INVESTIGATION TO DETERMINE THE EFFECTIVENESS OF A COMMERCIALLY AVAILABLE PIT LATRINE ADDITIVE AND THE DEVELOPMENT AND EVALUATION OF A TESTING PROTOCOL.

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PREFACE

I, Anna Maria Bindoff, hereby declare that the whole of this dissertation is my own work and has not been submitted in part, or in whole to any other University. Where use has been made of the work of others, it has been duly acknowledged in the text. This research work was carried out in the Department of Chemical Engineering, in the Pollution Research Group, at the University of KwaZulu Natal, under the co-supervision of Mr. C. Brouckeart, and the supervision of Professor Chris Buckley.

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As the candidates supervisor I have approved this dissertation for submission

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ABSTRACT

The provision of sanitation services during the apartheid era in South Africa was minimal or non-existent in the previous "black" areas and for farm workers. Whatever service that was provided was often in a bad state of disrepair. One of the priorities established in the post 1994 elections was to improve the quality of lives for the previously marginalised and neglected communities. This was done through the development and implementation of a policy for reducing the sanitation backlog, and for the provision of a basic level of sanitation. The principles encompassed in the policies developed for poverty alleviation and sustainable development had many points in common with the United Nations Millennium Development Goals and targets declared in 2000.

The provision of Ventilated Improved Pit (VIP) latrines by municipalities satisfies the minimum requirements for basic sanitation. This provision together with the awareness programs are seen to offer communities an improved environment and hence living conditions. Problems arise however, due to the rapid filling, blockages and even the overflow of these pits. The emptying of these pits is also hazardous due to the nature of the waste.

One of the solutions proposed by entrepreneurs was to supply additives that would enhance the degradation processes in the pit thereby increasing the lifespan of these pits as well as offering other benefits; reduced odours, and flies.

The aim of this research work was to test the claim of enhanced degradation by determining the effectiveness of an additive, M, which was deemed to be representative of a group of additive; made up of aerobic microbes and enzymes. The objective was to supply information to the municipality planners and decision makers in municipalities to assist them in their planning for improved management of pits.

Waste was removed from suitable VIPs and used as samples for laboratory scale experiments. Reactor vessels were designed to simulate pit conditions. The additive was tested on the waste as recommended by the supplier and compared in activity against waste tested as references. The reference tests had (i) no addition of additive or water, as well as (ii) varying the volume of water added and (iii) varying the frequency of water addition, no additive added. Measurements were made of the following variables:

- Total mass
- Chemical oxygen demand.
- Total solids
- Volatile solids.
- Ash.

The results of the experimental vessels were analysed and compared with the reference vessels to reveal any differences. The results obtained did not present enough precision and reliability to make any conclusive decision as to whether the additive is effective or not. Recommendations made were to improve the test methodology using the same additive, to obtain results that would make a conclusive decision possible.

PREFACE

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       <u>Professor C. Buckley</u>   **<u>Date</u>**

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LIST OF ABREVIATIONS:

AA:	Amino acids.
ANOVA:	Analysis of variances. A statistical tool available in Microsoft EXCELL spreadsheets.
COD:	Chemical Oxygen Demand measured as the amount of specified oxidant that reacts with a sample under controlled conditions. The quantity of oxidant used is measured in terms of its oxygen equivalence. This includes both organic and inorganic chemicals (APHA. 1997).
DWAF:	Department of Water affairs and Forestry.
GI:	Gastro intestine.
HBu:	Butyric acid.
HVa:	Valeric acid.
ID:	Inner diameter.
IDP:	Integrated development plan.
ISDRS:	Integrated Sustainable Rural Development Strategy.
LCFA:	Long chain fatty acid.
MS:	Monosaccharides.
NSTT:	National sanitation task team.
OD:	Outer diameter.
PVC:	Polyvinyl chloride.
SCFA:	Short chain fatty acid.
TBVC:	Transkei, Bophuthatswana, Venda and Ciskei.
TOC:	Total organic carbon.
TS:	Total solids.
UNMDG:	United Nations millennium development goals.
UD:	Urine diversion toilets.
VIDP:	Ventilation improved double pit.
VIP:	Ventilated improved pit latrine.
VS:	Volatile solids.
WRC:	Water Research Commission.

WSDP: Water service development plan.

GLOSSARY OF TERMS USED:

Adequate sanitation:	for a household means the provision and ongoing operation and maintenance of a safe and easily accessible means of disposing of human excreta and waste water, providing an effective barrier against excreta-related diseases, which is used by all members of a household, and does not have an unacceptable impact on the environment (National Sanitation Task Team (NSTT). 1995).
Basic level of service:	for a household means a VIP (Ventilated Improved Pit) latrine (in its various forms, to agreed standards) or its equivalent in terms of cost, robustness, health benefits and environmental impact; together with ongoing exposure to readily understandable information about correct hygiene practices (NSTT. 1995).
Between reactor vessel:	This term is used when comparing analytical results to determine whether there were any significant differences between results from different reactor vessels when compared at the same points in time. (See "Within reactor vessels")
Contents of reactor vessel:	Waste and any additions.
Extracellular:	Outside of the cell.
Gastrointestine:	The GI tract includes the digestive system that processes and digests food from the mouth through to the anus.
Intrinsic factor:	A protein that binds ingested vitamin B12 and enables it to be absorbed by the intestine.
Minimum acceptable basic level of sanitation:	(a) Appropriate health and hygiene awareness and behaviour. (b) A system for disposing of human excreta, household waste water and refuse, which is acceptable and affordable to the users, safe, hygienic and easily accessible and which does not have an unacceptable impact on the environment; and

(c) A toilet facility for each household (Department of water Affairs and Forestry. (DWAF). 2001).

Pepsin: Pepsin cleaves peptide bonds. Its action breaks long polypeptide chains into shorter lengths.

Pepsinogen: A precursor to the proteolytic enzyme pepsin.

Pit: A hole in the ground.

Pit latrine: A structure built over a hole in the ground. A pit latrine can provide inadequate or adequate sanitation. Examples of adequate basic sanitation would be VIPs.

Probiotic: "live microbial feed supplement which beneficially affects the host animal by improving its intestinal microbial balance" (Fuller 1989).

Reactor vessel: A vessel designed to simulate pit conditions. It contains a "bag" which held the waste (see reference to waste below). Each reactor vessel also represents a particular experimental set-up.

Sanitation: The principles and practices relating to the collection, removal or disposal of human excreta, household waste water and refuse as they impact upon people and the environment. Good sanitation includes appropriate health and hygiene awareness and behaviour, and acceptable, affordable and sustainable sanitation services.

Substrate: Biodegradable organic material contained in the waste collected from the pit.

Waste: VIP waste only.

Within reactor vessel: This term is used when comparing analytical results to determine whether there was any change in the characteristics of a specific reactor vessel over a period of time. (See "Between reactor vessels")

STRUCTURE OF THE DISSERTATION.

Chapter one has laid a foundation to the aim of this research project by briefly looking at the background to the sanitation situation that exists in South Africa even to this day. A brief historical account of pre 1994 South African sanitation service is given and the subsequent post 1994 government in South Africa's task of ensuring that all South Africans have access to at least a basic adequate sanitation service (VIPs). This was to be achieved by the elimination of the sanitation backlog by 2010, and to have by 2020 a significant proportion of the population with access to improved sanitation. VIP structures, basic design, operations and inputs are described. Problems have arisen with VIPs due to the rapid filling and even overflow of the pits as well as the required emptying of these pits. The result is greater risks associated with the hazards of emptying these pits.

Chapter two is the literature research, where an understanding of the processes in the pit as well as processes in the human digestive system is needed to develop the hypothesis and the methodology to test the hypothesis. Other natural processes in the macrobiota of the pit are also examined briefly to understand the mechanisms used in their systems of using the waste in the pit as substrate for growth in size and numbers. This should give a background to the understanding of mechanisms required by an additive to effectively degrade substrate in the pit. Previous studies on pit latrine additives are explored briefly to examine the outcomes.

Chapter three describes the project hypothesis and objectives using the principles obtained in chapter one and two.

Chapter four describes the methodologies of all the aspects of the experimental stage of the project. This involved descriptions of:

     i.   how to choose the pits for sample collection,
     ii.   sample collection,
     iii.   the design of the testing equipment,
     iv.   additive M,
     v.   the reactor vessel experimental configuration and testing protocol,
     vi.   sampling procedures for laboratory analysis,

vii.   description of the analysis as well as any special preparation techniques needed,

viii.   data processing and statistical analytical processes needed to present laboratory results for discussion.

The results are presented in chapter five. Tables and graphs are presented of the averages together with the standard deviations, ANOVA statistical results and the arithmetic differences, to present aspects of the results.

The discussion, conclusions and recommendations are presented in chapter 6.

1. INTRODUCTION.

The provision of sanitation services in South Africa prior to the 1994 elections was considered to be minimal or non-existent in the "black" urban and rural areas. Farm dwellers and rural schools in particular had no sanitation services and whatever service that was provided was often in a bad state of disrepair. One of the priorities established in the post 1994 elections in South Africa was the development and implementation of a policy for dealing with the issue of addressing the sanitation backlog and the provision of an equitable sanitation service. (Department of Water Affairs and Forestry (DWAF), 2001). In terms of the policy, the highest priority for the role out of sanitation services was established for those communities most at risk due to inadequate sanitation or those unable to afford basic sanitation services. This would be in line with the minimum acceptable basic level of sanitation (DWAF), 2001).

The principles encompassed in this policy developed for poverty alleviation and sustainable development had many points in common with the United Nations Millennium Development Goals (UNMDG) and targets. This was further re-enforced by the World Summit for Sustainable Development held in South Africa in 2002. The global community agreed in principle to reduce poverty and improve the lives of poor people through sustainable development. Global co-operation, funding and training would assist the developing countries achieve their targets in the eight goals set out in the MDG.

Ventilated improved pit (VIP) latrines are accepted as a basic level of sanitation (DWAF, 2002). Problems have arisen with these systems due to the rapid rate of filling, blockages and overflowing of the pits (Saaka, D.H., 2007). A solution to the problem of the management of the VIP waste could be achieved with the variety of pit latrine additives that have been made available by entrepreneurs (Foxon. 2008). The claim is that the additives enhance the degradation of the waste as well as reduce flies and odour. This leads to an improved environment, where the spread of disease through flies is reduced, odour reduction improves air quality, and the frequency of emptying the pit is reduced.

VIPs will be examined as well as the different biochemical processes that occur in the pit. The role of additives will also be explored in the context of the policies developed and the targets set by the MDG.

1.1   Background of sanitation service provision in South Africa prior to 1994.

Prior to 1994, the Republic of South Africa was divided into eleven different homeland administrative and political areas; the four independent Transkei, Bophuthatswana, Venda and Ciskei (TBVC) states, six self-governing territories, and the dominant South African territory, governed by the tri-cameral parliament. In addition, within the ten homelands, were a number of rural areas that were managed by tribal authorities. The effect of this was fragmentation due to too many institutional structures and thus little cohesion in terms of a strategic approach to sanitation. This in turn resulted in poor or no service provision and very little infrastructure development. There was very little or no service provision in the "black" urban and rural areas and in particular for farm labourers and farm schools. The service provision that was provided in these areas was often in a bad state of disrepair. Where there was a lack of capacity in the tribal areas, no assistance was requested, and in order not to interfere, the Department of Public Works did not take responsibility for the provision of these services. The responsibility then lay with the Department of Development, which did provide a service characterised by the lack of consultation and buy-in from stakeholders. The lack of clear institutional structures and guidelines, the lack of political will and the resultant failure to make resources available where they were needed, resulted in a number of poorly designed and operated sewerage systems and a number of people without adequate sanitation. These individuals had to rely on the bucket or other rudimentary systems or the open veld. Very little consideration was given to the education of the community in health and hygiene issues as well as addressing their needs. By 1991, approximately 21 million people did not have access to a basic level of sanitation (DWAF. 1994) (DWAF. 2002).

1.2   Post 1994 approaches to sanitation service provision.

This section deals with the formulation of a sustainable equitable sanitation service provision in post 1994 South Africa. The DWAF report: White Paper on Basic Household Sanitation.

2001, states that one of the priorities in the new democratic government of 1994 was the development and implementation of a policy for attending to the sanitation backlog as well as the provision of basic sanitation services for all communities (DWAF. 2001). This resulted in the Water Supply and Sanitation Policy, drawn up in 1994 that dealt with the strategic approach in implementing the priority needs of the community. (DWAF. 1994). The highest priority was for those communities most at risk due to inadequate sanitation and unable to afford the basic sanitation services (DWAF, 2002).

The principles in the policy drawn up had common goals with the MDG. The MDG was a result of a meeting of the United Nations in September 2000 at the Millennium Summit to condense the outcomes of international conferences and world summits from the previous decade. The result was the United Nations Millennium Declaration of 2000 with eight key goals and eighteen targets to be achieved between 1990 and 2015. The MDGs are an agenda agreed to by world leaders to reduce the world's poverty and to improve people's lives (UNDP: 2007). The goals, targets and their indicators of the MDG are outlined in Table 1-1 below

Table 1.1: Millennium Development Goals, targets and indicators (South Africa. 2007):

Goals and targets and their indicators

Goals and targets	Indicators
Goal 1: Eradicate extreme poverty and hunger	
Target 1: Halve, between 1990 and 2015, the proportion of people whose income is less than US$1 a day	• Proportion of the population below US$ 1 a day • Poverty gap ratio (incidence, times, depth of poverty) • Share of poorest quintile in national consumption
Target 2: Halve, between 1990 and 2015, the proportion of people who suffer from hunger	• Prevalence of underweight children (under five years) • Proportion of the population below minimum level of dietary consumption
Goal 2: Achieve universal primary education	
Target 3: Ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling	• Net enrolment rate in primary education • Proportion of pupils starting Grade 1 who reach Grade 7 • Literacy rate of 15- to 24-year-olds
Goal 3: Promote gender equality and empower women	
Target 4: Eliminate gender disparity in primary and secondary education preferably by 2005 and in all levels of education no later than 2015	• Ratio of boys to girls in primary, secondary and tertiary education • Ratio of literate females to males among 15- to 24-year olds • Share of women in wage employment in the non-agricultural sector • Proportion of seats held by women in the national parliament
Goal 4: Reduce child mortality	
Target 5: Reduce by two-thirds, between 1990 and 2015, the under-five mortality rate	• Under-five mortality rate • Infant mortality rate (IMR) • Proportion of one-year-old children immunised against measles
Goal 5: Improve maternal health	
Target 6: Reduce by three-quarters, between 1990 and 2015, the maternal mortality rate	• Maternal mortality ratio • Proportion of births attended by skilled health personnel
Goal 6: Combat HIV and AIDS, malaria and other diseases	
Target 7: Have halted by 2015, and begin to reverse the spread of HIV and AIDS	• HIV prevalence among 15- to 24-year-old pregnant women • Contraceptive prevalence rate • Number of children orphaned by HIV and AIDS
Target 8: Have halted by 2015, and begin to reverse the incidence of malaria and other major diseases	• Prevalence and death rates associated with malaria • Proportion of the population in malaria-risk areas using effective malaria prevention and treatment measures • Prevalence and death rates associated with tuberculosis • Proportion of tuberculosis cases detected and cured under directly observed treatment, short-course (DOTS)
Goal 7: Ensure environmental sustainability	
Target 9: Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources	• Change in land area covered by forest • Land area protected to maintain biological diversity • GDP per unit of energy use • Carbon dioxide emissions (per capita)
Target 10: Halve, by 2015, the proportion of people without sustainable access to safe drinking water	• Proportion of the population with sustainable access to an improved water source
Target11: Have achieved, by 2020, a significant improvement in the lives of at least 100 million slum dwellers	• Proportion of the population with access to improved sanitation • Proportion of the population with access to secure tenure
Goal 8: Develop a global partnership for development	
Target 12: Develop further an open, rule-based, predictable, non-discriminatory trading and financial system (includes commitment to good governance, development and poverty reduction – both nationally and internationally)	• Target and indicators are not presently being measured in South Africa

Target 13: Address the special needs of the least developed countries	• Official development assistance (ODA)
Target 14: Address the special needs of landlocked countries and small island developing states	• Target and indicators do not apply to South Africa
Target 15: Deal comprehensively with debt problems of developing countries through national and international measures in order to make debt sustainable in the long run	• Debt service as a percentage of exports of goods and services
Target 16: In cooperation with developing countries, develop and implement strategies for decent and productive work for youth	• Unemployment rate of 15 – 24 year olds, by each sex and in total
Target 17: In cooperation with pharmaceutical companies, provide access to affordable drugs in developing countries	• Measurement of target not available for South Africa (free primary health care for all)
Target 18: In cooperation with the private sector, make available the benefits of new technologies, especially information and communications	• Telephone lines and cellular subscribers • Personal computers in use per 100 of the population

In terms of these goals a significant improvement must be achieved in the lives of at least 100 million slum dwellers. The task that has been set is to have eradicated the sanitation backlog in the rural, peri-urban and informal settlements by the year 2010 and was to have eradicated the bucket system by 2007. The targets are to be met through deliverables, one of which is the promotion of sanitation, health and hygiene awareness training programs and the provision of a basic toilet facility (DWAF. 2002).

The 2007 update on the MDG reveals that the percentage of the total population that had received access to basic sanitation and water services as access to basic services had increased from 59% of the population (1994) to 94% of the population (2007) (South Africa. 2007).

Prior to the elections in 1994, there was no single government department responsible for water and sanitation services resulting in very different levels of service. After the 1994 elections, the metro and district municipalities had a constitutional obligation to supply water and sanitation services (South Africa. 2006). A range of municipal legislation was developed to transform the local government; the Local Government Municipal Demarcation Act 27 of 1998, the Municipal Structures Act 117 of 1998, the Municipal Structures Amendment Act 33 of 2000, and the Municipal Systems Act 32 of 2000 (DWAF. 2002). The local government structures were not fully developed, so DWAF was given the responsibility to ensure that all South Africans were given equal access to water supply and sanitation.

Through various initiatives, the White Paper on Basic Household Sanitation was endorsed by parliament in 2001 (DWAF. 2002). This gave among others policy principles to guide the intervention strategies required to address the sanitation problems. Institutional arrangements were also described to formalize the responsibilities; sanitation is everyone's business not only the government's. "The user pays" policy is a central principle to ensure sustainable and equitable development, as well as efficient and effective management (DWAF. 1994). Of concern in this research project are the responsibilities of municipalities and individuals.

1.2.1   Municipality basic service provision.

Clear roles were provided in the Constitution of the Republic of South Africa, Act 108 of 1996 to give responsibilities to the three spheres of government through legislation. Metro and district municipalities were to be accountable for the provision of sanitation services, to promote health and hygiene awareness and to monitor the health of its communities (DWAF.2001). The main roles of municipal government in implementing policy, in addressing the sanitation backlog and to address sanitation on a sustainable basis are to:

- create a demand for sanitation improvement through health and hygiene awareness programmes;
- identify local sanitation improvement needs;
- prioritise these needs;
- plan within the IDP/WSDP process to respond to these needs, including the need for health and hygiene awareness and for sanitation services, together with the needs for other services as an integrated package of services, where appropriate aligned with the development of the Integrated Sustainable Rural Development Strategy (ISDRS) nodes;
- align their budgets to achieve the planned objectives;
- ensure that sufficient and appropriate human resources are available to execute the plan including the development of building skills within the community;
- implement the plan;
- monitor and report on the results; and
- ensure sustainability.

Municipalities are supplying services consistent with their provision of basic sanitation levels to the community especially in the rural areas.

Ethekweni Municipality has embarked on a program that will reduce the backlog of the sanitation services to its rural and peri-urban areas (Ethekweni. 2003). To encompass all members of the community, a subsidised/grant system would be provided for in targeted areas where the community members cannot afford to pay for their own sanitation installation and services. The eThekweni Water Services Development Plan (WSDP) of 2004 outlines the free basic services for sanitation. In terms of the WSDP of 2004, no charges will be levied on properties valued at less than R30 000 as these are most likely owned by the poorest of the poor. In addition, block rebates are offered on properties valued between R30 000 and R100 000, as these properties are owned by relatively poor people (Ethekweni. 2004).

There were an estimated 150,000 pit latrines, of which 60 000 are VIPs within the Ethekweni Municipality boundary in 2006. (Stevens. 2006) (eThekweni. 2004). The informal pit latrines are to be replaced in line with the Water and Sanitation program. A tariff included the emptying of a VIP at a nominal rate of a heavily subsidised rate of R85.00 at 2004/2005 rates (eThekweni. 2004). The actual cost at that stage based on an "ad hoc" demand basis was R700. This was due to distances travelled to the sites to empty the pit latrines and also to the place of final disposal of the waste. Council adopted a policy to present a free service to empty the pits every 5 years to all households with a VIP, or an unimproved latrine. This was subject to cost assumptions underlying this policy decision. A pilot study was commissioned to investigate the most cost efficient method that can be evaluated with the appropriate machinery and equipment that can be used. (Ethekweni Municipality. 2004). At this point in time the outcome of the study is not known.

1.3   The Ventilated Improved Pit Latrine (VIP).

The simple pit latrine is the cheapest and most basic form of sanitation available. The task of providing adequate basic sanitation is the responsibility of the municipality. This section describes various types of VIPs. The VIP or its equivalent form if constructed to agreed standards is the minimum acceptable basic level of service for adequate sanitation. (DWAF.

1994) (NSTT. 1995). VIPs are similar to pit latrines; however, they have been improved in design to accommodate the requirements set out for basic adequate sanitation (NSTT. 1995) (Ethekweni Municipality. 2003). The requirement for a pit latrine to qualify as a VIP must fulfil the following requirements (Foxon. 2008):

      (i)   provide hygienic separation of human waste from contact with people,

      (ii)   have a vent pipe fitted with a fly-screen to minimize odour and flies;

      (iii)   be built on a secure slab that will resist collapse of the superstructure; and

      (iv)   provide privacy and dignity for the user.

VIPs can be constructed with or without a lining. It can be partially or fully lined.

1.3.1 Physical structure

An example of an unlined pit design is shown in Figure 1.1.
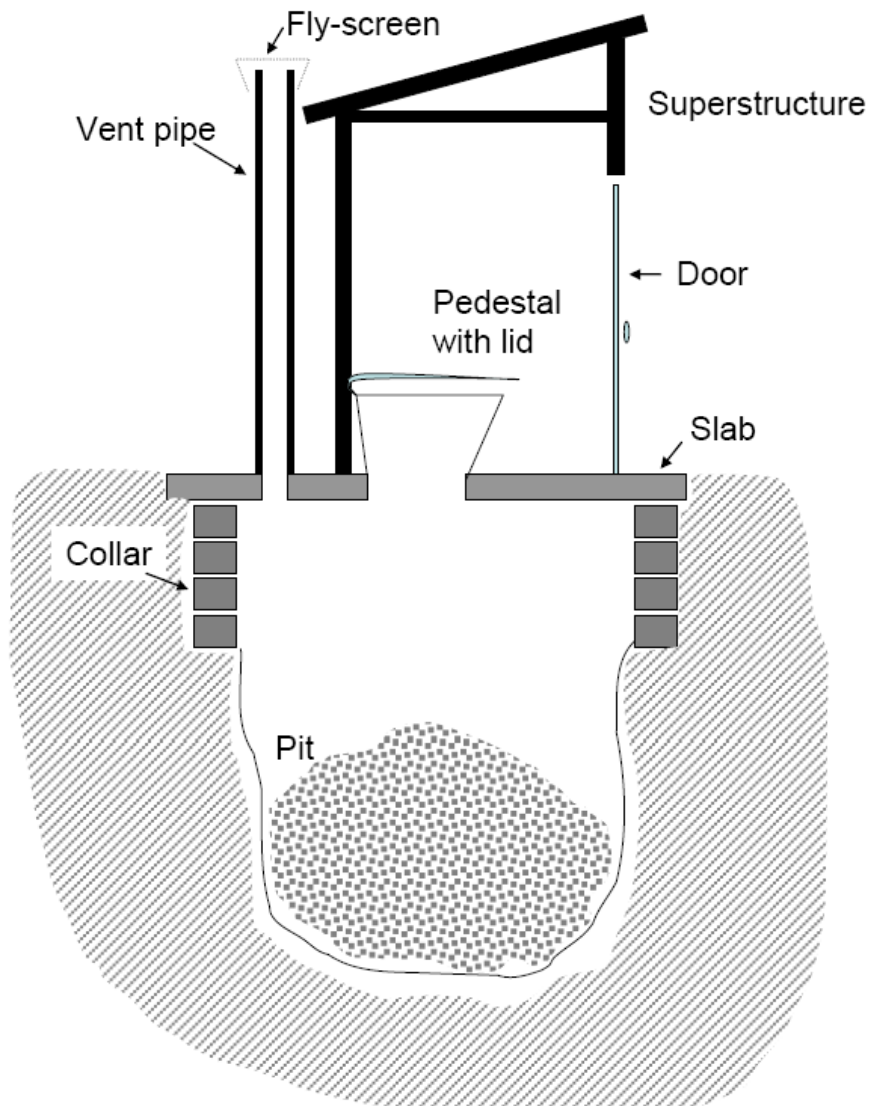
Figure 1.1: Structure of a basic VIP (Foxon. 2008).

The features that make up a well designed VIP are given as follows:

       i.   the pit,

     ii.   the superstructure and toilet are supported on a slab,

     iii.   superstructure with vents, door and roof,

     iv.   a vent pipe with mesh gauze covering the open end exit point

     v.   standard toilet pedestal with plastic seat

1.3.1.1   The pit.

This is the receptacle of faecal matter, urine, anal cleansing material as well as any other non-degradable matter. It may by lined (fully or partially) or unlined (Foxon. 2008). The design is for solids storage only. It could be circular of square in shape although circular pits have a stronger structure. The size of the pit is a 1 to 1.5 meter sides. The pit working volume can be calculated (Mara. 2006):

Pit working volume = rPn (m^3)

- Add 0.3 m - 0.5 m free space at top of pit.
- **r** = solids accumulation rate (m^3 per person per year);
- = 0.05 in dry pits and 0.03 in wet pits;
- increase by 50% if bulky anal cleansing materials used.
- **P** = household size,
- **n** = pit life (years).

Solids accumulation rate = 60 L/p/y (wet pit) (wet pit → faecal matter will be in wet pit)
            (WHO. 2003).

            = 90 L/p/y (dry pit) (dry pit → faecal matter not in moist pit)
            (WHO. 2003).

The lining provides structural strength to the sides of the pit and prevents it from collapsing if the surrounding soil is loose soil, sandy or clay which is prone to shrinkage (WHO. 2005). If a pit is fully lined, no liquids can enter or exit the pit. The top 0.5m (collar) of the pit should be lined and sealed in stable soil to provide a platform for the slab and to prevent permeation into the shallow soils (WHO. 2005). In a partially lined pit, the lining would not be sealed below the collar to allow for liquid to permeate out of the pit (WHO. 2005). Foxon

(2008) quotes Bester and Austen (2000) in the construction of a pit on a mound should there be shallow bedrock at the location of the pit or a high water table. The pit should be at least 2m above the water table (WHO. 2005).

The infiltration capacity of a pit also has to be considered, as this will need to be sufficient to allow any liquids in the pit to flow away. The infiltration capacity depends on the type of liquid, the surface area that allows infiltration, and the nature of the soil (WHO. 2003).

1.3.1.2   Cover slab.

This is a strong reinforced steel structure that covers the pit. It has two holes; one for the vent pipe and the other for the toilet seat or the squatting hole. The squatting hole should be sized for safety of children so they cannot fall through. The purpose is to support the user as well as the toilet seat (WHO. 2005).

1.3.1.3   Superstructure.

The superstructure provides privacy and dignity for the user. It also protects the pit and user from the sun and rain. The prevention of light is also important as this will prevent newly hatched flies from escaping through the toilet or squat hole in the slab from the pit. The design of the superstructure is also such that air is channelled through this same hole in the slab to the vent pipe thereby managing odours and hence flies (Foxon. 2008).

1.3.1.4   Vent pipe with fly screen.

The main function of this structure is to manage flies and odour. The pipe would extend 500 mm above the roof structure. This would be to direct odours away from the VIP. Light enters the pit through this pipe. This would be for the newly hatched flies to be attracted to the light and exit the pit through the vent pipe. These would be captured by the screen on top of the pipe. Equally, flies are attracted to the faecal odours, so directing the odours away from the VIP would reduce the number of flies in the area (Foxon. 2008).

It draws air through the pit by convection that is induced by heating of the vent pipe by the sun, or as a result of wind activity. (Mara. 2006). Fresh air is drawn through the pit above the waste layer and exits through the vent pipe thereby removing odours. The air (oxygen) may

diffuse to the waste layer surface, thus providing an aerobic environment at this interface. (Foxon, *et.al.* 2006)

1.3.1.5 The toilet seat and superstructure door.

Toilet seats are commonly used in South Africa. The toilet seat has a lid to prevent light from entering the pit, thus causing flies to be a nuisance for the user inside the structure. The lid must still allow air to flow into the pit. The door keeps the light out of the superstructure (Foxon. 2008).

1.3.2 Physical processes occurring in a VIP.

The following physical processes occur in a well maintained pit;

    i.   accumulation of human faecal waste as well as anal cleansing materials,

    ii.   the flow of liquids into and out of the pit through the walls and the floor of the pit, and

    iii.   gas emissions from the degradation processes.

In general pits are allowed to fill to within 300 mm of the top and are then either physically emptied (by pumping or in the case of solid contents, digging out) or abandoned and covered over. In the latter case, a new pit is dug in close proximity to the existing pit, and the superstructure moved or rebuilt (Foxon *et. al*. 2006). The calculations for the filling rates in the pit have been described in 1.3.1.1. Foxon (2008) reports on factors that studies have shown determine the rate of filling. These studies reveal that the extent that the pit is used for the disposal of other household waste and drainage from the pit influences the filling rate. The relative quantities and distribution of the non-biodegradable material can affect the degradation processes in the pit (Foxon. 2008).

The flow of liquids in unlined or sealed pits with no lining is dependant on the permeability of the soil, the geology of the area and the level of the water table. In the case of low water

tables, soluble and suspended particulate matter would be carried by liquids through the contents of the pit and may drain away through the walls of the pit. The soil permeability would be a factor on the extent of the resultant contaminated liquid plume. The liquid level may also remain constant should the water table be high, resulting in a high mobility of nutrients into the surrounding soil environment. Liquids may also be retained in the pit should the permeability of the surrounding soils be very low or the surrounding area be rocky or have a high clay content (Foxon *et. al*., 2006) (Foxon. 2008).

Should the pits be lined and sealed the only liquid flow should be through urine. This is not always the case in reality, as liquids can also enter by users discarding wastewater into the pits (Foxon. 2008). .

1.3.3   Problems arising from the use of VIPs.

The main problems that are encountered by the community utilising VIPs are;
♦   odours,
♦   flies and the
♦   rapid accumulation of solids within the pit.

Foxon (2008) reported that flies are a problem in the areas where pit latrines abound, as they are attracted to odours resulting from decaying and fermenting substances (Foxon. 2008).

The most significant problem however remains the rapid build up of solids in the pits due to bad user habits. eThekweni Municipality, in line with its responsibility is rolling out VIDPs with urine diversion as appropriate basic on-site sanitation to poor communities. The pits as noted require emptying at some point in time. The problem of emptying the pit is solved by either emptying the pit by hand or mechanically by pump or digging another pit (van Vuuren. 2008). Urban areas are constrained by the availability of space for new pits. In addition VIPs have a permanent/immovable superstructure that does not allow any easy or simple transfer of this structure to a new pit (van Vuuren. 2008). Emptying of the pit is challenging as the construction of the superstructure according to the guidelines does not allow ease of access except through the pedestal (van Vuuren. 2008).

The challenges encountered by the municipality when emptying the pit latrines are (eThekweni. 2004):

- the distances to be travelled to the place of dumping the waste incurring an expense to the municipality,
- the awkward location of the pits to be emptied; steep terrain, overcrowding of the homes preventing easy access,
- the hazardous nature of pit emptying due to the presence of pathogens in the waste; this poses a risk of infecting the workers tasked with emptying the pits when they separate the solid non-degradable materials from the faecal waste

The provision of basic on site sanitation by municipalities has profound implications in that pits are being provided in increasing numbers to fulfil the backlog of sanitation requirement targets by 2010. These pits however will have to be emptied at some point in time (van Vuuren. 2008) (Water Research Commission. 2003). If the life of these pits can be extended there will be a concurrent address of expenses for the municipalities.

1.4   The role of pit latrine additives.

Pit latrine additives have been marketed for their ability to reduce odours, fly problems and reduce pit solids. These microbial-based additives have been marketed by the suppliers without any scientific verification of the effectiveness of their product. The problem with the lack of scientific data is that the possibility exists that optimistic expectations would cause political pressure to use particular products to alleviate problems associated with pit latrines. (Foxon. 2008)

Foxon (2008) reported that studies on septic tank additives have shown that they are either strong acids or alkalis or they are chlorinated hydrocarbons, thus they destroy or disrupt microbial activity due to their chemical nature, or they mimic normal biological decomposition without significantly enhancing the degradation. The results would not be valid to use in a pit latrine as the conditions are different in the two systems; namely the

concentrations of organics is much higher in the pit, the septic tank is a flow through system whereas the components in a pit latrine remain for a much longer period (Foxon. 2008).

1.5   Aim of the research.

Chapter 1 has presented the background to the aim of the research project. The provision of basic sanitation services to address the backlogs and gaps have resulted in problems associated with the VIPs. These problems are flies, odours, the rapid filing rate and the hazards associated with the emptying of the pits. Various pit latrine additives have been presented as a management options by entrepreneurs to address the problems without independent scientific verification of their effectiveness. The aim of this research project is to provide verification of the effectiveness of a particular additive and to develop a testing protocol and to evaluate it. In order to test the additive and develop a testing protocol; faeces, as feed to the pit, the nature of the contents of the pit, the possible actions of additives, biochemical processes, as well as degradation methods used by macrobiota in the pit needed to be understood. This is the approach that is developed in chapter two.

2. LITERATURE RESEARCH.

Properly designed, built and maintained VIP latrines are a sanitation system that meets the criteria for the National Sanitation Draft White Paper. In terms of the definition of "adequate sanitation" it is used as a "safe and easily accessible means of disposing of human excreta and waste water, providing an effective barrier against excreta-related diseases, which is used by all members of a household, and does not have an unacceptable impact on the environment". (DWAF.1995).

Faecal matter is the primary feed into the pit. It is what remains of food after it has been consumed by people and digested in the gastro intestinal tract, to extract nutrients and energy. It is thus seen fitting to briefly examine the source of faeces to understand its character. The processes that are required to degrade it further can then be anticipated. Some information on the action of probiotics is supplied to examine the action of externally introduced micro organisms on the nature of faeces. Once this is established, the general mechanisms in a pit are examined. A comparison is made with the waste in a pit and of faeces to establish what the different environments have established. The character of pit latrine additives are then summarised together with suggested mechanisms that are possibly used to enhance the degradation in the pit. Some studies on pit latrine additives are then summarised to establish further information.

2.1   The human gastrointestinal tract.

Humans digest all their food extracellularly. The approach used is to secrete digestive enzymes from specific cells lining glands in the GI tract. The enzymes hydrolyse the macromolecules of food into small soluble molecules which can be absorbed into cells (The human gastrointestinal tract. 2008). An outline of the main organs involved in the digestion of food is given in Figure 2.1. This diagram is to be referred to when the outline of the digestion of food is presented in section 2.1.1.
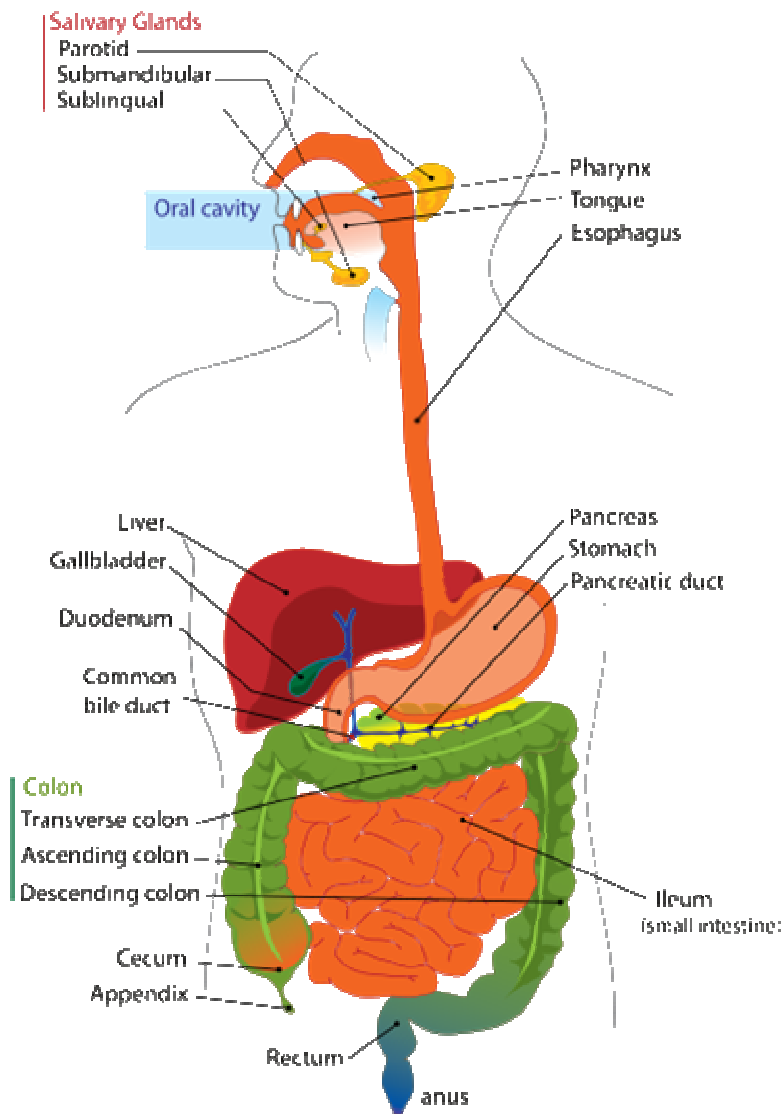
Figure 2.1: Outline of the human gastrointestinal tract. (Wikipedia. The digestive system diagram: 2008.)

2.1.1   The process of digesting food in the GI tract.

The upper GI tract consists of the mouth, pharynx, oesophagus and stomach (Wikipedia: 2008). The ingestion of the food proceeds as follows (The human gastrointestinal tract. 2008):

The mouth:

    i.   teeth ground food to finer particles,

    ii.   the food is moistened and lubricated by saliva (secreted by three pairs of salivary glands)

    iii.   small amounts of starch are digested by amylase, an enzyme, present in saliva

    iv.   the resulting bolus of food is swallowed into the oesophagus and

    v.   carried by peristalsis to the stomach.

The stomach:

Several types of cells are present in the stomach. These cells secrete hydrochloric acid, intrinsic factor, and pepsinogen. Mechanical churning of the food breaks down the big food particles and mixes the gastric juices into these small particles, thereby liquefying the food. Most micro organisms that entered the stomach are destroyed in the stomach (Villee, *et. al*. 1973). The hydrochloric acid can take the pH of the stomach contents to approximately 2 (Salminen. *et. al.* 1998). Very little absorption happens in the stomach; some water and ions are absorbed. (The human gastrointestinal tract. 2008):

The liquefied food enters the lower GI tract that consists of the intestines and the anus (Wikipedia: 2008). The intestines consist of the small intestine and the large intestine.

The small intestine:

The liver secrets bile into the small intestine. Bile consists of bile acids that are amphiphilic steroids that emulsify fats into smaller droplets for ease of digestion and absorption. Another component of bile are the bile pigments; the breakdown products of haemoglobin from old red blood cells (The human gastrointestinal tract. 2008). The pancreas secretes:

    i.   sodium bicarbonate ($NaHCO_3$). This neutralizes the acidity of the fluid arriving from the stomach raising its pH to about 8.

    ii.   pancreatic amylase. This enzyme hydrolyzes starch into a mixture of maltose and glucose.

iii. pancreatic lipase. The enzyme hydrolyzes ingested fats into a mixture of fatty acids and monoglycerides. Its action is enhanced by the detergent effect of bile.

iv. 4 "zymogens" — proteins that are precursors to active proteases. These are immediately converted into the active proteolytic enzymes:

    a. trypsin, which breaks peptide bonds.

    b. chymotrypsin breaks the peptide bonds (the same bonds as pepsin, whose action ceases when the $NaHCO_3$ raises the pH of the intestinal contents).

    c. elastase breaks the peptide bonds.

v. carboxypeptidase, which removes, one by one, the amino acids of peptides.

vi. nucleases that hydrolyze ingested nucleic acids (RNA and DNA) into their component nucleotides (The human gastrointestinal tract. 2008).

Digestion within the small intestine produces a mixture of disaccharides, peptides, fatty acids, and monoglycerides. These are finally digested in the villi that line the inner surface of the small intestine. These villi are in turn lined with microvilli (The human gastrointestinal tract. 2008). The microvilli have incorporated into their plasma membranes a number of enzymes that complete the digestion:

i. aminopeptidases producing amino acids from peptides.

ii. disaccharidases that convert disaccharides into their monosaccharide subunits.

    a. maltase hydrolyzes maltose into glucose.

    b. sucrase hydrolyzes sucrose into glucose and fructose.

    c. lactase hydrolyzes lactose into glucose and galactose (The human gastrointestinal tract. 2008).

The large intestine is described in more detail in section 2.1.2.

2.1.1.1 The human large intestine as source of faecal matter.

The function, content, transit times, regional differences and environment of the human large intestine are examined to understand the nature of the faecal matter and how it was generated, s this is the feed which enters the pit.

Cummins (1997) reports the following; the function of the human large intestine is to break down the complex carbohydrates and proteins not digested in the preceding small intestine. This is a fermentation process undertaken by bacteria that degrade large molecules that were not digested by the small intestine and to absorb water. The contents of the large intestine are biomass, epithelial cells, residual food particles, mucus, as well as carbon dioxide, nitrogen, hydrogen and methane gas. In addition acetate, propionate and butyrate are the principle anions, with a small amount of branched chain fatty acids. Lactate, phenols, sulphides and amines are also present. The principle cations present are; sodium, potassium, calcium, magnesium and ammonium, with plant sterols, and the degradation products of cholesterol and bile acids. It also provides a mechanism to dispose of waste products of digestion in an orderly manner. Mouth to anus transport for the average United Kingdom (UK) adult is on average sixty hours; four to six hours from mouth to caecum, the balance is spent in the large intestine. Transit time in Africans is much quicker; between twenty four to forty eight hours; mouth to caecum is seven to twenty four hours and the right colon, nine to thirty hour and the left colon twelve to forty four hours (refer to Figure 2.2) (Cummings. 1997). Significant regional differences in bacterial activity occur in the large intestine (Salminen. *et. al.* 1998). This is illustrated in the diagram below:

Right Side: Ascending Colon.
Carbohydrate rich
Moisture +
SCFA +
PH acidic
Residence time: 6-16hrs
Bacterial Growth +

Ileum

Left Side: Descending Colon.
Protein rich
Less free water
SCFA less
PH near neutral
Residence time: 12-36hrs
Bacterial growth slower
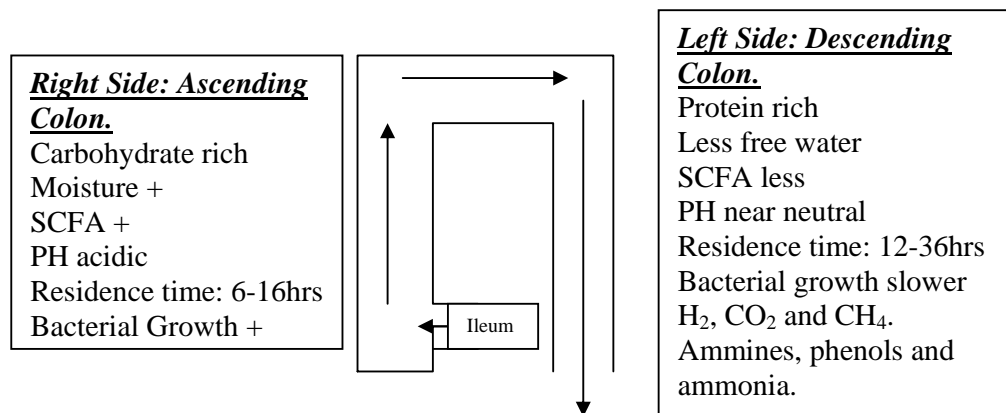H_2, CO_2 and CH_4.
Ammines, phenols and ammonia.

Figure 2.2: Diagrammatic representation of the regional differences in the bowel function of humans (Adapted from Cummings, J.H. 1997).

The environment in the human rectum (refer to Figure 2.1) is described as being anaerobic and the temperature is controlled at between 37 and 40 ^{o}C (MicrobeWiki. 2008). The bacterial population exceeds 10^{11} per gram of dry matter. Several hundred species have been identified, but some 30 to 40 species belonging to 5 or 6 genera (Bacteroids, Bifidobacterium, Eubacterium, among others, [Salminen, et. al. 1998]) account for 99% of the biomass. The profile of the micro organisms in the colon is a reflection of the fermentable substrates that reach the large intestine (Cummins, *et. al.* 1997). Undigested and partially digested carbohydrates entering the large intestine; generally the nonstarch polysaccharides, oligosaccharides and any monosaccharides escaping complete digestion in the small intestine enter the large intestine for fermentation and provide the substrate for microbial proliferation, aided by the nitrogen from the hydrolysis of the proteins entering the system (Bird, *et. al*., 2000). An overview of the fermentation products found in faecal samples is given in Figure 2.3 below.

Faecal matter is a combination of the products from the microbial fermentation of complex carbohydrates, proteins and fats, as well as the undigested complex organic matter (Cummins. 1997).

Factors such as retarded hydrolysis of physically inaccessible starch due to inadequate chewing of food, the amount of non-digestible fibre, inhibition of proteolytic enzymes and reduction of transit time, are some factors which contribute to undigested complex protein and carbohydrate matter in faeces, as well as ammonia, amines, phenols, acetate, propionate, butyrate and biomass. (Cummins. 1997) (Blackburn, *et. al.* 1981). Typical composition of faeces is given in Table 2.1 below: (Chaggu. 2003).

Table 2.1: Table showing the quantity, composition and characteristics of human faeces (Chaggu. 2003).

Approximate Quantity	Faeces
Quantity (wet) per person per day (g)	70-520
Quantity (Dry solids) per person per day (g)	30-70
Approximate Composition (% of dry weight/matter$^{\#}$)	88-97
Moisture content	66-85
Organic matter	88-97
Nitrogen (N)	5.0-7.0
NKj (gN)	1.4-2.46
Phosphorus (as P_2O_5)	3.0-5.4
PO_4-P	-
Total Phosphorus (gP)	0.69-2.5
Potassium (as K_2O)	1.0-2.5
Potassium (K)	0.80-2.1
Carbon (C)	44-55
Calcium as (CaO)	4.5
Calcium (Ca)	2.9-3.6
C/N ratio	5.0-10
COD_{total} (g/l)	46.23-78.31
$COD_{soluble}$	-
$COD_{particulate}$	-
TS (%)	33
pH	-
Protein (g)	4-12
Total lipids (g)	4-6
Polysaccharides (g)	4-10

Faecal matter is made up of the biochemical components as well as microbial matter. Faeces are received into the VIP, thus changing from one environment to another. Some pit latrine additives are also made up of microbes. The following section explores micro organisms and their ability to survive in particular environments.

2.2   Micro organisms

In ecosystems where there is a sufficient diversity of species, that species best suited to the prevailing environment will flourish often at the expense of those less able to do so (Henze, *et. al.* 2002). Various parameters determine the microbial species that survive within a particular environment, these include; growth rate, temperature, substrate quality, presence of oxygen, pH, toxic substances, nitrogen, phosphorus and environmental conditions. (Henze, *et. al.* 2002). Should environmental circumstances change, or better microbial competitors be added to the system, then the original microbial population may decline and be overcome by more competitive microbes (Henze, *et. al.* 2002) (Madigan *et.al*. 2003).

There is a typical growth cycle that cell populations go through when environmental conditions are changed. This is described in the following way by Madigan, *et.al.* (2003):

Lag phase: When a microbial population is inoculated into a fresh medium, growth usually does not begin immediately, but only after a period of time.

Exponential phase: This phase is where the organisms are growing in mass and number extremely rapidly. The rate of growth in this phase is dependent on several factors being at their optimum; temperature, genetics, substrate, etc. The growth in cell number exceeds significantly the decay of the older cells.

Stationary phase*:* This is the mature healthy stage of population growth where there is very little net change in the number of cells, however, there is growth and there is decay, which is happening at the same or similar rate. The factors that determine the level of this stage is the amount of nutrients that are available to sustain the metabolic requirements of all the cells, as well as the metabolic by-products that may be toxic to the organisms, or a combination of both effects.

Death phase*:* This is a phase that shows a net decline in growth. The factors would be similar to the stationary phase, however, the amount of nutrient is diminishing significantly, and the amount of by-product is increasing.

An example of the results of the effects of environmental influences on microbial survival is shown in a study by Cotta, *et. al.* (2003). The study describes the comparison and characteristics of bacteria from swine faeces and swine manure storage pits. Indications were that although being similar, there is a broader bacterial range present in faeces than in the storage pit. There was a dominance of particular bacterial species in the storage pit, whereas there was a much broader representation of species in faeces (Cotta, *et. al.* 2003). Foxon, *et. al.* (2006) proposed conceptual methods that may influence the degradation rates in the pit. These are to increase the:

i. number of micro organisms. Since the rate of degradation of substrate depends on the concentration of micro organisms, a reasonable assumption to make would be to increase the number of appropriate micro organisms to increase the degradation rate.

ii. number of specific micro organism groups. Following on from the reasoning given above; the numbers of specific types of micro organism could be increased to effect an improvement in degradation rates.

iii. specific hydrolytic enzymes, to increase the rate of hydrolysis and thus making available smaller molecules for microbial degradation.

The physical processes occurring in a VIP was outlined in section 1.3.2. A summary of the present knowledge of the processes in pit latrines was reported by Foxon (2008). This summary of microbial requirements to survive in particular environments requires a study of the two broad processes that occur in the systems that are being examined; the human GI tract which produces faeces as waste which is fed into the pit and the VIP itself.

2.3   The general theory of processes occurring in the pit.

Foxon (2008) reports that faeces that arrive in the pit contain up to 30% by mass on a dry faeces basis of active micro organisms. The other material has been described in the preceding sections. The structure, typical sizes, filling rates, etc. of a VIP is described in section 1.3.1. The nature of the faecal matter that is received into the pit contains viable micro organisms with biodegradable matter. The environment in the pit needs to be understood to determine what degradation processes are occurring. A diagram illustrating the different theoretical layers is presented in Figure 2.3. The theory is now challenging the

original concept of the pit latrine being an anaerobic digester. Layers (i) and (ii) are aerobic and thus the easily degradable material in (i) is rapidly consumed. Layer (ii) has material that is degradable, and is limited only by the rate of aerobic hydrolysis of complex molecules. Layer (iii) is an anaerobic layer, where oxygen has been consumed by the microbial activity in the layers above, and the material is partially degraded anaerobically. The final layer (iv) is stabilised and the conditions are anaerobic (Foxon. 2008).

Foxon (2008) reports further that the principle component in layer (iv) consists of dead micro organisms and their respective cell matter from the original faecal matter, or from the micro organisms that have become inactive or have died in the course of time. These proposals are theoretical as they have not been scientifically verified, but have been suggested by results obtained in various projects. Thus, anaerobic and aerobic processes will be summarised in the sections that follow (Foxon. 2008).

The anaerobic processes that are described in the human GI tract also follow the same principles (Bird, et. al. 2000) (Cummins. 1998).
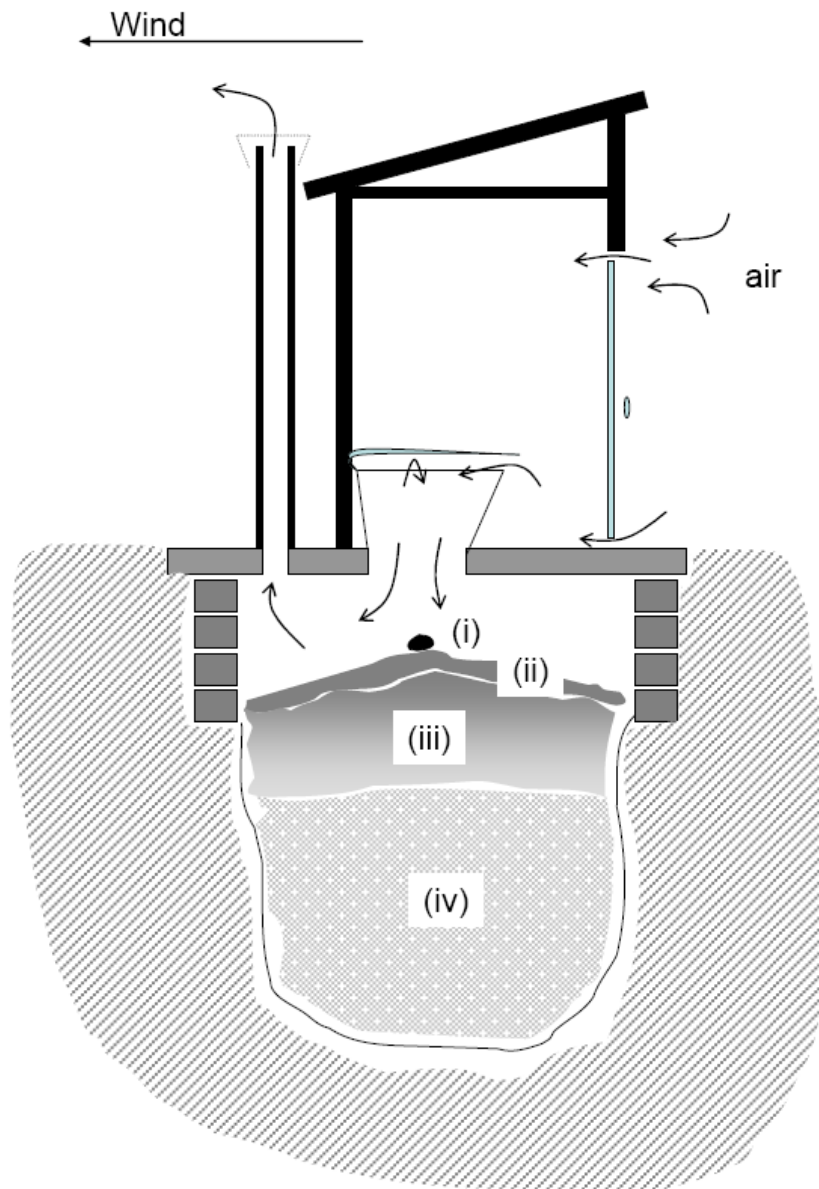
Figure 2.3: Theoretical layers of a VIP: (i) fresh faecal matter, (ii) partially degraded aerobic surface layer, (iii) partially degraded anaerobic layer beneath surface, (iv) completely stabilised anaerobic layer.

2.2.1 Anaerobic processes.

The mechanism of degradation in the pit is given in section 2.2. Anaerobic degradation is one of the processes that occur in the deeper layers of the pit (Chaggu. 2004) (Foxon. 2008). Anaerobic digestion is described simply as macromolecules degraded in the absence of oxygen to the final products of methane and carbon dioxide along a series of complex chemical interactions between different microbial species (Batstone, *et. al.* 2002). Batstone *et. al.* (2002) have developed a generalised anaerobic digestion model that describes the multiple steps of the biochemical as well as the physicochemical processes (Batstone, *et. al.* 2002). These processes are summarised in Figure 2.4.

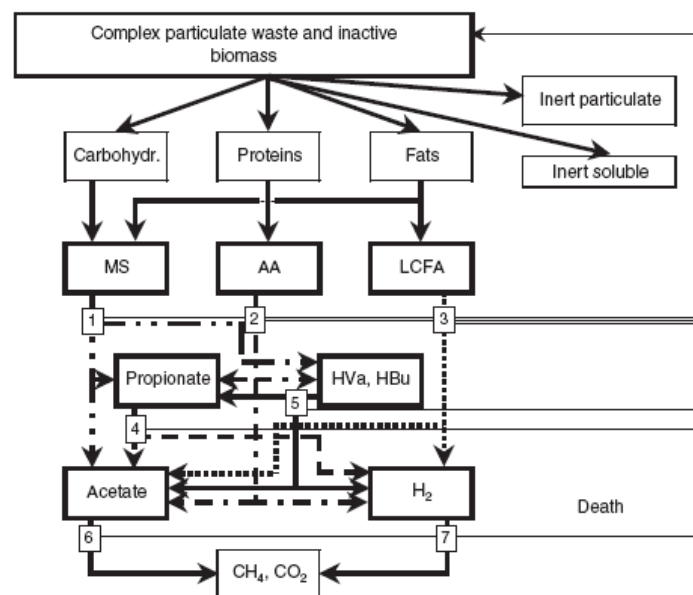**Figure 2.4:** The anaerobic model as implemented including biochemical processes: (1) acidogenesis from sugars, (2) acidogenesis from amino acids, (3) acetogenesis from LCFA, (4) acetogenesis from propionate, (5) acetogenesis from butyrate and valerate, (6) aceticlastic methanogenesis, and (7) hydrogenotrophic methanogenesis. (Batstone, *et.al.* 2002)

A brief overview of the various stages of anaerobic digestion is given as follows.

i. Particulate degradation: Complex particulates and dissolved biopolymers in waste are first degraded to carbohydrate, protein and lipid as well as particulate and soluble inert material. It includes lysis and non-enzymic decay (Batstone, *et. al.* 2002).

ii. Hydrolysis: Microbes cannot take up particulate matter directly, so, as the first step, enzymes produced by specific bacteria hydrolyse particulate matter to produce smaller soluble molecules that are directly degradable molecules. There may be degradation of both particulate and dissolved solids. The hydrolysis processes are normally slow compared to the biological growth processes. Hence, in term of rates of reaction, hydrolysis will often be the rate-limiting step. Products expected at the first step would be; amino acids, fatty acids and simpler carbohydrates (Henze, *et. al.* 2002).

iii. Acidogenesis: Another set of microbes use the soluble products of hydrolysis for further degradation. Volatile fatty acids (acetate, propionate, and butyrate) (VFA) and carbon dioxide, hydrogen and ammonia are among the end-products of acidogenesis (Henze, *et. al.* 2002).

iv. Acetogenesis: The organic acids from acidogenesis are converted to hydrogen, carbon dioxide and acetate (Henze, *et. al.* 2002).

v. Methanogenesis: Acetate is the substrate used by acetoclastic bacteria to produce methane and carbon dioxide, and methanogenic bacteria utilise hydrogen and carbon dioxide as substrate to produce methane (Henze, *et. al.* 2002).

2.2.2   The aerobic process.

Aerobic digestion occurs at upper layers of the pit contents (Foxon. 2008). Aerobic respiration described by Madigan, *et. al.* (2003) uses oxygen as an electron carrier to oxidize organic molecules to produce carbon dioxide and water.

 Henze, *et. al.* (2002) describes the aerobic processes in a waste water treatment plant where organic molecules can be exposed to the following:

- Oxidation to carbon dioxide and different nutrients.
- Assimilation in biomass (sludge). Typically, for aerobic growth of microbial biomass, the maximum amount of organic material that is converted to new biomass is around 50% on a chemical oxygen demand (COD) basis.
- Unchanged passage, which means that the matter is biologically non degradable = inert (in the time frame of the plant).
- Conversion into other organic matter.

A simplified summary of aerobic degradation is given as:

Organic degradable matter $\rightarrow$ CO_2 + H_2O + biomass,

2.4 Previous studies conducted on additives.

An investigation was conducted by the CSIR to investigate the activity of several additives. The objective of the study was to (i) do a market survey on what products were available at the time of the study, and (ii) to compare the efficacy of the products and their mode of action in terms of their waste reduction and odour control. The products were evaluated at a small laboratory scale, and the two best performing products rated according to certain criteria were rated in the field (Taljaart, *et. al*. 2005).

The methodology used for the market survey was to obtain information on different biological products from municipalities, enzyme companies and private traders. This was done over the telephone, email and by doing internet searches. The products were evaluated by their mode of action, product specification, dosage and price (Taljaart, *et. al*. 2005).
.
One kilogram of each type of additive was obtained for the laboratory trails (twelve products), and five kilograms of selected products were obtained of specific additives to conduct field trials. The actual dosages were not easily available due to the lack of records kept by the suppliers to pit latrine users, the uncertainty of the number of users of each pit and the variation in pit size. The dosages were based on adapted septic tank dosage rates. The estimated annual cost per pit latrine varied between R13.86 to R3180 (Taljaart, *et. al*. 2005).

The types of additive obtained contained microbes and enzymes. The exact constituents of the particular additives could not be ascertained as the information was confidential and would not be revealed by the suppliers.

The efficiency of these products was tested in the laboratory to select the "top performing" products for field trials. The dosage protocol as recommended by the supplier was calculated to the laboratory scale. The treatment time in the laboratory was five days under aerobic conditions. The faeces stock tested was supplied by one person for all the experiments. Oxygen consumption, carbon dioxide production and removal of ammonia, total kjeldahl nitrogen (TKN), chemical oxygen demand (COD), total suspended solids (TSS) and volatile suspended solids (VSS) were monitored for the duration of the laboratory trials. Once the results had been assessed in terms of the best results for reduction of the variable measured, two of the most suitable products were selected (Taljaart, *et. al*. 2005).

The site chosen was in Hekpoort, on a rose farm in the District of Magaliesburg, for practical reasons. Latrine buildings were built to service two hundred to two hundred and fifty people. The buildings were arranged in four blocks, each block contained three individual pits. Three blocks were selected for field trials, one block of three for the control, and the other two blocks of three pits for the two pit additives selected for testing. The pits selected to conduct the field trials were not used by the community during the three months of testing. Prior to the start of the experiments, the pits were not used often due to their physical state, the presence of flies as well as odour. During the trials, the pits were not to be used, or to be kept to a minimum. The constraints reported on the field trails were the compactness of the waste; the amount of non degradable foreign materials in the pit, as well as the low temperatures (8 – 10 ^{o}C) possibly slowed the activity of the additives considerably. (Taljaart, *et. al*. 2005).

The field trial results did show that there were positive results obtained from one of the additives added to the pit. At the end of the three month test period, there was a small drop in level (160 mm, average of 3 test pits) of the solid waste in the pit with the better performing additive added, compared to only 60 mm (average of 3 test pits) in the second test pit with another brand of additive added. There was no drop in level in the control pit which had no additive added. Observations made at the end of the experimental period showed that the

bulk of the solids were looser and softer, with signs of liquefaction from the better performing pit (Taljaart, *et. al.* 2005).

The experimental observations were noted as information to be used in this research project. The points noted from the trials were that:

i. The faecal samples were collected sometimes weeks apart. This was a possible cause for the laboratory results from the degradation processes to vary because of the differences in faecal samples and differences time, rather than the actual differences in additive activity,

ii. The time taken to test the samples was only five days, whereas, there may have been a change in activity subsequent to this time as reported in Section 2.2

iii. After the preliminary tests were conducted in the laboratory, the number of additives should have been reduced to increase the attention to the more effective additives. This would have included the time frames for obtaining faecal stock and for the laboratory analyses.

iv. There is a possibility that pit latrine additives do have some effect on the degradation of the waste in the pit.

v. This was one of the experiments that was available at the time of researching scientifically verifiable experiments done on pit latrine additives (early 2006).

Saaka, (2007) reports from the research conducted on all known publications and analysing the content available on experiments conducted on bio augmentation of conventional waste treatment works. This was compared with pit latrine performance. His conclusion was that bio augmentation is possible in pit latrines.

Couderc, *et. al.* (2008) report on tests conducted on the effect of moisture content and alkalinity on the anaerobic digestion activity on VIP waste. Using modified serum bottle tests with VIP waste collected from the top layer of a VIP, significant amounts of gas were produced with the addition of moisture and alkalinity. The results from this set of experiments support the hypothesis that moisture content and the pH buffering capacity obtained in VIP material is low and may be limiting factors in the rate of stabilisation of the

pit contents. The implication is that by increasing the moisture content and the alkalinity may increase the stabilisation rate when the contents are not fully stabilised.

2.5.3   Summary of chapter 2.

Chapter 2 examines the human GI tract the processes in the breakdown of foods to extract nutrients and energy for the body and to produce waste from this process. The waste; faeces is the fed into the pit. Faeces consists of microbes, thus microbes are briefly examined to understand their environmental requirements in order to flourish. The general theory of biochemical processes in the pit is examined briefly. The principles in anaerobic degradation are common to waste degradation in waste water treatment works, the waste from VIPs as well as the large intestine in the human GI tract. Then previous studies on the effectiveness of bio augmentation of VIPs and conventional waste are examined to determine whether there is potential in the use of microbial additives.

The information obtained in this chapter allows a formulation of the hypothesis and the objectives of the research work that follows in Chapter 3.

3.   PROJECT HYPOTHESIS AND OBJECTIVES

The problem presented in 1.3.2 above outlines the problems faced by municipalities and communities in terms of filling rates and the emptying the VIPs. Suppliers of additives are marketing their products for their ability to reduce the pit contents, odours and flies.

This study was undertaken to determine the effectiveness of a particular pit latrine additive to examine its activity on VIP waste. A specific additive, M, was selected for testing as it is being used with alleged success locally as well as internationally. Specific information relating to the composition of M would not be revealed by the suppliers, however, brochures and material safety data sheets (MSDS) that are supplied (refer to appendix 3 for all information), state that M is made up of a "mixture of enzymes, single celled aerobic natural hydrocarbon oxidizing microbes concentrated onto a dry inert clay base" (refer to section 4.2.2).

It is acknowledged that there would be differences in the activity of different additives available on the market. M, which is one of these, has characteristics represented in three broad categories of VIP additives in the market (Foxon, *et.al.* 2006):

    i.   Additives containing aerobic micro organisms, possibly with nutrients to ensure reactivation of micro organisms during preparation prior to application.

    ii.   Additives containing both aerobic and anaerobic micro organisms, possibly with nutrients.

    iii.   Additives containing enzymes, sometimes in conjunction with micro organisms for rapid solublisation of particulate substrate.

The objective set in this project was to obtain scientifically verifiable information to determine whether M as representative of a type of additive, reduces the volume and mass of waste in the pits. Should the outcome of the work be positive, then the information is to be used for further study to develop the concept of bio augmentation in pit latrines.

The hypothesis proposed is that the addition of the particular additive M to the VIP contents will cause the enhanced reduction of organic matter. A laboratory based experimental procedure was developed to test this hypothesis. A reactor vessel waste with an additive solution added weekly was compared with references reactor vessels without additive added; no additions, and water additions of different volume and frequency. The proposed mechanism for this would be:

i. the solids can be suspended or solubilised and exit the pit with any water that leaches from the pit, and/or

ii. the solids leave the pit as carbon dioxide and water.

The method developed for testing the hypothesis is described in Chapter 4.

4. MATERIALS AND METHODS.

The project had been designed to test the effectiveness of bio augmented degradation of VIP waste. Table 2.1 contains information on the quantity, composition and characteristics of faeces. There is 88 - 97 percentage of organic matter relative to the dry mass of the waste. This is the material that has the potential to be degraded. It is made up of soluble and particulate matter (Henze, *et. al*. 2002). Microbes can only metabolise soluble organic matter. Enzymic hydrolysis reduces particulate organic matter to smaller particulates and to soluble degradable matter. Thus the additive M is expected to:

i. reduce total organics by hydrolysis of the particulates and to
ii. degrade and thus reduce soluble organics.

4.1 Materials

VIP waste and the additives were contained in reactor vessels. These are the materials and equipment used in this experiment. These are described in the sections that follow.

4.1.1 VIP waste.

Magagna (2006) described the geology of the Pinetown area as mostly Natal Sand that is commonly highly porous to water. No water table information could be found. The climate in the eThekwini Metro is described as described as "mild" with temperatures ranging from $16 – 25 \ ^{o}C$ during the winter months of June, July and August. The summer temperatures can reach $32 \ ^{o}C$ with high levels of humidity. The rainfall in this area can vary between $58 – 125$ mm per month in summer and $34 – 44$ mm per month in the winter months. This time of the year is dry with moderate. (eThekwini. 2008)

The VIP waste was collected at Marianhill Ridge in Pinetown outside of Durban in August 2008. I drew up a questionnaire to ascertain whether the householder had added any toxins (bleach, disinfectant, sheep dip, etc.) to the pit recently, to establish the age of the pit and the size of the household. The information was important as the activity of the additive M, being microbial in nature would have been adversely affected by any residual toxins. The other

information gave some indication on the management of the latrine. The responses to the questionnaire was the indicator used for choosing suitable VIPs to draw samples from for testing; VIPs that had any toxic additives added less than 10 days prior to sampling were excluded, as these additives would affect the experimental results. The questions posed in the questionnaire are given in Appendix 2.

Two pit latrines were chosen because toxins were added lore than 10 days prior to the samples being collected. There were 5 and 6 members in the household respectively. Each VIP had been in use since 1992. Both households do put chemical toxins in about twice a month to stop the smell. The smell returns after approximately 4 – 5 days. They had added the chemicals in approximately 3 weeks prior to the date of sampling.

 50 litres of waste sample was collected from each of the two suitable VIPs. They were taken from a layer no greater than the upper 150 mm of the pit with a spade. The waste was stored in 2 x 50 litre plastic containers with sealable lids to prevent any spillage or sample contamination. The sealed containers were kept in a cold room for the duration of the experiments at a temperature of approximately 10 ^{o}C. Samples were taken on 21st August 2006, and the experiments started on 28th October 2006. The experiment was completed on the 9th December 2006 completing 6 weeks of experimental work. The time frame was only half of that conducted by Taljaart *et. al.* (2005), but the time allocated to these tests was deemed enough to have some measurable differences in activity.

4.1.2   Nature of additive used in the test.

The additive M chosen for testing in this project is being used widely with alleged success both locally and internationally. The exact microbial characteristics of the additive could not be ascertained as the vendor was reluctant to give specific information on the quantitative and qualitative nature of the mix. It is a mix of aerobic microbes and enzymes mixed in a clay base. The advertised information given by the vendor to clients is given in Appendix 5.

4.1.3   Reactor vessels

Reactor vessels were used to represent the pit in this project. A "bag" was used to contain the waste within each reactor vessel. The following figures give the diagrammatic representation and photographs of the reactor vessels and the inner bags used for the experiments.
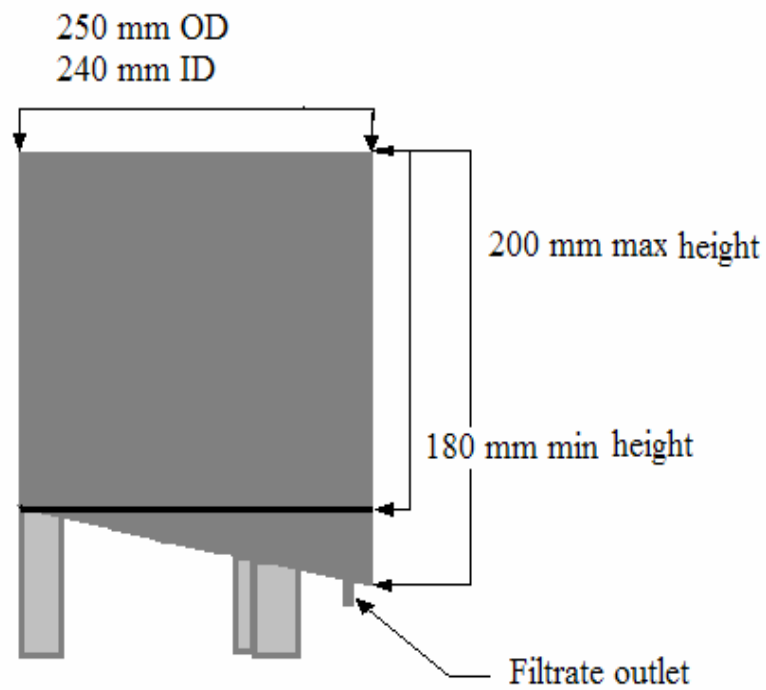

Figure: 4.1:   Schematic of the reactor vessel. Side View

Figure 4.2:   Photo of the base of the reactor vessels during the experiment.

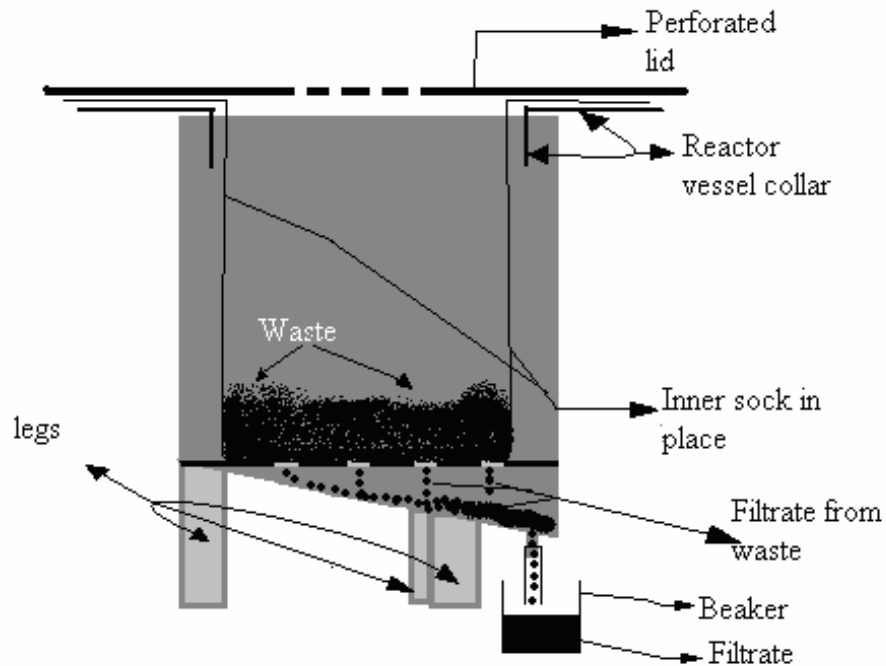**Figure 4.3**:   Photo of the inner bag. Oblique view.

Figure 4.4: Schematic diagram showing the basic set-up of the experiment.

4.1.3.1.1 Description of reactor vessels.

(Refer to the Figures 4.1, 4.2 and 4.4)

A standard pipe section, 250 mm outer diameter (OD) and 240 mm inner diameter (ID) polyvinyl chloride (PVC) was used to form the outer core of the reactor vessels. The base was sloped with a minimum distance of 180 mm and a maximum distance of 200 mm from the top of the pipe. A flat PVC plate was cut to shape and welded onto the bottom forming the outside sloped base plate. This ensured a sloped bottom to direct the filtrate to an outlet. The outlet pipe (approximately 10 mm OD and 8 mm ID) was welded into the base plate at the lowest extremity of the sloped base plate.

A horizontal perforated base plate was welded to the inside of the reactor vessel 180 mm from the top of the pipe. The base plate supported the synthetic cloth bag that contained the VIP waste. A separate collar was built to support the bag over which the excess fabric from

the bag could be folded. The bag had a loose fit so that it could be removed easily. The collar had an inner sleeve to give additional support to the bag.

A PVC lid was placed on top of the vessel to keep the system to prevent any external matter from falling into the reactor vessel. 12 x 100 mm holes were drilled into the lid to allow some air into the system, as would be the case in a pit, where the pedestal would have a gap in the concrete slab for the waste to enter the pit from the pedestal (refer to Figure 1.1).

4.1.3.1.2   Description of the bags for the degradation tests.

(Refer to Figure 4.3 and 4.4)

The degradation experiments required bags to contain the solid waste and allow the filtrate to escape from the reactor vessels. These were made from 100% polyester with a 2 in 1 Panama weave, and a mass per unit area of 0.340 kg.m^{-2}.

The diameter of the base of the bag was 210 mm leaving a gap of 10 mm between the wall of the reactor vessel and the sock. The sock was sewn with a 10 mm double lining at the seams for strength and to prevent leakage of any solids. The height of the inner bag was 230 mm to allow for structural strength when the edge was folded over the collar.

4.2   Method used for the degradation trials

The reactor vessels, bags, collars and lids were each numbered and weighed on a 20 Kg Mettler balance. The waste that was collected from household VIPs was stored in the cold room. Prior to weighing the waste in the reactor vessels, it was cleared of as much non biodegradable matter as possible. An appropriate amount of waste (500 g – 900 g) was then transferred into the bag in the reactor vessel and the combined masses were then weighed. The waste was not evenly distributed in the bag, so a 100 ml beaker was used to level the surface as evenly as possible. This was possible without affecting the permeability of the waste as a whole because about 75 – 85 % (mass moisture/mass waste) was moisture, which is incompressible.

The ratio of the surface area of the base of the "bag" to the surface area of the base of the square pit was calculated (refer to section 4.3.1). For convenience, the dimension of a square pit with sides of 1 m width and length was used for calculations. This is a size and shape used in latrines (Mara. 2006). This ratio was used to calculate the proportion of the additive M added to the reactor vessels. The reactor vessel with M added weekly was used as the test vessel. The other reactor vessel with additive added as a once off was used as a reference vessel, as this would be used to determine what activity would be measured due to the residual micro organisms without further addition over the 6 weeks. This reactor vessel was one of 5 reference vessels that were used to compare against the activity of the test vessel. The reactor vessel experimental set up is described in Section 4.3.2.

4.2.1 Calculations to determine dosage of M to the reactor vessels (T1 and T2):

The supplier's recommended dosage to the pit is:

	Pit	Surface area ratio. (bag:pit)	Reactor vessel
First shock dose of additive	100g	$\dfrac{\Pi \times (0.105)^2}{1m^2}$ $= 0.035$	3.5g
Weekly maintenance dosage	20g		0.7 g
Volume of water	20 L		700 mL

4.2.2 Reactor vessels experimental configuration and testing protocol.

- **Dry Reference (DR):**
  Dry reference: No additions made to the reactor vessel. Very little or no filtrate expected. Any reductions expected would be due to evaporation and some gas losses due to microbial activity.

- **Water additions:**
  All reductions in the variables measured expected to be from leaching out of fine

particulates, soluble (organic and inorganic) matter and gaseous emissions. These tests were set to measure the loss of matter (organic and inorganic), by adding different volumes of water, and varying the frequency of water additions to determine whether water additions alone would contribute to solids reduction.

o **Wet Reference 1 (WR1):**   Maximum volume of water possible that could be added to the reactor vessel; 5 L once a week.

o **Wet Reference 2 (WR2):**   700 mL, daily addition.

o **Wet Reference 3 (WR3):**   70 mL, daily addition.

- **M additive vessel:**   Reductions of organic matter are expected to be greater than those of the water additions.

o **Test 1 (T1):**   An initial *shock* dose of 3.5g M followed by a weekly maintenance dose of 0.7 g additive mixed with 700 mL water per week.

o **Test 2 (T2):**   A single once-off shock dose 3.5 g additive in 700 mL water.

The tests were run for 42 d (6 weeks).

4.2.3 Sampling for laboratory analysis.

One small sample of waste solids (approximately 4 g; 1 g for COD, 1 g for each triplicate test for the other analyses) was collected at the end of each week (7 days) and stored in a clean glass vial in the cold room for analysis. Samples were taken from the same area on the surface of the waste, midway between the centre and edge of the bag each week. The samples were also taken slightly below (about 0.5 – 1 mm) the surface of the waste as the test reactor vessel would have had a small layer of inert clay on the surface. This was to ensure uniformity in sample, should there have been any migration of matter to the edge of the bags during the experiments. Thus any changes detected would be from changes in the quality of the waste rather than the changes due to the location of the sample area.

4.2.4 Analyses.

Samples were taken once a week prior to making the new additions for the week. Only one sample was taken from each reactor vessel every week. This single sample was split in two; one sample was used for COD analysis and the other for moisture, TS, VS Ash and COD content. These analyses were done in triplicate. The moisture, TS, VS and ash were all done on the same sample.

4.2.4.1   Laboratory tests methods

Analysis	ASTM reference (APHA.1998)
Total Solids (TS)– soluble and total,	2540-B. Page 2-55
Volatile Solids (VS)	2540-E. Page 2-58
Ash	2540-G. Page 2-59
Moisture	By Difference. Waste sample -TS
COD – Total, (Closed reflux method)	5220 D. Page 5-17
Mass of the reactor vessels.	None

COD was one of the measurements used to determine solids reduction. There are two analytical methods for determining COD; these are the closed reflux method and the open reflux method. The closed reflux colorimetric method was chosen for determining COD because; (i) only small sample sizes were used and (ii) the resources available to analyse all the samples using the open reflux method simultaneously were limited. The limitation to using small sample sizes was that it was not necessarily representative of the total waste in the reactor vessel.

4.2.4.2   Laboratory sample preparation for COD analysis

Waste samples used for COD analysis of about 1g were accurately weighed and then transferred into a conical flask. After appropriate sample preparation by dilution and blending, it was found that analytical results were differing widely. One possible reason for this was that the solid sample was not adequately dispersed in the water. It was then found to be necessary to disperse the mixture vigorously and simultaneously flushing with nitrogen gas to ensure an inert atmosphere to avoid any possibility of further degradation of the solids. This method of sample preparation gave more reproducible results.

Due to the nature of the waste and the time needed to establish the COD sample preparation method and dilutions needed for the colorimetric closed reflux method, only one point want recorded for the week 0 samples. This was used as a common point at week 0 for all the reactor vessels.

4.3   Data processing

The following section describes the calculations required to present analytical results for discussion.

4.3.2   Raw data processing and presentation.

i.   All the raw analytical data of each variable were calculated as a percentage (g variable/100 g wet sample). Refer to Appendix 3 for all the worksheets.

ii. Results were presented in tables of the percentage of the variable and time. The standard deviation of each point was included. Refer to the Appendix 4 for all the tables, the analysis of variances (ANOVA) statistical results and the standard deviations of each data point.

iii. Graphs were drawn (% of the variable against time in weeks) of all the reactor vessel results to visually compare the variables over time. The graphs also served to illustrate the quality of the results in terms of whether trends were apparent over time. Standard deviation error bars were also included.

iv. The comparison of each variable was then done in the following way:

a. between the different reactor vessels over the same time. The objective was to test for any significant differences between each reactor vessel over the same time using ANOVA as a tool, and

b. within each reactor vessel using ANOVA result for the full duration of the experiment (6 weeks). The arithmetic differences were also calculated to determine the extent of the differences within each reactor vessel between the start and sixth week (Wk0 – Wk6) as well as between the start and the fifth week (Wk0 – Wk5) to assert the results.

v. The differences in the variables were presented in Table 6.1, and Table 6.2. The greatest and smallest differences were highlighted. The differences between week 0 and weeks 5 and 6 were presented to determine whether the results presented would be consistent.

vi. The differences between the results of the earlier weeks were also calculated and are presented in the worksheets in Appendix 4.

5. RESULTS

Note: Refer to Appendix 4 for the full set of the waste results from which the following Tables are presented.

All t-test comparisons were conducted against T1, the test reactor vessel.

Comments will be provided after the results of each variable are presented.

The sample taken from each reactor vessel was only analysed once at the start of the experiment for the following analyses; TS, Moisture, VS and Ash. This was because the pit latrine waste stored in plastic containers was used in all the reactor vessels, thus the results from each reactor vessel served as the replicate for each of the variables at the start of the experiment. Thereafter, every sample from each reactor vessel was tested in triplicate.

5.1   Total mass of waste

Table 5.1: Table showing the total mass of the contents in the reactor vessels.

| Frequency of additions	No additions	Weekly additions	Daily additions	Daily additions	Weekly additions	Once off addition.
Vessel No.	**DR** – No additions	**WR1**- 5 L water	**WR2** – 700 ml water	**WR3** – 70 ml water	**T1** – additive + 700 ml water	**T2** – additive shock dose + 700 ml water
Wk 0	922.70	892.70	839.90	574.00	794.00	900.40
2	752.60	702.90	886.80	547.40	738.70	757.30
4	671.60	758.90	869.80	539.40	625.70	682.30
5	609.60	721.90	832.80	535.40	591.70	631.30
Wk 6	537.60	660.90	852.80	524.40	587.70	565.30
Diff = (wk0-wk6)	**385.10**	**231.80**	**-12.90**	**49.60**	**206.30**	**335.10**
%Diff = **%(Diff/Wk 0)**	**41.74**	**25.97**	**-1.54**	**8.64**	**25.98**	**37.22**
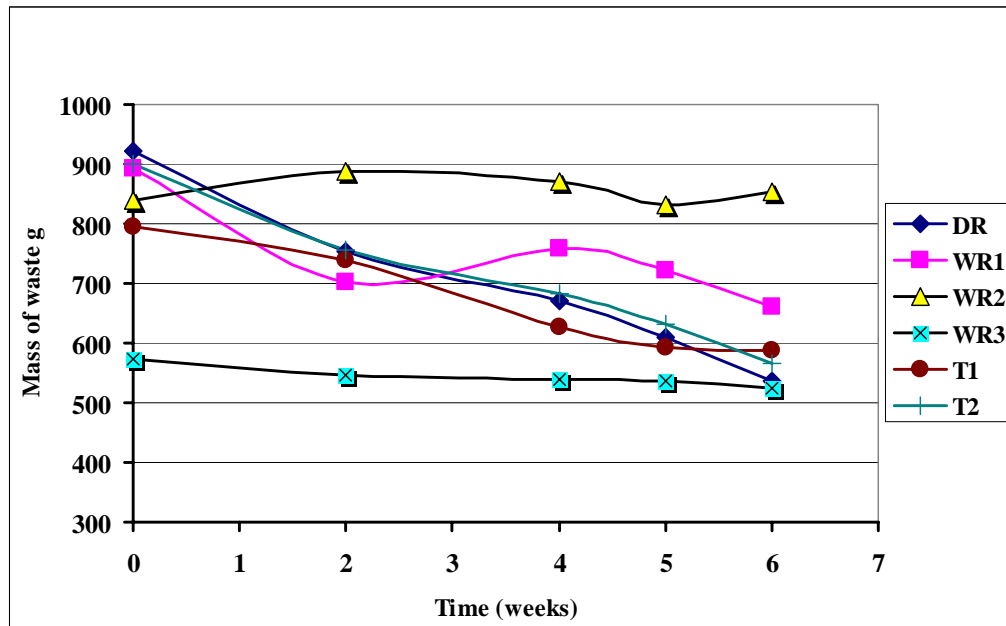
Figure 5.1: Graph showing total mass of the contents in the reactor vessel.

The results obtained are illustrated in Figure 5.1.

The difference shown between the reference vessels (DR, WR1, WR2, WR3 and T2) and the test reactor vessel (T1) were with the two wet reference reactors that had water added daily (WR2 and WR3).

The following reactor vessels showed similar results:

i.   weekly liquid additions: test reactor vessel 1 (TR1) and the wet reference reactor vessel 1 (WR1)

ii. daily water additions: wet reference reactor vessel 2 (WR2) wet reference 3 (WR3). These also showed little change in mass.

iii. no addition: the dry reference reactor vessel (DR) and the once off M addition, (TR2).

These results appear to indicate that M was not a factor in the mass loss of the contents of the reactor vessels.

5.2   Moisture:

Table 5.2: Table showing moisture of the contents in the reactor vessel.

% Total Moisture (g Moisture/100 g wet waste)

Numbers in italics are standard deviations for the triplicate results

| Vessel no.	No additions	Weekly additions	Daily additions	Daily additions	Weekly additions	Once off addition.
	DR – No additions	**WR1**- 5 L water	**WR2** – 700 ml water	**WR3** – 70 ml water	**T1** – additive + 700 ml water	**T2** – additive shock dose + 700 ml water
Wk0	85.07 *1.86*	82.08 *1.86*	82.71 *1.86*	80.28 *1.86*	85.00 *1.86*	82.04 *1.86*
2	80.12 *0.55*	84.32 *1.01*	84.88 *0.31*	77.77 *0.84*	86.70 *0.85*	85.41 *0.19*
3	78.16 *1.27*	82.45 *0.22*	76.27 *12.12*	80.38 *1.24*	83.94 *0.88*	84.08 *1.32*
5	82.80 *1.30*	84.76 *1.31*	87.36 *0.73*	85.26 *0.76*	82.04 *0.94*	81.82 *2.87*
Wk6	79.51 *2.71*	80.99 *3.09*	86.25 *0.02*	81.72 *1.04*	83.19 *0.51*	83.87 *0.90*
Diff =Wk0-Wk6	**5.56**	**1.08**	**-3.54**	**-1.43**	**1.81**	**-1.83**
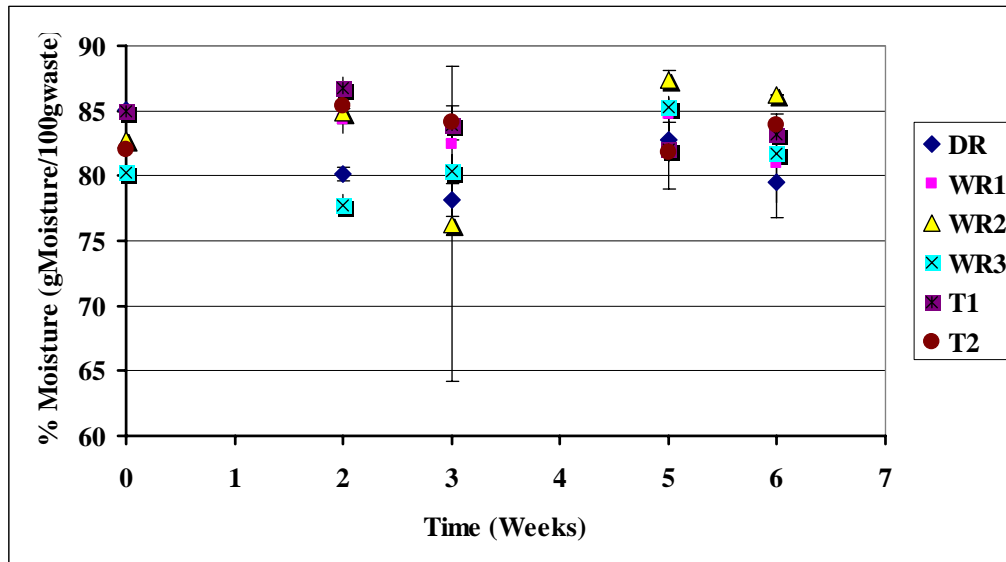
Figure 5.2: Graph showing moisture of the contents in the reactor vessels.

The results show some spread at the same points in time between reactor vessels, namely WR2 and WR3. (Variance = 12 and 10 units respectively. The others showed variances of between 3 and 6). There is also scatter within some reactor vessels over time, particularly DR, WR2 and WR3. (Variances: 8, 19 and 7 respectively. The others only gave variances between 2 and 3). ANOVA (single factor) statistical analysis (refer to Appendix 4) also reveals that there is no significant difference in the results both within and between each reactor vessel.

The results of the arithmetic differences within the reactor vessels for the duration of the experiment show only small differences (see Table 5-2), Thus, the moisture levels remained at a similar proportion throughout the experiment.

5.3   Total solids results.

Table 5.4: Table showing the total solids of the contents in the reactor vessel.

% Total solids (gTS/100g wet waste)

Numbers in italics are standard deviations for the triplicate results

|	No additions	Weekly additions	Daily additions	Daily additions	Weekly additions	Once off addition.
Vessel no.	**DR** – No additions	**WR1**- 5 L water	**WR2** – 700 ml water	**WR3** – 70 ml water	**T1** – additive + 700 ml water	**T2** – additive shock dose + 700 ml water
Wk0	14.93 *1.86*	17.92 *1.86*	17.29 *1.86*	19.72 *1.86*	15.00 *1.86*	17.96 *1.86*
2	19.88 *0.55*	15.68 *1.01*	15.12 *0.31*	22.23 *0.84*	13.30 *0.85*	14.59 *0.19*
3	21.84 *1.27*	17.55 *0.22*	23.73 *12.12*	19.62 *1.24*	16.06 *0.88*	15.93 *1.32*
5	17.20 *1.30*	15.24 *1.31*	12.64 *0.73*	14.74 *0.76*	17.96 *0.94*	18.18 *2.87*
Wk6	20.49 *2.71*	19.01 *3.09*	13.75 *0.02*	18.28 *1.04*	16.81 *0.51*	16.13 *0.90*
Diff Wk0-Wk6	-5.56	-1.08	3.54	1.43	-1.81	1.83
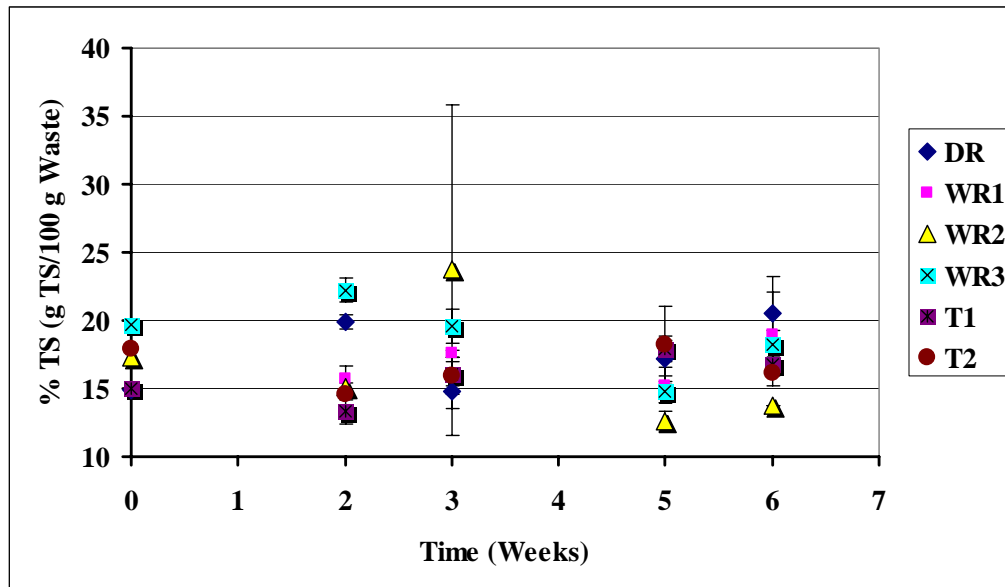
Figure 5.4: Graph showing total solids of the contents of the reactor vessels.

ANOVA (single variable) results for percentage TS indicate with 95% certainty that there is no significant difference **within** and **between** each reactor vessel over time (refer to Appendix 4). Variances for DR, WR2 and WR3 are: 7, 19 and 7 respectively for results within the vessels that indicate scatter. Variances of 12 and 10 were obtained for weeks 2 and 3 between the reactor vessels. The arithmetic differences in the percentage of total solids given in table 5-4 show that there was very little difference in percentage total solids except for

    i.   WR2, where there was a decrease in %TS, and
    ii. DR, where there was an increase of %TS.

However, the differences are small and as can be seen in the variances are not precise.
Week three results for WR3 gave a very big standard deviation for the triplicate result.

5.4 Volatile solids results

Table 5.5: Table showing volatile solids of the contents of the reactor vessels.

% Volatile Solids (gVS/100gwaste)

Numbers in italics are standard deviations for the triplicate results

| Vessel no.	No additions	Weekly additions	Daily additions	Daily additions	Weekly additions	Once off addition.
	DR – No additions	**WR1**- 5 L water	**WR2** – 700 ml water	**WR3** – 70 ml water	**T1** – additive + 700 ml water	**T2** – additive shock dose + 700 ml water
0	4.16 *1.62*	5.41 *1.62*	4.25 *1.62*	7.59 *1.62*	3.50 *1.62*	6.81 *1.62*
2	6.76 *0.53*	4.25 *0.46*	4.71 *0.93*	8.61 *0.80*	4.83 *1.62*	3.57 *1.05*
3	8.16 *1.60*	6.91 *0.52*	4.67 *0.52*	8.19 *1.19*	6.08 *0.56*	4.07 *0.01*
5	6.74 *1.48*	4.68 *0.25*	4.28 *0.30*	6.03 *2.20*	6.37 *4.51*	7.10 *3.35*
6	7.57 *2.77*	6.78 *3.32*	3.84 *0.26*	7.54 *1.72*	7.38 *1.09*	5.64 *0.85*
Diff Wk0-Wk6	**-3.42**	**-1.37**	**0.41**	**0.04**	**-3.88**	**1.17**
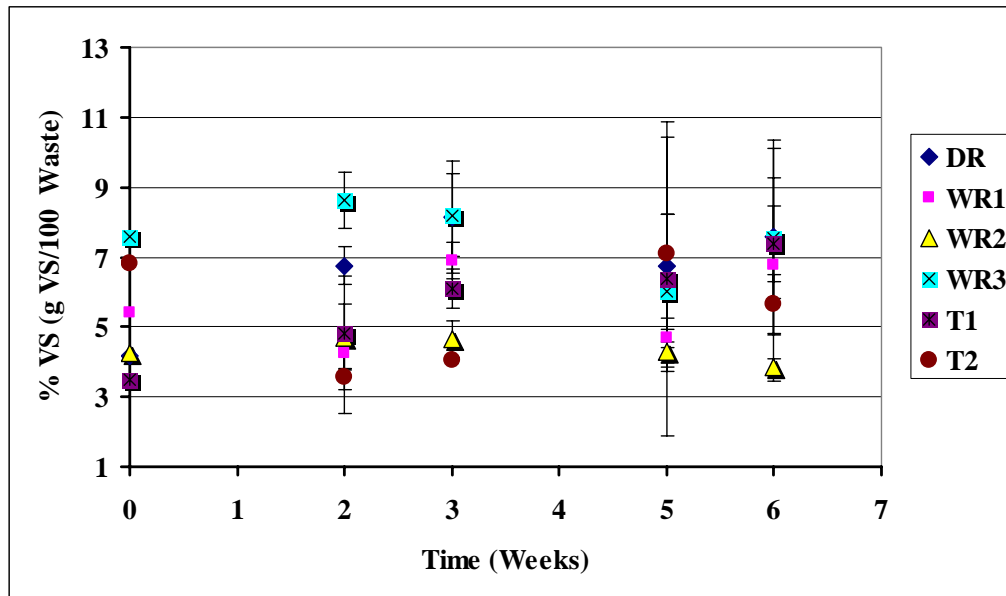
Figure 5.5: Graph showing the volatile solids in the contents of the reactor vessels

ANOVA (single variable) results for % VS reveals with 95% confidence that there was a significant difference of results within the reactor vessels over the same time. The t-test indicates that there is a significant difference between T1 and W3.

The graph gives a visual illustration of the relative spread of the data points **within** and **between** each reactor vessel test. The variances are between 0.1 and 3 within the reactor vessels, and between 1 and 3 between each reactor vessel.

Some of the data points:

i.   (DR, WR2, T1 and T2) appeared to give some indication of a trend, but
ii. other points (WR1 and WR3) are scattered thus making a reliable observation difficult.

The arithmetic differences in % VS for the duration of the experiment are small. DR and T1 had the greatest increase in VS. This result indicates that there may have been a concentration effect due to evaporation. T2 showed a slight decrease, implying that there is a

possibility of a greater rate of degradation attributed to the activity of M. These observations however, cannot be made with reliability, due to the variances shown.

5.5   Total ash

Table 5.6: Table showing ash in the contents of the reactor vessels.

% Ash (gAsh/100gwaste)

Numbers in italics are standard deviations for the triplicate results

|	No additions	Weekly additions	Daily additions	Daily additions	Weekly additions	Once off addition.
Vessel no.	**DR** – No additions	**WR1**- 5 L water	**WR2** – 700 ml water	**WR3** – 70 ml water	**T1** – additive + 700 ml water	**T2** – additive shock dose + 700 ml water
0	10.77 *0.86*	12.52 *0.86*	13.04 *0.86*	12.13 *0.86*	11.51 *0.86*	11.15 *0.86*
2	13.12 *0.96*	11.43 *0.65*	10.41 *0.64*	13.63 *1.64*	8.47 *0.78*	11.02 *1.01*
3	13.11 *0.51*	10.65 *0.52*	19.06 *11.73*	11.43 *0.39*	9.98 *0.95*	11.54 *1.07*
5	10.46 *2.17*	10.56 *1.42*	8.37 *0.45*	8.71 *1.45*	11.59 *3.59*	11.08 *0.57*
6	12.92 *0.70*	12.23 *0.32*	10.13 *0.41*	10.74 *0.70*	9.43 *0.59*	10.49 *1.63*
Diff Wk0-Wk6	-2.15	0.29	2.91	1.39	2.08	0.66
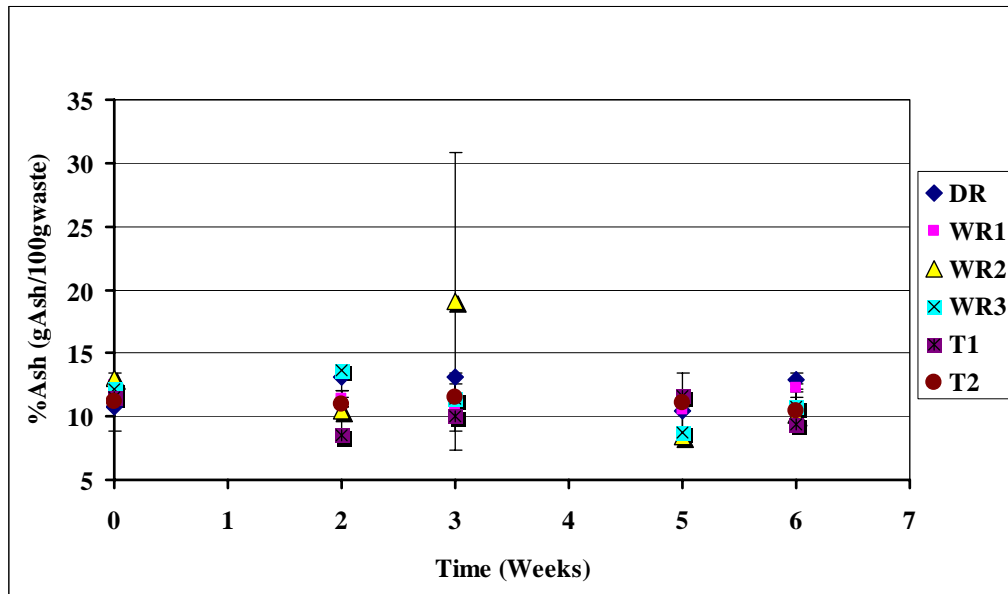
Figure 5.6: Graph showing the ash in the contents of the reactor vessel.

ANOVA (single variable) results for Ash showed with 95% confidence that there was no significant difference between each group. The table and graph show that the percentage ash does not change significantly. The variances within and between the reactor vessels are not great, except for WR2, which shows a variance of 17 of the data points during the experiment. The others show a variance of between 0.1 and 2. The variance at week 3 is 11, however, between the other reactor vessels between 0.7 and 4). The arithmetic differences shown in Table 5.6 show that the percentage ash content increased by 2 % in DR. The other rector vessel ash content decreased, with WR2 showing the greatest decrease of 2.9%. T1 showed a decrease of 2.1%. This indicates that some ash was lost during the experiment possibly due to liquid addition.

5.6 COD.

Due to time constraints in developing the methodology, the COD analysis was done in triplicate for one pit latrine waste sample only at the start of the experiment, so, only one data point is presented at the start. This is recognised as not giving precise results.

Table 5.3: Table showing the chemical oxygen demand of the contents in the reactor vessels.

Results of %COD (mgCOD/100gwaste)

Note: only one sample was tested in triplicate for COD at the start of the experiment

Numbers in italics are standard deviations for the triplicate results

|	No additions	Weekly additions	Daily additions	Daily additions	Weekly additions	Once off addition.
Vessel no.	**DR** – No additions	**WR1**- 5 L water	**WR2** – 700 ml water	**WR3** – 70 ml water	**T1** – additive + 700 ml water	**T2** – additive shock dose + 700 ml water
1	20.11 *0.31*	20.11 *0.31*	20.11 *0.31*	20.11 *0.31*	20.11 *0.31*	20.11 *0.31*
2	23.04 *1.04*	18.77 *0.83*	16.64 *0.52*	20.91 *0.43*	11.48 *0.78*	16.44 *0.63*
3	19.67 *0.95*	19.80 *0.41*	16.99 *0.66*	17.54 *0.36*	12.65 *0.52*	17.67 *0.60*
4	18.43 *0.52*	17.54 *1.25*	12.03 *0.63*	14.92 *1.58*	13.62 *0.62*	12.72 *0.32*
5	22.21 *1.14*	36.65 *0.60*	14.72 *0.63*	17.33 *1.99*	16.78 *0.48*	18.50 *0.78*
6	23.79 *0.43*	19.94 *0.43*	21.73 *2.11*	19.94 *0.93*	17.47 *0.43*	14.85 *0.83*
Diff (Wk0-Wk6)	-3.68	0.17	-1.62	0.17	2.65	5.26
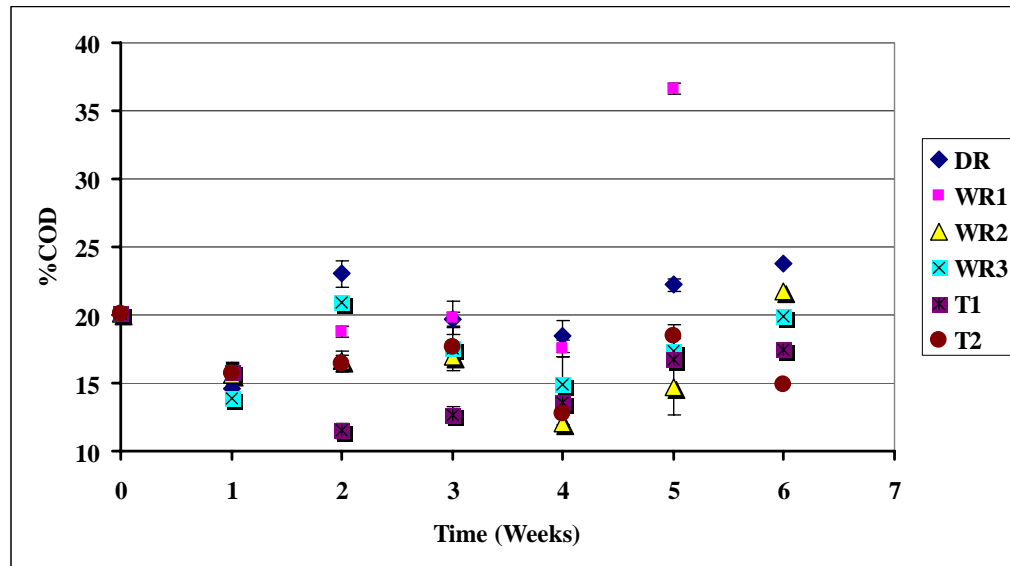
Figure 5.3: Graph showing the chemical oxygen demand of the contents in the
reactor vessels.

ANOVA (single factor) statistical analysis on COD's revealed with 95% confidence that there was not a significant difference **within** each reactor vessel over time.

ANOVA reveals a statistically significant difference **between** the reactor vessels. However, there is a large variance at weeks 2 and 5 (16 and 65 respectively) that would have affected the analysis.

The arithmetic differences give results that are very similar, with the exception of DR that showed an overall increase and T2, which showed a decrease.

The effect of having only a single COD data point at the start of the experiment may affect the analysis of the data. The reason for this singular point was given in Section 4.5.2.

The total mass of the waste in each of the reactor vessel changed, except for WR2 and WR3. Thus, if the % COD decreased, this implies that there is a possibility of some effect due to

the additive M. This result needed to be verified by the TS and VS results. These results do not give any conclusive evidence of any significant differences attributed to the additive M.

6. DISCUSSION, CONCLUSIONS and RECOMMENDATIONS.

6.1   Expected results.

The hypothesis made was that the additive M would have an affect on the rate of degradation of the waste. The result would be to reduce the volume of the VIP waste at a greater rate than its normal degradation rate or than if only water had been added. For the hypothesis to be true, the test reactor vessel (T1) results should show a rapid drop in organic content in the waste when compared against the other reactor vessels. This would be due to the faster rate of hydrolysis of macromolecules to soluble smaller molecules as well as the faster rate of degradation of the soluble fraction to the respective gaseous components. Thus, any decrease in measured organic content in the dry reactor vessel would be attributed to gaseous and liquid emissions. If no liquid filtrate was discharged, then all reductions would be as a result of gaseous emissions.

The relative ash content of the contents in the vessel would increase due to the concentrating effect of the loss of moisture if no filtrate was generated.

It was anticipated that any additional water would leach out the soluble phase and fine particulates in the wet reference reactor vessels. The anticipated general effect would be one of reducing the organic component at a rate faster than the dry reactor vessel, but slower than the test (additive) vessel. The test vessels should produce soluble COD fractions faster than the reference/control vessels.

6.2   Discussion of the Results

The results of interest for discussion are the arithmetic differences between the start and the end of the experimental period. The following tables are the combined results of the arithmetic differences between weeks 0 and 6, as well as between weeks 0 and week 5 to confirm a trend if any that could be noted. The greatest reduction means the greatest arithmetic difference that was calculated in a particular variable between all the reactor vessels. Likewise, the smallest reduction is the smallest difference measured in a particular variable between the reactor vessels.

The greatest and smallest reductions are highlighted in the tables, to see if there is any trend to be noted with all the variables when compared between the reactor vessels. Week 5's differences were also presented to verify any particular trend that may be noted.

Table 6.1: Table showing the results of the percentage differences of all the variables (Week 0 – Week 6).

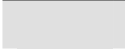| Difference	No additions **DR** – No additions	Weekly additions **WR1**- 5 L water	Daily additions **WR2** – 700 ml water	Daily additions **WR3** – 70 ml water	Weekly additions **T1** – additive +700 ml water	Once off addition **T2** additive shock dose + 700 ml water
Moisture	5.56	1.08	-4.10	-1.43	1.81	-1.83
COD	-3.65	0.20	-1.59	0.20	2.67	5.29
TS	-5.56	-1.08	-30.89	1.43	-1.81	1.83
VS	-3.42	-1.37	0.41	0.04	-3.88	1.17
Ash	-2.15	0.29	2.91	1.39	2.08	0.66

	Greatest reduction
	Smallest reduction

Table 6.2: Table showing the results of the percentage differences of all the variables (Week 0 – Week 5).

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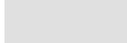| Diff	No additions **DR** – No additions	Weekly additions **WR1**- 5 L water	Daily additions **WR2** – 700 ml water	Daily additions **WR3** – 70 ml water	Weekly additions **T1** – additive +700 ml water	Once off addition **T2** additive shock dose + 700 ml water
Moisture	2.27	-2.69	-4.65	-4.97	**2.96**	0.22
COD	-2.07	-16.51	**5.42**	2.81	3.36	1.64
TS	-2.27	2.69	4.65	**4.97**	-2.96	-0.22
VS	-2.58	0.73	-0.03	**1.55**	-2.88	-0.29
Ash	0.31	1.96	**4.67**	*3.42*	-0.08	0.07

Greatest reduction

Smallest reduction

Table 6-1 gives a summary of the reduction of the variables between the start and the finish (6 weeks) of each experiment. The results show:

i. T1, the test reactor vessel having M added each week, not to be greater than the other reactor vessels.

ii. T2, the reference reactor vessel, with a once off shock dose of M, appears to have the greatest differences with TS, VS and COD values.

When Table 6-2 is examined, the results do not match the results of Table 6-1. The contradiction may indicate that; the results obtained from the experiments do not exhibit the degree of precision necessary to assess whether the hypothesis is true or not, or that any processes would take 5 to 6 weeks to take place. The differences of the earlier weeks are recorded in Appendix 4, in the respective variable worksheets. The variability of the results needs to be eliminated to enable any valid observations to be made.

6.3   Conclusion

Results obtained from the measurement of the variables could not be used with any degree of reliability to make any decision. The overall effectiveness is not adequately and conclusively tested in these experiments. Further rigorous testing needs to be conducted.

The information gained in these series of experiments to assist the municipality planners and decision makers to apply M or any equivalent additive to the VIPs and pit latrines is not conclusive enough to make the decision whether the M is effective or not. There are indications that there are possibilities for additives to be of some use.

6.4   Suggestions

The following are suggestions, put forward to enable a reduction of uncertainties and improve the test methodologies.

6.4.1   Reducing uncertainties.

The reliability of some of the results, specifically the volatile solids results and the variability of the arithmetic differences over the duration of the experiment is questionable. One source of uncertainty would be from the VIP waste itself, as it is heterogeneous. It is very difficult to get a set of results that would be reproducible from one VIP to another, or even possibly from one reactor vessel to another. To minimize this effect, the waste collected from the pit could be homogenised in a way that would not change the microbial activity from the normal activity. Air intake must be reduced. Analysis of the samples to measure all the variables would need to be done on unmixed and mixed waste. A large number of samples should be tested to determine the variability.

Another source of uncertainty is in the sampling method during the experiments. One particular sector on the surface of the reactor vessel contents should be allocated for sampling. This will ensure uniformity in the case of possible changes inherent on the surface of the waste. Possible causes of change would be from the migration of the particulate solids

as well as dissolved solids to the edges of the waste. Another cause of change would be through degradation.

The experience gained during the experiments is in the management of the samples and the analyses. The analyses should always be done using a consistent period between sampling and storage. This time needs to be kept to a minimum.

With regard to the laboratory analyses;

i.   the testing of the samples needs to include separate testing of the leachate as well as the solid phase.

ii. the reference manual for testing for the variables (APHA. 1998) does suggest that tests for moisture could also include volatile organic material with boiling points lower than 105 ^{o}C. COD and volatile solids tests could also include inorganic chemicals. This suggests that total organic carbon tests need to be done separately on the liquid and solid phases of the waste, to get specific organic content results.

6.4.2   Recommendations.

The opportunity did not present itself to repeat the tests, however, should this have happened, the new series of tests would have been:

- Dry reference,
- Water, 700ml weekly,
- Water, 700ml once off,
- T1
- T2
- T1 + waste added daily.

I would also like to run the tests over a much longer period then six weeks. This would be to explore the possibility of allowing any possible microbial dynamics to develop as in the case stated in Section 2.2, where the various acclimatising stages are required by a new set of microbes once certain substrates have been exhausted. This is also seen in Section 2.1

dealing with the human GI tract, where regional differences in the large intestine and the functions are explained.

These tests would possibly give a clearer comparison to determine additive effectiveness. The mass of waste used would be greater so that adequate numbers of samples could be taken. Each of these reactor vessels would be run in at least duplicate. Analyses would also include TOC tests on the solid phase and the leachate of the waste.

The summary of the break down of food in the human GI tract as presented in the literature research is also to be explored as a means to develop a methodology to degrade faecal waste rapidly. The literature gives an indication that food remains in the GI tract from twenty four hours in a typical African GI tract and up to seventy hours in the GI tract of a UK adult. The large intestine is where the macro molecules of the slow biodegradable foods are degraded. This is where microbes thrive. The processes preceding the large intestine are; mechanical breakdown of food particles, acidic processes which include gastric juices and enzymes which are involved in the breakdown of easily degradable foods. These processes are typical of natural processes that utilise complex macro molecules for energy and nutrient absorption.

Studies on macro biota such as earthworms have been conducted to determine their affect on the stabilization rate on mixtures that included sewage sludges. Divers (2005) reported on work in Chennai, India on the activity of Anaecic earthworms (Lampito mauritii). The report suggests findings that the use of earthworms stabilized mixtures of sludge obtained from a waste water treatment works, rice straw and cow dung. The experiment was conducted over seventy days. The reported results were:

i.   significant removal of total organ carbon and increase in kjehdal nitrogen – enhanced the decomposition process,
ii. reduced pathogens such as Salmonella, Shigella and colliforms in thirty five days, and increased the population of heterotrophic bacteria,
iii. a possibility that earthworms use micro organisms as a food source.

The disposal of VIP sludges is a problem. Alternative methods need to be explored to examine the stabilization and elimination of pathogens in the sludge for the possibility of re use.

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APPENDICES

Appendix 1.   Variables measured: Total mass, total solids, moisture content, volatile solids, ash and chemical oxygen demand.

Appendix 2:   Householder questionnaire.

Appendix 3:   Excel spreadsheet showing raw experimental data. 4 Worksheets: (i) Raw Data. (ii) COD Raw Data. (iii) Mass of all Reactor Vessels (iv) % Raw Data

Appendix 4:   Processed results. 7 Worksheets: (i) Total mass of reactor vessels. (ii) % Ave TS. (iii) % Ave VS. (iv) % Ave Ash. (v) % Ave Moisture. (vi) % Ave COD. (vii) Consolidated % results.

Appendix 5:   Information on additive M.

Appendix 6:   ANOVA and calculations for processing results.