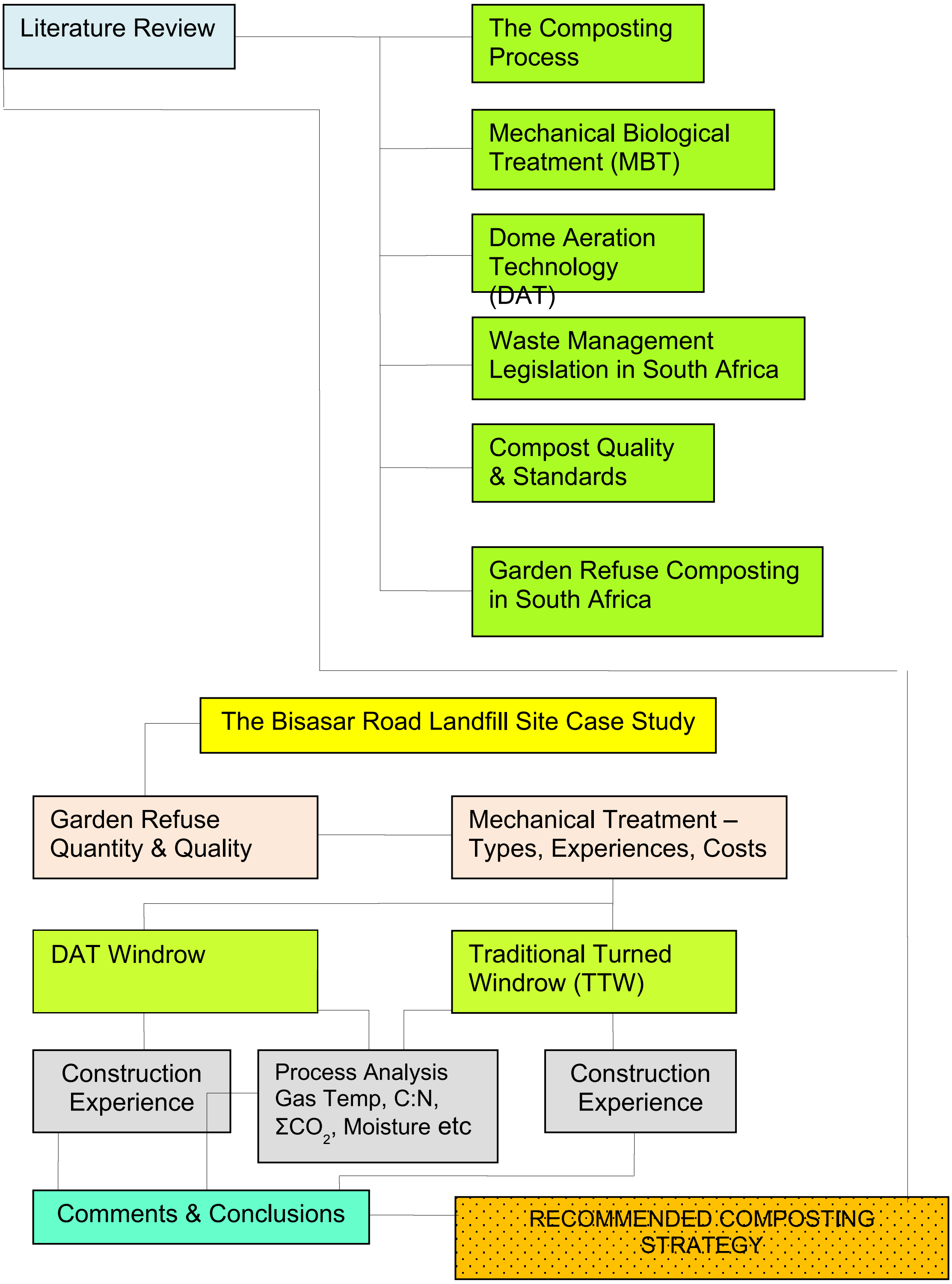

Figure 3.1: Methodological approach of the research

3.1.1 Description of the eThekwini Municipality, (DSW, 2008)

- **The Geographical Location**

The eThekwini municipality is an African metropolitan area (on the eastern seaboard of South Africa, in Kwa-Zulu Natal) embracing a full range of global sustainable development challenges. Within it is the city of Durban where population ranges from the rural to the urbanised and from the formally serviced to the unserviced. It is a multi-cultural society which faces a complex mix of social, economic, environmental and governance challenges. The ethekwini Municipality is the local government body responsible for managing Durban. The eThekwini Municipal Area (EMA):

- Is 2297 km^2 in size (1.4% of the province)
- Has a population of 3.1 million (over a 1/3 of the province)

- **The Economy, (DSW, 2008)**

The eThekwini Municipality was awarded the highest credit rating in Africa for a Municipality in October 2003 by the Global Credit Rating Company.

- Durban has the largest and busiest port on Africa's east coast – over 80 000 containers each month.
- Manufacturing (30%), tourism (24%), finance and transport are the four largest economic sectors.
- Tourism is concentrated along the coast, with emerging eco and cultural-tourism opportunities in the western areas.
- ethekwini Municipality's Gross Value Added Product comprises 39.1% of the total GVA for Kwa-Zulu Natal and 5.1% of the National Economy

- **The Ecosystem, (DSW, 2008)**

South Africa is the third most diverse country in the world, and Durban contains:

- Three of the country's eight biodomes
- Seven broad vegetation types
- Over 2000 plant species
- 97 kilometres of coastline
- 18 catchments, 16 estuaries
- 4000 kilometres of rivers
- An open space system of 63 115 ha.

Valued at approximately R3.1 billion per annum, the environmental services provided by Durban's open space system makes the preservation of this resource a priority. Figure 3.2, presents all active, closed and rehabilitated landfills including defunct dumps located throughout the city's service delivery area.

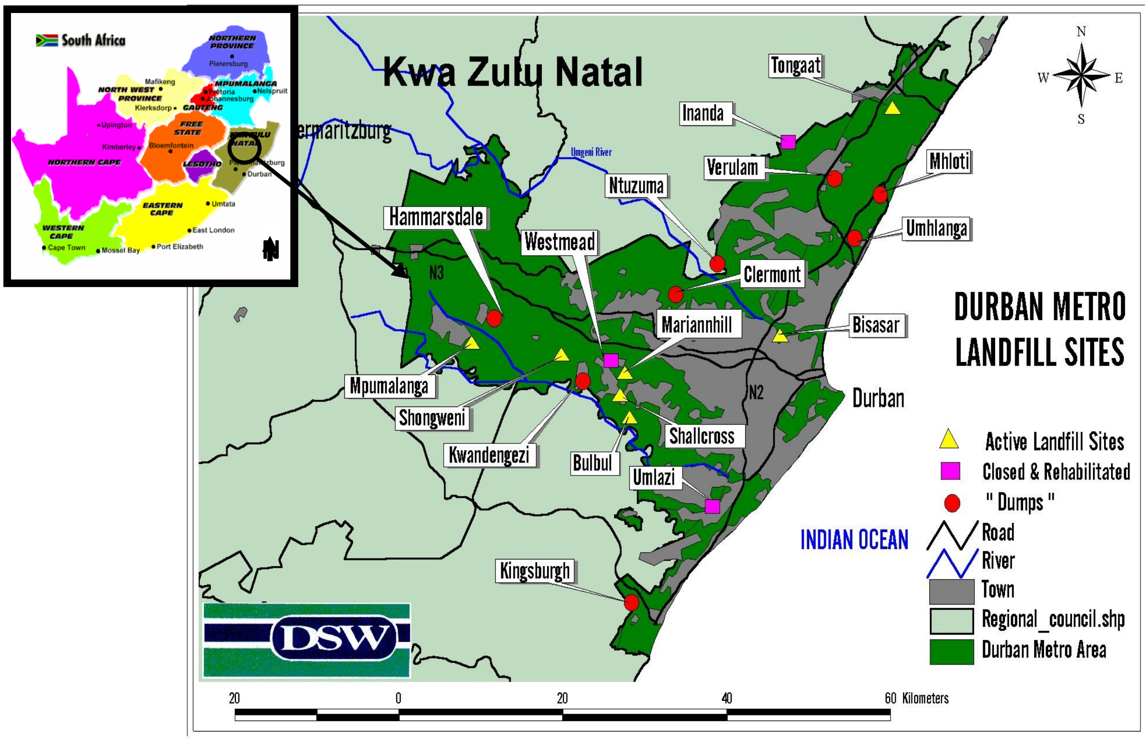

Figure 3.2: Map of the EMA showing the location of the various landfills

3.1.2 The Bisasar Road Landfill Site

The Bisasar Road Landfill Site was first established in the early 1980's and is cited some ten kilometers outside the central business district (CDB) of Durban. The site is arguably the busiest landfill on the African continent accepting a daily average of some 3,500 tons of MSW, which has peaked at some 5,200 tons at 1000 vehicles per day serving the site (Table 3.1). This site neighbours a residential area, namely Clare Estate as typical of "old generation" landfills. It is permitted by as a GLB^+ landfill site in accordance with the Minimum Requirements for Landfill Design (DWAF, 2005) and audited on a bi-annual basis. The site has a footprint of 44 hectares with a 21 million cubic metre airspace capacity. Recent airspace calculations carried out at the time of writing reveal that the site is drastically running out of available airspace and is anticipated to reach closure in March 2013. As such, the site management is maintained at a distinctly high level and the agreed development plans rigidly adhered to (Strachan et al, 2002).

- **Climate**

The climate in the region is characterized by sub-tropical conditions with relatively high rainfalls in the region of 900mm – 1200mm average annual rainfall. The average ambient temperature is 21°C with a typical range of 8^0C. The highest temperatures occur in February with the lowest temperatures in July and the average humidity is 80%. The prevailing wind directions of the KwaZulu-Natal coastal belt are predominately from the north east and south west. Winds from these broad sectors occur with frequencies in excess of 255 days a year. South westerly winds are generally stronger and may be accompanied by rain. Mean monthly wind speeds are lowest in May and June. Highest mean wind speeds occur in September and October, a transitional period at the end of winter. Maximum wind speeds occur in the early afternoon and minimum wind speeds between 06:00 and 08:00.

The site is equipped with a weather query station that is used as a tool to gather both real time and archived weather data. The data is used as information which is transferred to an Odour Management System (OMS). The OMS receives information from the on-site weather station, various static parameters and the odour source (generally the filling location) to generate the visual display on an on-site computer every 10 minutes, which is readily accessible to the landfill operator. This allows DSW to accurately determine where odour is expected to be problematic, and therefore time to introduce mitigation strategies. Figure 3.3 below illustrates a typical weather query data information sheet for the Bisasar Road Landfill Site.

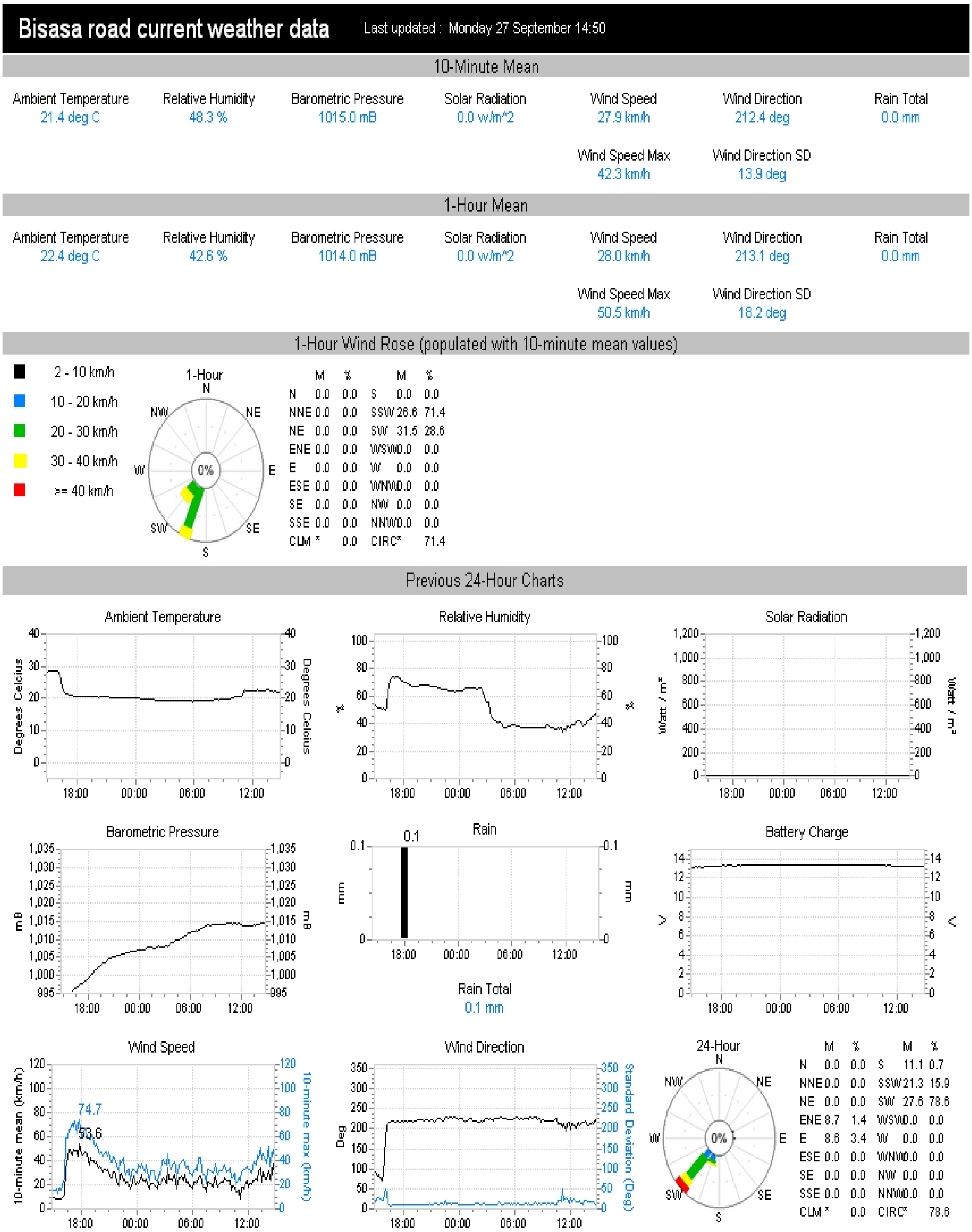

Figure 3.3: Typical weather query data from the Bisasar Road Landfill Site weather station

- **Landfill Engineering**

The site boasts innovative engineering with regard to the management of the natural environment. Since the site does not effectively have a buffer zone, the ongoing rehabilitation of this landfill site has ensured the "Extending Green Carpet" approach away from the residential houses at a rate of some 100m per annum. The site uniquely adopts the "PRUNIT" (Plant Rescue Unit) programme, along with its Mariannhill landfill site, whereby all indigenous vegetation planted is "rescued" within landfill site areas and for rehabilitation of completed cells. This landfill site is developed and managed in a series of containment cells (Parkin, 2006, Strachan et al, 2010). These completed cells can then be rehabilitated and introduced back to the natural environment during the operational life of the site, with the associated return of flora and fauna to the site. In order to combat landfill odour emissions, the approved capping system may be described as being a phytoremediation cap, comprising clay-soil layers and layers of a "fabricated topsoil" (Strachan et al, 2002).

The landfill engineering applied proves that an uncontrolled site can be operated and evolve into a proper engineered landfill. Such engineering operations onsite involve adequate stormwater control and leachate drainage systems for the site as a whole, the daily placement of waste is essentially a bulk earthworks operation, with the requisite intermediary stability requirements and stormwater control being intrinsic in the operation. In addition to this, the management of odours during the operation of a landfill and the long term management of odourous and potentially explosive landfill gas (LFG) and the management of leachate are pertinent to the operation of a sustainable landfill (Parkin, 2006). The landfill boast's Africa's first landfill gas-to-electricity project whereby landfill methane gas is converted to electricity thereby addressing global warming and renewable energy issues. This viable project provides income from the selling the emission reductions (ERs) to fund the management of the landfill sites together with conservation and social improvements, (Couth, et al). The Department of Cleansing and Solid Waste – DSW is currently compiling a closure strategy for the site. The closure plan will address the economic and social needs of the city and the local community. Preliminary discussion of the closure strategy may include and is not limited to waste treatment of selected waste streams i.e. green waste treatment, inert waste crushing, recycling etc. However at present the site is operated as an earthworks operation with full heavy plant compliment. Typical plants being used are landfill trash compactors, dozers, front end loaders, water tankers, padfoot rollers and articulated dump trucks (ADT's). Figure 3.3 below illustrates an aerial view of the Bisasar Road Landfill Site.

Figure 3.4: Aerial view of the Bisasar Road Landfill Site

- **Waste Streams**

The landfill site is permitted only to receive general waste i.e. no hazardous waste and as mentioned above the site receives some 3500 ~ 5000 tons per day. Landfill statistic show that there is gradual growth to waste tonnages received annually and reason attributed to this is primarily due to urban sprawl into the CBD. Table 3.1 below represents weighbridge data for periods 2007 up to and including 2010. The landfill receives approximately one million tons of waste per annum of which some 50% is made up of biodegradable fraction (general solid waste and garden refuse) and some 45% being that of inert material.

Table 3.1: Bisasar Road Landfill Site Waste Tonnages – 2007 to 2010 (DSW, 2010)

Waste Type	2007	2008	2009	2010
01 - DSW	413,112.89	417,265.97	409,782.37	432,175.10
02 - GENERAL SOLID WASTE	58,598.72	67,089.61	75,736.88	69,507.43
03 - GARDEN REFUSE	38,840.89	39,919.78	34,651.37	35,274.20
04 - BUILDERS RUBBLE	102,682.32	72,438.29	73,425.21	155,582.20
05 - MIXED LOADS	10,903.89	12,734.40	12,627.30	15,456.55
06 - SAND & COVER MATERIAL	306,025.76	380,872.68	372,822.42	485,346.66
07 - PURCHASE COVER	16,136.88	93,513.83	23,249.98	4,821.38
08 - TYRES	1,780.26	1,776.54	1,102.14	684.46
09 - LIGHT TYPE REFUSE	179.86	186.34	196.15	135.44
10 - OTHER	43,643.87	53,969.93	42,817.24	21,988.49
Total Waste (Kg)	991,905.33	1,139,767.37	1,046,411.05	1,220,971.90
Percentage Biodegradable Fraction (%)	51.47	46.00	49.71	43.98
Percentage Inert Fraction (%)	42.83	47.98	44.87	52.89

It is interesting to note that there is a decreasing trend in the percentage of general waste received i.e. 51.47% in 2007 as opposed to 43.98% in 2010. This shows that, in general, there is a diversion of waste from landfill through recycling etc. On the other hand there is an increasing trend in the percentage of inert material i.e. builders rubble and suit able sand material. The year 2007 received some 42.83% which increased to 52.89% in 2010. The development towards the 2010 FIFA Soccer World Cup played a contributing role in such an increase. However this material is stockpiled on site for re-use as cover material and pioneering of access roads on the waste body especially during the wet season.

3.2 THE COMPOSTING PILOT PROJECT

3.2.1 Introduction

At the initial stage of the research it was decided to set up a pilot composting project at the Bisasar Road landfill site to gain knowledge on the garden refuse quantity and quality. DSW had further purchased a wood chipper and a preliminary chipping operation was undertaken in mechanically treating the garden refuse. The objective of the pilot project was to study the garden refuse waste stream and use the findings from the chipping operation to make informed recommendations for a full scale composting operation at the Bisasar Road Landfill.

3.2.2 Garden Refuse Quantity

As discussed in section 3.1.2, Durban is situated in a wet sub-tropical climate which is favourable for all year vegetative growth. The Bisasar Road Landfill Site is serviced by a number of garden refuse customers such as the local parks and recreation department, garden refuse transfer sites sited in close proximity to residential areas which are serviced by DSW, private contractors i.e. landscapers and garden service contractors and public. This waste stream enters the site in peaks and dips on a daily basis. Moreover, general peaks are mid morning between 09:00am to 10:00am as most contractors and DSW garden sites service the site after their first collection. Thereafter the number of incoming garden refuse loads decrease and increase gradually at midday and later afternoon.

The site receives in excess of 37000 tons of garden refuse per annum which equates to some 110 tons per day (Figure 3.5). DSW identified the potential of this waste stream to be diverted from disposal to composting and subsequent re-use on landfills which would result in direct airspace saving costs.

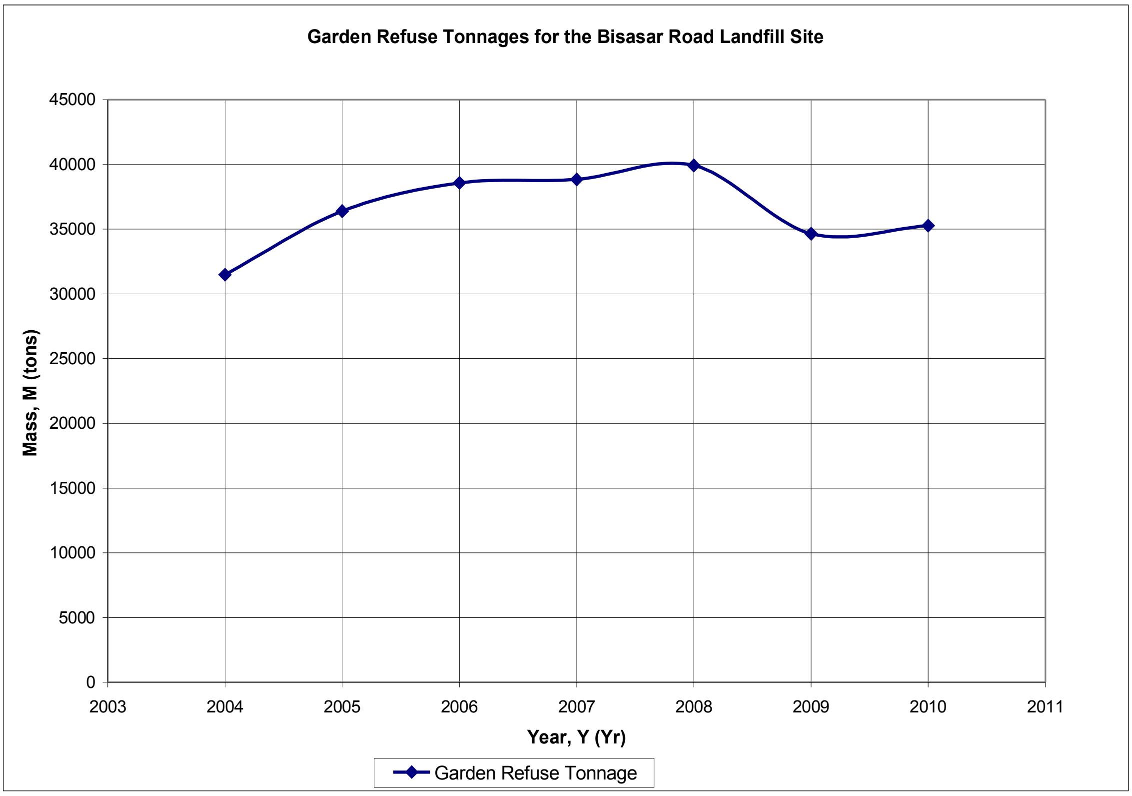

Figure 3.5: Garden refuse tonnages received at the Bisasar Road Landfill Site from 2004 to 2010 (DSW, 2010).

3.2.3 Garden Refuse Quality

At the outset of the research the first step taken was to fully understand the quality of the incoming garden refuse. Literature reviews indicated that the preparation of the input material is essential for the efficiency of the biological treatment i.e. sorting of wastes, required particle size reduction, etc. Visual surveys undertaken onsite revealed that garden refuse is predominately made up of tree feelings, branches, leaves, grasses, fibrous material and large woody material. It was often found that some 50%of loads were separately collected garden refuse whilst others were contaminated with waste streams such as rubble, sand and general municipal waste (Moodley, 2006), refer to Appendix D for survey results.

Plate 3.1: A typical load of garden refuse

Plate 3.1 above depicts a typical load of garden refuse delivered to the site and it can be seen that it is generally consists of heterogeneous mix from fibrous material to woody species. The results from a survey carried out by Moodley, 2006 revealed that the garden refuse waste stream is dis-homogeneous and this resulted due to different origins of the garden refuse. This was evident from the nature of the garden refuse loads disposed at the site as loads varied from small branches and leaves from the public to large woody material from the Parks Department. In general, some 60% of the garden refuse consisted of woody material and it was expected to have a high C:N ratio.

3.2.4 Mechanical Treatment of Garden Refuse using the DSW Chipper

At the outset of the research, DSW had purchased a wood chipper that was capable of chipping particle sizes up to a maximum of 75 millimeters. A decision was taken to carry out a pilot chipping project to evaluate applicability of such a chipper for garden refuse volume reduction on a landfill site. The results from the pilot exercise would assist DSW in determining a way forward for a composting strategy. Figure 3.6 below illustrates the pilot composting strategy and subsequent use of the DSW chipper for mechanical treatment of the garden refuse within the process.

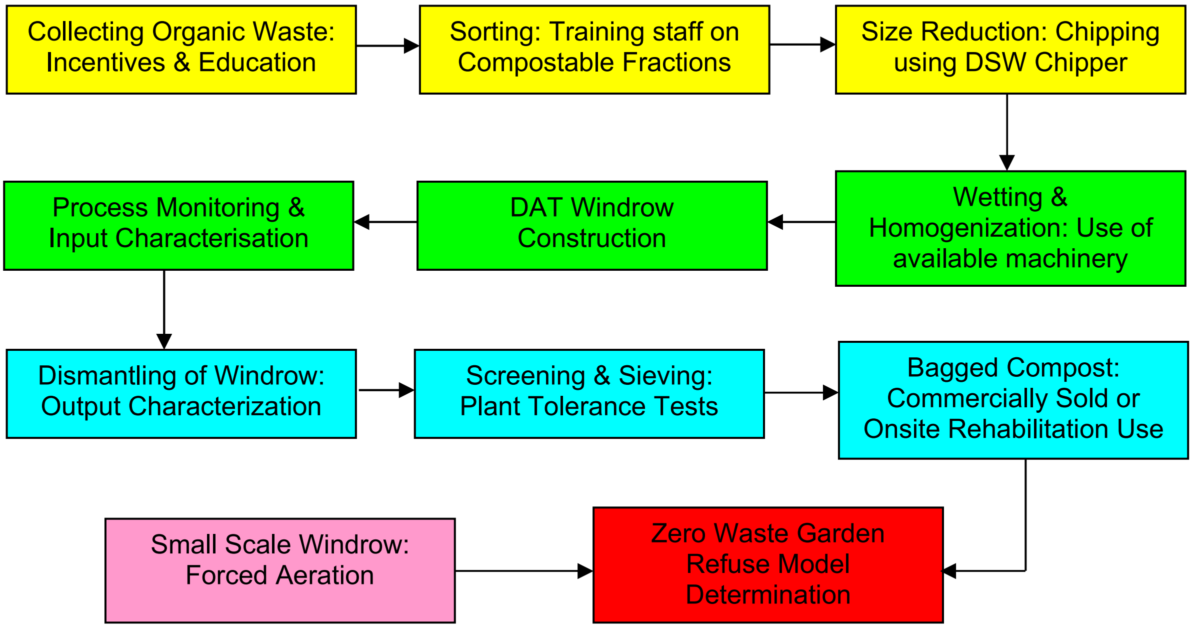

Figure 3.6: Steps illustrating pilot composting strategy (Moodley 2006)

An area of 2 hectares onsite was identified for the pilot exercise and garden refuse loads were diverted for chipping. Seeing that incoming loads were of a mixed garden refuse nature, the green waste had to be separated and sorted to suit that of the chipper in the following categories:

- Chippable fraction: particle sizes up to a maximum of 75 millimeters in diameter
- Oversized fraction: particle sizes in excess of 75 millimeters in diameter. It was decided to use this fraction as structural material for windrow stability.
- Grasses and leaves to be used as nitrogen source for composting
- Fibrous fraction: such as palms, banana trees etc as these had to be discarded from the volume reduction exercise since the fibres of the material would tangle and jam the chamber of the cutting knives.

The Sorting Operation

The exercise proved that significant efforts were required in separating and sorting incoming loads in the above category. The exercise was extremely labour intensive and time consuming as majority of the time was spent sourcing chippable fractions from mixed loads. Further to this, there was a fair degree of contamination of other waste streams with garden refuse. This was very difficult to identify as contamination could only be seen after loads were offloaded. Results showed that some 40% of loads could be practically chipped (Moodley, 2006). Contaminated and oversized material had to be double handled by DSW's landfill trucks and taken for disposal as the area had to be cleared for the following day operations.

Plate 3.2: Mixed garden refuse loads

Plate 3.3: Efforts required in sorting material

The above Plates 3.2 and 3.3 show the efforts required in separating and sorting the garden refuse prior to chipping. Another factor that attributed to the sorting was education and training of the labour team that physically separated the chippable fractions. Time had to be invested in training the team on what to sort and how to do so in a safe manner. This part of the operation was not successful in ensuring that a constant and uniform flow of chippable garden refuse was supplied to warrant an optimum production of the chipper. At total of 8 labourers were used in the sorting operation i.e. 6 labourers sorting and 2 supplementing the feed of the chipper.

The Chipping Operation

This preliminary exercise yielded 20 cubic meters per day and proved to be extremely time consuming and labour intensive as the chippable garden refuse had to be fed individually into the chipping chamber (Moodley, 2006). There were often stop-start conditions whereby the in-feed rollers of the chipper would jam resulting in downtime for the operation. A trained operator was responsible for the feeding of the material into the chipper together with the assistance of 2 labourers. Plates 3.4 – 3.7 below illustrate the chipping exercise undertaken.

Plate 3.4: Feeding of the Chipper

Plate 3.5: Chipping set up

Plate 3.6: Chipping into a stockpile

Plate 3.7: Typical chip sizes

Lessons Learnt

- The garden refuse disposed at the landfill is highly dis-homogeneous.
- The mechanical treatment operation is a function of the chipper.
- The sorting operation as well as the chipping operation are extremely time consuming and labour intensive.

For the reasons set out above, it was concluded that a chipper was not applicable for use on landfills as it was most suited for smaller waste streams such as small communities, home composting etc. It was recommended to DSW a volume reduction plant that could mechanically treat a heterogeneous mix of garden refuse i.e. oversized material, fibrous material etc be obtained. The lessons learnt from the chipping operation as well as the research undertaken in section 2.7 guided DSW in concluding that a *high speed organic waste shredder* was required for a full scale composting operation. For the interest of the research, refer to Appendix E for the procurement of DSW's high speed shredder.

3.2.5 Mechanical Treatment at the Bisasar Road Landfill Site Using the Shredder

After successfully procuring the required shredder for the mechanical treatment of garden refuse, the next step was to establish the operation within an existing landfill operation. The Bisasar Road Landfill Site is predominately operated in two distinct activities namely: landfilling and a transfer station. The landfilling activity or working face area accepts all vehicles that self tip or eject loads i.e. mechanical off-loading of waste. The reason for this is that of safety associated with having heavy plant such as landfill compactors, dozers etc compacting the working face. The transfer station accepts all vehicles that are required to be hand off-loaded, commonly referred to as the "moms and dads" area. The off-loaded waste is thereafter stock piled and loaded in articulated dump trucks (ADT's) by front end loaders. The ADT's thereafter haul the waste to the working face for final disposal thereby ensuring the safety of customers. Seeing that bulk of the garden refuse was being brought in by hand off-loaders, it was decided to establish a green waste mechanical treatment area on the transfer station. Further to this, another rationale in having the operation on the transfer station was that people do not like change and emphasis was placed on taking an existing drop off facility to suit shredding of garden refuse. Figure 3.7 below illustrates the flow path of garden refuse customers to the green waste shredding area.

Figure 3.7: Flow path of garden refuse for shredding on transfer station

The pilot shredding operation was successfully set up on the transfer station. An available front end loader was modified to be the designated feeder of garden refuse into the shredder. The plates below show that incoming garden refuse could be easily loaded onto the horizontal chute without extra efforts required in sorting the waste. The shredded particles sizes ranged from 5 millimeters to 50 millimeters as required for optimum biological composting without the need of structural material (Llyod, 2006. It was noted that the shredded particles were dependant on the nature of the garden refuse i.e. woody species were split into elongated shreds whilst the greens were smaller shred sizes. It was evident that after one days shredding, the stockpiled shredded material began composting temperatures were recorded up to 40°C. Plates 3.8-3.9 present below show the mechanical treatment operation of garden refuse. The next chapter details the composting operational set up.

Plate 3.8: Front end loader feeding the shredder with mixed garden refuse

Plate 3.9: Shredded output of garden refuse

CHAPTER 4
MATERIALS AND METHODS

4.1 METHODOLOGICAL APPROACH

Planning of where activities that form links to the composting process are designated to occur at is crucial in terms of achieving flow to a composting system in a landfill. One should consider the operational flow that's required from receiving the input green waste to the outgoing end useful product. It is in this light that an area on site was clearly zoned for such activities to occur bearing in mind that "capacity is a function of width" and therefore the different activities need to be separate from each other but at the same time be planned to avoid traffic congestion and minimise diesel costs of the plant used in the composting operation. There are different processes that have been thoroughly studied and documented, but no matter which system used, the requirements for microorganisms to survive are specific, therefore the initial stages of the composting process i.e. sorting, shredding, wetting, homogenizing, etc (Figure 4.1) are crucial for these requirements to be met. Designated areas are required for the following activities below:

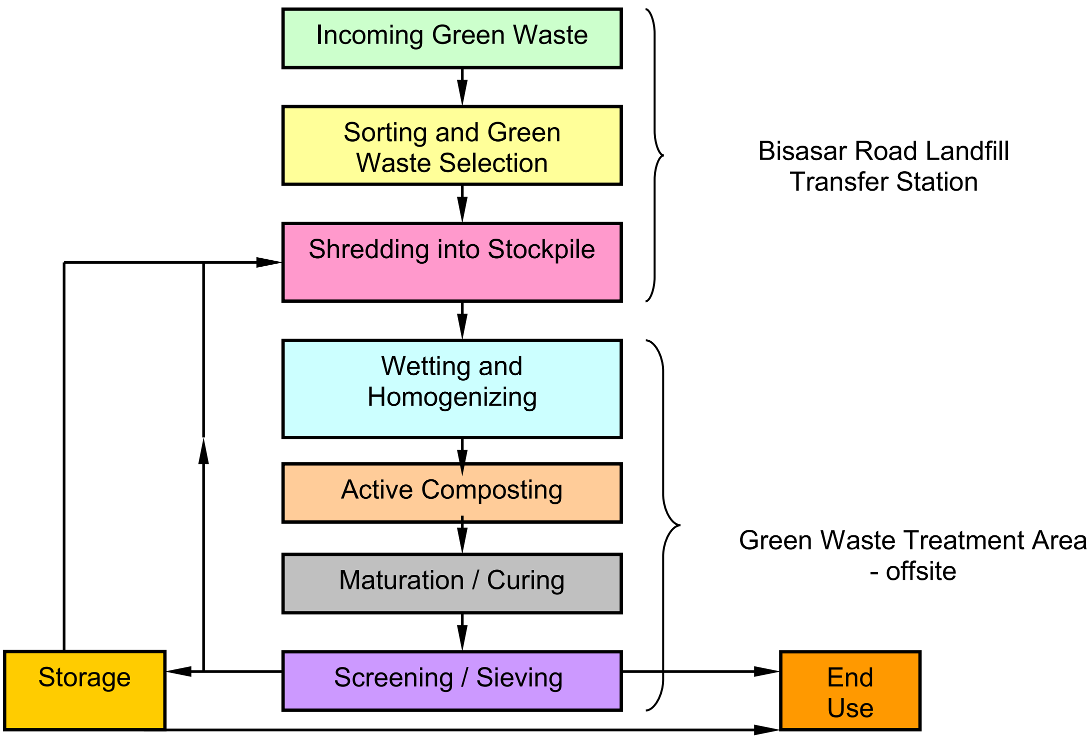

Figure 4.1: Flowchart showing activities that form a composting process (Moodley, 2006)

Two full scale windrows were constructed at the Bisasar Road Landfill Site that being a DAT and traditional turned windrow. After the mechanical treatment of garden refuse (as detailed in section 3.3.4), it was decided to undertake the biological treatment i.e. composting away from landfill activities inorder to ensure minimal interference to the windrows. A green waste research area was designated for such treatment and this sited on the site's northern boundary i.e. north of the landfill gas to electricity plant. Figure 4.1 above further illustrates the location of each activity within the landfill footprint.

4.1.1 Windrow Dimensions

- **DAT Windrow**

The German experience of the DAT yielded the configuration of the domes and channels ensured constant self aeration of the windrow (Mollekopf et al, 2002, Trois and Polster, 2006). Further, local research by Trois and Polster, 2006 concluded that the DAT is effective for pine bark composting and appropriate for South Africa in terms of low capital costs, low energy inputs, limited plant requirements and potential for labour intensive operations. It was on this basis that the dimensions used for this case study were unchanged to that used by Polster in 2003. The cross sectional details of the DAT windrow constructed at the Bisasar Road Landfill Site are shown in Figure 4.2.

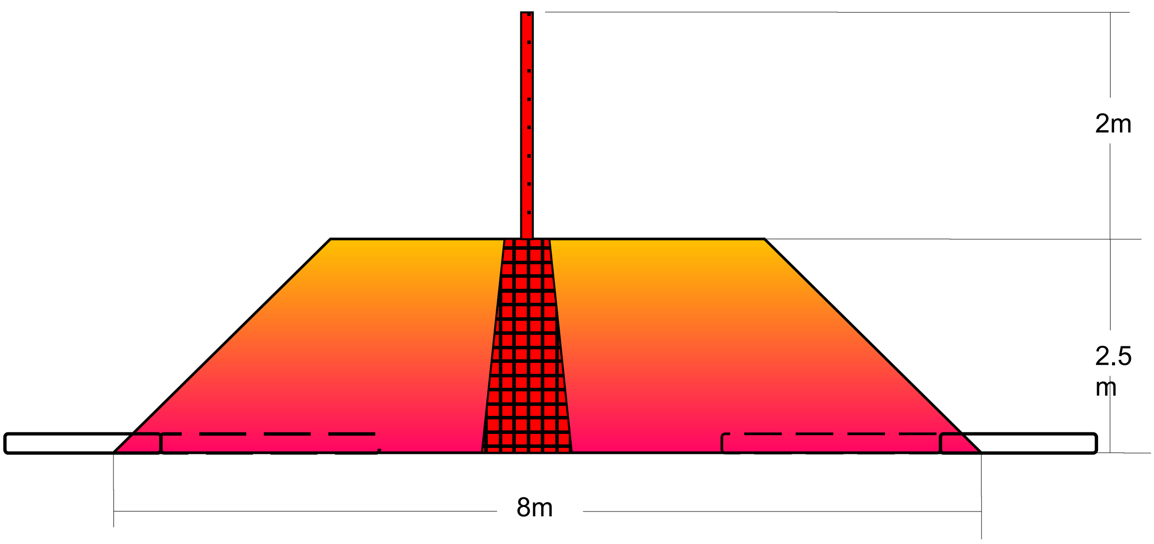

Figure 4.2: Cross section of DAT windrow constructed at the Bisasar Road Landfill Site – Not to scale

The length of the windrow is an independent variable in the construction of DAT windrows but is determined by the number of domes used. Each section of the windrow was made up of one dome and four channels whereby spacing in-between dome were fixed at 5 meter intervals and channels 3.5 meters and 5 meters from the edge of the windrow and in-between centres of channels respectively. The DAT windrow constructed consisted of four dome sections which resulted in an effect length of 22 meters.

- **Traditional Turned Windrow (TTW)**

The dimensions selected for the TTW was determined by two criteria, namely: the limitation of the front end loader used in the construction of the windrow and the space required for regular turning of the windrow. The front end loader (FEL) designated for the construction was a BELL 1206 FEL that was capable of a 3 meter loader reach and therefore a 2.5 meters height was selected. As mentioned above that the area designated for the biological treatment was in the northern area of the site and site constraints allowed for 10 meters wide windrow. Therefore the dimension selected for the TTW was 25 meters long, 10 meters wide and 2.5 meters high.

4.2 CONSTRUCTION OF THE WINDROWS

4.2.1 DAT Windrow

- **Input Material**

As discussed in section 3, one of the objectives of the research was to biologically treat commercial garden refuse received at landfills and evaluate the use of such a composted product with landfills. The input material used for treatment was that of the commercial garden refuse waste stream. The nature of the material was predominately made up of tree feelings, branches, leaves, grasses, fibrous material and large woody material.

There was no need for the uses of any structural material as the volume reduction described below allowed for a range of particle sizes that would ensure structural integrity of the windrow and avoid any risk of collapse. Plates 4.1 and 4.2 below show the signage and the typical nature of the commercial garden refuse respectively.

Plate 4.1: Information signage for garden refuse customers

Plate 4.2: Typical nature of commercial garden refuse

- **Shredding**

As previously discussed in section 3.3, the commercial garden refuse was shredded using a high speed organic waste shredded that was specifically purchased the mechanical treatment of garden refuse. The shredder was capable of shredding garden refuse sizes up to a maximum of 300millimeters and the output shredded material ranged in particle sizes between 5 to 50 millimeters and this variability avoided the use of oversized garden refuse as structural material. A front end loader with a modified fork was used to load the shredder and move the shredded garden refuse into a stockpile. Plates 4.3 and 4.4 below show the input commercial garden refuse being mechanically treated.

Plate 4.3: FEL loading the shredder

Plate 4.4: Shredded garden refuse product

- **Wetting and Homogenizing**

Following shredding, the stockpiled commercial garden refuse was loaded using a 966 CAT FEL into 3 ADT's that hauled the material to the green waste treatment area for preparation and construction into windrows. As depicted in Figure 4.1 above, the next step entailed wetting and homogenizing the shredded material. It must be noted that a shredded volume had to be built up in order to justify efficient use of the ADT's. The ADT's tipped loads on an open gravel hardstand in 3m grid spacing which was thereafter uniformly spread using the bucket of a 966 FEL, this was done is preparation of wetting the material with a water tanker. The volume of water required was calculated by estimating the required moisture content for initial composting conditions. Literature moisture content values stated are in the region of 55% to 60%. The moisture content of the shredder input garden refuse was some 38% and therefore approximately 20% additional moisture was required to bring up to the required optimum range and this equated to 17 000 litres of water required. However, past experience with the construction of garden refuse windrow shows that the windrows tend to desiccate and dry out quickly (Trois et al, 2006 and Moodley 2005) thereby inhibiting the biological process. Although an initial theoretical volume of additional water was calculated, water is also lost through whilst wetting due to runoff are and evaporation. It then followed that a practical volume should be applied and past experience has shown that an approximate 60% moisture content of the input material would be recommended (Trois and Polster, 2006 and Moodley, 2006). This conservative approach resulted in four 18 000 litre water tanker truck loads being used over the construction period. Plates 4.5 and 4.6 below illustrate the wetting and homogenizing process.

Plate 4.5: Water tanker spraying water on shredded material during construction

Plate 4.6: FEL mixing and homogenizing water into shredded material

- **Forming the windrow**

Since the designated area for composting was outside the lined footprint of the landfill, there was concern of possible leachate draining into the catchment below, therefore previously shredded garden refuse that had dried out was used as a "filter layer" at the base of the windrow. A 300mm thick layer was evenly distributed using the FEL. The wetted material was placed using the FEL and method of placement commenced from forming the dome and thereafter working outwards. Plates 4.7 and 4.8 below illustrate the setting out of the DAT materials and placement of wetted garden refuse in windrow respectively.

Plate 4.7: Setting out of DAT materials and filter base

Plate 4.8: Placement of wetted garden refuse by FEL in windrow

- **Cover Material**

Since no compost material was available, a 1 meter thick layer of pine bark was used as cover material on the windrow. Plates 4.9 and 4.10 show the dressing of pine bark cover material and completed DAT windrow respectively.

Plate 4.9: Excavator dressing pine bark cover

Plate 4.10: The completed DAT windrow

4.2.2 Traditional Turned Windrow (TTW)

The construction of the TTW followed the same procedure as detailed above for the DAT. The same input material was used with the only exception that there were no domes and channels. The dimensions used for the windrow are as discussed in section 4.1.1. Plate 4.11 and 4.12 below illustrates the completed windrow.

Plate 4.11: An excavator shaping the TTW

Plate 4.12: The completed TTW

The construction requirements for each windrow are summarized and presented in Table 4.1

Table 4.1: Summary of Windrow Construction Requirements

Requirement	DAT Windrow	Traditional Turned Windrow
Start Date	September 5, 2008	October 11, 2008
Input Material	Commercial Garden Refuse	Commercial Garden Refuse
Plant Utilised	FEL	FEL
	ADT x 3	ADT x 3
	Water Tanker	Water Tanker
	Excavator	Excavator
	Shredder	Shredder
	Bobcat	
Materials Utilised	Domes and Channels	None
Labour Utilised (N^0)	6	1
Windrow Dimension	4 Dome Sections	25m long, 2.5m high & 10m wide
Windrow Volume (m^3)	220	450
Construction Time (hr)	32	24

4.3 PROCESS MONITORING

4.3.1 Objectives of the Process Monitoring

The objectives of the process monitoring of the DAT windrow are the following:

- Maintain constant aerobic conditions: The principle of the DAT windrow revolves around the self aeration technique. An indicator to monitor this condition is the oxygen concentration. The recommended range for the required oxygen concentration within the windrow should be within 10 to 20%. Concentrations less that 10% indicate are early warning indicators that anaerobic conditions may follow with the production of methane gas.
- Maintain thermophilic conditions: the degradation of the garden refuse within the windrow is a function of the biological activity. It is ideal to ensure thermophilic conditions maintained as biological activity is expected to be at an increased rate. The recommended temperatures to maintain are in the range of upper mesophilic to the thermophilic i.e. 35°C to 55°C. Further to this, thermophilic temperatures are also required to ensure full sanitisation of the windrows i.e. destruction of all weed seeds and pathogens.
- Organic material degradation: the conversion of garden refuse into a compost product can only be achieved through biological degradation of the material. An indicator of this degradation can be described as a kinematic reaction where the cumulative carbon dioxide resulting from respiration would describe the degradation process.

4.3.2 Process Performance Parameters

The following parameters were monitored and analysed over the composting time:

- **Windrow Temperature**

The monitoring of the windrow temperature would indicate the temperature trend of the composting process which would be used to evaluate the process. As discussed above, high temperature in excess of 55°C would indicate thermophilic conditions with a high rate of degradation whilst low temperatures i.e. less than 35°C would indicate that the degradation process is inhibited. As a result, temperatures were monitored using a thermocouple inserted into the windrow through the top of the aeration tube. Different depths from the top of the aeration tube were monitoring. The monitoring of the TTW windrow temperature was done by opening a hole some 2 meters into the windrow and monitoring the temperature with the thermocouple. TTW were only turned when temperatures stabilised as this was an indicator that the process was slowing down and windrows required turning for the supply of oxygen and wetting for addition of moisture. Plate 4.13 below shows the thermocouple that was used for monitoring windrow temperatures.

- **Gas Quality Concentrations**

The monitoring of the windrow in terms of the gases related to the respiration equation 1 in section 2.4.1 would evaluate the aerobic conditions as well as the rate of degradation. The following gases were monitored:

- **Oxygen:** The oxygen concentrations within the windrow were used to evaluate the aerobic and anaerobic conditions as well as the aeration potential of the DAT.
- **Carbon Dioxide:** The carbon dioxide concentrations produced through the aerobic digestion was used to evaluate the degradation of the garden refuse.
- **Methane:** The methane concentrations were monitored to evaluate if anaerobic conditions were present. This is also partially linked to the aeration potential of the windrows and the oxygen conditions.

The above gas parameters were measured using an infrared gas analyser (Geotechnical Instruments – GA 94A). Careful monitoring was carry out by ensuring that a primary and secondary filter attached to the pump tube. Further, the sampling tube attached to the pump extraction tube was kept in a bucket of ice to ensure that any condensate within the sampling tube does not enter the analyser and alter the calibration. Gas was sampled from the exit of the aeration tube at regular intervals. It must be noted that there was no such monitoring for the TTW as windrows were regularly turned and made installing monitoring probes impractical. Plate 4.14 below shows the GA 94A that was used for monitoring windrow gas concentrations.

- **Exit Gas Velocity**

The velocity of the gas exiting the aeration tube of the DAT windrow was monitored as it was used to evaluate the airflow through the windrow and comments on the mass balance of the process. This was measured using an anemometer (Geotechnical Instruments – Mini Air 2). The probe of the anemometer was set to be inserted inside half the diameter of the aeration tube. This was done through a pilot hole that was purposely drilled on the wall of the aeration tube noting that the probe had to be orientated perpendicular to the flux of the exit gas. Plate 4.15 below shows the Mini Air 2 that was used for monitoring exit gas velocities of the domes.

Plate 4.13: Thermocouple used for monitoring windrow temperatures

Plate 4.14: GA 94A gas analyser used for monitoring DAT gas concentrations

Plate 4.15: Mini Air 2 anemometer used for monitoring DAT exit gas velocity

- **Ambient conditions**

The ambient conditions such as temperature, pressure, rainfall and wind speed was recorded of the Bisasar Road weather station.

The monitoring intervals for the DAT parameters where carried out twice a day for the first week of composting and thereafter once a day from the second week and eventually once a week for the remaining composting time. The temperatures for the TTW were monitoring twice a week for the first week of composting and thereafter once a week. The reason for monitoring more frequently during the first week of composting was due to the quick onset of thermophilic conditions.

4.4 CHARACTERISATION OF COMMERICAL GARDEN REFUSE

4.4.1 Introduction

One of the deliverables of this research was to recommend which composting technique either the DAT or TTW was applicable to composting of garden refuse on landfill sites. The comparison of the compost quality parameters between both systems was carried out to help draw a conclusion on which system to be recommended. This characterization therefore concentrated on Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Carbon Content, Nitrogen Content, Ammonia (NH_4) and Nitrates (NO_x). On the other hand, factors that influence the composting process such as moisture content, C:N, pH, conductivity, Total Solids (TS), Total Volatile Solids (TVS), and Respiration Index (RI_7) had to be measured for determining the efficiency of the composting process.

All laboratory tests were performed at the University of Kwa-Zulu Natal, Environmental Engineering Laboratory with the exception of the carbon, nitrogen and C:N which were out-sourced to Bemlab (Pty) Ltd laboratories for chemical testing. Standard methods according to the American Society for Testing Materials were used for the analysis (Plug, 2009). Part of the characterisation tests were also presented as part of Iyilade and Plug's MSc Eng dissertation in 2009.

In order to evaluate the compost quality, representative samples of the input material i.e. commercial garden refuse (CGR) mechanically treated by the Morbark shredder and the output compost material were taken from the DAT and TTW. Sampling intervals for the output compost were: after 6weeks, (immature compost 8-10 weeks, Iyilade, 2009) and (mature compost 16-20weeks, Plug, 2009).

It must be noted that the TTW was constructed 2 weeks after the DAT windrow and as a result the TTW was therefore not sampled at 6weeks sampling.

4.4.2 Representative Sampling

The solid substrates were sorted and sifted by hand to remove any irregular waste matter, as well as ensuring that the materials were of a relatively uniform size of approximately 4 - 5cm in length (as suggested by previous research: Chapter 2). Both windrows were opened partially using an excavator for sampling as shown in Plates 4.16 and 4.17 below. Approximately 25 kilograms of each sample was taken to the laboratory for testing. To obtain an accurate representative sample of the solid substrates, the materials were divided into eighth fractions using the standard quartering method (Pisano, 2007) .The solid substrates were mixed and turned to ensure homogeneity and was then halved. These two separate halves were then mixed in turn and separated into two halves once again. This system was repeated until eight equal samples were prepared. The remaining samples were immediately refrigerated for preparation of other testing.

Plate 4.16: Sampling of the DAT Windrow using an excavator

Plate 4.17: Sampling of the TTW using an excavator

4.4.3 Waste Characterisation Tests

The laboratory analysis was broken up into two batch of testing are solid and eluate.

Characterisation of solid materials

The solid substrate materials were tested for the following parameters:

- · Moisture content (w)
- · Total solids (TS)
- · Volatile solids (VS)
- · Respiration Index (RI_7)
- · Total Carbon
- · Total Nitrogen
- · Carbon to nitrogen ratio (C:N)

Eluates

The eluates of the substrates were tested for the following parameters:

- Total solids (TS)
- Volatile solids (VS)
- pH
- Conductivity
- Chemical Oxygen Demand (COD)
- Biochemical Oxygen Demand (BOD_5)
- Ammonia (NH_3)
- Nitrates (NOx)
- Total Carbon
- Total Nitrogen
- Carbon to nitrogen ratio (C/N)

The procedure entailed placing a 100 gram dry mass sample placed in a 1ℓ vessel and adding 1000 milliliters of distilled water to reach a liquid solid ratio of 1: 10 (Griffith, 2009). The vessel was thereafter placed in a shaker to mix thoroughly for 24 hours. At the end of the mixing, the preparation was completed and the eluate extracted analysed as detailed above.

4.4.3.1 Tests on Solids

- **Moisture Content (w)**

The maximum practical moisture content depends on the structural wet strength of the materials (Haug, 1993). It is necessary to provide additional moisture for efficient composting. The optimum moisture content for garden refuse composting is within the range of 55% - 60%. The determination of the input and output materials were found by allowing a known mass of a representative sample to dry for 24 hours in an oven at 105°C. An electronic weighing balance was used to weigh all crucibles and material to the accuracy of 0.1 mg. The moisture content (ω) was calculated using the following equation:

$$\omega\_(\%) = \frac{M_{wet} - M_{dry}}{M_{wet}} \times 100 \qquad \text{Eq (2)}$$

Where: M_{wet} = Wet mass (before) in grams

M_{dry} = Dry mass (after) in grams

- **Total Solids (TS) – ASTM B2450**

This method is used to determine the total solids in a solid or semisolid sample. This parameter is measured by evaporating a sample to dryness and weighing the residue. The total quantity of residue is expressed in terms of a percentage on the mass of the wet sample of solid. The test was conducted as follows:

Clean, empty crucibles were weighed. A mass of sample was then placed in each crucible. The crucibles were placed in an oven and heated at 105ºC for 24 hours to evaporate the liquid leaving a residue. The crucibles were allowed to cool in a desiccator. The crucibles and dessicator are shown in Plate 3.9. The crucible was weighed again after drying to determine the mass of the dried residue. The total solids were calculated using the following equation:

$$TS(\%) = \frac{(A - B)}{(C - B)} \times 100 \qquad \text{Eq (3)}$$

Where:

A = mass of dried residue + dish (grams)
B = mass of dish (grams)
C = mass of wet sample + dish (grams)

- **Volatile Solids (VS) (Ignition Losses) – ASTM B2450**

The determination of the total volatile solids would give an approximation of the amount of organic matter present in the solid fraction of the material being tested, (Moodley, 2005). An optimum of 35% would be considered ideal for garden refuse composting. The dried material used in the moisture content test was used and ignited in a muffle furnace at 550^{o}C until a constant masses was achieved. The ignition period usually would have been 15 minutes to 20 minutes but an hour was allowed on the basis that the material did have large amounts of organic matter from the garden refuse. The following equation was used to calculate the Volatile Solids:

$$Ignition\_Losses\_(\%) = \frac{M_{dry} - M_{ignition}}{M_{dry}} \times 100 \qquad \text{Eq (4)}$$

Where: M_{dry} = Dried mass

$M_{Ignition}$ = Mass after ignition

- **Respiration Index – RI_7 (Plug, 2009)**

The Respirometric Index at 7 days (RI_7) was used to evaluate the biodegradability of each of the substrates and their level of stability. A respirometric system type OxiTop® was used to determine the Respiration Index at 7 days (RI_7) using the following procedure. The test was performed by adding five drops of allylthiourea to 25 g of solid material and distilled water to achieve field capacity in an airtight 1500 mℓ vessel. Five drops of potassium hydroxide was then added to a rubber thimble before an electronic pressure sensor head was screwed on. As biodegradation of the material occurs, oxygen is consumed and carbon dioxide produced. The added potassium hydroxide added in the head of the vessel along with Allythiourea (ATH) absorbs the carbon dioxide (CO_2) to prevent nitrification. The apparatus was then placed in an incubator at 20°C for seven days. The Oxitop bottles equipped with a pressure sensor lid records the gas pressure developed during the biodegradation process of the organic matter.

Readings of pressure were taken by an electronic handset, set at a range of 2000 mg/ℓ. These pressure readings were then used to determine the mass of oxygen consumed. The negative pressure measured by the pressure sensor and the amount of carbon dioxide absorbed by the potassium hydroxide which is, hence, equal to the amount of oxygen consumed in the biodegradation process is directly proportional.

The partial pressures of Nitrogen (Pp_N) and Oxygen (Pp_O) are measured as follows:

Pp_N = 101.3 kPa* 0.78

Pp_O = 101.3 kPa* 0.21

The small amount of CO_2 absorbed is ignored. Using the Perfect Gas Law PV = nRT, the number of the moles is calculated for the oxygen and nitrogen moles at the start of the test. As seen in the following equation:

$$n_{O_2} = \frac{P_{O_2}V}{RT} \qquad \text{Eq (5)}$$

As nitrogen is an inert gas the number of moles of nitrogen (n_N) does not change throughout biodegradation reaction. Thus the change in pressure recorded by the pressure sensor lid is used to calculate the moles of oxygen (n_{of}) at the end of the test. This, in turn, is used to determine the mg of oxygen consumed using the molecular weight. However, the RI_7 is measured in terms of the mass of oxygen consumed in relation to the mass of the dry material. Thus using the moisture content of the substrate, the dry mass is calculated and the RI_7 is expressed in $mgO_2/g_{\text{dry mass}}$.

- **Total Carbon, Total Nitrogen and Carbon to Nitrogen Ratio (C:N) (Plug, 2009)**

The total carbon, total nitrogen and C:N ratio testing was out-sourced to Bemlab (Pty) Ltd in the Western Cape and tested using standard methods as referred to in section 4.4.1.

4.4.3.2 Eluate Tests

- **Total Solids - ASTMB2540**

Solids refer to the matter suspended or dissolved in water or wastewater. The total solid test quantifies all the solids in the substance, suspended and dissolved, organic and inorganic (Tchobanoglous et al., 1985). This parameter is measured by evaporating a sample to dryness and weighing the residue. The total quantity of residue is expressed in terms of grams per litre (g/ℓ) on a basis of the dry mass of solids. The test was conducted as follows:

Clean, empty crucibles were weighed. 25 mℓ of sample were then placed in each crucible. The crucibles were placed in an oven and heated at 105ºC for 24 hours to evaporate the liquid leaving a residue of the total solids. The crucibles are allowed to cool in desiccators and then the crucibles were weighed again after drying to determine the mass of the dried residue. The total solids were calculated using the following equation:

$$TS(\frac{g}{\ell}) = W_d \frac{1000}{V_s} \quad \text{Eq (6)}$$

Where:

Wd = dry mass of residue (grams)

= (mass of residue + dish before ignition) – (mass of dish)

Vs = volume of sample (mℓ)

1000 = multiple to convert the concentrations to g/ℓ

- **Volatile Solids (VS) - ASTME2540**

The volatile solids are usually the organic content represent both the total and suspended solids (Clesceri et al., 2005). The volatile solids can be determined by firing the residues from the total solids test in a furnace at approximately 550ºC for about 20 minutes until the residue is converted into ash. The crucibles were then once again weighed to determine the mass of the non-volatile fixed residue after incineration.

The non-volatile fixed solids are calculated using the following equation:

$$FS(\frac{g}{\ell}) = W_{FS}\frac{1000}{V_S} \qquad \text{Eq (7)}$$

Thus the volatile solids are determined using the following equation:

$$VS(\frac{g}{\ell}) = TS - FS \qquad \text{Eq (8)}$$

Where:

WFS = mass of the fixed residue (ashes) remaining after firing (grams)
= (mass of residue + dish after ignition) – (mass of dish)
WVS = mass of the volatile residue (ashes) remaining after firing (grams)
= (mass of residue + dish before ignition) – (mass of residue + dish after ignition)
Vs = volume of sample (mℓ)
FS = concentration of non-volatile fixed solids (g/ℓ)
1000 = multiple to convert the concentrations to g/ℓ

- **pH - ASTM4500-H^+**

pH is one of the most important parameters tested as a low pH is a limiting factor and has an inhibitory effect on denitrification (Trois et al., 2007; Gomez et al., 2000). The pH value of a substance is the hydrogen ion concentration. The pH is used to express the intensity of acidity or alkalinity of a solution. A pH of 7 is considered to be neutral. The basic principle of the electrometric pH measurement is the determination of the activity of the hydrogen ions. The pH of the various substances was measured using a Labotec Orion 410A pH meter. The pH was determined by dipping the electrode into the sample. Prior to testing the electrode had is calibrated using buffer solutions of a pH of 4 and 7.

- **Conductivity - ASTMB2510**

Conductivity is a measure of the ability of an aqueous solution to allow the passage of an electric current. This ability depends upon the presence of ions, their concentration, mobility, valence and the temperature at which the measurement is conducted. Conductivity in water is affected by the presence of inorganic dissolved solids. The conductivity of a solution is the measure of the ionic concentration or the amount of dissolved ions and total dissolved solids. The basic unit of measurement of conductivity is the mho or siemens. Conductivity was measured in microsiemens per centimetre (µs/cm) and millisiemens per centimetre (ms/cm).

- **Chemical Oxygen Demand (COD) - ASTM5220D**

Chemical oxygen demand is defined as the amount of a specified oxidant that reacts with a sample under controlled conditions. The chemical oxygen demand is used to characterise the organic strength of wastewater. The test measures the amount of oxygen required for chemical oxidation of organic matter in the sample to carbon dioxide and water. The COD test followed the procedure of the ASTM standard method. This entailed the use of the closed reflux colorimetric method. A known sample of effluent was combined with a 1.5 mℓ solution of potassium dichromate ($K_2Cr_2O_7$), which is a strong oxidant, and 3.5 mℓ of sulphuric acid (H_2SO_4) in vials. 3 standard as well as 4 blank samples were used. The vials were placed in a digester block for two hours at 180ºC and then left to cool. A spectrophotometer set to a wavelength of 600 nm was then used to measure the remaining dichromate in each sample. The COD was calculated using the following equation:

$$COD\_\left(\frac{mg.O_2}{\ell}\right) = \frac{(A - B) \times M \times 8000}{V_S} \qquad \text{Eq (9)}$$

Where:

A = ml FAS used for blank

B = ml FAS used for sample

V_s = volume of eluate sample (ml), and

M = Molarity of FAS = 0.0862

- **Biochemical Oxygen Demand (BOD) - Aqualytic, AL 99005**

The biochemical oxygen demand is the amount of oxygen consumed during microbial utilisation of organics. It is an important parameter used to define the biodegradable organic strength of a wastewater. The BOD is measured by placing a sample of effluent in an air-tight container which is then kept in a controlled environment, in this case an incubator for a pre-selected period of time, thus determining the amount of oxygen which is consumed. BOD is usually measured over a period of 5 days (BOD_5) and is expressed in mg/ℓ of oxygen. The samples are placed in amber bottles to prevent light from penetrating the sample and thus causing algae growth. The standard method for BOD testing was followed using the Aqualytic Application Report Al 99005, “Determining the Biochemical Oxygen Demand (BOD) with BSB/ BOD Sensors, manometric method” (Aqualytic, Application Report AL 99005, Robertz).

- **Ammonia (NH_4) and Nitrates (NO_x) – SABS 217:1990**

The test in question was once again performed on an eluate sample. The presence of nitrogen in the form of ammonia can be traced to the microbial metabolism of protein. When oxygen is readily available, together with nitrifying bacteria, the nitrogen can be oxidized to nitrate (NO^{-3}), which is utilized for plant growth, in the form of a nutrient source (Moodley, 2005). The factors affecting the composting process have to be with optimum ranges since these affect the amount of nitrogen lost as ammonia.

The eluate sample was steam distilled and collected in a boric acid solution. The continuous removal of ammonia by distillation led to the quantitative conversion of ammonium to ammonia. The distillate in excess boric acid produced a borate. The borate of approximately 250ml was titrated with a standard acidic solution. The second part of the test for the NO_x was thereafter conducted. Devardas alloy and magnesium oxide was added to the residue in the tube and the procedure was repeated.

The following equations were used in the calculation of NH_4 and NO_x:

$$NH_4 - \left(\frac{mg}{\ell}\right) = \frac{V_1 \times M \times 14.01 \times 1000}{V_O} \qquad \text{Eq (10)}$$

$$NO_x - \left(\frac{mg}{\ell}\right) = \frac{V_1 \times M \times 14.01 \times 1000}{V_O} \qquad \text{Eq (11)}$$

Where:

V_1	=	Volume of hydrochloric acid used in titration		
V_o	=	Volume of test sample	=	50ml
M	=	Molarity of HCl	=	0.088

Table 4.2 above summarises the process monitoring and waste characterisation tests that required to be undertaken of the research period. The next chapter presents the results for both the process monitoring and waste characterization.

Table 4.2: SUMMARY OF DAT/TTW WINDROWS - PROCESS MONITORING PARAMETERS AND SAMPLING POINTS

Area of sampling	**Parameters tested**	**Measuring device**	**Location of sampling**	**Sampling intervals**
		ANALYSIS IN THE WINDROWS		
Exhaust gas	Velocity Temperature Gas Composition (O_2, CO_2, CH_4)	Anemometer Thermo couple GA94 – GA2000	1m from the top of the exhaust pipe	Every day for the first week, once a week thereafter for 8-16 weeks
Waste body	Temperature at 1.5m dept Gas composition at 0.5m, 1m and 1.5m depth	Thermo couple GA94/2000	From fixed gas probes in each of the worst ventilated area in the middle between two domes – control areas	Every day for the first week, once a week thereafter for 8-16 weeks
Waste body	Temperature at 1.5m dept Gas composition at 0.5m, 1m and 1.5m depth	Thermo couple GA94/2000	From fixed gas probes in selected best ventilated areas, in the middle of the line between an east side channel and the next dome – control areas	Every day for the first week, once a week thereafter for 8-16 weeks
External environment	ambient temperature atmospheric pressure wind velocity	Weather station on site (Bisasar Road Landfill Weather Station)	Area surrounding the windrow	Every day for the first week, once a week thereafter for 8-16 weeks
		ANALYSIS ON SOLID REFUSE (RAW – AFTER 8 WEEKS – AFTER 16 WEEKS)		
Representative sample	Moisture content pH Total and Volatile solids Total Kjeldahl Nitrogen (Total-N) Total Organic Carbon Self Heating test Germination tests	Oven Hanna pH meter Furnace TKN apparatus TOC apparatus Incubator	Representative sample, dried at 105 degrees and finely comminuted	Input material After 8 weeks MBP After 16 weeks MBP
		ANALYSIS ON LIQUID FROM LEACHING TESTS		
Representative sample	pH and Cond. TOC TKN COD and BOD N-NH_4 N-NOx (NO_3 and NO_2)	TOC TKN COD – BOD apparatus Ammonia Distiller Photometer	Leaching tests using a L/S=10 20g solid in 200ml water	Input material After 8 weeks MBP After 16 weeks MBP

CHAPTER 5
RESULTS AND DISCUSSION

5.1 INTRODUCTION

This chapter presents the results and discussion of the process monitoring of the DAT and TTW composting systems as well as the characterisation of the commercial garden refuse (CGR). It should be noted that the temperature monitoring was carried for both composting systems but gas concentration monitoring was only carried out for the DAT system as it was not practical to monitor the gas concentrations for the TTW system (as discussed in section 4.3.2).

The characterisation section of the CGR was done on the input shredder material which was the same material used for the construction of windrows. The output material characterisation was carried out at 6 weeks, 8-10 weeks and 16-20 weeks for the DAT and 8-10 weeks and 16-20 weeks for the TTW. The 6 weeks for the TTW was not done as this windrow was constructed some two weeks after the DAT windrow.

The last section in this chapter discusses the comparisons of both systems in terms of implementation, feasibility, efficiency of the treatment and potential markets for use the composted material.

5.2 TEMPERATURE PROCESS MONITORING

The DAT and TTW body temperatures are presented and discussed in section 5.1.1 and 5.1.2 respectively. It should be further noted that shredded commercial garden refuse (CGR) volume had to be built up to justify construction of the windrows. In doing so, there was a noticeable increase of the temperature within the stockpiled mechanically treated CGR. Random temperatures recorded from these piles were in upper 40°C temperature range which indicated that there was an increase in microbial activity. Shredded stockpiles were usually moved for biological treatment within 3 days of being shredded.

5.2.1 DAT Temperature Monitoring

The temperature monitoring for the DAT system was carried out at each dome at the exit of the aeration tube, 1 meter into the aeration tube, 1.5 meters into the aeration tube, at the bottom of the dome and the ambient. Figures 5.1, 5.2 and 5.3 present the temperature profiles at the respective depths whilst Figure 5.4 presents the average temperature from the body of the CGR to the top of the aeration tube.

During the first week after construction the temperatures of the exhaust gas rapidly rose to the thermophilic stage (in excess of 60^{0}C). This would indicate that there was a rapid increase in microbial activity whereby the microorganisms would have multiplied and as a result producing heat as a by-product in the degradation process represented by equation 1. Figure 5.1 shows that that the dome 1 reached a maximum temperature of 67^{0}C within 9 days of composting whilst domes 2 to 4 reached maximum temperatures within some 6 days after construction of the windrow. This was expected as the windrow was initially partially built and dome 1 had to be opened to complete construction of the windrow. The general trend shown is that temperatures reached thermophilic conditions with 6~9 days and thereafter tended to gradually decrease.

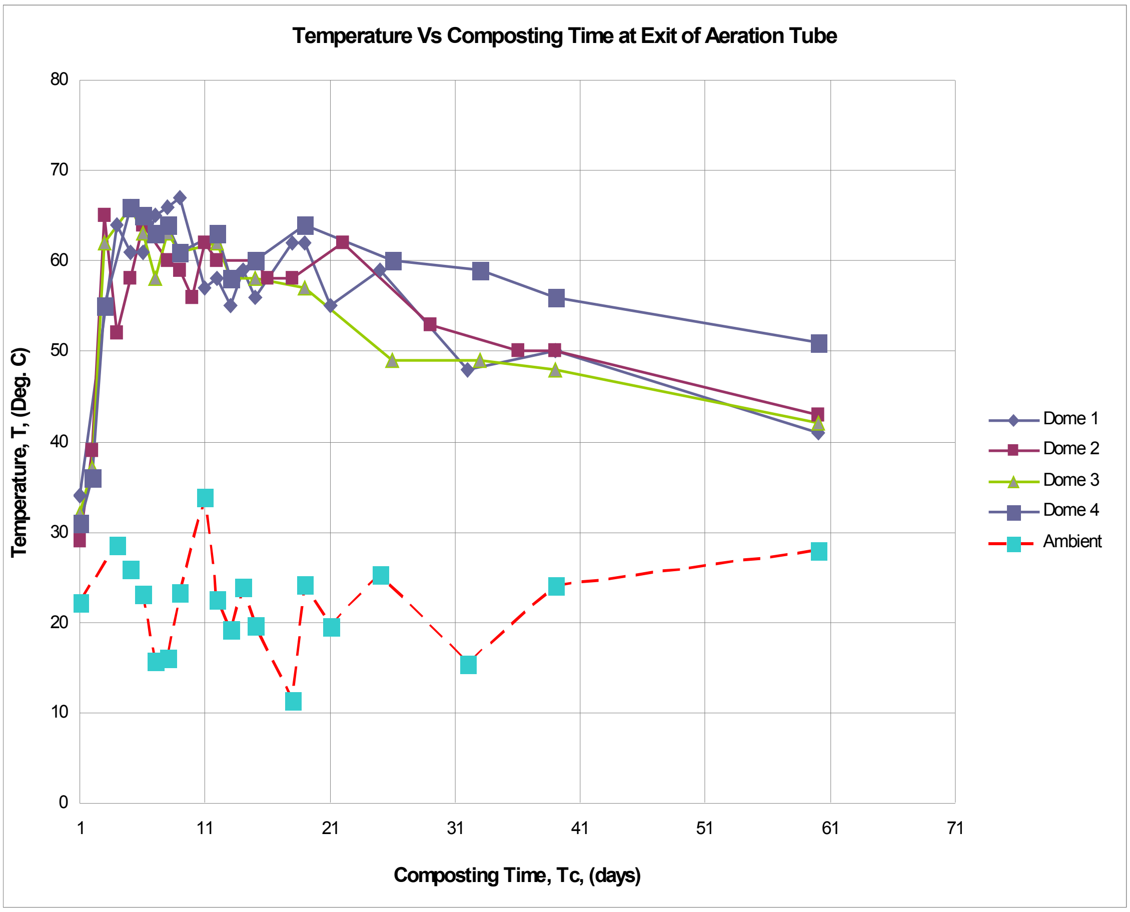

Figure 5.1: DAT Windrow temperatures at the exit of the aeration tube

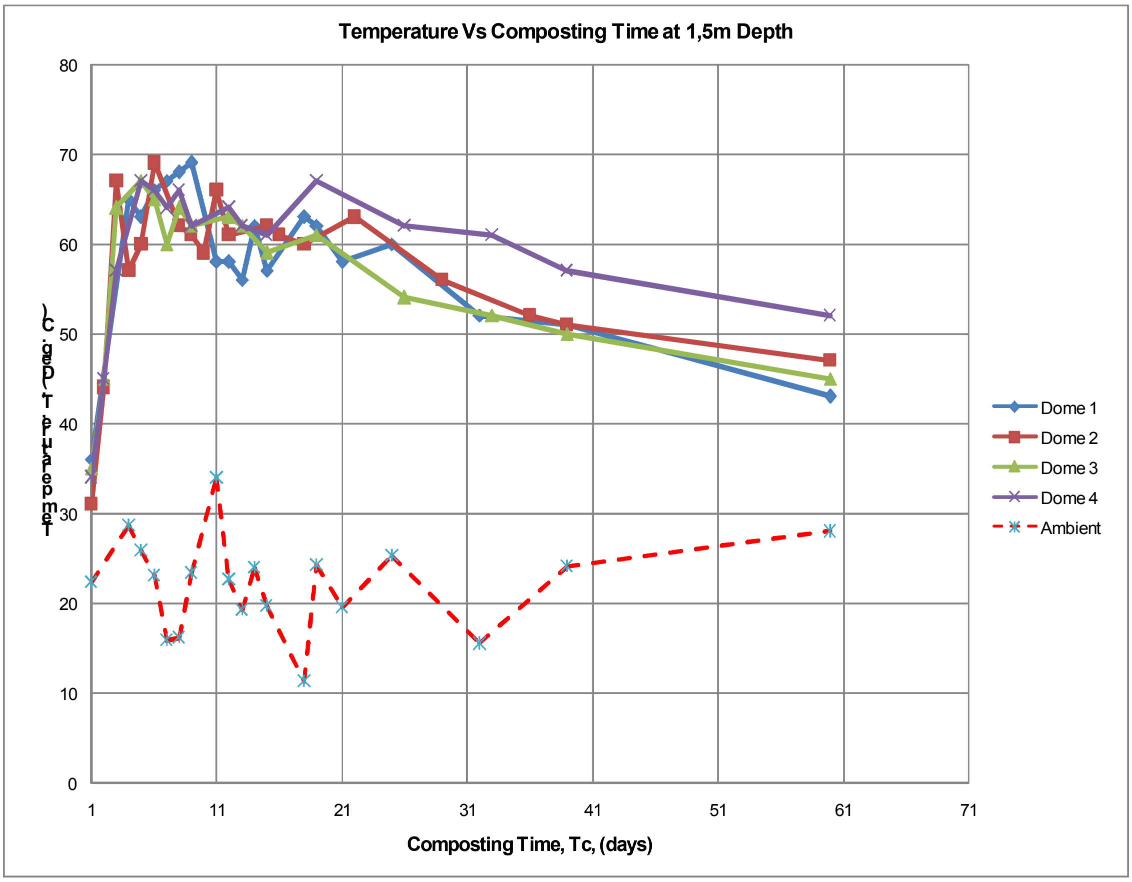

Figure 5.2: DAT Windrow temperatures at the 1.5m from the aeration tube

Soon after a decrease in the temperature, there is a noticeable second increase in the windrow temperatures some 10 days after the first peak. This is clearly seen in both Figure 5.1 and Figure 5.2. The reason for this behaviour most probably is related to climatic conditions such as atmospheric pressure, wind and rain. There is no noticeable relationship between the ambient temperature and the windrow body temperatures. Temperatures thereafter gradually decrease over the balance of the composting period after the second peak to that of the mesophilic range i.e. (40^0C~50^0C) indicating a decrease in microbial activity.

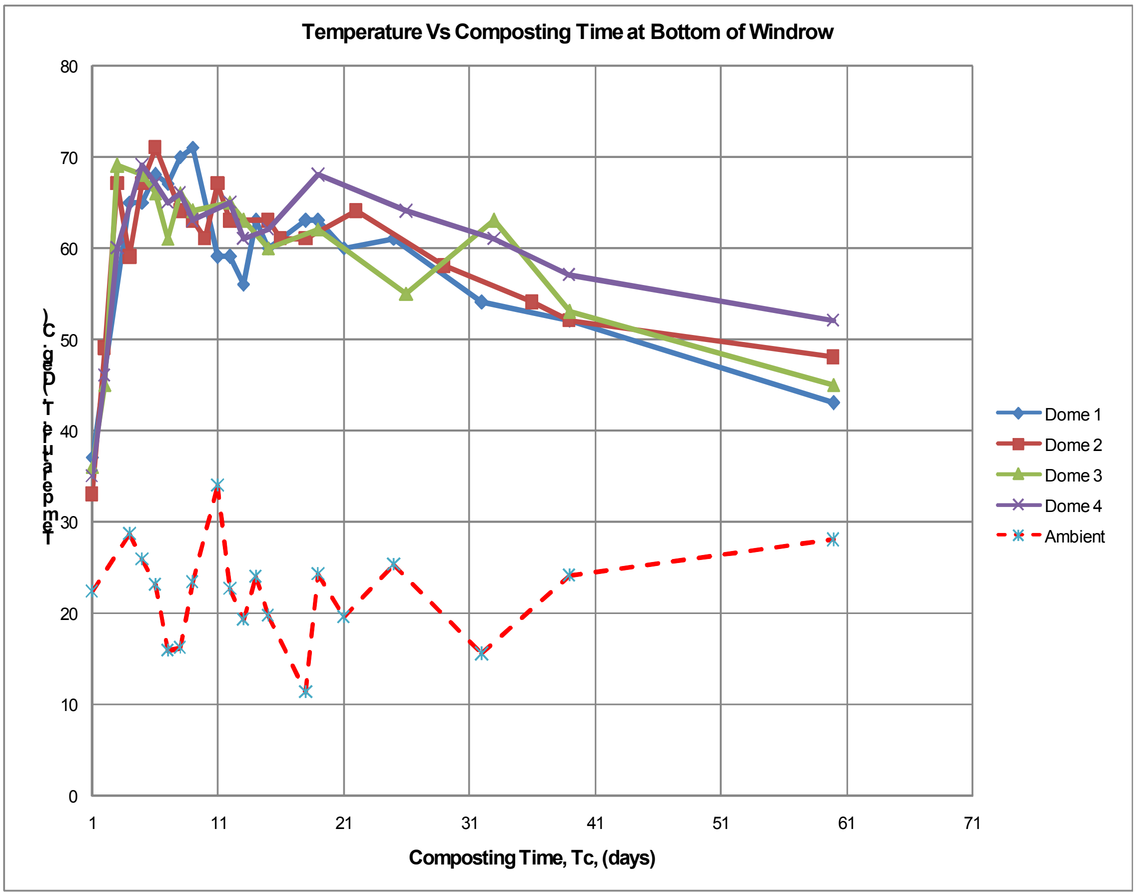

Figure 5.3: DAT Windrow temperatures at the bottom of the dome

The dome temperatures at the bottom of the windrow presented by Figure 5.3 above show that the temperature are some $3^{0}C{\sim}5^{0}C$ higher that the points monitored above. Comparisons are similar to that of monitoring points 1.5 meters and at the exit of the aeration tube as shown in Figure 5.2 and Figure 5.1 respectively. This phenomenon can be attributed to the bottom of the windrow and channels lay in the same horizontal plane, maximum air is passively drawn from the channels through to the composting CGR resulting in an increased microbial activity. Further to this, the volume of composting CGR increase from the top of the windrow to the bottom and as a result there is more CGR being composted and hence a higher biological activity.

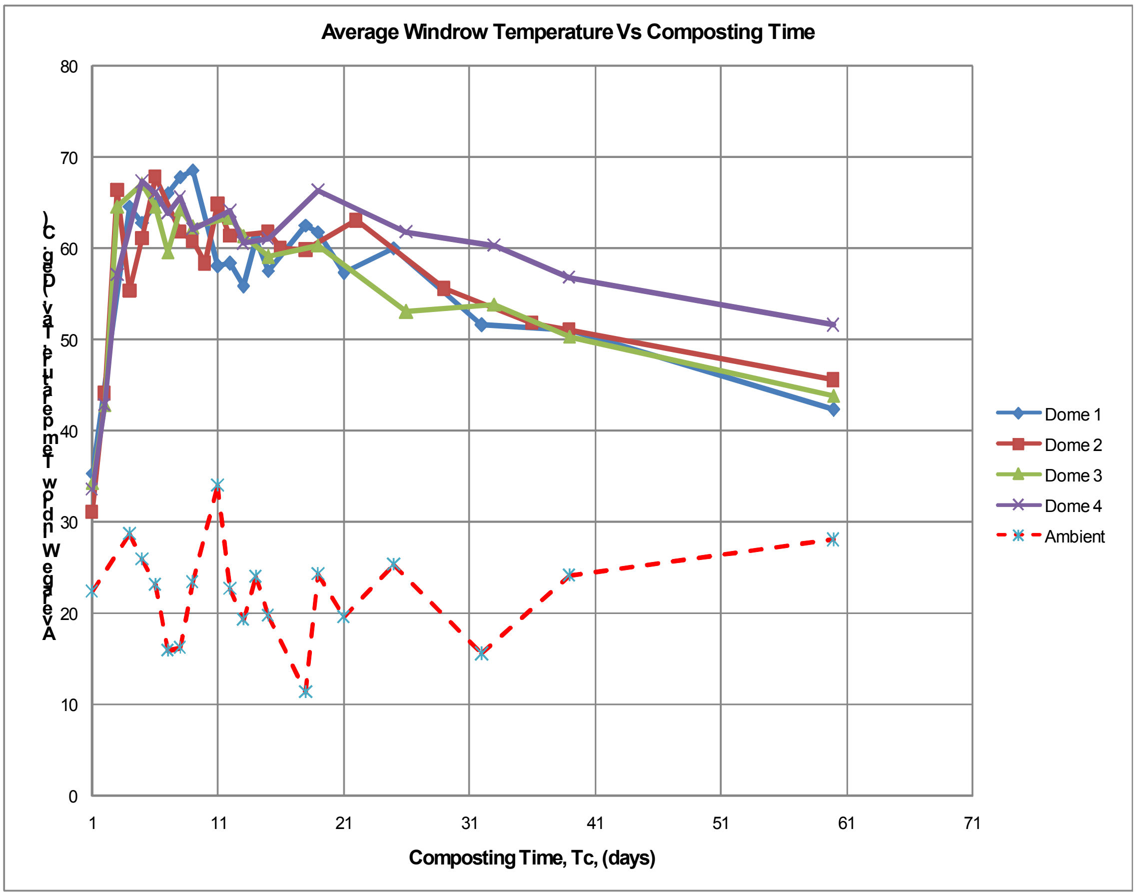

Figure 5.4: DAT Windrow average temperatures

Nevertheless, the difference in temperatures throughout the cross section of the windrow confirms self aeration potential of the windrow as the change in temperature induces a change in pressure which ultimately results in natural passive aeration. Figure 5.4 presents the average temperatures recorded over the composting period and depicts a similar temperature profile as explained above. In general thermophilic conditions were reached with the first 9 days of composting and were maintained for some 22 days of composting. This would of ensured full sanitisation of the windrow i.e. destruction of all weed seeds and pathogens. Temperatures of each dome vary by some 5^0C~10^0C amongst each other throughout the composting period and this was expected as domes were constructed in a staggered or lag fashion i.e. progression from dome 1 to dome 4. This is evident as the temperatures of latter constructed domes are generally higher than the earlier constructed domes. Temperature are shown to decreases after the second thermophilic peak i.e. after day 22 gradually to the mesophilic conditions and as a result there would have been a consequential decrease in the biological activity. The behaviour depicted by the temperature above follows that of typical composting process whereby a mesophilic to themophilic stages occur respectively and followed by a decrease to mesophilic temperatures as cited in composting literature.

5.2.2 Traditional Turned Windrow Temperature Monitoring

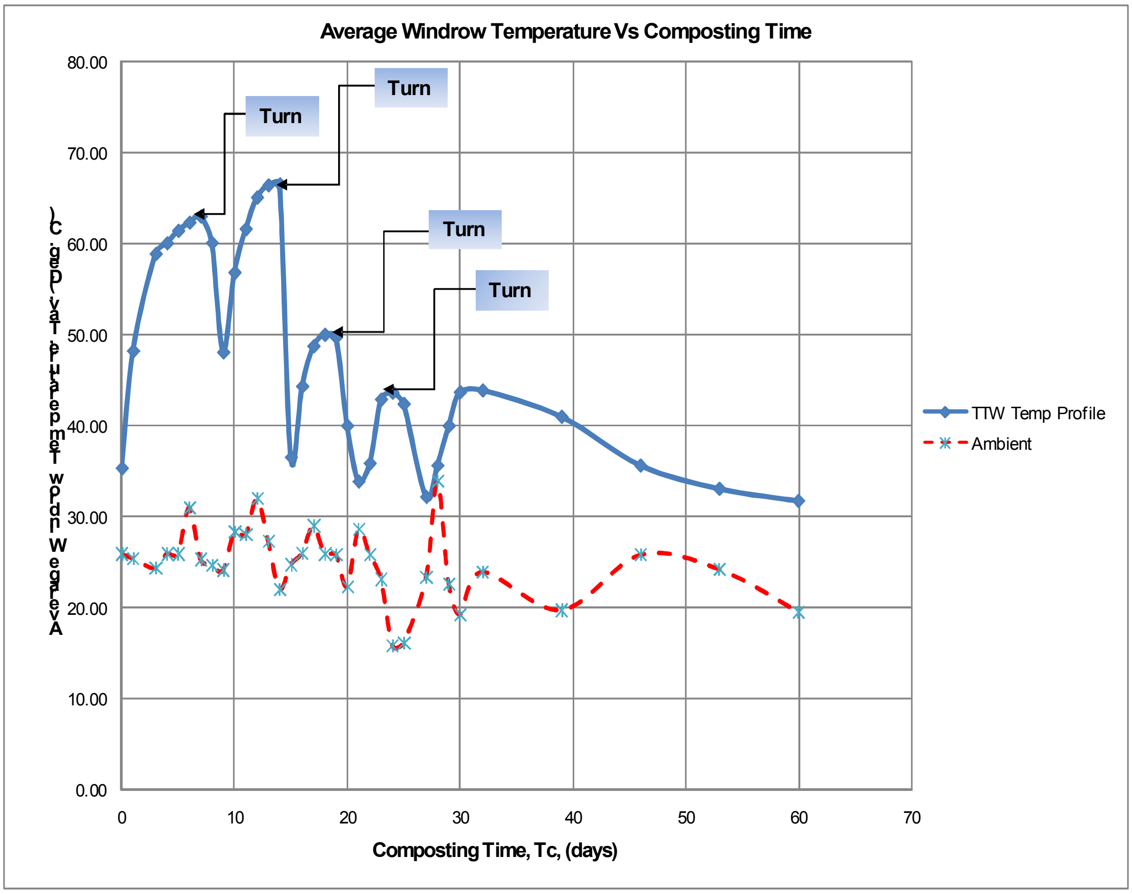

Figure 5.5: TTW average temperatures

As described in section 4.3.2, the monitoring of the TTW windrow temperature was done by opening a hole some 2 meters into the windrow and monitoring the temperature with the thermocouple. TTW were only turned and wetted when temperatures stabilized. The rationale behind was that a stabilizing temperature would indicate a decrease in the rate of biological activity. This decrease in biological activity would have been as a result of either insufficient oxygen or moisture availability. Therefore after each temperature peak, the TTW was wetted using a water tanker and turned using a FEL.

The TTW temperatures presented in Figure 5.5 above show that temperatures rapidly increased to the thermophilic range within 7 days of composting i.e. some 64°C. A decision was taken at this point to turn and wet the pile as there was risk that temperatures would increase further and resulting in the biological activity being inhibited. Following turning and wetting on the 7th day of composting, the temperature rapidly decreased to 48°C two days later. Thereafter temperature steadily increased back to a thermophilic peak of 66.5°C. The second peak following wetting and turning was higher than that of the first peak by some 4°C. This rapid increase in temperature was as a result of oxygen supply and addition of moisture that favours optimum conditions for increased biological activity. The third turn and wet cycle was undertaken on the 18th day of composting and the temperature trend thereafter is seen to be similar to that of the previous cycle. The only difference in the temperature profile is that temperatures did increase to thermophilic but instead the upper range of the mesophilic conditions. It was evident that the rise in temperatures following the 3rd and 4th wet and turn cycle was not significant to reach thermophilic levels but instead the increase indicated a rise in biological activity at a very slow rate. The temperatures indicated that in general the TTW requires turning and wetting between 7~10 days.

5.2.3 DAT and TTW Temperature Comparison and Discussion

The average temperatures of the DAT and TTW are shown in Figure 5.6 below.

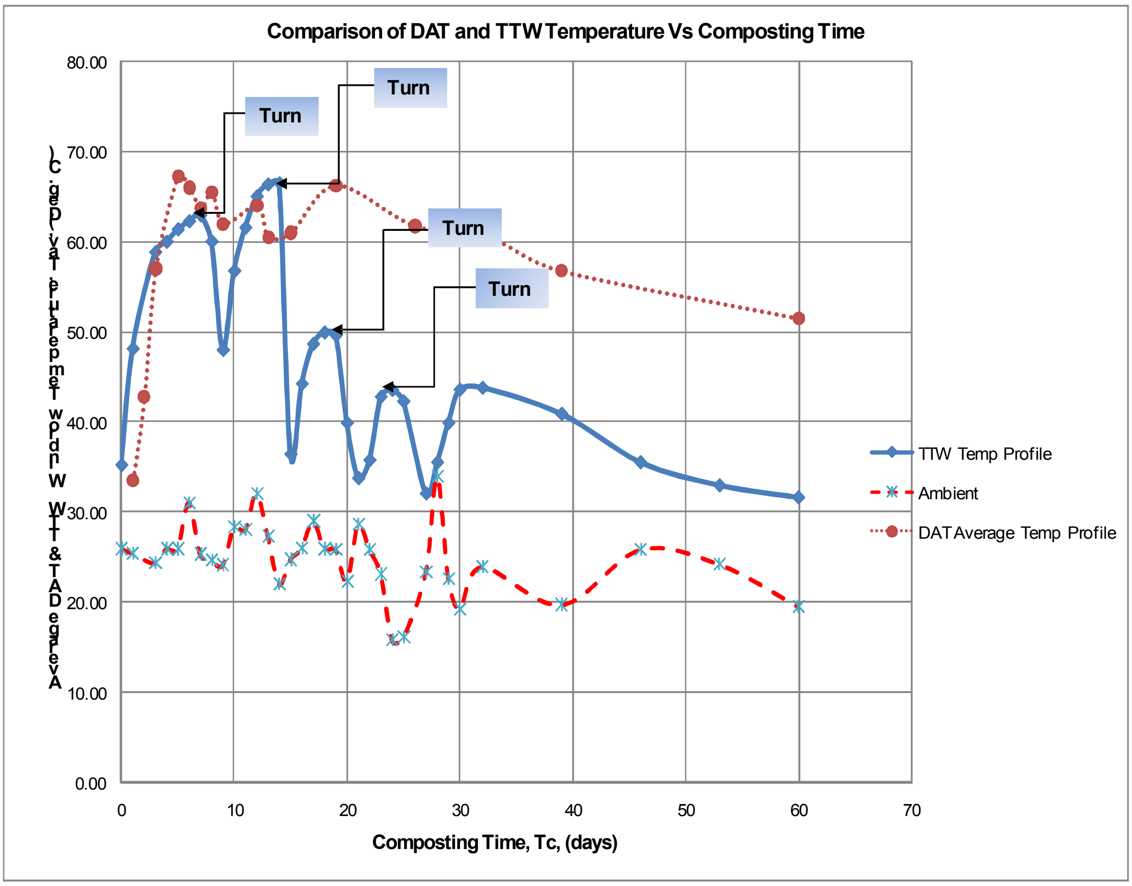

Figure 5.6: Comparison of DAT and TTW average temperatures

Both windrows reached approximately the same range of thermophilc temperatures. However the TTW required two turning and wetting cycles to maintain the same effective thermophilic duration compared to the DAT system. The temperatures for the DAT system were much more consistent with a slow rate of decrease over the composting time as opposed to the TTW were temperatures increased and decreased frequently over short durations. In general the DAT system shows to be more effective from a temperature point of view that favours steady conditions for an effective biological degradation of CGR. This demonstrates that the passive supply of oxygen to the composting process without interference of the windrow leads to an optimum environment for effective biological activity with minimal operation efforts.

The difference in temperatures after the active thermophilic zone is some 20^{o}C between both systems and an explanation for this is likely due to a lack of a constant oxygen and moisture supply for the TTW. It may probably be argued that oxygen and wetting was supply but seeing that the composting process is a biological one, the method in which it was done may in fact not have been appropriate for the maintaining sustainable biological activity.

5.3 WINDROW GAS CONCENTRATIONS

5.3.1 DAT Gas Concentrations

The monitoring of gas emissions from the composting process provides essential information on the evolution of the biological treatment process. The concentrations of oxygen and methane assist to validate if the process is aerobic or anaerobic. Further the carbon dioxide emission trends helps to evaluate the biological metabolic process.

5.3.1.1 Oxygen (O_2)

The concentration of O_2 was measured throughout the composting process is presented in Figure 5.7 below. The O_2 concentration in each dome followed a similar profile to each other in that there was an initial quick increase with the first 7~9 days of composting to a concentration above some 17% O_2. As discussed in section 2.4.2 the optimum O_2 concentration should be greater than 10% O_2 and all domes maintained an average of some 16.5% O_2 over the composting time. It was noted that only domes 3 and 4 initially recorded levels below 10% O_2 i.e. 8.3% and 5.3% respectively. Upon investigation it was discovered that one of the channels in-between domes 3 and 4 had been damaged by the FEL during construction and this was repaired on the third day of composting. There was noticeable difference in the O_2 concentration for this area as concentrations immediately increased to some 16% O_2 thereafter and this once again demonstrates the unique aeration effect of the DAT.

Figure 5.8 below presents the cumulative oxygen percentage during the composting time. The trend in the oxygen confirms the result of Trois and Polster, 2006. The first 22 days of composting were in the thermophilic range resulting in increased biological activity that consumed oxygen. Thereafter oxygen was still consumed but at a low rate and this is due to a decreased in the biological activity from thremophilic to mesophilic conditions. However, Figure, 5.8 shows that the oxygen concentration was sufficient in ensuring constant aerobic conditions. This excessive supply of oxygen may have contributed to a decrease in biological activity by desiccating the windrow i.e. moisture loss due excessive aeration.

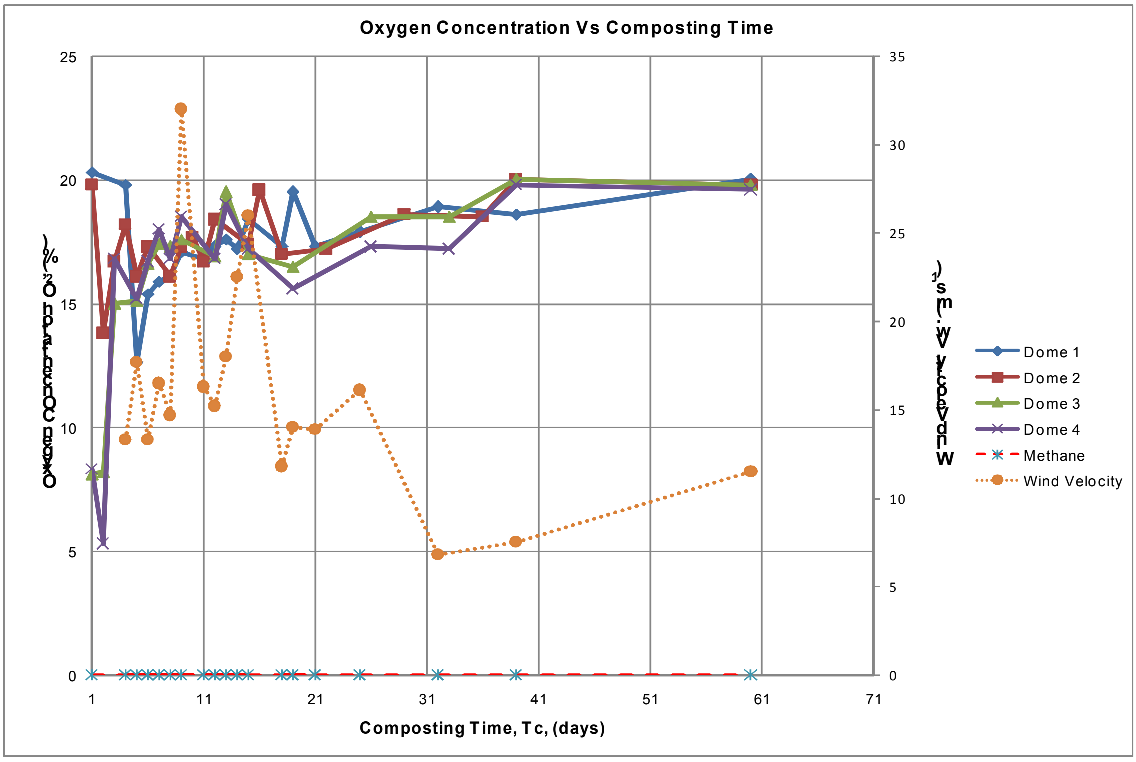

Figure 5.7: DAT Oxygen concentrations

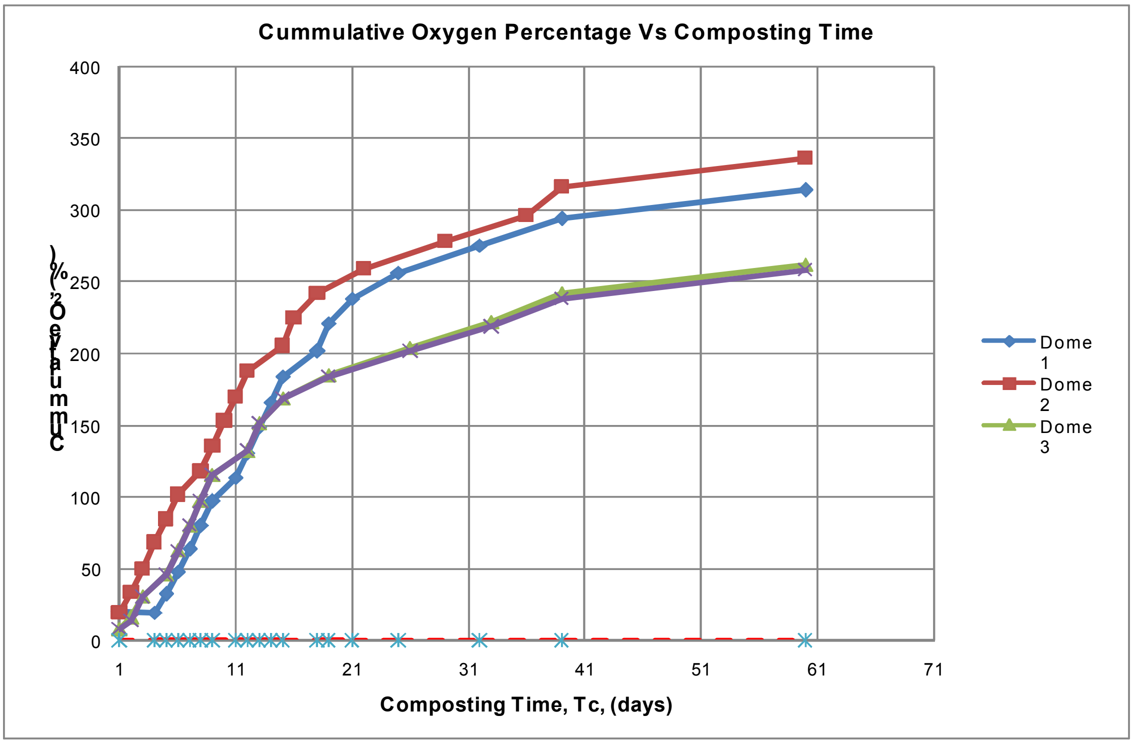

Figure 5.8: DAT Cumulative Oxygen concentrations

The O_2 concentration remained well above the minimum of 10% O_2 and further there no recording of CH_4 were produced during the rotting period. This would therefore imply that the windrow was well aerated for aerobic composting. The wind velocity is shown to have an effect on the O_2 consumption as days with high wind velocities resulted in the windrow having a higher concentration of oxygen and hence an increased microbial activity. This resulted in higher corresponding temperatures presented in Figure 5.1 - 5.4 above. This behaviour was also confirmed by Polster, 2003. The evolution of the O_2 concentration also needs to be judged against other factors such as the cumulative CO_2 production to draw global O_2 effects.

5.3.1.2 Carbon Dioxide Production (CO_2 and ΣCO_2)

The production of CO_2 serves as an excellent tool in considering the biological degradation of the rotting CGR in the composting process. Therefore the cumulative production of CO_2 would describe the rate of the biological degradation during the composting time on the assumption that the total CO_2 produced was that given off by the microorganisms in the composting process. Figure 5.9 and Figure 5.10 below presents the CO_2 and cumulative CO_2 production results.

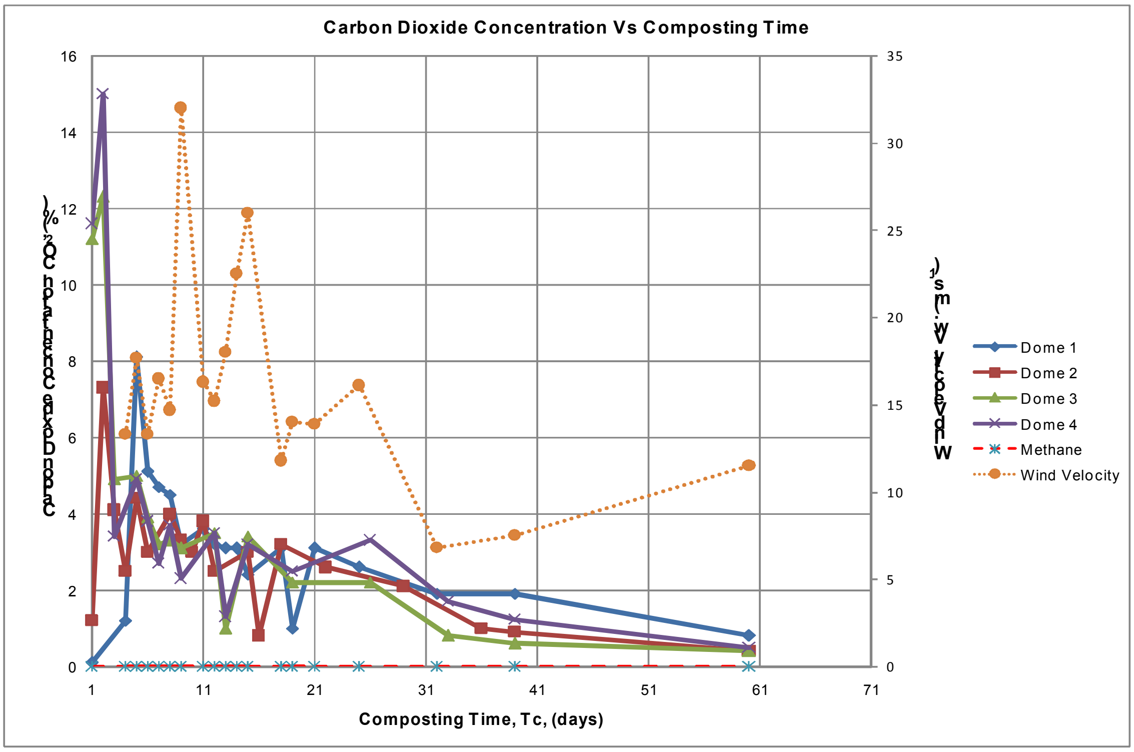

Figure 5.9: DAT Carbon Dioxide Production

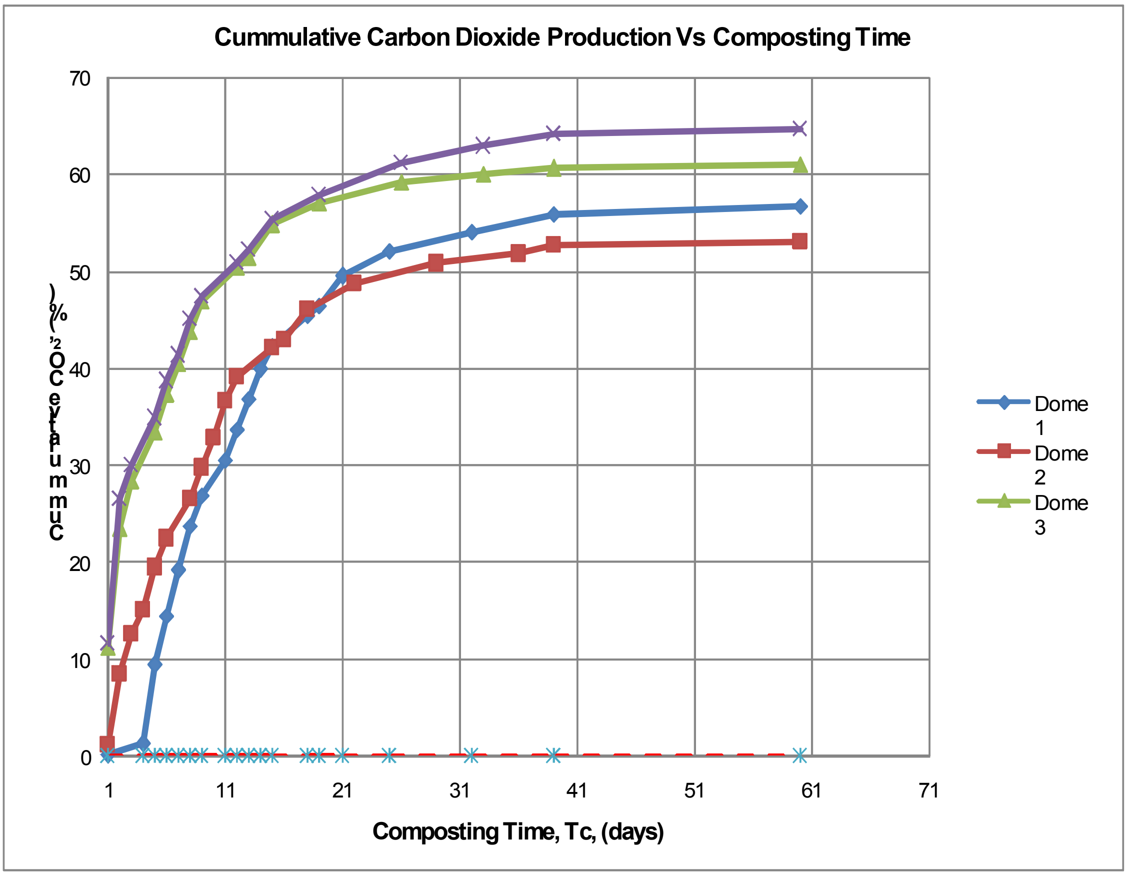

Figure 5.10: DAT Cumulative Carbon Dioxide Production

Figure 5.9 above shows that the increase in the wind velocity contributed to the production in CO_2 as a result of oxygen supply for biological activity. The CO_2 production was produced at a high rate during the thermophilic phase as this was expected and thereafter decreased as temperatures reached mesophilic conditions. This decrease in CO_2 production is likely to be attributed by excessive oxygen conditions resulting in moisture loss. The moisture loss may have caused a decrease in the biological activity. The result obtained in this research confirms similar results by Trois and Polster, 2006.

The cumulative CO_2 emission profile presented in Figure 5.10 illustrates that majority of the production occurred within the first 22 days of composting. This corresponds directly the intense thermophilic phase held over the first 22 day and as discussed in section 5.1.1. Since the thermophilic phase resulted in an increased biological activity, this in turn resulted in an increased respiration as CGR was degraded. In general the cumulative CO_2 increased to a peak after 22 days of composting and thereafter the production increased at a very low rate and eventually followed a plateau trend indicating that the biological degradation was decreasing. This was expected as the initial degradation phase would have been rapid due to all easy biodegradables material being decomposed followed by a decrease as a result of slowly biodegradable being degraded. This typical trend in the CO_2 production is similar to that of the temperature as the common phenomenon of the growth phase followed by a decrease in the metabolic process is evident. Moreover, there was no record of CH_4 produced and this confirms the aerobic respiration and constant passive aeration of the windrow.

5.3.2 TTW Gas Concentrations

As discussed in section 4.3.2, there was no quantitative monitoring for the TTW gas concentrations as windrows were regularly turned and made installing monitoring probes impractical. The frequent turning intervals presented in Figure 5.5 above, avoided the risk of any CH_4 or onset of anaerobic conditions. Since there is a noticeable correlation between CO_2 production and temperature for the DAT windrow, an assumption can be made that the same principle would be applicable to the TTW in terms of general composting behaviour. Therefore, biological activity would have reached a maximum after the second turn and thereafter further turning and wetting despite their effectiveness were not able to increase biological activity.

The regular turnings after the second cycle would have most probably guaranteed aerobic conditions but could have resulted in adverse effect of cooling the composting process. This is likely to have resulted in a decrease in the rate of CO_2 produced and can be substantiated by the temperature profile of the TTW as the later of the composting process after the thermophilic phase drops to that the low mesophilic ranges resulting in decrease in the metabolic process.

5.4 DOME FLOW VELOCITY

The results of the dome flow velocity for the DAT system is presented in Figure 5.11 below. It can be seen that high wind velocities corresponds to high exhaust gas velocities which relates to high temperatures differences illustrated in section 5.1.1. These findings confirm the work done by Polster, 2003. Another effect from the wind would result in suction forces created at the exit of the aeration pipe, which would therefore increase the exhaust gas velocity.

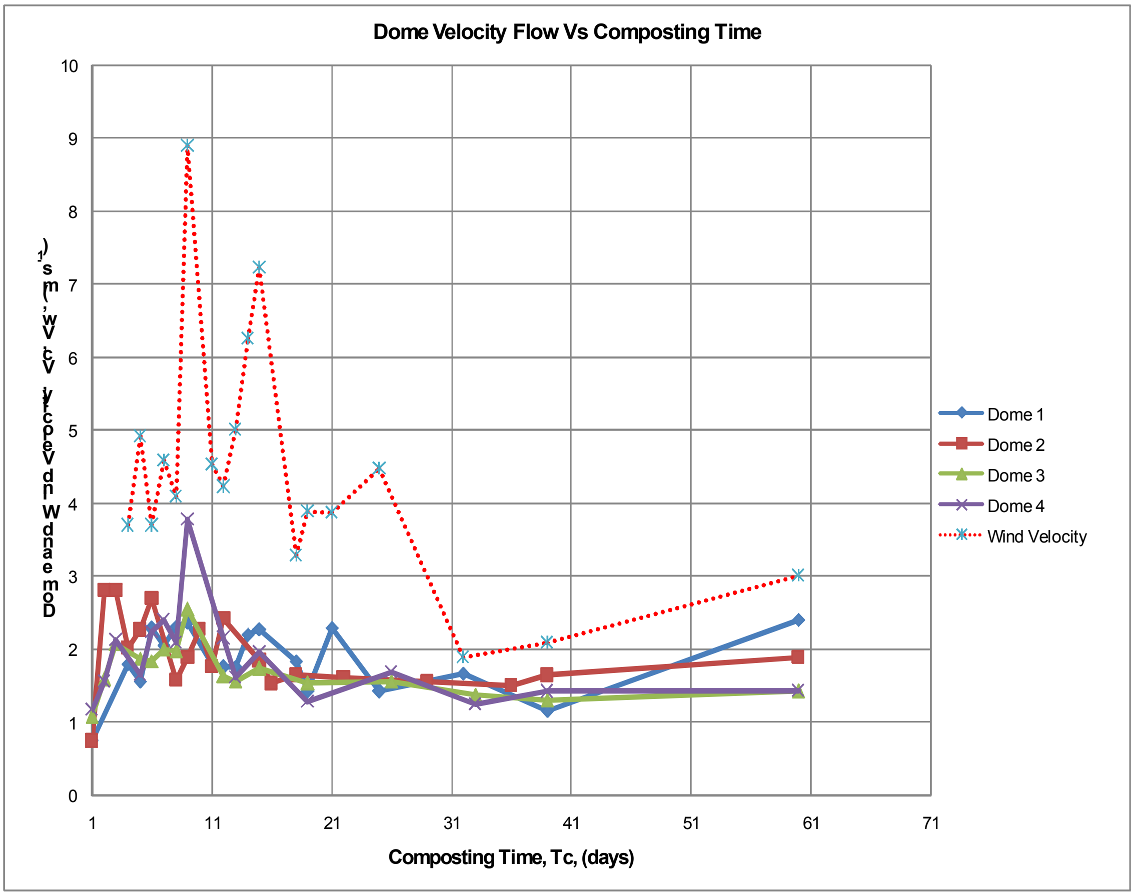

Figure 5.11: Dome flow velocity

In general the high flow dome velocities correspond to the thermophilic range as this is where there were increased biological activities which results in increased respiration i.e. faster emission of dome gases. The wind velocity influences the effective temperature difference between the outside and inside of the domes. The wind causes an additional suction head at the end of the aeration pipe and therefore increases the effect on the exhaust velocity. This confirms the results concluded by Polster, 2003. Figure 5.11 above shows, increases in the wind velocity effects the degradation process i.e. as oxygen is supplied, the biological activity increased resulting in an increase in the exit gas velocity. However, as the biological decreased from thermophilic to mesophilic, there is a resulting decrease in the exit gas velocity. It is interesting to note that although there is a decrease in the biological degradation there was still sufficient oxygen supplied as seen in Figure 5.7.

5.5 CHARACTERISATION OF COMMERCIAL GARDEN REFUSE

The section presents the input and output material characterisation results for both the solid and eluate test as summarized in Table 5.1 below. All laboratory tests carried out were done in accordance with section 4.4 and all the results presented in this section are an average of the results calculated. All detailed solid and eluate testing raw data is attached in Appendix A for reference.

Table 5.1: Summary of characterisation of input and output material

Test/Substrate	INPUT	OUTPUT				
	CGR RAW	DAT 6weeks	DAT 8-10weeks	TTW 8-10weeks	DAT 16-20weeks	TTW 16-20weeks
Solid						
MC (%)	37.14 ± 3.17	56.60	52.71	66.36	54.24 ± 2.90	59.28 ± 3.22
TS (%)	62.86 ± 3.17	50.80	45.82	32.2	45.76 ± 2.90	40.72 ± 3.22
VS (%)	96.37 ± 0.75	90.65	90.81	82.1	87.20 ± 8.68	71.73 ± 2.42
RI_7 (mg.O_2/g DM)	7.77	60.50	N.D	N.D	6.987	9.823
Total C (%)	49.6	N.D	41.35	38.65	22.04	29.04
Total N (%)	0.55	N.D	1.15	1.31	0.96	1.65
C : N	90.19	55.70	36.16	29.71	22.96	17.6
Eluate						
TS (g/ℓ)	4.08 ± 0.02	5.77	6.29	13.13	11.78 ± 0.26	12.55 ± 0.14
VS (g/ℓ)	3.04 ± 0.02	3.96	1.97	3.63	7.55 ± 0.29	8.61 ± 0.14
pH	5.45	7.07	7.13	7.13	6.93	7.27
Cond (mS/cm)	1.653	1.62	2.14	1.76	1.23	2.69
COD (mg/ℓ)	4253	7698.43	4610.81	8128.22	10080	11270
BOD_5 (mg/ℓ)	1101	506.30	642.25	515.5	348	474
NH_3-N (mg/ℓ)	12.74	12.00	40.32	30.66	29.4	50.12
NO_x-N (mg/ℓ)	6.86	10.73	685.37	9.31	8.96	14.56
Total C (%)	0.083	N.D	N.D	N.D	0.6	0.67
Total N (%)	0.0183	N.D	N.D	N.D	0.07	0.09
C : N	4.54	N.D	N.D	N.D	8.57	7.44
*ND - Characterisation test not done						
±: Refers to the standard deviation of the result only if tests were done for three trials or excess						

5.5.1 Moisture Content

DAT Windrow

The DAT 6 weeks shows a marked increase in the moisture content to that of 56.6% than the input material. This was expected as the input material had to be wetted in excess of 60% moisture to reach optimum composting conditions. The moisture content thereafter is seen to decrease by some 7% to 52.71% at 8-10 weeks of sampling. This was also expected as the subsequent elevated thermophilic temperatures experienced inside the windrow body resulted in removal of the moisture from the windrow. Thereafter the final moisture content at 16-20 weeks increases slightly by 3% to 54.25%. This noticeable increase is not significant and could be as a result of rainfall infiltration through the pine bark cover into the CGR composting body. It was noted that 16-20 week sampling interval coincided with the January rainy season experienced in Durban and this may have contributed to the increase on moisture content.

TTW Windrow

The TTW 8-10weeks results show that the moisture content had increased to 66.36% from the initial 37.14%. This also follows a similar trend to that of the DAT however TTW moisture content at 8-10 weeks is some 18% higher than the DAT windrow. This increase in moisture content is likely to be as a result of excessive moisture supply through the wetting and turning process. Thereafter the moisture content decreased to 59.28% during the 16-20 week sampling interval. The higher moisture content in the TTW could have probably hindered to the biological treatment process as the excessive supply of moisture resulted in a cooling effect of the process. The minimal decrease in moisture during the last composting interval indicated that there was biological activity at a very low rate. This can also be related back to the low mesophilic temperatures that were recorded over the same composting time whereby there the biological activity did not increase to thermophilic conditions irrespective of the efforts placed in turning and wetting.

5.5.2 Total Solid (TS) and Volatile Solids (VS) in the Solid Test

DAT Windrow

The determination of the total volatile solids would provide an approximation of the amount of organic matter present in the solid fraction of the material being tested An optimum of 35% would be considered ideal for garden refuse composting (Polster, 2003). The total solids (TS) concentration of the waste influences the pH, temperature and effectiveness of the microorganisms in the decomposition process (Palmisano, 1996). The input TS value was recorded to be 62.86% of which 96.37% was of a volatile nature. Both the values decrease over the composting time to some by 27% for the TS and 9% for the VS. The garden refuse input material was expected to have a high organic content and hence the relatively high values shown in the results. The fact that there was reduction in the volatile solids from 96.37% to 87.2%, is indication enough of microbial activity degrading the rotting material. The particle size of the material would also affect the ignition loss; larger size particles would take longer to degrade and vice versa.

TTW Windrow

The TTW windrow results for the TS and VS also follow the same trend to that of the DAT system with the concentrations of 40.47% and 71.73% respectively. The decrease in the VS can be attributed to the fact that readily biodegradable components of the CGR composting body were decreased as a result of decrease in the metabolic process. This was expected for both the systems as the rate of biological degradation of the CGR was likely to decrease. However, the concentrations are still of a high order indicating that the material is not that easily biodegradable.

5.5.3 Carbon to Nitrogen Ratio (C : N)

DAT Windrow

There is a gradual decrease in the C:N ratio from 90.19 for the input material to 22.96 at 16-20weeks of composting. This decrease is due to mineralization of organic matter, (Rasapoor, 2009). Microorganisms require carbon for their energy and nitrogen for protein synthesis in - order to reproduce. The rate of decomposition is dependent on the balance of carbon to nitrogen ratio in the composting input raw materials. Since the final C:N at 16-20weeks was 22.96, indicates that the excessive carbon of the input material content would cause an initial high rate of decomposition and biological activity followed by a steady decrease thereafter. This behaviour is presented in the cumulative carbon dioxide production whereby there is an initial high respiration which is followed by a plateau.

TTW Windrow

The TTW C:N ratio trend presents the same trend again as the DAT windrow however the final 16-20week value is lower than the DAT by some 23%. This indicates that the material has become mature and has stabilized with a very low rate of biological activity as most of the carbon has been utilized and micro-organisms will therefore not have enough energy for further degradation.

The C:N ratio results for the solid presented in Table 5.1 show that the composting process effectively reduces relatively high C:N over time to a low ratio. The last section of this chapter discusses the C:N ratio in relation to the compost quality and some interesting comments can be drawn from this.

5.5.4 Respiration Index (RI_7)

DAT Windrow

As indicated in chapter 4, the respiration index at 7 days results can be used to evaluate the biodegradability of samples at respective sampling intervals. The results show that the input CGR has a RI_7 of 7.7 7mg.O_2/g DM before biological treatment in windrows. The DAT 6 weeks results shows a significant increase to that of 60.57mg.O_2/g DM indicating that there was a spike in the biological activity of the process. This can be related back to Figure 5.8 above where there was a maximum peak in the cumulative CO_2 production approximately at the 6 week sampling. This would have indicated that the RI_7 test for 6 weeks showed a high amount of CO_2 absorbed which can be related to the O_2 consumed in the biodegradation process. The DAT 8-10 week was unfortunately not done but the DAT 16-20 weeks shows a result of 6.987mg.O_2/g DM. This decrease was expected as the cumulative CO_2 monitored from the gas concentrations were decreasing which as a result of a decrease in the biological activity. The result of a decrease in the RI_7 confirms this theory.

TTW Windrow

The TTW RI_7 for the input material is the same result as the DAT input material as both windrow were composting using the same material. It was unfortunate that no RI_7 testing was carried out at 6 and 8-10 weeks as this would have helped in evaluating the biological activity within this period. However, the TTW 16-20 week test was undertaken and the result shown in Table 5.1 is 9,823987mg.O_2/g DM. It can only be assumed that a similar trend would have been followed to that of the DAT windrow with much less O_2 been consumed as the temperature monitoring after approximately 2 weeks of composting as shown in Figure 5.6 indicates a decrease in the thermophilic temperatures to a constant mesophilic range. This can be related to an overall decrease in the metabolic activity.

5.5.5 Total Solid (TS) and Volatile Solids (VS) in the Eluate Test

DAT and TTW Windrow

The general result for both composting systems shows an overall increase in the TS and VS concentration over the composting duration. An understanding to this trend is likely due to the fact that the composting process ensures that there is degradation of the organic material. Particle sizes of the shredded CGR are physically being broken into smaller sizes by microbial activity feeding of this substrate. As a result, smaller particle sizes in the form of fines are found in the leaching process and therefore there is an increase with time of the TS and VS concentrations. The values of the TS (4.08g/ℓ) and VS (3.04 g/ℓ) for the input material increase to TS (12.55 g/ℓ) , VS (8.61 g/ℓ) and TS (11.78 g/ℓ), VS (7.55 g/ℓ) for 16-20 week TTW and DAT respectively.

5.5.6 pH and Conductivity

DAT and TTW Windrow

The pH for both the composting systems at the start of compost was 5.45 and thereafter showed an increased trend from acidic to neutral. As discussed in section 2.4.2, during the composting process, the material will become slightly acidic and then return to near neutral conditions as stability is approached. The result obtained confirms that of literature and the final pH at 16-20 weeks are 6.93 and 7.27 for the DAT and TTW respectively. The slowing down of the rate of pH increase in the latter stages of composting could also be attributed to the volatisation of ammonical nitrogen and the H^+ ion release as a result of microbial nitrification process by nitrifying bacteria (Elkind, 2000).

The electrical conductivity for both systems was 1.653mS/cm and in general showed an increasing trend for both composting systems. Seeing that conductivity gives an approximation of the amount of dissolved ionic compounds, it can be used to estimate the total dissolved solids in the leaching liquid (Griffith, 2009). It would follow that the results showing an overall increase in the conductivity would imply that the total dissolved solids over time increases.

5.5.7 Chemical Oxygen Demand (COD)

DAT and TTW Windrow

The COD concentration of the input commercial garden refuse was 4253mg/ℓ. The results thereafter showed an overall increase to 10080mg/ℓ and 11270mg/ℓ for the DAT and TTW respectively. Seeing that the COD is defined at the amount of oxygen required to fully oxidize organic compounds i.e. COD values would give the representation of all organic matter that is degraded without bacterial activity. Previous research on garden refuse composting showed a decrease in the COD concentration (Moodley, 2005) to approximately half of the input material concentration. The result obtained in this research does not confirm similar results but instead are haphazard. It is assumed that the COD characterisation on the input material by Plug, 2009 is questionable as the COD results by Iyilade, 2009 shows a concentration of 15603.16mg/ℓ which is more likely to be correct as a high initial COD concentration was expected for garden refuse due its organic nature. Should this be the case, then there will effectively be a reduction in the COD concentration over the composting time.

5.5.8 Biochemical Oxygen Demand (BOD)

DAT and TTW Windrow

The BOD_5 concentration undertaken usually represents 70% of the total BOD concentration, (Strachan, 1999). The input commercial garden refuse result was 1101mg/ℓ and the trend thereafter showed a general decrease to 348mg/ℓ and 474mg/ℓ for the DAT and TTW respectively at 16-20 weeks. It can then be deduced from this result that the composting process effectively reduces the BOD concentrations by some 50%.

This trend can also be related to the aerobic respiration whereby there in an initial increase in biological activity and thereafter decreases as a result of the substrate becoming less easily biodegradable and therefore less carbon available for bacterial energy and therefore less oxygen being consumed.

5.5.9 Ammonia (NH_3-N) and Nitrate (NO_3-N)

DAT and TTW Windrow

The input material was shown to have a nitrogen content (12.74mg/l) as ammonia and (6.86mg/ℓ) as nitrate. This particular input would be toxic to plants and the only way to break down the ammonia would be to supply sufficient oxygen with the action of nitrifying bacteria, (Mkhize, 2004). It would follow that the aerobic composting techniques applied i.e. the DAT and the TTW should satisfy this theory. The DAT 6 weeks shows a drop in the ammonia to 12mg/ℓ however there is a sudden spike to 40.32mg/ℓ in the 8-10 weeks testing followed by a decrease to 29.4mg/ℓ at 16-20 weeks. This increase in ammonia is questionable as previous research on garden refuse composting, (Mkhize, 2004 and Moodley, 2005) showed that aerobic composting reduces the ammonia and nitrate concentrations. Although there seems to be a decrease in the results from the 8-10weeks to 16-20 weeks, the initial increase in the results can either be a result of an error in the test as the DAT 6 weeks also carried out by Iyilade, 2009 showed an input concentration of 63.7mg/ℓ and 14mg/ℓ for the NH_3-N and NO_3-N respectively. The only other factor that may hinder this process is insufficient supply of oxygen however, this can be eliminated as a cause since the process monitoring showed a relatively high concentration of oxygen for the DAT process monitoring (average of 18% O_2) and the TTW was well turned between 7 to10 days. Further to this, the cumulative CO_2 production of the DAT monitoring displayed a typical trend where there was a high increase in CO_2 production i.e. evidence if O_2 supply for aerobic respiration followed by a plateau. Therefore the probability of insufficient O_2 supply can be disregarded.

5.6 COMPARISONS BETWEEN THE DAT AND TTW SYSTEMS

Seeing that the overall objective of this research entailed determining the efficiency between the DAT and TTW and recommending the most applicable technology that could be integrated into current landfill operations, the best approach in satisfying this objective would be to discuss the following efficiencies in comparison to each system:

5.6.1 Efficiency of the Treatment in terms of Compost Quality

In most cases the classification of compost is linked to set a set of guidelines and standard that need to be adhered to ensure it can be a marketable product. Generally these composting standards are based on quality parameters that describe the quality of the compost and these include the following:

- **Physical Properties**: example the output compost particle size and moisture content

- **Biological Properties**: example the temperature required to bring about complete pathogen destruction

- **Chemical Properties**: examples such as pH, Carbon content, nitrogen content, Volatile Solids and the C:N ratio

Standards are vital in environmental and consumer protection and international experiences shown that the different classes of compost and its corresponding standard legislative standards and quality assurance tests (Fiehn, 2005). As discussed in section 2.8.2.3, South Africa does not have a standard for composting of garden refuse (Moolman, 2010). Therefore the best approach to determine the compost quality would be to judge the compost output parameters against international standards.

Previous work conducted on composting of pine bark using the DAT by Trois and Polster, 2006 referred a German compost quality standard and Table 5.2 below shows the comparison of the DAT and TTW in relation to the German DIN 4187 standard. This was chosen as an appropriate standard to use for reasons such as it has been used previously as a reference in South African research and has not been questioned but accepted. It would be a good starting point for South Africa to set a similar local standard that is relevant to organic waste composting and the DIN 4187 compost standard can be used as a guideline.

Table 5.2: Comparison of Compost Parameters with the DIN 4187 Compost Standard

Parameter / Test	Moisture Content [%]	pH	Carbon (C) [%]	Total nitrogen [%]	C:N
DAT 8-10weeks	52.71	7.13	41.35	1.15	36.16
TTW 8-10weeks	66.36	7.13	38.65	1.31	29.71
DAT 16-20weeks	54.24 ± 2.90	6.93	22.04	0.96	22.96
TTW 16-20weeks	59.28 ± 3.22	7.27	29.04	1.65	17.6
DIN 4187 : Minimum	24,9	6,6	14,5	0,6	-
DIN 4187 : Maximum	52,6	8,2	27,1	2,1	-
DIN 4187 : Average	35,6	7,3	19,6	1,1	19-21:1

- **Moisture Content**: Comparison of the moisture content shows that the TTW contained too much of moisture and fell outside the DIN4187 standard. The minimum recorded moisture content for the TTW was some 59.28% at 16-20 weeks which is greater than the maximum DIN 4187 standard. The reason attributed to this is likely due to excessive or frequent wetting during operation of the system. On the other hand, the DAT 8-10 weeks and DAT 16-20weeks were 52.71% and 54.24% respectively. These results indicate that the DAT 8-10weeks meets that of the DIN 4187 standard and is most suitable from a moisture content point of view.

- **pH**: As described in section 2.4.2, initial stages of the composting process, the pH drops as a result of organic acids being released from the degradation of the green matter. Thereafter the pH gradually rises as the organic acids are being broken down and eventually reached a level that is neutral i.e. pH ~ 7 for the final maturation phase. The result for both the DAT and TTW fall within the neutral range and is an indicator that the compost has reached maturation. Both the DAT and TTW meet the DIN 4187 compost standard.

- **% Carbon (C)**: on examination of the results shows that the DAT 16-20weeks falls within the DIN 4187 standard.

- **% Nitrogen (N)**: Both the DAT and the TTW fall within the DIN 4187 standard however the DAT 8-10weeks is closer to DIN 4187 standard average.

- **C: N Ratio**: According to Trois and Polster, 2006, the C: N ratio decreased with composting time and a low ratio indicates that the compost can be classed as a matured product. Both results for the DAT and TTW show this trend and results show that the 16-20week testing indicates that the compost is well matured. The DIN 4187 refers to an average C: N ratio of 19-21:1 and both the DAT and TTW 8-10 week are 36.16 and 29.71 respectively. It was expected to achieve a high C:N ratio as the input material consisted of a high C:N ratio (90.19) indicating a relatively high carbon content with a low nitrogen content. Thereafter the DAT and TTW 16-20weeks shows a C:N ratio of 22.96 and 17.6 respectively. As discussed above, these ratios are indicative of mature quality compost.

On comparison of both C:N ratio's, the higher DAT C:N ratio for both the 8-10 and 16-20 week is likely to be as a result of desiccation of the windrow. The process monitoring of the temperature indicated that thermophilic conditions were maintained for some 42 days (Figure 5.8) however the first 22 days showed indication high biological activity (Figure 5.10) and thereafter showing biological activity decreasing to a minimum. This can only be attributed to two conditions i.e. either insufficient oxygen or lack of moisture in the windrow. Figure 5.7 and 5.8 show that the windrow maintained relatively high oxygen concentrations (>18%O_2) ensuring that the process was fully aerated. More importantly, there is a noticeable decrease in the oxygen consumed after day 22 and this confirms that biological activity decreased as a result of bacteria not consuming oxygen to produce carbon dioxide. The constant oxygen supply thereafter is likely to have created "sweep out" conditions resulting in moisture loss from the flow of oxygen through the passive aeration system. The TTW at 16-20 weeks shows a much lower C:N ratio (17.6) and this low value is as a result of constant wetting and turning ensuring favourable conditions for biological activity. Both systems produce a good quality compost but if moisture can be added during the composting process for the DAT, then the DAT in terms C:N ratio can yield a better quality of compost.

5.6.2 Efficiency in terms of Implementation

This section can be evaluated by discussing the energy requirements in terms of work done and time taken (referred to as the operational requirements) for each system.

- **Implementation: Operational Requirements**

  - ✓ **Step1**: Prior to composting, garden refuse is required to be diverted for mechanical treatment. The area used for the case study was the Bisasar Road Landfill Transfer Station whereby the platform consisted of a hardstand. The operation consisted of using one labourer for diverting and controlling of incoming garden refuse loads and one front end loader operator. The front loader was used to load the garden refuse into the hopper of a remotely operated high speed shredder i.e. the Morbark 2600 shredder as well as load and move the shredded product within the transfer station.

- ✓ **Step 2**: The shredded product was loaded into Articulated Dump Trucks (in this case three were used) using a neighbouring front end loader that loads waste on the transfer station. The material was hauled offsite some 1 kilometer for in-situ biological treatment.
- ✓ **Step 3**: This was followed by preparing the shredded material for composting by wetting using a water tanker and mixing using a front end loader. It must be noted that portable water was not used but instead an onsite ground water borehole was used.
- ✓ **Step 4A**: This step entailed the construction of the DAT windrow. A base using old shredded garden refuse was used on which the dome and channels were accordingly set out as per the German recommendation discussed in chapter 4. The windrow was then constructed using 6 labourers to set out the steel domes and channels sections as well holding domes and channels in place during construction. The front end loader was used for forming and shaping of the windrow whilst the labourers were thereafter used for final shaping of the windrow.
- ✓ **Step 4B**: This step involved the construction of the TTW windrow. This construction only used 1 labour for co-ordination onsite and final shaping. The construction of the windrow i.e. placement of the wetted material was carried out using a front end loader.
- ✓ **Step 5**: This involved insulating the composting material using pine bark. This covering operation was done using an excavator for both windrows

Table 5.3 presented below summarises the operational requirements for the DAT and TTW windrows. The comparison shows both windrows had the same plant requirements for the mechanical treatment and construction of the windrow but the DAT was more labour intensive by using a total of 6 labourers. The DAT windrow took 32 hours to construct whilst the TTW took 24 hours to construct. It must be highlighted that the shredded material had to be first stockpiled for some 3days before construction occurred and this was done to justify the operational use of the landfill plant. In doing so, it resulted in an increased construction time to complete the full scale windrow.

Since the TTW was constructed some 2 weeks after the DAT, lessons learnt from the DAT construction enabled the operational to complete construction of the TTW within 24 hours. Should another full scale DAT windrow be constructed in the future, it would definitely be less than 32 hours.

Table 5.3: Summary of operational requirements for the DAT and TTW systems

Requirement	DAT Windrow	Traditional Turned Windrow
Start Date	September 5, 2008	October 11, 2008
Input Material	Commercial Garden Refuse	Commercial Garden Refuse
Plant Utilised	FEL BELL 1206 and CAT 966G	FEL BELL 1206 and CAT 966G
	ADT x 3	ADT x 3
	Water Tanker	Water Tanker
	Excavator	Excavator
	Shredder	Shredder
Materials Utilised	Domes and Channels	None
Labour Utilised (N^{o})	6	1
Windrow Dimension	4 Dome Sections	25m long, 2.5m high & 10m wide
Windrow Volume (m^3)	220	450
Wetting Source	Onsite Groundwater Borehole	Onsite Groundwater Borehole
Cover Material	Pine Bark	Pine Bark
Aeration Method	Passive Aeration - No Turning	Mechanical Turning (4 Cycles)
Wetting Frequency	Once at Construction	Four Cycles
Construction Time (hr)	32	24

Further the TTW required 4 turning and wetting cycles over the same composting time as the DAT. This required additional space for the front end loader to turn the windrow for aeration. The approximate effective space required for a TTW windrow was 1.5 times the base width of the windrow. Therefore it is noted that the construction of the DAT is most efficient in terms of operational requirements and space required.

5.6.3 Efficiency in terms of Feasibility

A critical decision making factor in industry is related to the economic viability of implementing any project. A detailed capital and operating cost financial model can be compiled a full scale composting windrow however for the purpose of this research, only the operating costs were considered as it could be compared to the operating costs of landfilling as opposed to composting. Table 5.4 presented below details the operating cost of the DAT and the TTW system. Seeing that the bulk density of the shredded garden refuse was unknown, it was decided to randomly record the mass of the ADT's hauling the shredded material for composting and calculate the density from a known volume, (refer to Appendix C).

The operational costing results show that the DAT costs R67/ton as opposed to the TTW that costs R121/ton. Apart from the DAT being labour intensive compared to the TTW, the additional cost is as a result of the turning and wetting from for the TTW system. This increase in cost is some 45% more than the operating cost of the DAT system. It would then follow that the DAT system is effectively cheaper to implement and operate and therefore more efficient in terms of feasibility.

- **Effective Landfill Airspace Cost Saving**

The current landfill airspace cost for DSW is approximately R150/m^3 of waste landfilled. Assuming a compacted density of 1ton/m^3 of waste would result in the composting operation being a financially viable waste management option for treating garden refuse other than landfilling. This would be in DSW's best interest as it is some 55% lower in operating costs than landfilling. There financial saving could be more attractive if there is sale from the compost or through the sale of emission reductions.

Table 5.4: Comparison of the total operating costs for the DAT and TTW

OPERATING COSTS FOR COMPOSTING SYSTEMS : THE BISASAR ROAD LANDFILL SITE					
Item	**Description**	**Unit**	**Quantity**	**Rate**	**Total (R)**
A	Dome Aeration Technology Windrow				
1	***Mechanical Treatment***				
1.1	Shredder	tons	360	23.5	8,460.00
1.2	Front End Loader BELL 1206	tons	360	10	3,600.00
2	***Biological Treatment Preparation***				
2.1	ADT Haulage of shredded material	tons	360	5	1,800.00
2.2	Water Tanker	hr	16	180	2,880.00
2.3	Front End Loader CAT 966G	tons	360	14.5	5,220.00
2.4	Excavator	hr	4	175	700.00
2.5	Labour x 6	hr	108	15	1,620.00
	Total DAT Operating Cost			**R**	**24,280.00**
	DAT Operating Cost per Ton			***R***	***67***
B	Traditional Turned Windrow				
1	***Mechanical Treatment***				
1.1	Shredder	tons	360	23.5	8,460.00
1.2	Front End Loader BELL 1206	tons	360	10	3,600.00
2	***Biological Treatment Preparation***				
2.1	ADT Haulage of shredded material	tons	360	5	1,800.00
2.2	Water Tanker	hr	16	180	2,880.00
2.3	Front End Loader CAT 966G	tons	360	14.5	5,220.00
2.4	Excavator	hr	4	175	700.00
2.5	Labour	hr	18	15	270.00
3	***Turning and Wetting***				
3.1	Front End Loader BELL 1206 (4 Turn Cycles)	tons	1440	10	14,400.00
3.2	Water Tanker (4 Wet Cycles)	hr	32	180	5,760.00
3.3	Labour	hr	32	15	480.00
	Total TTW Operating Cost			**R**	**43,570.00**
	TTW Operating Cost per Ton			***R***	***121***

5.7 POTENTIAL MARKETS FOR THE COMPOSTED PRODUCT

The last objective of the research was to recommend potential markets and re-utilisation of the composted garden refuse *within landfill sites*. This section therefore comments on the typical uses of the composted garden refuse on the landfill sites. During the later stages of the research an opportunity arose with the eThekwini Municipality's Roads Rehabilitation Department whereby double deck screen was loaned to DSW for use on screening the composted product. A trial exercise was undertaken and the particle sizes screened were dependant on the screens installed on the machine. Three screen products were obtained, namely, 10mm to dust, 10mm to 50mm and oversize particles (> 50mm). Plates 5.1 to 5.4 present the screening trial.

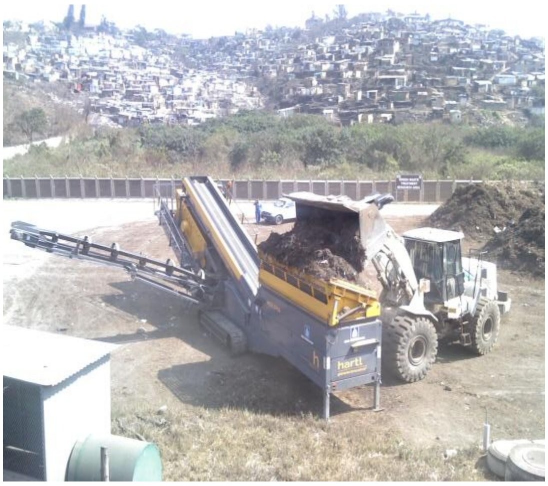

Plate 5.1: FEL Loading the Screen

Plate 5.2: Screen in Operation

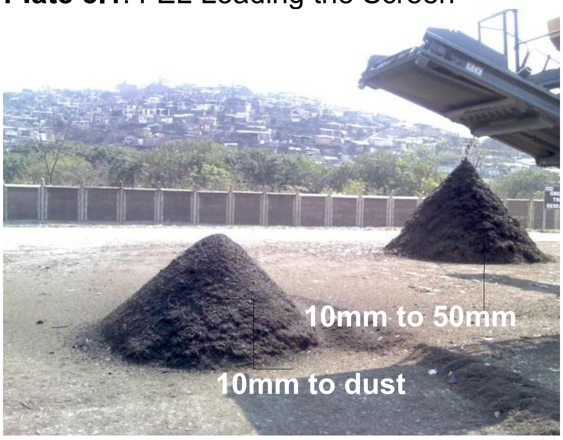

Plate 5.3: Screened Product

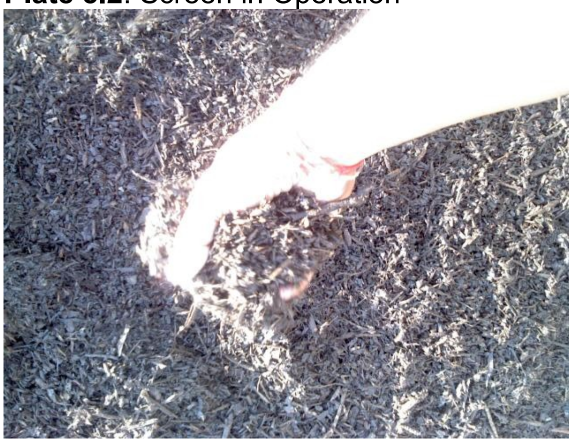

Plate 5.4: Particle sizes of 10mm to dust

5.7.1 Use for Rehabilitation

The continuous closure and rehabilitation of small landfill cells and introduction of indigenous vegetation through DSW's 'PRUNIT' method creates an ideal opportunity to integrate the use of the composted product within PRUNIT. Different end use markets can be formed within the PRUNIT use of both the screened and unscreened product. The waste characterisation results presented in section 5.5 show that a good quality compost can be achieved within 8-10 weeks of composting and this will be of direct benefit as the plants can be bagged using a mix of the compost with topsoil as well as using the product directly in the rehabilitated environments. The following are typical uses of the compost with the landfill rehabilitated areas:

- Screened 10mm to dust product: Can be used as growing medium for seedlings and potting of indigenous plant species.
- Screened 10mm to 50mm: Can be mixed in different proportions of top soil for soil amelioration. Plates 5.10 and 5.11 present the use in PRUNIT.
- Oversized material from screen: Can be utilized as mulch in open grassed areas.
- Unscreened material: Seeing that the end composted product has a mixed particle size distribution, it can be applied on rehabilitated cells and vegetated garden beds as mulch and as a soil amendment. This will have a high demand as the mulch increases the porosity in-between particle resulting in increased moisture retention. The application of such a product will be compatible for the robust landfill engineering with the environment as the rehabilitation will be self sustaining and can thrive on available resources without adding water as opposed to being natured. DSW is currently using the composted product to mulch all final levels of the landfill as well the landfill gas extraction well fields.

5.7.2 Use for Dressing of Final Side Slopes

The Bisasar Road Landfill Site is known to be a controversial site with regards to community acceptance of site. The main reason attributed to this general attitude is linked to the fact that the site is located in a 'heart of a community' and the 'Not in my back yard' (NIMBY) concept is realized. One of the causes of this has led from the site not having a minimum buffer zone and therefore DSW ensures a continual rehabilitation of all final areas and side slopes. The model behind this is to give the community an aesthetically pleasing sight that resembles one of an African ethic bush.

The ultimate vision of DSW is ensure all final side slopes resembles a 'green blanket' image so that the community can foster acceptance of landfill, as they are seen to add value rather than to detract from the surrounding environment. DSW has already linked the use of the unscreened compost to dress all final side slopes as it first improves the aesthetics of the site and secondly adds nutrients to the soil to allow for self seeding of grass species and this results in instant rehabilitation. These rehabilitated areas prevent erosion following heavy storm water runoff's and also attracts biodiversity to the local area e.g. insect life, rodents, snakes etc that all bring about a balance in the ecosystem. Plates 5.5 to 5.7 present a typical final slope dressing using the composted product.

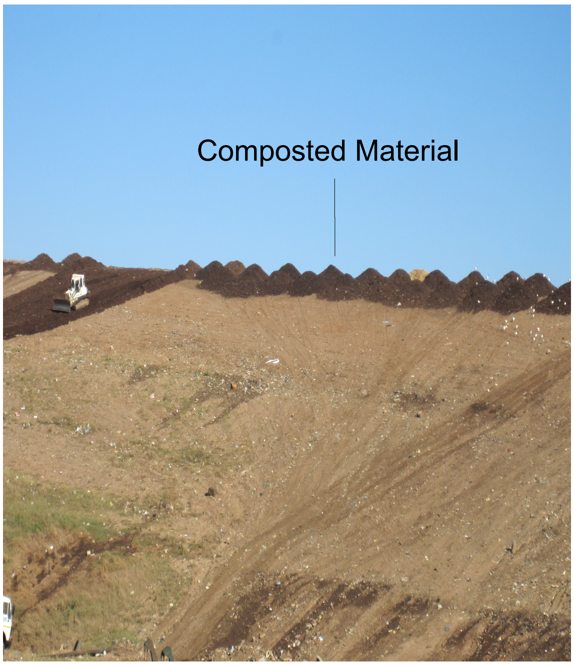

Plate 5.5: Compost tipped on final side slope

Plate 5.6: Dozer dressing side slope

Plate 5.7: Final slope partially dressed with the compost

5.7.3 Organic Gardens

One of the added measures leading form this research was to show people of eThekwini (municipal officials and the local community) that composting of garden refuse can realise social and economic benefits to the city. The concept of implementing an organic garden evolved so that the composting process and its benefits can be visualized and understood. DSW uses a designated area neighbouring the green waste treatment area to grow organic vegetation. Plates 5.8 and 5.9 present the compost use in the organic gardens at the Bisasar Road Landfill Site.

Plate 5.8: Organic garden using compost

Plate 5.9: Herbs grow organically using compost

Although no quantitative testing was carried out in the form of germination test, the qualitative results from the organic garden presents a lush, green and healthy look. This is evidence that the compost produced added nutrients to the soil and confirmation is in the quality of the plants. It may be noticed from the above plates that tyres were used as pots. These tyres were salvaged from the landfill and the concept behind this was to use resources within the site as part of an integrated green waste solution for landfills. Plates 5.10 and 5.11 present the use of compost in vertical stack growing of potatoes and use of compost in PRUNIT respectively.

Plate 5.10: Compost used for vertical stack growing of potatoes

Plate 5.11: Use of compost in PRUNIT for propagating seedlings and bagging

5.7.4 Other Related Landfill Use

- Soil Amendment: To build the organic matter in soils or as a cover material
- Use in DSW garden maintenance contracts for landscaping.
- Use as a bio-filter for odour or absorption of leachate weeps on side slopes.
- Use for denitrification of leachate using compost: Results from Plug, 2009 show that this is evident.
- Runoff retardation of storm water from open areas on landfill cells.
- Divert compost off site for use within the eThekwini Municipality for greening projects.

CHAPTER 6
CONCLUSIONS AND RECCOMENDATIONS

Introduction

The findings of this research has provided valuable information on the mechanical treatment of garden refuse and the subsequent biological treatment through the implementation of two aerobic composting systems i.e. the DAT and the TTW composting systems. The results obtained from the process monitoring, waste characterisation and the comparisons drawn between both systems as discussed in chapter 5 can be evaluated to recommend the best solution for implementation in municipal landfills and this is discussed in the last section of this chapter. The chapter sets out to *summarise the outcomes* of the research and to review the success of the objectives and aims presented in chapter 1, namely:

- The main objective of this study was to optimise full scale green waste composting as part of an established waste minimisation system in municipal landfills by carrying out a comparative study between the DAT and the TTW composting system. The aims in terms of achieving the objective of the pilot project are as follows:

▪ To establish a mechanical treatment operation for garden refuse at the landfill. Volume reduction particle size preparation of the garden refuse was seen as essential prior to biological treatment in windrows.

▪ To construct a DAT and TTW using the mechanically treated garden refuse for biological treatment.

▪ To carry out process monitoring of the each windrow to evaluate the operation of each windrow system.

▪ To carry out waste characterisation evaluations on the composted product of each system at regular intervals in order to assess the quality of the compost.

▪ To evaluate and report on the operational costing of each composting system.

- The second objective entailed determining the efficiency between the DAT and TTW and recommending the most applicable technology that could be integrated into current landfill operations.

- A further objective of the study was to recommend potential markets and re-utilisation of the composted garden refuse within landfill sites.

Optimise full scale green waste composting as part of an established waste minimisation system in municipal landfills using the DAT and TTW composting system

The composting process was shown to be a combination of both mechanical and biological treatment of garden refuse. The first phase of the research focused predominately on understanding the garden refuse waste stream and gathering information that was used in selecting the most appropriate mechanical treatment method. Many lessons were learnt such as the garden refuse waste composed of a heterogeneous mix and the solution to the mechanical treatment found was that of the implementation of a high speed shredder. Following this, an area on the transfer at the Bisasar Road Landfill Site was used to set up for mechanical treatment of the incoming garden refuse in a stream lined flow where the public was educated on the process which assisted in the garden refuse waste streams being received uncontaminated with other waste types. The mechanical treatment proved to be a success as well as the particle size reduction was of a varied nature for biological treatment and this avoided the need for structural material to be used in the windrow construction.

The second phase entailed that of biological treatment in the DAT and TTW windrow. Available landfill plant and resources such as borehole water was used in the preparation and construction of the shredded material in both windrows.

A detailed monitoring of the process conditions were undertaken as well as the waste characterisation of the input and output material was tested. The construction experience in terms of operational requirements and lessons learnt were document for each composting system. The process monitoring of the windrows revealed that both were fully aerobic and reached thermophilic temperature ensuring sanitisation/sterilisation of the windrows however, the TTW system had to be frequently turned and wetted some four cycles to ensure oxygen supply and moisture for enhancing biological activity.

Determining the efficiency between the DAT and TTW and recommending the most applicable technology that could be integrated into current landfill operations

This objective was discussed in detail in section 5.6 where the approach in evaluating the applicable technology for integration into current landfill operations were assessed on the following treatment efficiencies:

- **Efficiency of the treatment in terms of Compost Quality**

As detailed in section 5.6.1, seeing that South Africa does not have a compost quality standard for garden refuse, the German DIN 4187 was used in evaluating this efficiency. The evaluation between both composting systems shows that the DAT 8-10 week produced a good quality compost in relation to the quality parameters.

Therefore, Efficiency of the treatment in terms of Compost Quality = DAT System

- **Efficiency of the treatment in terms of Implementation**

As discussed in section 5.6.2, both the systems had the same operational requirements for mechanical treatment of the CGR and for the preparation of the material for composting. It was found that the much more energy was required for the TTW system and in order to ensure aerobic composting, the windrow has to be turned every 7~10 days. This implied more energy was required in terms of landfill plant and water. Further to this, it was concluded that the TTW requires additional space (1.5 meters x the base width of the windrow) for accommodating wetting and turning of the windrow.

Therefore, Efficiency of the treatment in terms of Implementation = DAT System

- **Efficiency of the treatment in terms of Feasibility**

The operational costing results show that the DAT costs R67/ton as opposed to the TTW that costs R121/ton. The additional 45% cost for the TTW was as a result of the turning and wetting required.

Therefore, Efficiency of the treatment in terms of Feasibility = DAT System

It would then follow from the summary of the above indicators that **DAT is the most applicable technology for integration into current landfill operations** and is accordingly recommended. The last section of this chapter discusses the DAT's implementation into municipal landfills.

Recommendation on potential markets and re-utilisation of the composted garden refuse within landfill sites

The compost output was seen as having the potential to be linked with the landfill rehabilitation environment. As a result of this research, DSW has already set up landfill use of the product and these were detailed in section 5.7. The markets that are already proven are the following:

- Use in DSW's PRUNIT operation for bagging of plants, propagating seedlings and for ongoing rehabilitation of closed cells
- Dressing of final side slopes for soil amelioration and improving aesthetics of the site
- Use as a mulch
- Use in organic gardening
- Other internal uses such as landscaping, use as a bio-filter, denitrification of landfill leachate, storm water retardation, daily cover material etc

Apart from use of the compost within landfills there can also be collaboration with the eThekwini Parks and Recreation Department for use in nurseries, mulching of sports and recreational areas, landscaping of city verges etc. There is also a market for use of the garden refuse material as a bulking agent in the composting of excess sludge from municipal waste water treatment works. The use of the compost within other department in the municipality would be of a financial benefit as the purchase of compost, mulch and bulking agents from private enterprises can be avoided resulting in an effective saving to the city. The compost can also be can also be given to rural communities surrounding the city to ensure that there is nutrient addition to subsistence farming and the promotion of agricultural business whereby previously disadvantaged people from the outskirts of the city can supply local produce to bigger suppliers. This is seen as a sustainable market as it addresses poverty alleviation, promotes economic development and assists the city in controlling urban sprawl. All of the above is beneficial in terms of sustainable use of the composted garden refuse as landfill airspace saving can be realised which effectively results in the lifespan of the landfill being extended.

INTEGRATION OF THE DAT FOR GARDEN REFUSE COMPOSTING INTO MUNICIPAL LANDFILLS

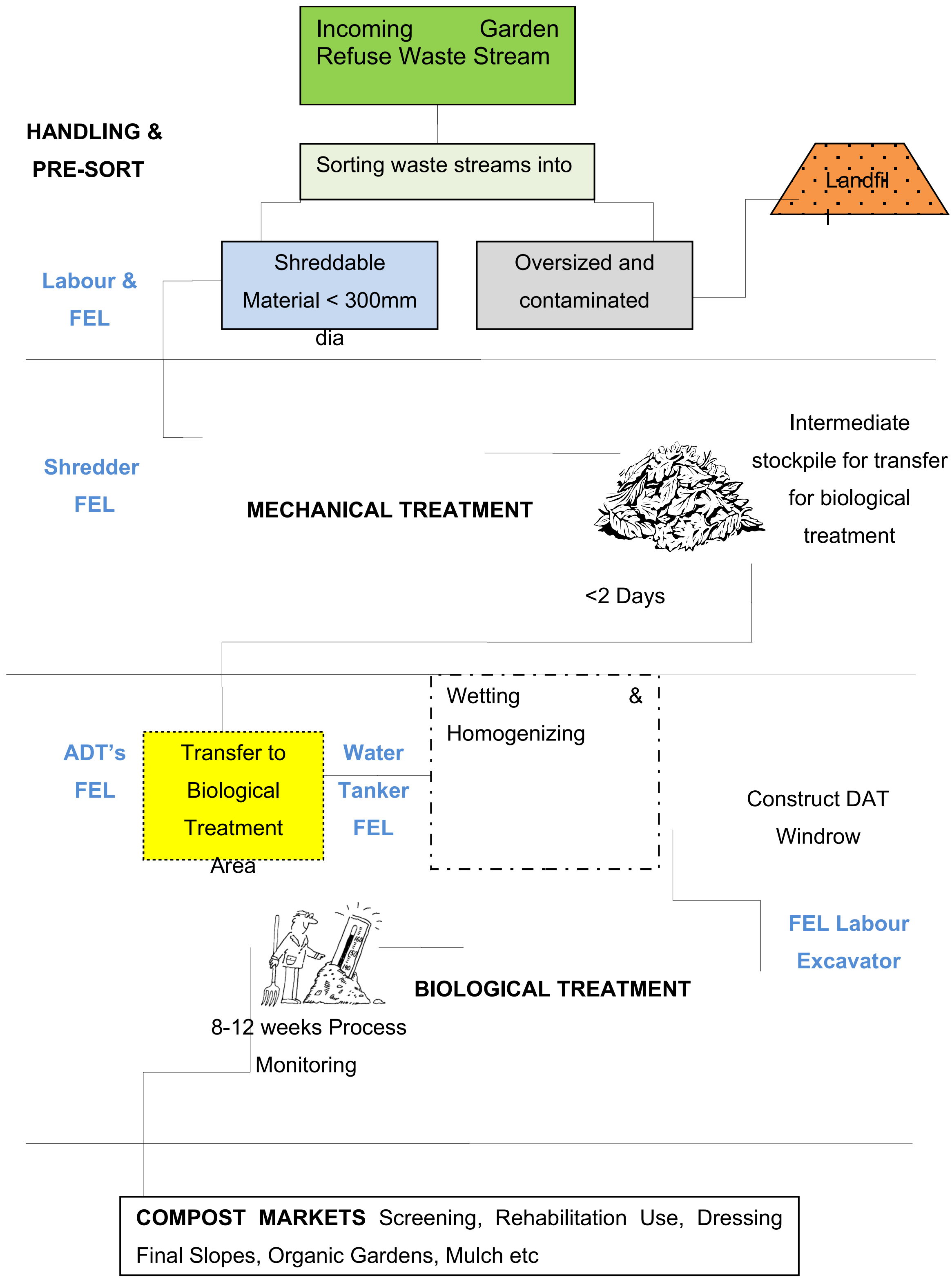

Figure 6.1: Integration of DAT into Municipal Systems

The implementation of the above composting operation presented in Figure 6.1 shows that it can easily be integrated into landfill operations. All incoming garden refuse can be sorted on a designed handling area which can be a transfer station or even on a closed cell that has minimal interference from the landfill operations. The garden refuse can be sorted according to the capabilities of the mechanical treatment equipment using a front end loader (FEL) and labourers into shreddable material and oversized. All oversized material can be loaded using a FEL into articulated dump trucks (ADT's) and hauled to the working face of the landfill for disposal. This step will entail close communication with site controllers and the public. It is recommended that DSW enforces an incentive scheme to get people to bring separately collected garden refuse loads that are compatible for shredding. This incentive could be a free bag of compost for a clean garden refuse load however this must be approved by the senior management of DSW.

The suitable garden refuse can then be loaded into the shredder using an available FEL that will further load the shredded material into ADT's for transfer to a designated biological treatment area. Attention is drawn to the fact that the stockpiled shredded material should be moved within two days to avoid the onset of early thermophilic conditions. The material can then be hauled for preparation to optimum conditions prior to placement in the DAT windrows. The operation will comprise of spreading the material with the FEL, followed by wetting using a water tanker filled with onsite borehole water and then homogenizing using the FEL. Labour can then be utilised to set out domes and channels and the FEL can thereafter place the prepared material into and form the windrow. Labour can once again be used to ensure final shaping and clearing of the site. An excavator can then be used to dress suitable insulating material over the windrow.

A total duration of 8-12 weeks composting time is required as the C:N was found to fall with the DIN 4187 just over 10 weeks however this waste characterisation testing prior to this can facilitate when to stop composting. A further recommendation is made to allow for wetting of the windrow during biological treatment and this can be in the form of a sprinkler or slow drip system. Regular process monitoring is also required to evaluate the windrow performance. DSW can then dictate which compost market has a demand and amend the process to suit that compost market. It is interesting to note that the landfill plant usage can be staggered with the landfill operations and this will ensure maximum production efficiencies of the plant as there will be minimal standing time. In general, it can be concluded that the DAT can be integrated into current landfill operations as it requires low energy, has a 8-12 week treatment time that ensures a good quality compost which is feasible.

In conclusion the composting of garden refuse as part of an integrated zero waste strategy for South African municipalities can be implemented to minimise the amount of waste being landfilled. However, municipalities should investigate waste reduction, reuse and recycling of other waste streams in order to work towards “zero waste”. There is no assurance that zero waste will be achieved and therefore landfill will still remain an integral part of waste management. The initiative of municipalities implementing garden refuse composting will be a step towards alleviating the pressure off landfills.

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APPENDIX A: WINDROW PROCESS MONITORING RESULTS

DOME 1

Day	emperature						Gas velocity(m/s)	composition%					pressure(mb)		ambient conditions
	at exit	1m	1.5m	at bottom	Average temp	ambient	mean at 1m	CO2	accCO2	O2	accO2	CH4		wind vel(Km/hr)	wind vel (m/s)
1	34	34	36	37	35.25	22.3	0.74	0.1	0.1	20.3	20.3	0	1004		
4	64	64	65	65	64.5	28.6	1.8	1.2	1.3	19.8	19.8	0	1004	13.3	3.69
5	61	62	63	65	62.75	25.8	1.55	8.1	9.4	12.6	32.4	0	1006	17.7	4.92
6	61	64	66	68	64.75	23.1	2.28	5.1	14.5	15.4	47.8	0	1016	13.3	3.69
7	65	65	67	67	66	15.8	2.05	4.7	19.2	15.9	63.7	0	1025	16.5	4.58
8	66	67	68	70	67.75	16.1	2.31	4.5	23.7	16.1	79.8	0	1030	14.7	4.08
9	67	67	69	71	68.5	23.3	2.36	3.2	26.9	17.1	96.9	0	1018	32	8.89
11	57	58	58	59	58	33.9	1.79	3.6	30.5	16.8	113.7	0	1004	16.3	4.53
12	58	58	58	59	58.25	22.6	1.75	3.2	33.7	17.3	131	0	1010	15.2	4.22
13	55	56	56	56	55.75	19.2	1.76	3.1	36.8	17.6	148.6	0	1023	18	5.00
14	59	60	62	63	61	23.9	2.2	3.1	39.9	17.2	165.8	0	1007	22.5	6.25
15	56	57	57	60	57.5	19.7	2.27	2.4	42.3	18.4	184.2	0	1026	26	7.22
18	62	62	63	63	62.5	11.3	1.83	3.1	45.4	17.3	201.5	0	1013	11.8	3.28
19	62	60	62	63	61.75	24.2	1.42	1	46.4	19.5	221	0	1004	14	3.89
21	55	56	58	60	57.25	19.5	2.29	3.1	49.5	17.3	238.3	0	1014	13.9	3.86
25	59	60	60	61	60	25.3	1.42	2.6	52.1	17.9	256.2	0	1011	16.1	4.47
32	48	52	52	54	51.5	15.5	1.66	1.9	54	18.9	275.1	0	1026	6.8	1.89
39	50	51	51	52	51	24.1	1.15	1.9	55.9	18.6	293.7	0	1008	7.5	2.08

DOME 2

Day	emperature						Gas velocity(m	composition%					pressure(mb	bient conditio
	at exit	1m	1.5m	at bottom	Average temp	ambient	mean at 1m	CO2	acc CO2	O2	accO2	CH4		wind vel (m/s)
1	29	31	31	33	31	28.6	0.74	1.2	1.2	19.8	19.8	0		3.69
2	39	44	44	49	44	25.8	2.8	7.3	8.5	13.8	33.6	0	1006	4.92
3	65	66	67	67	66.25	23.1	2.8	4.1	12.6	16.7	50.3	0	1016	3.69
4	52	53	57	59	55.25	15.8	2.02	2.5	15.1	18.2	68.5	0	1025	4.58
5	58	59	60	67	61	16.1	2.26	4.4	19.5	16.1	84.6	0	1030	4.08
6	64	67	69	71	67.75	23.3	2.69	3	22.5	17.3	101.9	0	1018	8.89
8	60	61	62	64	61.75	33.9	1.57	4	26.5	16.1	118	0	1004	4.53
9	59	60	61	63	60.75	22.6	1.88	3.3	29.8	17.3	135.3	0	1010	4.22
10	56	57	59	61	58.25	19.2	2.27	3	32.8	17.7	153	0	1023	5
11	62	64	66	67	64.75	23.9	1.76	3.8	36.6	16.7	169.7	0	1007	6.25
12	60	61	61	63	61.25	19.7	2.42	2.5	39.1	18.4	188.1	0	1015	7.22
15	60	62	62	63	61.75	11.3	1.84	3	42.1	17.4	205.5	0	1014	3.27
16	58	60	61	61	60	24.2	1.53	0.8	42.9	19.6	225.1	0	1004	3.88
18	58	60	60	61	59.75	19.5	1.64	3.2	46.1	17	242.1	0	1014	3.86
22	62	63	63	64	63	25.3	1.61	2.6	48.7	17.2	259.3	0	1011	4.47
29	53	55	56	58	55.5	15.5	1.56	2.1	50.8	18.6	277.9	0	1026	1.89
36	50	51	52	54	51.75	24.1	1.5	1	51.8	18.5	296.4	0	1008	2.08
39	50	51	51	52	51	28	1.64	0.9	52.7	20	316.4	0		2.4

DOME 3

Day	Temperature						Gas velocity(m	composition%					pressure(mb)	ambient conditions
	at exit	1m	1.5m	at bottom	Average temp	ambient	mean at 1m	CO2	accCO2	O2	accO2	CH4		wind vel (m/s)
1	32	34	35	36	34.25	15.8	1.07	11.2	11.2	8.1	8.1	0	1026	4.58
2	37	44	45	45	42.75	16.1	1.58	12.3	23.5	8.2	16.3	0	1029	4.08
3	62	63	64	69	64.5	23.3	2.07	4.9	28.4	15	31.3	0	1018	8.89
5	66	67	67	68	67	33.9	1.87	5	33.4	15.1	46.4	0	1004	4.53
6	63	64	65	66	64.5	22.6	1.83	3.9	37.3	16.6	63	0	1009	4.22
7	58	59	60	61	59.5	19.2	1.99	3.2	40.5	17.4	80.4	0	1023	5
8	63	64	64	66	64.25	23.9	1.97	3.3	43.8	17.3	97.7	0	1006	6.25
9	61	62	62	64	62.25	19.7	2.54	3.1	46.9	17.6	115.3	0	1015	7.22
12	62	63	63	65	63.25	11.3	1.63	3.5	50.4	16.9	132.2	0	1014	3.27
13	58	62	62	63	61.25	24.2	1.55	1	51.4	19.5	151.7	0	1004	3.88
15	58	59	59	60	59	19.5	1.73	3.4	54.8	17	168.7	0	1013	3.86
19	57	61	61	62	60.25	25.3	1.53	2.2	57	16.5	185.2	0	1011	4.47
26	49	54	54	55	53	15.5	1.56	2.2	59.2	18.5	203.7	0	1026	1.89
33	49	51	52	63	53.75	24.1	1.37	0.8	60	18.5	222.2	0	1008	2.08
39	48	50	50	53	50.25	28	1.3	0.6	60.6	20	242.2	0		
60	42	43	45	45	43.75	28	1.42	0.4	61	19.8	262	0		

DOME 4

Day	Temperature						Gas velocity(m	composition%					pressure(mb)	ambient conditions
	at exit	1m	1.5m	at bottom	Average temp	ambient	mean at 1m	CO2	acc CO2	O2	accO2	CH4		wind vel (m/s)
1	31	34	34	35	33.5	15.8	1.17	11.6	11.6	8.3	8.3	0	1026	4.58
2	36	44	45	46	42.75	16.1	1.56	15	26.6	5.3	13.6	0	1029	4.08
3	55	56	57	60	57	23.3	2.12	3.4	30	16.8	30.4	0	1017	8.89
5	66	67	67	69	67.25	33.9	1.65	4.9	34.9	15.2	45.6	0	1003	4.53
6	65	66	66	67	66	22.6	2.23	3.8	38.7	16.7	62.3	0	1008	4.22
7	63	63	64	65	63.75	19.2	2.39	2.7	41.4	18	80.3	0	1022	5
8	64	66	66	66	65.5	23.9	2.09	3.7	45.1	16.8	97.1	0	1006	6.25
9	61	62	62	63	62	19.7	3.78	2.3	47.4	18.5	115.6	0	1015	7.22
12	63	64	64	65	64	11.3	2.15	3.5	50.9	16.8	132.4	0	1014	3.27
13	58	61	62	61	60.5	24.2	1.61	1.3	52.2	19	151.4	0	1004	3.88
15	60	61	61	62	61	19.5	1.96	3.2	55.4	17.2	168.6	0	1013	3.86
19	64	66	67	68	66.25	25.3	1.28	2.5	57.9	15.6	184.2	0	1011	4.47
26	60	61	62	64	61.75	15.5	1.68	3.3	61.2	17.3	201.5	0	1026	1.89
33	59	60	61	61	60.25	24.1	1.24	1.7	62.9	17.2	218.7	0	1008	2.08
39	56	57	57	57	56.75	28	1.42	1.23	64.13	19.8	238.5	0		
60	51	51	52	52	51.5	28.6	1.43	0.5	64.63	19.6	258.1	0		1.2

TRADITIONAL TURNED WINDROW : TEMPERATURE MONITORING DATA SHEET						
Day	Temperature (Deg C)					
	North End	Middle	South End	Average temp	ambient	Turn + Wet
0	35	35.5	35.3	35.27	25.9	
1	47.8	48	48.7	48.2	25.4	
3	58.6	57.9	60.1	58.9	24.3	
4	58.7	60.4	61	60.0	25.9	
5	59.9	62.7	61.6	61.4	25.9	
6	62	63.3	61.6	62.3	31	
7	63.1	63.8	62	63.0	25.3	
8	58.6	64	57.6	60.1	24.6	X
9	47.9	49	47.2	48.0	24.1	
10	56.4	57	57	56.8	28.3	
11	62	62	60.8	61.6	28	
12	64.3	65.8	65.1	65.1	32	
13	66.3	66.7	66.2	66.4	27.3	
14	66.2	66.9	66.5	66.5	22	X
15	35.1	37.1	37.2	36.5	24.7	
16	42.3	45	45.5	44.3	26	
17	48.7	48.5	48.9	48.7	29	
18	48.9	52	49	50.0	25.9	X
19	48.8	51.7	48.5	49.7	25.8	
20	36.2	41	42.6	39.9	22.3	
21	33	34.4	34	33.8	28.6	
22	35	36.4	36	35.8	25.8	
23	42.3	44	42.2	42.8	23.1	
24	42.3	44.5	44	43.6	15.8	X
25	42	43	42	42.3	16.1	
27	31	33.3	32	32.1	23.3	
28	35.1	34.4	37.2	35.6	33.9	
29	36.2	41	42.6	39.9	22.6	
30	43	42.4	45.5	43.6	19.2	
32	43	44.5	44	43.8	23.9	
39	41	41	40.8	40.9	19.7	
46	35.1	34.4	37.2	35.6	25.8	
53	33	33	33	33.0	24.2	
60	30.6	33	31.4	31.7	19.5	

APPENDIX B: INPUT & OUTPUT MATERIAL CHARACTERISATION RESULTS

SUMMARY OF CHARACTERIZATION of DAT 6 weeks

Characterisation	COD (mg/l)	BOD_5 (mg/l)	TOC	TKN	NH_3 (mg/l)	NO_X (mg/l)	MC (%)	C/N	pH	K (ms/cm)	TS Solid	VS (mg/g)	TS Eluate	VS (mg/l)	RI_7
1.Input material(windrow)	15603.16	317.5	N/A	N/A	63.7	14.00	37.7	40.21	5.46	2.400	0.595	0.5126	6.8967	1.195	74.8
2.Pine bark(cover)	2458.65	371.0	N/A	N/A	8.4	18.06	56.3	31.5	5.33	0.498	N/A	N/A	3.388	0.600	128
3.Dry commercial garden refuse(Base)	2078.47	381.5	N/A	N/A	40.46	39.62	28.9	40.92	5.81	2.350	N/A	N/A	4.180	1.188	171
Compost Produced After Six Weeks															
4.Between Dome 1-2	7560.90	421.5	N/A	N/A	14.0	12.32	48.6	45.0	7.19	1.658	0.489	0.461	8.230	2.827	74.8
5.Between Dome 2-3	8159.17	629.5	N/A	N/A	11.2	9.52	63.6	70.0	7.03	1.714	0.458	0.4556	6.987	1.912	53.4
6.Between Dome 3-4	7375.23	468.0	N/A	N/A	10.92	10.36	57.7	52.05	6.98	1.495	0.486	0.4455	8.185	2.323	53.4
7.Average over all domes	7698.43	506.3	N/A	N/A	12.0	10.73	56.6	55.7	7.067	1.622	0.478	0.4541	7.8006	2.354	60.5

DAT 6 Weeks waste characterisation from J. Etti, 2008 that was corrected!

Date	Sample	Cruc No	DRY INITIAL	Before dryi	After drying	After firing	TS mg/g	VS mg/g	Cruc No	DRY INITIAL	before drying	After dryi	After firing	TS mg/l	VS mg/l
	Solid														
15/09/08	D1-2	2	40.5643	54.556	47.4649	41.1455	0.4932	0.4517	25	57.1796	63.986	60.686	57.4834	0.4848	0.4705
	D2-3	16	52.8955	57.595	55.0299	53.0845	0.4542	0.4140	W	41.2304	48.119	44.9422	41.5171	0.4612	0.4972
	D3-4	C	43.3835	48.268	45.7679	43.653	0.4882	0.4330	54	45.0362	48.868	47.011	45.256	0.4846	0.4580
							check							**check**	
							49.32	91.58						51.52	91.34
							45.42	91.15						53.88	92.28
							48.82	88.70						51.54	88.87
			After Correction of Etti Lab Results:												
						TS (%)	**50.08**								
						VS (%)	**90.65**								
	Eluate														
22/10/08	D1-2	61	48.8651		49.0159	48.9189	7.5400	2.6900	56	48.547		48.6993	48.5995	7.6150	2.6250
	D2-3	59	45.5219		45.6657	45.563	7.1900	2.0550	60	45.403		45.5311	45.4408	6.4050	1.8900
	D3-4	53	42.926		43.0454	42.9627	5.9700	1.8350	58	46.1204		46.2911	46.1693	8.5350	2.4450
							check							**check**	
							6.0320	3.8800						6.0920	3.9920
							5.7520	4.1080						5.1240	3.6120
							4.7760	3.3080						6.8280	4.8720
			After Correction of Etti Lab Results:												
						TS (g/ℓ)	**5.77**								
						VS (g/ℓ)	**3.96**								

SUMMARY OF CHARACTERIZATION DAT 8-10 weeks - Iyilade, 2009

ELUATE

SAMPLE	**TS(mg/l)**	**VS(mg/l)**	**PH**	**CONDUCTIVITY (mS/cm)**	**COD (ms/l)**	**NH3 (ms/l)**	**NOx(ms/l)**	**BOD (ms/l)**
DAT1	5.6907	1.8707	7.01	2.26	4394.19	16.52	7.28	508
DAT2	6.8840	2.0760	7.24	2.01	4827.42	64.12	1363.46	776.5
TTW1	11.0827	3.0560	7.21	1.83	11243.35	34.44	9.66	459
TTW2	15.1773	4.2080	7.04	1.69	5013.09	26.88	8.96	572
DAT av	**6.29**	**1.97**	**7.13**	**2.14**	**4610.81**	**40.32**	**685.37**	**642.25**
TTW av	**13.13**	**3.63**	**7.13**	**1.76**	**8128.22**	**30.66**	**9.31**	**515.50**

Results from Bemlab for Dry Solid Only and no Eluate C:N carried out

Reference No.	Lab. No.	N %	C %	C:N Ratio
DAT 1	649	1.09	40.4	37.06
DAT 2	650	1.2	42.3	35.25
Turned Window 1	651	1.4	39.8	28.43
Turned Window 2	652	1.21	37.5	30.99
DAT av		1.15	41.35	36.16
TTW av		1.31	38.65	29.71

SUMMARY OF CHARACTERIZATION				DAT 8-10 weeks - Iyilade, 2009	
			DRY SOLID		
			Moisture	**Field**	
SAMPLE	**TS(%)**	**VS(%)**	**Content(%)**	**Capacity**	**RI7(mg/l)**
				ml/100g	
DAT1	51.6213	92.6823	45.13	67.95	819
DAT2	40.0189	88.9461	60.28	48.84	890
TTW1	33.0367	81.4044	65.64	31.51	833
TTW2	31.3604	82.8009	67.08	21.29	212
DAT av	**45.82**	**90.81**	**52.71**	**58.395**	**854.50**
TTW av	**32.20**	**82.10**	**66.36**	**26.400**	**522.50**

8-10 WEEKS Ammonia and Nitrate Tests

Abbreviations

Dome Aeration Technology (DAT)

Traditional turned windrow (TTW)

NH_3									
				Reading					
Date	Sample	Volume	Constant	1	2	Average	**Result**	Std Dev	Var
1/29/09	DAT1	50	28	0.66	0.52	0.59	**16.52**	2.772	7.683
1/29/09	DAT2	50	28	2.32	2.26	2.29	**64.12**	1.188	1.411
1/29/09	TTW1	50	28	1.21	1.25	1.23	**34.44**	0.792	0.627
1/29/09	TTW2	50	28	0.98	0.94	0.96	**26.88**	0.792	0.627

			NO_x						
			Reading						
Date	Sample	Volume	Constant	1	2	Average	**Result**	Std Dev	Var
1/29/09	DAT1	50	28	0.25	0.27	0.26	**7.28**	0.396	0.157
1/29/09	DAT2	50	28	48.94	48.45	48.70	**1363.46**	9.702	94.119
1/29/09	TTW1	50	28	0.37	0.32	0.35	**9.66**	0.990	0.980
1/29/09	TTW2	50	28	0.34	0.30	0.32	**8.96**	0.792	0.627

Abbreviations					8-10 WEEKS COD Tests				
Dome Aeration Technology (DAT)									
Traditional turned windrow (TTW)									
				Readings			Ave	**Result**	Std Dev	Var
Sample	Date	Volume (mL)	Blank Ave	1	2	3				
Std	2009-10-02	1	-0.0410	0.049	0.048	0.044	0.047	**544.63**	0.003	0.000
Dat 1	2009-10-02	0.1	-0.0410	0.030	0.029	0.031	0.030	**4394.19**	0.001	0.000
Dat 2	2009-10-02	0.1	-0.0410	0.038	0.038	0.035	0.037	**4827.42**	0.002	0.000
Ttw 1	2009-10-02	0.1	-0.0410	0.144	0.140	0.138	0.141	**11243.35**	0.003	0.000
Ttw 2	2009-10-02	0.1	-0.0410	0.038	0.037	0.045	0.040	**5013.09**	0.004	0.000
Ttw 2	2009-10-02	0.2	-0.0410	0.093	0.098	0.098	0.096	**4249.78**	0.003	0.000
Dat 1	2009-10-02	0.2	-0.0410	0.106	0.114	0.115	0.112	**4724.27**	0.005	0.000

ELUATE ANALYSIS			**8-10 weeks Tests**				
Abbreviations							
Dome Aeration Technology (DAT)							
Traditional turned windrow (TTW)							
Date	Sample	Cruc No	DRY INITIAL	After dryir	After firing	TS mg/l	VS mg/l
09/01/28	DAT1	9	54.5811	54.6745	54.6201	3.7360	1.5600
09/01/28	DAT2	w	41.2324	41.4056	41.2850	6.9280	2.1040
09/01/28	TTW1	15	47.1661	47.4364	47.2370	10.8120	2.8360
09/01/28	TTW2	58	46.1205	46.4976	46.2256	15.0840	4.2040

ELUATE ANALYSIS			8-10 weeks Tests		
Cruc No	DRY INITI	After dryir	After firing	TS mg/l	VS mg/l
25	57.1808	57.3712	57.2349	7.6160	2.1640
z	40.5662	40.7360	40.6172	6.7920	2.0400
57	48.1833	48.4665	48.2635	11.3280	3.2080
55	44.7072	45.0845	44.8116	15.0920	4.1760

ELUATE ANALYSIS							
Cruc No	DRY INITI	After dryir	After firing	TS mg/l	VS mg/l	TS	VS
						Average	Average
23	53.8433	53.9863	53.8905	5.7200	1.8880	**5.6907**	**1.8707**
1	53.9086	54.0819	53.9607	6.9320	2.0840	**6.8840**	**2.0760**
50	46.8983	47.1760	46.9764	11.1080	3.1240	**11.0827**	**3.0560**
54	45.0334	45.4173	45.1395	15.3560	4.2440	**15.1773**	**4.2080**

DRY SOLID ANALYSIS				8-10 Weeks Tests					
Date	Sample	Cruc. Nur	Cruc.dry	Cruc+wet	Cruc+drie	Cruc+Fired w	Mass of dry	TS mg/l	VS mg/l
09/01/28	DAT1	20	54.4877	61.9535	58.4550	54.7808	7.4658	53.1397	92.6121
09/01/28	DAT2	p	40.7610	47.0631	43.2939	41.0087	6.3021	40.1914	90.2207
09/01/28	TTW1	6	54.2639	66.1266	58.1853	54.9472	11.8627	33.0566	82.5751
09/01/28	TTW2	blank	44.4225	54.7517	47.5239	45.0008	10.3292	30.0256	81.3536

DRY SOLID ANALYSIS				8-10 Weeks Tests			
Cruc. Nur	Cruc.dry	Cruc+wet	Cruc+drie	Cruc+Fire	Mass of d	TS mg/l	VS mg/l
19	49.3421	57.6576	53.5783	49.6597	8.3155	50.9434	92.5027
21	52.4782	60.0813	55.5336	52.7972	7.6031	40.1862	89.5595
29	56.4316	65.7915	59.6668	57.0187	9.3599	34.5645	81.8527
16	52.8982	63.4711	56.3460	53.4445	10.5729	32.6098	84.1551

DRY SOLID ANALYSIS				8-10 Weeks Tests					
								TS	VS
Cruc. Nur	Cruc.dry	Cruc+wet w	Cruc+dried	Cruc+Fire	Mass of d	TS mg/l	VS mg/l	Average	Average
32	62.2672	70.6369	66.5174	62.5676	8.3697	50.7808	92.9321	**51.6213**	**92.6823**
b	43.8585	52.6858	47.3611	44.3118	8.8273	39.6792	87.0582	**40.0189**	**88.9461**
c	43.3851	57.3528	47.7834	44.2742	13.9677	31.4891	79.7854	**33.0367**	**81.4044**
m	45.5430	56.7362	49.0628	46.1451	11.1932	31.4459	82.8939	**31.3604**	**82.8009**

Summary of Waste Characterisation Results

Test/Substrate	INPUT	OUTPUT				
	CGR RAW	DAT 6weeks	DAT 8-10weeks	TTW 8-10weeks	DAT 16-20weeks	TTW 16-20weeks
Solid						
MC (%)	37.14 ± 3.17	56.60	52.71	66.36	54.24 ± 2.90	59.28 ± 3.22
TS (%)	62.86 ± 3.17	50.80	45.82	32.2	45.76 ± 2.90	40.72 ± 3.22
VS (%)	96.37 ± 0.75	90.65	90.81	82.1	87.20 ± 8.68	71.73 ± 2.42
RI_7 (mg.O_2/g DM)	7.77	60.50	N.D	N.D	6.987	9.823
Total C (%)	49.6	N.D	41.35	38.65	22.04	29.04
Total N (%)	0.55	N.D	1.15	1.31	0.96	1.65
C : N	90.19	55.70	36.16	29.71	22.96	17.6
Eluate						
TS (g/ℓ)	4.08 ± 0.02	5.77	6.29	13.13	11.78 ± 0.26	12.55 ± 0.14
VS (g/ℓ)	3.04 ± 0.02	3.96	1.97	3.63	7.55 ± 0.29	8.61 ± 0.14
pH	5.45	7.07	7.13	7.13	6.93	7.27
Cond (mS/cm)	1.653	1.62	2.14	1.76	1.23	2.69
COD (mg/ℓ))	4253	7698.43	4610.81	8128.22	10080	11270
BOD_5 (mg/ℓ))	1101	506.30	642.25	515.5	348	474
NH_3-N (mg/ℓ))	12.74	12.00	40.32	30.66	29.4	50.12
NO_x-N (mg/ℓ))	6.86	10.73	685.37	9.31	8.96	14.56
Total C (%)	0.083	N.D	N.D	N.D	0.6	0.67
Total N (%)	0.0183	N.D	N.D	N.D	0.07	0.09
C : N	4.54	N.D	N.D	N.D	8.57	7.44

*ND - Characterisation test not done

Report No.: **NR649/2009**

ANALYSES REPORT

Yemisi Lyilade
University of Kwazulu Natal
Date received: 29/01/2009
Date tested: 05/02/2009

Reference No.	Lab. No.	N %	C %	C:N Ratio
DAT 1	649	1.09	40.40	37.06
DAT 2	650	1.20	42.30	35.25
Turned Window 1	651	1.40	39.80	28.43
Turned Window 2	652	1.21	37.50	30.99

Sample conditions

Samples in good condition.

Statement

The reported results may be applied only to samples recieved. Any recommendations included with this report are based on the assumption that the samples were representative of the bulk from which they were taken. Opinions and recommendations are not accredited.

Dr. W.A.G. Kotzé (Director) 12-02-2009

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for BemLab Date

Enquiries: Dr. W.A.G. Kotzé

APPENDIX C: WINDROW OPERATIONAL COSTING CALCULATIONS

Estimation of Garden Refuse Shredded Bulk Density

ADT Registration	Nett Mass (Kg)	Volume ADT (m^3)
NDM 4300	12240	15
NDM 4431	6480	10
NDM 4407	7600	10
NDM 4431	7220	10
NDM 4300	11940	15
NDM 4407	7820	10
NDM 4431	7440	10
NDM 4300	12880	15
NDM 4407	12320	15
NDM 4431	7460	10
NDM 4431	9680	10
TOTAL	103080	130

Using the Relationship of	Density (BD) =	Mass / volume
Therefore:		
Shredder BD of CGR =		0.8 tons/m^3

Assumptions

1	Although TTW was larger than the DAT, assume TTW Volume = DAT Volume for costing purposes				
2	Assume shredded bulk density of garden refuse	=	0.8	tons/m^3	from BD Calc.
3	Assume water costs are "R 0" as borehole water used				
4	All plant used except the shredder have effectively ben depreciated and hence onlt operate and maintenance costs included i.e. cost per hour inclusive of fuel				
5	Shredder cost are as detailed in running costs calculation for Morbark 2600				
6	18000 litres of borehole water used per water tanker. Total of 4 loads used				

OPERATING COSTS FOR COMPOSTING SYSTEMS : THE BISASAR ROAD LANDFILL SITE					
Item	**Description**	**Unit**	**Quantity**	**Rate**	**Total (R)**
A	**Dome Aeration Technology Windrow**				
1	***Mechanical Treatment***				
1.1	Shredder	tons	360	23.5	8,460.00
1.2	Front End Loader BELL 1206	tons	360	10	3,600.00
2	***Biological Treatment Preparation***				
2.1	ADT Haulage of shredded material	tons	360	5	1,800.00
2.2	Water Tanker	hr	16	180	2,880.00
2.3	Front End Loader CAT 966G	tons	360	14.5	5,220.00
2.4	Excavator	hr	4	175	700.00
2.5	Labour x 6	hr	108	15	1,620.00
	Total DAT Operating Cost			**R**	**24,280.00**
	DAT Operating Cost per Ton			***R***	***67***
B	**Traditional Turned Windrow**				
1	***Mechanical Treatment***				
1.1	Shredder	tons	360	23.5	8,460.00
1.2	Front End Loader BELL 1206	tons	360	10	3,600.00
2	***Biological Treatment Preparation***				
2.1	ADT Haulage of shredded material	tons	360	5	1,800.00
2.2	Water Tanker	hr	16	180	2,880.00
2.3	Front End Loader CAT 966G	tons	360	14.5	5,220.00
2.4	Excavator	hr	4	175	700.00
2.5	Labour	hr	18	15	270.00
3	***Turning and Wetting***				
3.1	Front End Loader BELL 1206 (4 Turn Cycles)	tons	1440	10	14,400.00
3.2	Water Tanker (4 Wet Cycles)	hr	32	180	5,760.00
3.3	Labour	hr	32	15	480.00
	Total TTW Operating Cost			**R**	**43,570.00**
	TTW Operating Cost per Ton			***R***	***121***

Assumptumtions	2600 Wood Hoh fitted with 250hp Cat				HRS
Period (years)	5	1 to 5 till write off or R0.00 Value	Time breakup	Years	5
Total (Hours) for above ye	10500		Hrs per day	7	7
Annual (Hours)	2100		Days per week	6	42
Purchase Price	R 1,800,000.00	Fill this figure in on Loan Breakdown page	Weeks per year	50	2100
Intrest Rate	10%	Fill this figure in on Loan Breakdown page			
Payment Per Month	R 38,244.68				
Total intrest	R 494,681				
Insurance Rate	5%				
Insurance PA	R 90,000.00				

Estimated Owning & Operating Cost

		Annual	Hourly Cost
Owning Cost			
	Purchase	R 360,000.00	R 171.43
	Interest	R 98,936.17	R 47.11
	Insurance	R 18,000.00	R 8.57
	Total Owning Cost	R 476,936.17	R 227.11
Operating Cost			
	Machine Maintenance	R 399,701.99	R 190.33
	Fuel Cost	R 357,000.00	R 170.00
	Labour cost		Incl
	Total Operating Cost		R 360.33
TOTAL OWING AND OPERATING COST			**R 587.45**

ESTIMATED COST PER TON

Tons		Cost/Ton
10		R 58.74
20	<-Machine averages	R 29.37
25		R 23.50
30		R 19.58
40		R 14.69
50		R 11.75
60		R 9.79
70		R 8.39

Estimated Detailed Maintenance Cost
Model 2600 Wood Hog

Units	Description	Unit Cost	Total	Hours	Total Cost/hour	
18	inserts	198.00	3564	120	R	29.70
36	Bolts	32.99	1187.64	200	R	5.94
36	Nuts	8.91	320.76	200	R	1.60
3	Grates	16,609.00	49827	700	R	71.18
18	Hammers	548.63	9875.34	1200	R	8.23
18	Rakers	980.91	17656.38	700	R	25.22
8	Rods	978.45	7827.6	2200	R	3.56
8	Labour	160.00	1280	200	R	6.40
1	Grease Tube	70.00	70	20	R	3.50
1	Misc Maintenance	950.00	950	50	R	19.00
2	Misc Parts (Body)	200.00	400	50	R	8.00
2	Misc Parts (Engine)	200.00	400	50	R	8.00
	Total Maintenance	**Per Hour**			**R**	**190.33**
		Liters/hour	Cost			
	Fuel Consumption	20	R 8.50		R	170.00

APPENDIX D: LANDFILL WASTE STATISTICS

Table D1: The Bisasar Road Landfill Waste Tonnages for 2004 – 2010, Courtesy DSW

	Year						
Waste Type	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
01 - DSW	313,658.23	328,114.98	379,688.17	413,112.89	417,265.97	409,782.37	432,175.10
02 - GENERAL SOLID WASTE	63,869.78	54,533.63	51,208.42	58,598.72	67,089.61	75,736.88	69,507.43
03 - GARDEN REFUSE	31,485.77	36,403.18	38,568.96	38,840.89	39,919.78	34,651.37	35,274.20
04 - BUILDERS RUBBLE	47,875.55	63,017.89	79,266.46	102,682.32	72,438.29	73,425.21	155,582.20
05 - MIXED LOADS	10,668.09	9,853.65	9,633.48	10,903.89	12,734.40	12,627.30	15,456.55
06 - SAND & COVER MATERIAL	210,765.84	269,190.06	341,076.58	306,025.76	380,872.68	372,822.42	485,346.66
07 - PURCHASE COVER MATERIAL	67,221.46	30,802.12	16,020.06	16,136.88	93,513.83	23,249.98	4,821.38
08 - TYRES	1,258.88	1,330.44	1,661.84	1,780.26	1,776.54	1,102.14	684.46
09 - LIGHT TYPE REFUSE	98.48	99.14	174.94	179.86	186.34	196.15	135.44
10 - OTHER	17,518.24	42,760.10	36,813.64	43,643.87	53,969.93	42,817.24	21,988.49
Total Waste (Kg's)	764,420.32	836,105.20	954,112.54	991,905.33	1,139,767.37	1,046,411.05	1,220,971.90
LESS: SAND & COVER MATERIAL	277,987.30	299,992.18	357,096.64	322,162.64	474,386.51	396,072.40	490,168.04
TOTAL ETHEKWINI WASTE GENERATED	486,433.02	536,113.02	597,015.91	669,742.69	665,380.86	650,338.65	730,803.86
LESS: PUBLIC WASTE (DSW)	313,658.23	328,114.98	379,688.17	413,112.89	417,265.97	409,782.37	432,175.10
TOTAL: PRIVATE WASTE	172,774.79	207,998.04	217,327.74	256,629.80	248,114.89	240,556.29	298,628.76

GARDEN REFUSE WASTE - STREAM ANALYSIS : PILOT PROJECT												
	WEEKDAY WASTE SREAM ANALYSIS				23rd March 2006							
Time	Vehicle Reg No.	Chippable Material		Oversize Material		Fibrous Material		Grass		Leaves		Total Mass (Kg)
		% Mass	Mass (Kg)	% Mass	Mass (Kg)	% Mass	Mass (Kg)	% Mass	Mass (Kg)	% Mass	Mass (Kg)	
9:00		80	384	10	48	0	0	0	0	10	48	480
		60	12	0	0	0	0	20	4	20	4	20
		70	406	0	0	0	0	20	116	10	58	580
		0	0	0	0	100	90	0	0	0	0	90
	NU 47893	80	432	0	0	0	0	10	54	10	54	540
		80	592	10	74	0	0	0	0	10	74	740
	NDM	75	600	5	40	5	40	10	80	5	40	800
	ND 463317	90	216	10	24	0	0	10	24	0	0	240
	NPN 34654	70	56	25	20	0	0	0	0	5	4	80
	NU 16120	30	48	0	0	30	48	10	16	30	48	160
	ND 102760	50	80	0	0	20	32	10	16	20	32	160
	NDM Parks big	10	56	0	0	0	0	80	448	10	56	560
	NDM Parks small	90	558	0	0	0	0	0	0	10	62	620
12:00	ND 376144	0	0	0	0	80	272	10	34	10	34	340
	NPN 4294	100	100	0	0	0	0	0	0	0	0	100
	ND 204795	30	24	30	24	0	0	20	16	20	16	80
	NPN 34173	0	0	0	0	25	20	40	32	35	28	80
	NU 16120	0	0	5	9	10	18	45	81	40	72	180
	ND 474759	60	108	0	0	10	18	20	36	10	18	180
	NDM 5819	70	112	5	8	0	0	10	16	10	16	160
	ND 153195	0	0	0	0	60	168	20	56	20	56	280
	NPN 45570	60	540	0	0	10	90	20	180	10	90	900
	ND 129576	90	666	0	0	0	0	0	0	10	74	740
	ND 1020760	0	0	0	0	0	0	0	0	100	120	120
	NDM 5915	0	0	0	0	20	228	40	456	40	456	1140
	ND 8120	50	380	10	76	0	0	0	0	40	304	760
	NPN 4313	0	0	0	0	100	260	0	0	0	0	260
	NU 5300	50	740	20	296	10	148	10	148	10	148	1480
	NPN 29768	0	0	0	0	40	40	30	30	30	30	100
	NU 154765	50	320	10	64	0	0	10	64	30	192	640
	ND 252768	70	70	0	0	0	0	10	10	20	20	100
	NPN 61120	50	870	30	522	0	0	0	0	20	348	1740
	NPN 92417	0	0	0	0	80	208	10	26	10	26	260
	NPN 4294	100	80	0	0	0	0	0	0	0	0	80
	NU 146379	30	54	0	0	50	90	0	0	20	36	180
	NDM Parks	90	198	0	0	0	0	0	0	10	22	220
15:00	LGK 640 GP	10	26	0	0	5	13	25	65	60	156	260
	NPN 29768	100	120	0	0	0	0	0	0	0	0	120
	NPN 23327	80	144	0	0	0	0	10	18	10	18	180
	ND 129576	70	406	0	0	0	0	10	58	20	116	580
	NPN 9325	0	0	0	0	5	6	25	30	70	84	120
		51	8398	***7***	1205	***11***	1789	***13***	2114	***18***	2960	16450

GARDEN REFUSE WASTE - STREAM ANALYSIS : PILOT PROJECT												
	WEEKEND WASTE STREAM ANALYSIS 3rd To 4th June 2006											
Time	Vehicle Reg No.	Chippable Material		Oversize Material		Fibrous Material		Grass		Leaves		Total Mass (Kg)
		% Mass	Mass (Kg)	% Mass	Mass (Kg)	% Mass	Mass (Kg)	% Mass	Mass (Kg)	% Mass	Mass (Kg)	
)06_07:35:00 AM		0	0	0	0	0	0	0	0	100	0	100
7:55		60	408	0	0	0	0	0	0	40	272	680
8:04				10	20	0	0	90	180	0	0	200
8:05		40	120	60	180	0	0	0	0	0	0	300
8:23		100	100	0	0	0	0	0	0	0	0	100
8:23		0	0	0	0	0	0	0	0	100	100	100
8:48		80	144	20	36	0	0	0	0	0	0	180
8:53		100	780	0	0	0	0	0	0	0	0	780
8:54		0	0	0	0	0	0	100	200	0	0	200
9:04		0	0	0	0	0	0	0	0	100	40	40
9:11		0	0	0	0	0	0	0	0	100	340	340
9:26		80	224	20	56	0	0	0	0	0	0	280
9:22		0	0	0	0	0	0	60	24	40	16	40
9:32		0	0	0	0	0	0	100	280	0	0	280
9:33		0	0	0	0	0	0	100	280	0	0	280
9:43		80	352	20	88	0	0	0	0	0	0	440
9:50		100	280	0	0	0	0	0	0	0	0	280
9:58		100	220	0	0	0	0	0	0	0	0	220
9:59		40	152	0	0	0	0	0	0	60	228	380
10:15		50	110	50	110	0	0	0	0	0	0	220
10:33		50	50	0	0	0	0	20	20	30	30	100
10:46		0	0	0	0	0	0	80	400	20	100	500
10:47		100	300	0	0	0	0	0	0	0	0	300
10:50		0	0	0	0	0	0	100	300	0		300
11:03		0	0	0	0	0	0	60	180	40	120	300

GARDEN REFUSE WASTE - STREAM ANALYSIS : PILOT PROJECT													
	WEEKEND WASTE STREAM ANALYSIS 3rd To 4th June 2006												
Time	Vehicle Reg No.	Chippable Material		Oversize Material		Fibrous Material		Grass		Leaves		Total Mass (Kg)
		% Mass	Mass (Kg)	% Mass	Mass (Kg)	% Mass	Mass (Kg)	% Mass	Mass (Kg)	% Mass	Mass (Kg)	
11:09		100	160	0	0	0	0	0	0	0	0	160
11:18		100	600	0	0	0	0	0	0	0	0	600
11:49		60	180	10	30	30	90	0	0	0	0	300
11:50		70	196	30	84	0	0	0	0	0	0	280
11:57		0	0	0	0	0	0	100	100	0	0	100
11:59		0	0	0	0	0	0	0	0	100	80	80
12:09		0	0	0	0	0	0	100	0	0	0	40
12:12		0	0	0	0	0	0	50	20	50	20	40
12:12		100	140	0	0	0	0	0	0	0	0	140
12:21		0	0	0	0	0	0	50	50	50	50	100
12:31		100	160	0	0	0	0	0	0	0	0	160
12:33		0	0	0	0	0	0	50	450	50	450	900
12:41		100	200	0	0	0	0	0	0	0	0	200
12:44		60	276	10	0	0	0	30	138	0	0	460
12:45		0	0	0	0	0	0	100	180	0	0	180
12:59		50	120	0	0	0	0	50	120	0	0	240
13:10		100	120	0	0	0	0	0	0	0	0	120
13:11		0	0	0	0	0	0	80	80	20	20	100
13:12		0	0	0	0	0	0	100	220	0	0	220
13:26		0	0	0	0	0	0	100	100	0	0	100
13:31		70	308	0	0	0	0	10	44	20	88	440
13:37		0	0	0	0	0	0	70	112	30	48	160
13:52		90	540	10	60	0	0		0	0	0	600

GARDEN REFUSE WASTE - STREAM ANALYSIS : PILOT PROJECT												
	WEEKEND WASTE STREAM ANALYSIS 3rd To 4th June 2006											
Time	Vehicle Reg No.	Chippable Material		Oversize Material		Fibrous Material		Grass		Leaves		Total Mass
		% Mass	Mass (Kg)	% Mass	Mass (Kg)	% Mass	Mass (Kg)	% Mass	Mass (Kg)	% Mass	Mass (Kg)	(Kg)
9:53		60	48	0	0	0	0	40	32	0	0	80
9:53		50	120	40	96	0	0	0	0	10	24	240
9:56		50	130	50	130	0	0	0	0	0	0	260
0:00		0	0	0	0	0	0	100	60	0	0	60
10:02		0	0	0	0	0	0	0	0	100	60	60
10:05		0	0	0	0	0	0	0	0	100	220	220
10:06		60	60	0	0	0	0	0	0	40	40	100
10:08		0	0	0	0	0	0	100	140	0	0	140
10:15		0	0	0	0	0	0	80	256	20	64	320
10:19		0	0	0	0	0	0	0	0	100	100	100
10:32		0	0	0	0	0	0	100	280	0	0	280
10:36		50	90	50	90	0	0	0	0	0	0	180
10:46		0	0	0	0	0	0	40	40	60	60	100
10:49		40	40	0	0	0	0	0	0	60	60	100
10:51		80	128	0	0	0	0	0	0	20	32	160
10:53		0	0	0	0	0	0	0	0	100	60	60
10:54		0	0	0	0	0	0	0	0	100	60	60
10:56		30	30	0	0	0	0	30	30	40	40	100
10:58		30	114	30	114	0	0	40	152	0	0	380
10:58		80	304	0	0	0	0	0	0	20	76	380
11:28		100	60	0	0	0	0	0	0	0	0	60
11:31		0	0	0	0	0	0	50	60	50	60	120
11:34		100	440	0	0	0	0	0	0	0	0	440
11:37		50	40	0	0	50	40	0	0	0	0	80
11:39		0	0	0	0	0	0	100	40	0	0	40
12:00		0	0	0	0	0	0	0	0	100	420	420
12:03		30	12	50	20	0	0	0	0	20	8	40
12:04		100	560	0	0	0	0	0	0	0	0	560
12:05		0	0	0	0	0	0	100	140	0	0	140
12:06		0	0	0	0	0	0	100	20	0	0	20
12:06		0	0	0	0	0	0	100	60	0	0	60
12:13		0	0	0	0	0	0	50	10	50	10	20

GARDEN REFUSE WASTE - STREAM ANALYSIS : PILOT PROJECT												
	WEEKEND WASTE STREAM ANALYSIS 3rd To 4th June 2006											
Time	Vehicle Reg No.	Chippable Material		Oversize Material		Fibrous Material		Grass		Leaves		Total Mass (Kg)
		% Mass	Mass (Kg)	% Mass	Mass (Kg)	% Mass	Mass (Kg)	% Mass	Mass (Kg)	% Mass	Mass (Kg)	
12:18		90	90	10	10	0	0	0	0	0	0	100
12:25		0	0	0	0	0	0	40	8	60	12	20
12:39		0	0	0	0	0	0	50	20	50	20	40
12:43		0	0	0	0	0	0	0	0	100	20	20
12:47		0	0	0	0	0	0	100	40	0	0	40
12:55		0	0	0	0	0	0	0	0	100	80	80
12:56		0	0	0	0	0	0	0	0	100	100	100
12:57		100	140	0	0	0	0	0	0	0	0	140
13:07		60	444	40	296	0	0	0	0	0	0	740
13:16		0	0	0	0	0	0	100	20	0	0	20
13:26		0	0	0	0	0	0	60	96	40	64	160
13:31		0	0	0	0	0	0	0	0	100	320	320
13:39		0	0	0	0	0	0	100	40	0	0	40
13:43		0	0	0	0	0	0	50	40	50	40	80
13:47		100	80	0	0	0	0	0	0	0	0	80
13:56		100	100	0	0	0	0	0	0	0	0	100
14:03		0	0	0	0	0	0	0	0	100	180	180
14:06		50	30	0	0	0	0	50	30	0	0	60
14:09		0	0	0	0	0	0	0	0	100	140	140
14:13		0	0	0	0	20	44	0	0	80	176	220
14:20		0	0	0	0	0	0	50	50	50	50	100
14:28		100	280	0	0	0	0	0	0	0	0	280
14:42		100	220	0	0	0	0	0	0	0	0	220
14:45		100	60	0	0	0	0	0	0	0	0	60
14:45		100	80	0	0	0	0	0	0	0	0	80
14:53		0	0	0	0	0	0	0	0	100	160	160
14:56		0	0	0	0	0	0	0	0	100	120	120
15:00		0	0	0	0	0	0	100	160	0	0	160
15:12		0	0	0	0	0	0	0	0	100	120	120
15:23		0	0	0	0	0	0	50	60	50	60	120
15:34		50	40	20	16	0	0	0	0	30	24	80
15:50		0	0	0	0	0	0	50	50	50	50	100
		46	12118	6	1710	1	174	23	6188	23	6124	26500

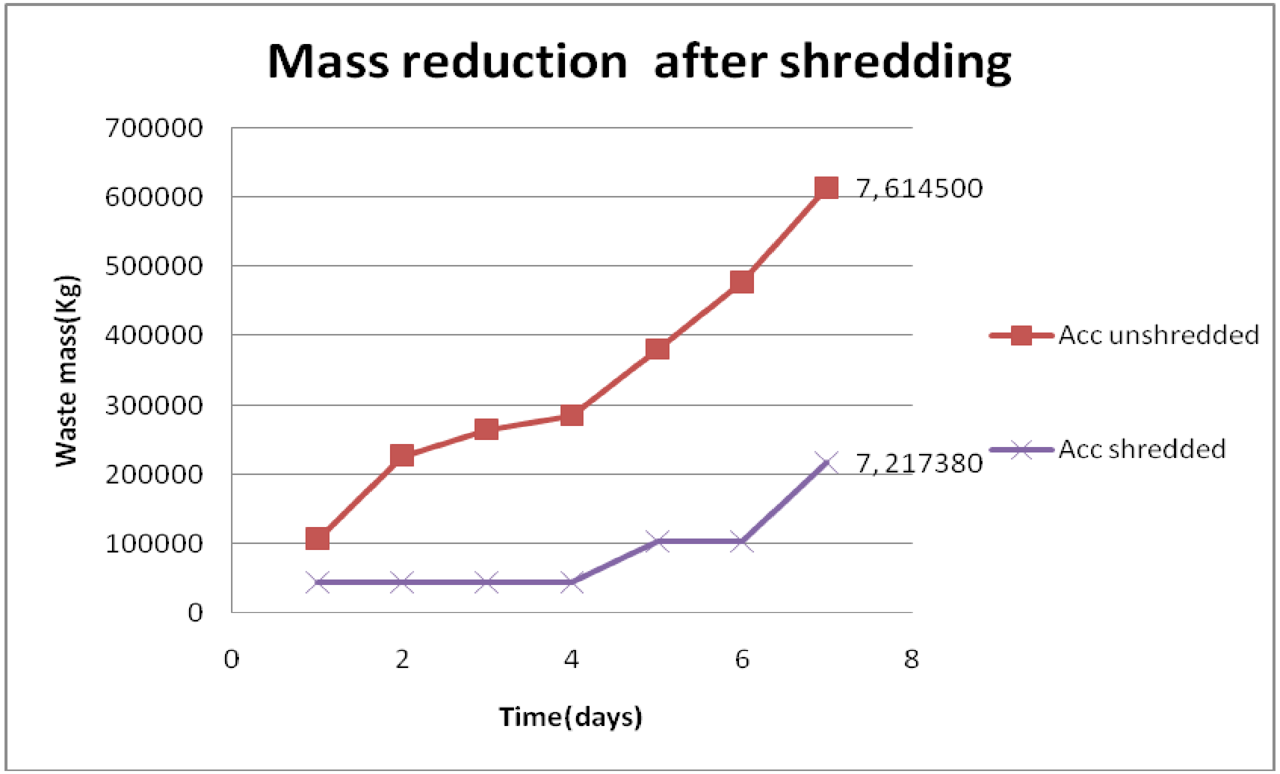

Figure D1: Mass reduction of garden refuse after mechanical treatment using shredder

APPENDIX E: PROCUREMENT OF A HIGH SPEED SHREDDER

Procurement of a High Speed Shredder, (Courtesy of DSW)

The City received two bids on the 23 February 2007 in response to a tender document that described the requirements, specifications and outputs for a high speed shredder for the mechanical treatment of garden refuse and wood waste through a public bidding process. The bids received were checked for correctness and analysed in detail as well as being assessed for rate, price sensitivity, technical specifications and delivery period. The lowest offer, which was submitted by Ritlee Xecutech sales & service Pty Ltd, was found to be approximately 33% lower than the second lowest offer from TFM Industries (Pty) Ltd and was accordingly accepted.

The shredder purchased was a Morbark 2600 which is manufactured in the United States of America with local agents Ritlee Xecutech. The shredder was specified to suit that of DSW requirements e.g. capable of shredding garden refuse up to 300 millimeters on diameter, fitted on tracks for ease of movabilty on landfills (similar to a dozer) etc. The shredder was designed to shred at a rate of 17 tons per hour of which the Bisasar Road receives some 15 tons per hour. The following specification was compiled for the tender WS 5802 and highlights the research vested in setting the requirements for shredder that would be applicable to DSW operations:

CONTRACT NO. WS. 5802

SUPPLY, DELIVER & COMMISSION OF A HIGH SPEED SHREDDER FOR TREATMENT OF ORGANIC WASTE

SCOPE OF CONTRACT AND SPECIFICATIONS

1. SCOPE OF CONTRACT

The contract covers the supply, delivery and commissioning of a high speed shredder for use in composting operations at the Mariannhill Landfill Site, thereby providing organic material for use in the rehabilitation of both the Mariannhill Landfill Site and other landfill sites within the eThekwini Municipality.

2. SPECIFICATIONS

One high speed shredder complying with the following minimum specifications must be supplied:

2.1. General Description

The shredder must be capable of reducing the volume of various organic waste types with minimum wear to the wearing parts. The shredder must be capable of shredding the following waste types:

2.1.1 Green Waste: General garden refuse as well as fibrous vegetative material.

2.1.2 Oversized material: Trunks and logs up to a maximum size or diameter of 350mm in diameter.

2.1.3 Wood Waste

2.1.4 Wood Pallets

2.2. General Specifications

2.2.1 The shredder must be capable of processing between 10 and 20 tons of material per hour.

2.2.2 The drive engine should be located away from the shredding units to ensure that the engine is not exposed to unnecessary vibration caused by the shredding units.

2.2.3 Ease of access must be provided for working components to ensure ease of maintenance and repairs thereby minimising machine downtime

2.2.4 The inlet feed chute should be horizontally aligned with the shredding rollers and must be equipped with a loading sensor on the roller.

2.2.5 The feeding roller and feeding chute floor should automatically reverse if the load on the shredding drum becomes too high i.e. automatic 'kick-back' emergency shut off system.

2.2.6 The in-feed floor and wheel should be able to process tangled material of point 2.1 above.

2.2.7 A manual adjusting mode should be provided to adjust the feed chute to suit the waste stream mentioned in point 2.1 above .i.e. variable in-feed system.

2.2.8 The driving motor of the feeding floor and the roller should be independently driven to ensure smooth flow of material into the shredder.

2.3 Shredding Description

2.3.1 The final material structure and particle size should be determined by a variable screen size ranging from 30mm to 300 mm screen.

2.3.2 The variable screen should be easily accessible for maintenance and repairs as well as changing the screen size to suit in-feed waste stream.

2.3.3 A variable screen is required for a diverse particle size mix that would ensure pore spaces for active aerobic composting.

2.4 Conveyor Description

2.4.1 The shredded material should be discharged on a continuous system for increased production.

2.4.2 The conveyors should be easily foldable for ease of transport from site to site.

2.5 Chassis Description

2.5.1 The undercarriage should be equipped with tracks to ensure mobility during wet conditions

2.5.2 A variable drive speed should be included for ease of mobility during the shredding operation.

2.6 Engine and Spares

The engine should be a well established brand in South Africa so as to ensure easy access to spares and maintenance.

A large-sized fan that works at low revolutions should be provided to reduce the noise level of the engine. It should be reversible, ensuring self-cleaning of the cooler by blowing out the cooler from the inside. This action should be done automatically or mechanically.

2.7 Optional Extras

A remote control with the following features:

- Engine speed
- Engine stop
- Scraper floor stop/forward/return
- Rear basket open/close
- Machine movement and steering

2.8 Manufacturers Specifications

Bidders/tenderers shall submit with their tenders, full manufacturers specifications together with any supporting information, brochures, pamphlets or any other material in assessing the suitability of the high speed shredding machines offered.

2.9 Spares

Bidders/tenderers shall supply the name and address of the spare parts supplier and guarantee that spares peculiar to the units offered will be available at all reasonable times, ex stock, during the life of the shredder.

2.10 Population

Bidders/tenderers shall supply the number of units offered currently in operation in the Republic of South Africa together with references.

2.11 Operator/Workshop Training

Bidders/tenderers shall upon delivery of the machine provide for operator and workshop maintenance training on site.

2.12 Alternatives/Variations

Bidders/tenderers may offer alternative purpose-built high speed shredders or with variations to the specifications above, but that will meet the minimum requirements stated in the Specifications. Alternatives offered must comply with the Conditions of Tender and include substantive and supporting information.

2.13 Warranty

The shredder supplied shall have the following warranties:

2.13.1 Engine

Warranty to be 12 months or 2500 hours (whichever is first) from date of delivery.

2.13.2 Chassis

Warranty to be 18 months or 3750 hours (whichever is first) from date of delivery.

2.14 General

The successful bidder/tenderer is to supply a comprehensive workshop manual

The shredder shall comply in all respects with the requirements of the Machinery and Occupational Health and Safety Act No. 85 of 1993, as amended and any other applicable relevant regulations.

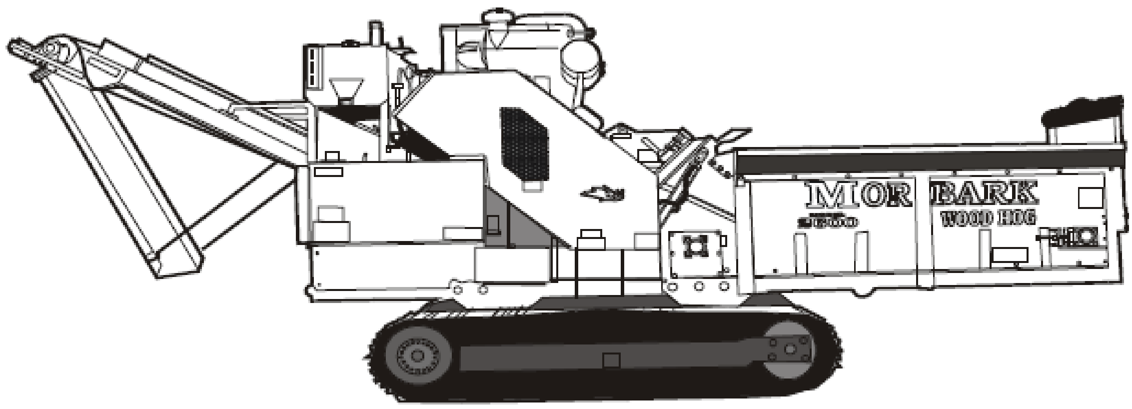

Figure 3.7: An image of the Morbark 2600 high speed organic waste shredder

APPENDIX F: TECHNICAL PAPER PRESENTED AT WASTECON 2006

TREATMENT OF GARDEN AND SELECTED ORGANIC WASTES ON LANDFILL SITES FOR REUSE IN COVER AND REHABILITATION SOIL AMELIORATION

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ABSTRACT

"Composting should be practiced not merely for the sake of composting but rather for the good it can do." (C.G. Golueke, 1973).

Garden refuse constitutes a large proportion of the total waste stream received at landfills in the eThekwini Metropolis and City of Durban. Full scale composting of garden and organic waste and reuse of the compost produced for landfill rehabilitation will be carried out at the Mariannhill landfill site as part of a complete zero waste scheme. The paper offers the rationale behind the setting up of the composting plan at Marinanhill, with particular focus on the dimensional analysis between small scale composting using passively aerated windrows and full scale operations. The study concludes with the proposed plan for a fully integrated *"waste treatment facility"*: the landfill of the future.

KEYWORDS

Aerobic Composting, Passive Aeration, Dimensional Analysis, Labour Intensive, Waste characterization, Process Monitoring, Microbial activity, Plant Tolerance, Windrows, Dome Aeration Technology.

INTRODUCTION

Composting is used in households and solid waste management in order to convert ''green'' organic waste into useful agricultural products such as compost, soil amendments or bulking agents. Recently, composting has attracted a lot of interest, for example in Europe, where, according to the Directive 99/31/EC, biodegradable components should be gradually diverted from landfills, necessitating the use of alternative MSW treatment techniques (Komilis, 2005). South Africa has recently tendered to follow a similar path to achieve the requirements of the Polokwane Declaration i.e. "*Reduce waste generation and disposal by 50% and 25% respectively by 2012 and develop a plan for ZERO WASTE by 2022".* Most areas are now adopting garden refuse composting as the first step towards the Polokwane's targets. Compost plays an important role in agriculture. If prepared correctly this is an environmental friendly product that can be used to reduce the cost and input of chemical fertilisers. When food crops are produced organically the use and role of compost becomes more important. The thumb rule is that healthy plants grown in a balanced environment are less prone to plant pathogens and predators. South Africa has a diverse use of composting systems from traditional static piles to turned windrows. The composting methods varies with the level of technology since higher level of technology requires higher capital investment but result in better control of the process and higher processing rates. Various types of waste pretreatment techniques have been reviewed with particular focus on passive aeration in aerobic windrows. The Dome Aeration Technology (DAT) (Mollekopf et al. 2002) was identified as an appropriate technology due to low construction and operational requirements.

COMPOSTING IN SA

Composting firstly started in the 1930's whereby compostable material where placed in a pit with alternative layers or were just piled in an open surface. The methods and techniques slowly evolved as technology advanced for example by turning the compost heaps for preventing anaerobic decomposition. Further developments such as forced aeration were introduced in the late 30'. By 1939, the aeration technology had led to multiple grate digesters with a continuous aerobic process. Many variations soon followed with the introduction of mechanized systems with controlled temperatures and injecting air supply (Golueke, 1974). The type of system used is dependant on factors such as available land area, cost of operation in relation to the size of community as well as markets for the end use product. There are three basic composting systems in South Africa, i.e. passive piles, turned/aerated windrows and in-vessel systems as compared in figure 1 below.

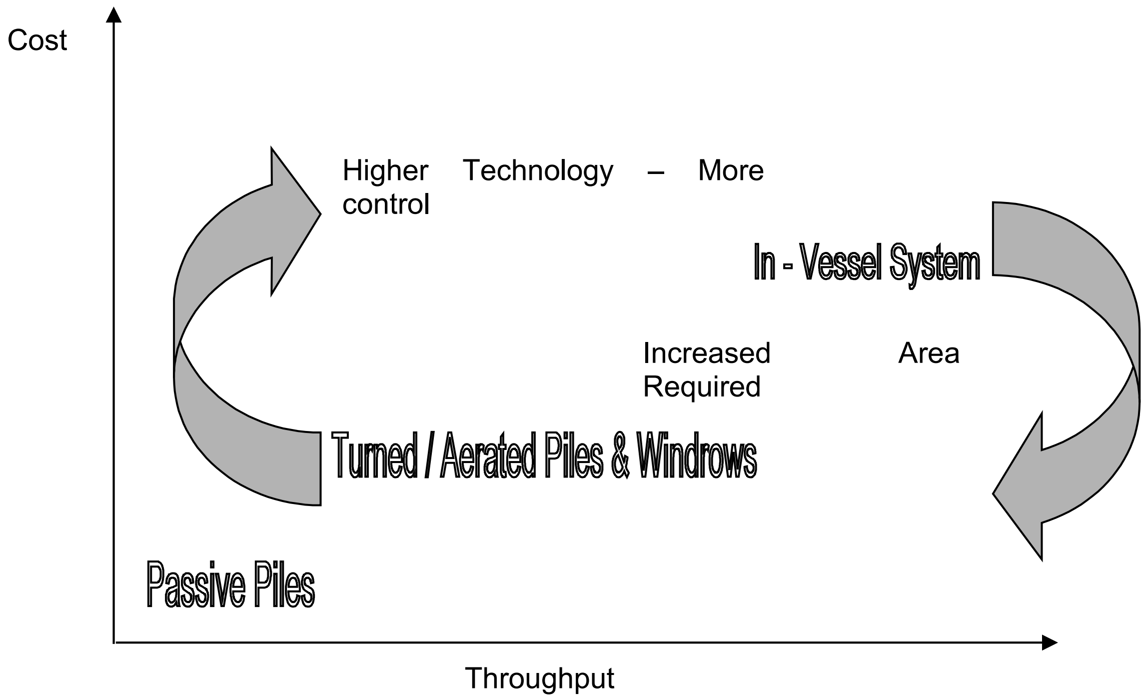

*Figure 1: Comparison of Composting Methods (*Leonard JJ and Schaub SM, 1996)

It can be seen from the above scheme that the higher level of technology require higher capital investment but results in better control of the process and higher processing rates. South being a developing country needs a composting system with low costs in terms of investment and operation and that promotes job creation but also sustainable development. In this context, composting with the Dome Aeration Technology (DAT) was adopted in this case study.

Dome Aeration Technology (DAT) is an advanced process for aerobic biological degradation of garden refuse and general waste (Paar, S., Brummack, J., Gemende, 1999).The system is based on open rotting windrow. The main operating principle is self-aeration achieved by installing chimneys inside the rotting waste body so to vent hot gasses through thermal advection outside and draw a continuous supply of fresh air in the pile. The main advantage of this technique is that there is no need to periodically turn the input material. The aim of this is to create a defined airflow through the composting material. The apparatus used are domes and channels, the domes generate hollow spaces inside the windrow whereby the hot gasses developed during the biological degradation of organic compounds accumulate. A temperature difference is created between the degrading input material and the surrounding ambient environment inducing a difference and a resultant thermal buoyancy effect which draws air from the outside to the inside of the compost heap i.e. effectively a ‘suction effect’.

The airflow pattern (can be seen in figure 2 below http://www.landfill.co.za/index.htm) allows for passive aeration throughout the compost pile.

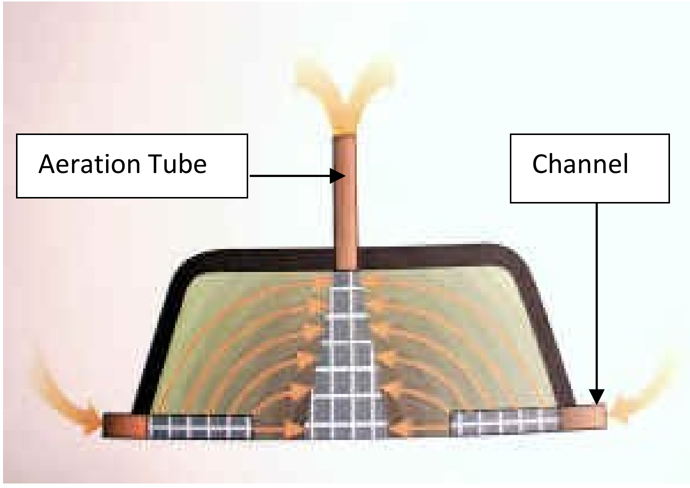

Figure 2: Cross-section of a typical DAT windrow showing the airflow patterns

SMALL SCALE COMPOSTING

Most land in South Africa, particularly in disadvantaged communities, bear infertile soils, which are prone to natural effects such as soil erosion and nutrient depletion of the soil. The main reason for these causes arises from continuous planting or sowing of crops and further harvests on a closed cycle. This depletes the soil of nutrients and organic matter that characterizes the soils fertility. For future harvesting not only on a production scale but also on a subsistence scale, these nutrients have to be returned to the soil. One possible way could be through chemical fertilizers but is relatively costly to rural communities. The only methodical approach would be to produce natural compost that helps the soils structure, supply nutrients, organic matter and increases the soils water holding capacity. The same needs are realized in the rehabilitation of landfill sites where the covering soil is often exposed to harsh conditions.

This study (Moodley, 2005) looked at using the Dome Aeration Technology as a low level composting technique to convert readily available resources such as garden refuse and domestic kitchen waste into compost which can be used by rural communities as organic soil amendment. This type of composting serves as an ideal approach since labour is readily available in rural areas and financial operation of the composting system is low. The advantage of small scale composting in this context is that individuals become self-supportive and also they have the opportunity to market their produce to which can lead to self-employment and future sustainability.

Full scale composting of pine bark and general waste has already been successful in various landfills in Durban (Trois et al., 2005;Trois and Polster, 2006), the results of this investigation will be used to set up a full scale composting system of garden refuse and organic waste at the Mariannhill landfill, so to encourage self-sustaining rehabilitation of the site and job creation.

METHODOLOGICAL APPROACH

The objective of the study was to design a self-aerated device that could be efficient for small communities and at full scale for composting operations in landfills. The full scale DAT windrows used in Durban for waste pretreatment were generally: 30m long, 11m wide and 3m high (Trois et al, 2005). A smaller version had to be designed but at the same time keeping all dimensional parameters constant. The operation and comparison of the small – scale model had to be investigated against the full – scale prototype.

A dimensional analysis was performed on the full scale windrows, based on the following assumptions:

a) *Geometric Similarity*: All length scale ratios had to have similitude
b) *Kinematic Similarity*: All ratios such as velocity had to have similitude and,
c) *Dynamic Similarity*: governing equations e.g. Reynolds number had to be conserved.

A set of parameters that describe the process were chosen on the basis of the pressure difference (Δp) between inside and outside of the compost heap since this principle governs the passively aerated systems. The functional relation taken was based on:

$$\mathrm{Pr}essure\_Drop\_[\Delta p] = f\{effective\_height, air\_density, gravitational\_acceleration, velocity\}$$

$$\mathrm{Pr}esuure\_Drop\_[\Delta p] = f\{h, \rho, g, v_{air}\} \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_(1)$$

Applying the dimensional scaling to the above functional relation, two equations that describe the same similarities as the full–scale prototype were found. This was given by the two independent π groups. Therefore the dimensional relational would be given by:

$$\frac{\Delta p}{\rho \cdot g \cdot h} = \phi \left\{ \frac{v}{\sqrt{g \cdot h}} \right\} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \qquad (2)$$

It was confirmed that the dimensional analysis performed does conserve all similarities above since the independent π group 1 yields the same formula as described by the dome aeration technology. The π group 2 described the relation between kinematic forces with gravitational forces as described by the Froude number that was used for scaling the prototype (full – scale) to an appropriate model size that conserves all similitude. Using the Froude number scaling from equation 2 above, the following relation was derived:

$$Froude\_Number_{\text{mod}\,el} = Froude\_Number_{prototype}$$

$$\left(\frac{v_v}{\sqrt{g_m \cdot h_m}} \right) = \left(\frac{v_p}{\sqrt{g_p \cdot h_p}} \right) ....where\_g_m = g_p = g$$

$$\frac{h_m}{h_p} = \left(\frac{v_m}{v_p} \right)^2 \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_}(3)$$

The above relationship was used to yield the following model DAT windrow: (4m x 4.4m)

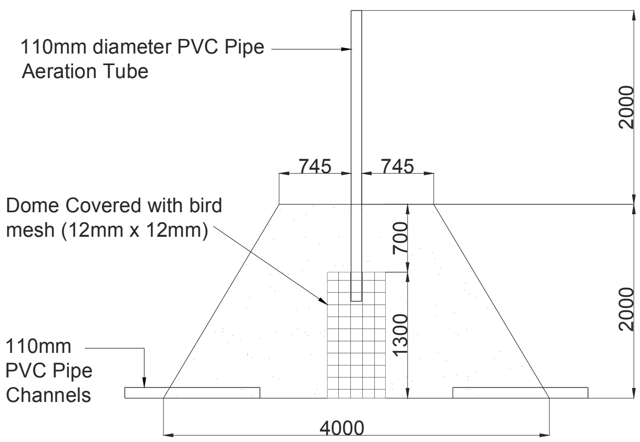

Figure 3: Section View for model dome aeration

A small DAT windrow, with the dimensions presented in Figure 3, was constructed at the University of KwaZulu Natal by mixing chipped garden refuse with fresh vegetable waste (Figure 4). The supply of kitchen waste in terms of waste fruit and vegetables was limited; therefore a ratio of 95% chipped garden refuse to 5% kitchen waste was used. 7 barrows of chipped garden refuse, 2½ barrows of structural material and ½ barrow of waste fruit and vegetables. The pile was covered with a thin layer of pine bark for insulation.

Table 1 describes the characterization conducted on input and output material to the windrow.

Table 1: Standard Waste Characterisation Tests:

Solid Tests	**Eluate Tests (1:10)**	**Plant Tolerance Test**
Moisture Content	Biochemical Oxygen Demand (BOD)	Germination
Total & Volatile Solids	Chemical Oxygen Demand (COD)	
Self Heating Tests	Total Organic Matter (TOC)	
	Total Kjeldahl Nitrogen (TKN)	
	Ammonia & Nitrates	
	pH & Conductivity	

Figure 4: View of small scale test windrow.

An in-depth monitoring study on the model dome aeration windrow was conducted for 8 weeks in order to assess the efficiency of the scaling and the process, as described below:

- Monitoring of the exhaust gas velocity in aeration pipe
- Monitoring temperature in exhaust gas body
- Monitoring of gas compositions
- Monitoring of ambient conditions

The above parameters were measured daily for the first week of decomposition and thereafter once a week for 6 weeks.

RESULTS

The moisture content of the raw garden refuse was calculated to be 27% and a further 33% to attain a 60% moisture content for optimum composting conditions. Great efforts were invested through carting, mixing and final placement of the material on in the windrow. A total of three labourers were employed in the construction of the windrow over three days.

The evolution of temperatures in the pile during the composting time are presented in Figure 5.

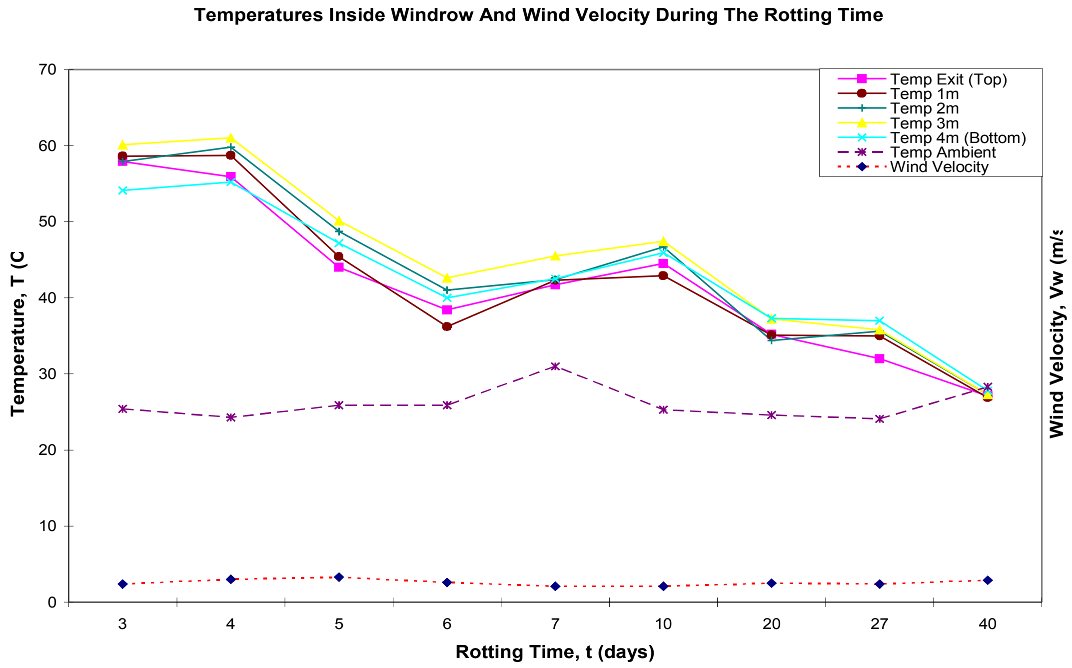

Figure 5: Temperature evolution at different depths in relation to ambient conditions.

During the first week after construction the temperatures of the exhaust gas reached thermophilic levels to ensure full sanitation of the compost.. The rapid increase in temperature shows that the thermophilic phase reached within 3 to 4 days after placement of the input material into the windrow. After a maximum temperature is reached, there is a gradual decrease from the 10^{th} day that signed the transition into mesophilic stage of decomposition. It can be seen that high wind velocities corresponds to high exhaust gas velocities and high temperature differences.

On dismantling the windrow for output sampling, it was found that different zones within the windrow had produced different textures of rotting material. There were particularly 3 areas of sampling and this was chosen to get a representative understanding of the types of compost quality produced.

Table 2: Summary of laboratory results

Sample	MC %	TS (%)	VS (%)	TOC (mg/l)	TKN (mg/l)	COD (mg /l)	BOD (mg/l)	NH_3 (mg/l)	NO_x (mg/l)	pH	Cond. (µs/cm)	Self Heating, T (°C)	C / N
Input	30.9	69.9	87.7	450	81	2396.4	1300	75.452	5.1781	6.5	1446	25.8	6:1
Output: Dry	24.7	76.6	47.4	340	43	2034.3	363	15.781	4.1918	6.89	909	24.2	8:1
Output: Bottom	51.3	96.6	44.3	126	11	834.4	153	5.9178	3.2055	7.09	622	---	11:1
Output: Dome	55.5	96	45.2	196	27	958.5	269	8.3836	3.9452	7.12	623	25.2	7:1

The quality of the compost produced during the experiment was compared with German Compost Quality standard – DIN 4187 as in Table 3.

Table 3: Comparison of input and output material to compost Standard DIN 4187.

Parameter	**Input Raw Garden Refuse**	**Output Compost**			**DIN 4187**
		Dry	**Bottom**	**Dome**	
Water Content (%)	30.9	24.7	51.3	55.5	50 - 65
pH	6.5	6.89	7.09	7.12	7.3
Carbon, C (%dm)	64.4	44.4	13.0	20.4	19.6
Total Nitrogen, N (%dm)	11.6	5.6	1.1	2.8	1.1
Volatile Solids, VS (%dm)	12.5	6.2	4.6	4.7	39.7
C: N Ratio	6	8	11	7	22.8

The above results show that the bottom and dome compost are within range of the moisture content standard. On the other hand, the dry compost had very low moisture content and this could be due to hyper aeration that induced a rapid desiccation of the area. To avoid desiccation regular wetting during the rotting period should be applied or the windrow should be made shallower so to reduce drainage from the steep side slopes. The above parameters show to be relatively close to the German standard.
It can be concluded that high quality compost can be achieved. The results are expected to improve with a longer rotting period to allow for further degradation.

ZERO WASTE PLAN AT MARIANNHILL LANDFILL SITE

A high mass of recyclable materials is disposed at the Mariannhill landfill site, which is currently being landfilled along with all other general waste types. The incremental improvements to the standards of living of people and expansion of the Municipality's service areas are primary reasons for an increase in "recyclable waste" production in the metro. The reduction of mass and 're-use' of this waste type is seen as the first step in reducing the mass of waste to landfill, in line with the goals of the Polokwane Declaration. The proposed project aims at establishing a full scale garden refuse treatment system based on the findings from the small scale study described above (Moodley, 2005) and the successful pine bark operation conducted at the Bisasar Rd landfill (Trois and Polster, 2006) that proved the DAT to be applicable for garden refuse composting in terms of low costs, low energy inputs and potential job creation. This treatment would form a link in the zero waste plan for the site aiming at removing all recyclable fractions before disposal into the landfill. The study would focus on composting the 40tons/day of garden refuse at the Mariannhill landfill site as well as selected organic waste to enhance biodegradation rates.

This project aims to develop a practical working system for the collection and sorting of incoming garden refuse at the Mariannhill Landfill Site, and the consequent treatment of the refuse. The treatment may include, but is not limited to, the mechanical shredding/chipping of the refuse to reduce volume and biological treatment in windrows.

In addition, the project requirements include the investigation of possible end-uses for the treated waste, whether it be commercially sold or for use by the eThekwini Municipality. Results from the study would provide recommendations for a permanent full scale composting programme for all eThekwini landfills and possible end markets for the compost material.

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