

# BIOLOGICAL DEGRADATION PROCESSES WITHIN A PIT LATRINE

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## ABSTRACT

Analysis of samples of fresh faecal material and samples from range of pit latrines and from pit latrines within a number of locations have been analysed for organic and inorganic characteristics including total COD, moisture, total solids and inorganic solids. Assessment of the results has led to the development of a conceptual model of biological degradation processes that occur in a pit latrine.

The faecal sludge portion of pit contents may be divided into four theoretical categories: (i) the first category is sludge where readily biodegradable components are still present, wherein rapid aerobic degradation occurs. This layer is negligibly small and is not measurable in practice; (ii) the second category is made up of the top aerobic section of the pit. In this layer, aerobic degradation of hydrolysable organic material occurs at a rate limited by the aerobic hydrolysis of complex organic molecules to simpler compounds; (iii) the third layer is anaerobic due to the occlusion of oxygen by covering material. Anaerobic digestion proceeds at a significantly slower rate than in the layer above, and is controlled by the rate of anaerobic hydrolysis of complex organic molecules to simpler molecules; and (iv) in the lowest layer, no further stabilisation of organic material occurs within the remaining life of the pit contents.

In this paper, qualitative and quantitative characteristics are reported for each of the layers described. Factors that affect the rates of degradation, and thus the relative sizes of each of the layers are discussed. This information is then used in a parallel paper to assess the feasibility of different routes for disposal of pit latrine contents, including disposal to sewer, wastewater treatment plant, burying and anaerobic digestion. The feasibility of each of the disposal routes depends on the inherent ability of the treatment to accept the load of solids, nitrogen and organic material in the VIP sludge, the residual biodegradability of the VIP sludge, and the health risks associated with handling the sludge

## INTRODUCTION

Lack of basic sanitation and access to clean water supply is a major cause of diseases and infant mortality in developing countries (1). Worldwide, approximately 2.6 billion people lack improved sanitation and the largest part of this resides in Africa and Asia. Sanitation options such as ventilated improved pit latrines (VIP) are considered by the World Health Organisations as improved. Consequently, around the world, there is a drive to ensure the provision of proper sanitation and access to clean water supply. In line with this, one of the Millennium Development targets is to reduce the number of people with no access to basic sanitation by 50 %, by 2015.

In South Africa, substantial advancement have been made since then to ensure access to basic water and sanitation services for all while ensuring environmental sustainability (2;3). The proportion of people with improved sanitation has increased by 20% since 1994 (4).

According to the Strategic Framework for Water Services, a target has been set to ensure access to improved sanitation by all by the year 2010 (5,6).

eThekweni municipality is centred on the South African coastal city of Durban, with approximately 3-million inhabitants (6) Ventilated improved pit (VIP) latrines are nationally recognized as the minimum level of acceptable sanitation in South Africa. However, a VIP latrine does not provide improved sanitation to users once it has become full. Thus the problem of providing improved sanitation is more complex than simply building new VIP latrines. Sanitation services must also consider means of emptying or replacing full pits, and this has been found to be an enormous challenge, particularly in communities where there is no space to construct new pits or to dispose of pit contents on site.

Consequently, as part of free basic sanitation services, eThekweni municipality is developing a pit emptying service.

As part of ongoing research into providing sustainable improved sanitation services, especially to households outside of the reach of existing sewer networks, the Water Research Commission and eThekweni Municipality supported research into the processes and nature of material that are found in pit latrines. This research endeavoured to provide information and decision support for managing pit latrines during their normal lifespan, and for managing pit emptying and associated sludge management.

This paper has three parts. In the first section, physico-chemical characterisation of VIP sludge from different layers of the pit. This information provides an indication of the nature of pit contents. In the second part, a theory describing the processes that occur in the pit latrine is developed through interpretation of the physico-chemical and biodegradation data. Finally, some conclusions and recommendations are made about the significance of the results in design and operation of pit latrines and management of sludge from pit latrine emptying exercises.

## **LITERATURE DESCRIPTION OF VIP WASTE CONTENTS**

Available literatures on the processes occurring inside a VIP pit are limited, but information on the rate of pit filling is documented (7). Furthermore, it is difficult to understand processes occurring inside the pit without a background knowledge on the nature of pit latrine contents. The pit if well operated contains faeces, urine, anal cleansing material and/or anal cleansing water (8). A pit should end up with stable sludge material, at the time when it is full and have approximately zero organic fatty acid (VFA) at the time of emptying (9). However, disposal of multiple wastes into the pit results in non-homogenous properties of pit contents. Additives expected to reduce smell or enhance biological processes may also be added into the pit.

In this section of the paper the physical, chemical and biological characteristics of fresh faeces from literature are discussed since it is the major feed material (or a starting material) and major contributor of the organic substance in the pit. Then based on the few available literatures on VIP wastes stabilisation processes, general observations from pit latrine engineers, pit emptier and other scientific literature the nature of a VIP sludge is described.

### Fresh Faeces

Faeces are the major feed material that goes into the pit. Studies done by (10) and (11) to characterise faeces and to describe the biodegradability of organic matter present in

faeces showed that 80% of human faeces comprised of slowly biodegradable organic matter ( $X_S$ ) while 20% is inert material ( $X_I$ ). Readily biodegradable organic matter ( $S_S$ ) was not regarded as a component of faeces (i.e. =0%). Furthermore, model results showed that only 15% of the slowly biodegradable was easily hydrolysable ( $X_{Se}$ ) whereas 65% was slowly hydrolysable ( $X_{Ss}$ ) (11). Human faeces are high in organic matter, contributing about 44% of COD load in domestic wastewater (12). The slowly biodegradable portion cannot be utilised directly by micro-organisms and so has to be made accessible through cell external hydrolytic (enzymatic) reactions (11). Thus, the micro-organisms come into close contact with the slowly biodegradable organic substrates and secrete their hydrolytic enzymes to carry out their activities. The kinetics and method of biodegradation of faeces can thus be related to its hydrolyzability.

### Pit latrine sludge

Literature values (9) estimated for faecal sludge collected from pit latrine and raw fresh faeces showed that fresh faeces resulted in higher values for characteristics and volume than the pit latrine sludge. This implies that the faeces undergo a certain degree of decomposition for the time it is inside the pit. Seasonal shifts in temperature and humidity are expected to alter both the physical and biochemical characteristics of faecal matter that have been deposited into a VIP pit (13).

Similarly, as part of this study, earlier studies have been done by (8) to characterize pit contents.

## **PROCESSES OCCURRING INSIDE THE PIT**

Based on the information that have been known on the nature of what goes into and comes out from the pit, a conceptual theory of the process occurring within the pit has been developed.

### Conceptual Theory of processes occurring within the pit

Major processes that occur inside the pit can thus be categorised into physical and biological (8). The filling rate of the pit and the hydraulic transport patterns of the soluble pit contents constitute the physical processes occurring inside the pit whereas biological conversion of organic matter constitutes the biological process.

In terms of hydraulic transport patterns, depending on the geological and topographical characteristics of the site where the pit is located (8), the solubles together with moisture will drain out or infiltrate into the pit. In most cases, water carrying solubles and colloidal materials seep into the pit contents or drain out through the pit walls (8). Alternatively, in situations where there is a high water table, or supply of water above the pit bottom, water may flow into the pit together with soluble materials from the pit surroundings (8). The rate at which the pit fills depends on the rate of accumulation of added material. Degradation of organic material causes the rate of pit filling to be lower than the rate at which material is added. The minimum filling rate depends on the amount of non-degradable material which is added to the pit.

Because oxygen is present at the surface of pit contents, aerobic processes may dominate in the top layer of pit contents. However, below this surface conditions are expected to be anaerobic.

It is hypothesized that through measurement of physical, chemical and biological characteristics of fresh faeces and, VIP sludge it is possible to deduce the extent of biodegradation in a pit latrine faecal sludge.

## METHODS

This section describes the techniques used to determine the various chemical physical and biological properties of fresh faeces and pit latrine samples. Fresh faecal samples that were used in the experiments were collected immediately after defecation from a particular household, whereas VIP sludge were collected from 16 different pits located within the eThekweni Municipality. The method of each technique and the reasoning behind is concisely explained and tabulated (**Table 1**).

**Table 1. Parameters used to measure the physico-chemical properties of fresh faeces**

Parameter	Reason	Method to use
inorganic solids content	To estimate the inorganic, non-biodegradable fraction of the total solids	(14)
Moisture	To quantify the moisture content of sample, and relate it to sample's biodegradability.	(14)
Total chemical oxygen demand	To measure oxidisable organic matter	(14)
Soluble chemical oxygen demand	To quantify dissolvable oxidisable organic matter	(14)
Particulate chemical oxygen demand	To quantify particulate oxidisable organic matter	(14)
Total solids	As a step to determine moisture, organic solids and inorganic solids	(14)
	To eliminate dilution effect of different moisture contents when quantifying COD.	
Organic solids	To quantify the organic material present in substrates.	(14)

## RESULTS AND DISCUSSIONS

This section presents key findings of this study, and compares the findings with previous findings. For the purpose of comparison, the fresh faeces data is presented initially (**Table 2**) before the VIP sludge data.

### Fresh Faeces

The Literature average values of the different parameters and the average values together with their limits at 95 % confidence for fresh faeces as obtained within this study are presented in **Table 2**,. COD was calculated per gram of dry solids for all samples analysed in this study so that comparisons could be drawn between different samples on a moisture-free basis.

**Table 2 Physico chemical characterisation of fresh faeces; comparison of literature and value**

Source		(10)	(12)	Within this study						
Parameter	Units	Mean	Mean	N	Mean	95% confidence interval for mean		Min	Max	C of V (%)
						Lower bound	Upper bound			
Total COD	mgCOD/mg dry sample	1.45	1.38	9	1.13	1.06	1.20	0.95	1.28	8
Soluble COD	mgCOD/mg dry sample	-	-	6	0.37	0.32	0.42	0.32	0.43	12.8
Particulate COD	mgCOD/mg dry sample	-	-	6	0.67	0.61	0.72	0.59	0.75	8.5
Moisture content	%/g wet sample	81.8	79.2	6	78	76	80	75	80	2.43
Total solids	%/g wet sample	18.2	20.8	6	22	20	24	20	25	8.7
organic solids	%/g dry sample	84.4	-	6	84	79	90	79	89	6.1
inorganic solids	%/g dry sample	-	-	6	16	11	21	11	21	-

obtained within this study

Where N = total number of samples, Min =minimum value, Max= maximum value, C of V= coefficient of variation

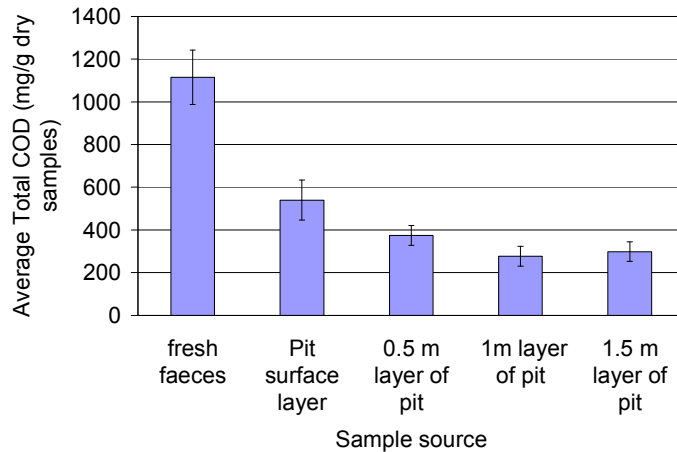
Percentage organic solids (84% See Table 2) value for fresh faeces indicates that faeces are high in organic matter that can be biodegradable, and contain less inorganic material. High ratio of particulate COD to soluble COD (Table 3) suggests that most of the biodegradable COD present in faeces are slowly biodegradable. This is supported by the results presented by (15 and 16). Average moisture (78%), Total solids (22%), and organic solids (84%), data also agree with the literature values (Table 2). However COD values measured in this study are slightly lower than those reported in the literature. This is possible since the physico chemical characteristics of faeces vary with age, health and diet of the individuals (10). In addition, less variability (C of V values in Table 3) between samples is due to the fact that faecal samples that were used in this study are from individuals of same household with same diets.

### VIP latrine sludge

For clarity, VIP sludge as defined in this study represent waste from the pit, but do not include domestic waste such as plastics, bottles and blankets as are usually found in these pits (17). To homogenise samples, samples were macerated using an electric blender. The physico- chemical characteristics of Pit latrine sludge was firstly compared to that of fresh faeces. COD results for 10 pits are presented. In addition, results for solids, and moisture analysis for the four different layers of 16 pits are presented.

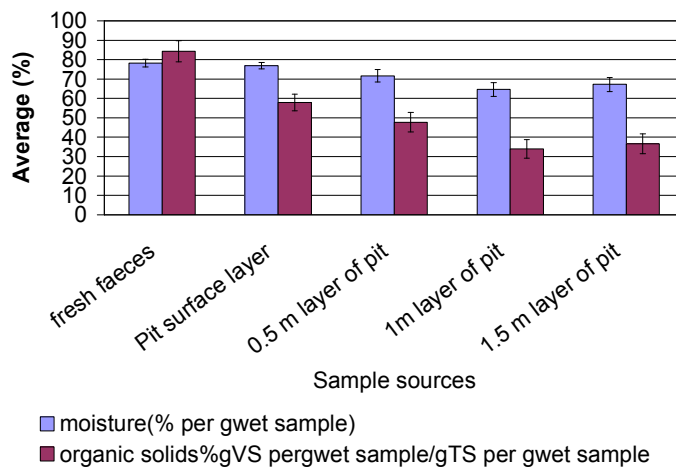
One will expect the surface layer to have values that are closest to that of fresh faeces for all the measured parameters. Although this was mostly found to be the case, there is a significant variance in all the measured parameters. The mean total COD value (539 mgCOD/g dry sample) for this layer was significantly less than that measured for fresh faeces (1130 mgCOD/g dry sample) (**Figure 1**). Assuming the fresh faeces analysed in this study were similar to those entering the pit, almost half of the biodegradable COD in fresh materials have been lost at the surface layer. From **Figure 1**, the trend in COD suggests that although the COD of the topmost layer is high compared to that of the other

layers beyond, and although it is closest to the fresh faeces value, the implication is that a significant loss of organic matter has occurred. This suggests that the contents of this layer have already started undergoing some degree of stabilisation that was not observed with the fresh faeces. This means that the other three layers beyond the surface layer have undergone even greater extent of stabilization since they have lesser COD values as compared to the topmost layer. This is reasonable considering their length of storage period. **Figure 1** shows that the mean COD value decreased while descending from the topmost layer to the bottom layer, implying that more stable material is found at the bottom of the pit.



**Figure 1 Mean total COD composition for fresh faeces and faecal sludge sampled from four different layers (depth) within the pit of VIP latrine**

The same trend is observed with organic solids and moisture contents. In **Figure 2**, the average percentage organic solids and moisture content that was measured for both fresh faeces and pit latrine sludge from the four different layers is shown. The mean plot of moisture contents for fresh faeces and the four different layers within the pit shows that although moisture content of fresh faeces may be higher compared to pit latrine sludge, the difference is not highly significant.



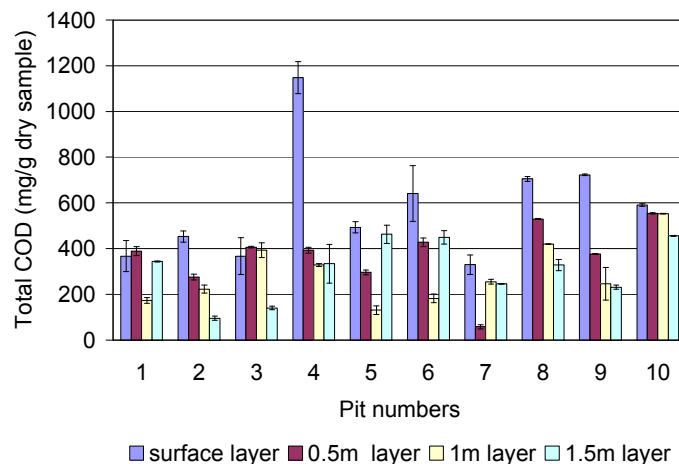
**Figure 2 Percentage moisture and organic solids composition for fresh faeces and faecal sludge sampled from four different layers (depth) within the pit of VIP latrine**

Average percentage organic solids (58 %) that were measured for the surface layer is less than that measured for fresh faeces (84 %). However this value was higher than that measured for the other layers below this point. This is as expected, since fresher material is expected at this layer. This means that much of the biodegradable organic matter present in fresh faeces degrades naturally after defecation. But there is some that is partially degraded remaining at the surface layer. For this reason, a reduction in organic solid value at the surface layer is observed relative to fresh faeces. For the other layers beyond given the duration of standing within the pit, they have lost more of the biodegradable organics with time than the surface layer. The bottom layer contains the least organic matter content.

### Variations within the different pits

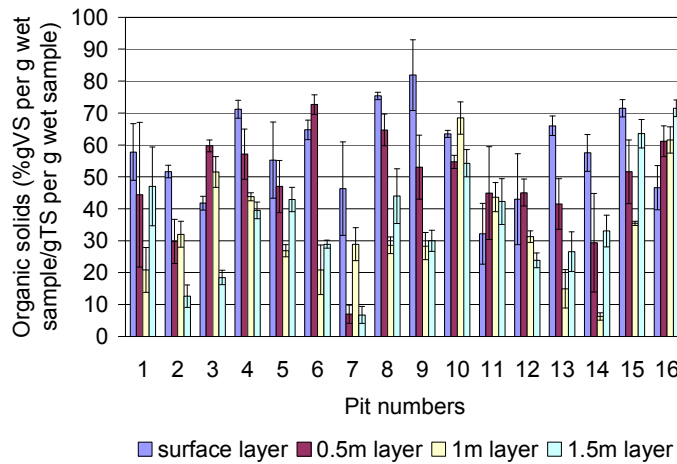
Although mean total COD and organic solids values decrease while progressing from the surface layer to the bottom layer, significant variability exists, judging from independent pits. Also the trend is not consistent for the individual pits.

**Figure 3** shows the COD characterisation results (in mgCOD/ g dry sample) for pit latrine sludge from 10 different pits. COD values for the four different layers of all the pits varied significantly. Thus there was no uniform COD value for these layers for all the different pits. However for all the different pits the surface layer is significantly higher in COD when compared to the bottom layer of the pits. Pit 5 is exceptional since both the surface and bottom layer has almost the same value.



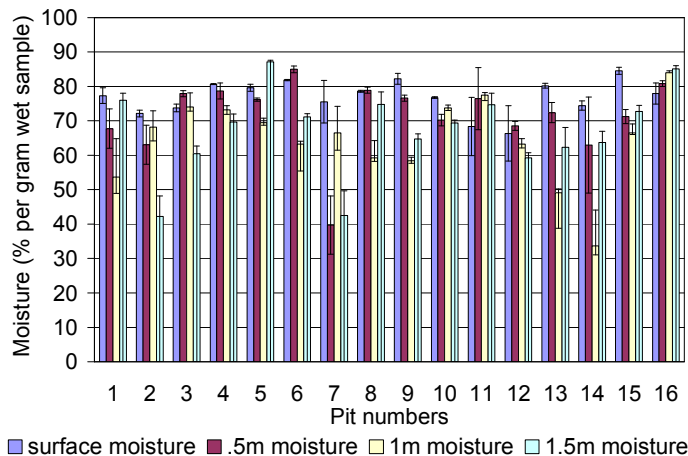
**Figure 3 COD distribution for faecal sludge sampled from different layers within the same pit and sampled from different pits**

For each of the 16 pits, the relative amount (percentage) of organic solids decreased with increase in depth (**Figure 4**). This implies that more stabilized materials are located at the lower layers of the pit. However it is notable that the trend within the layers is not uniform for the individual pits. Pit 16, is exceptional, as the pattern of decrease was regular, but rather than decreasing from the surface layer downwards, an unexpected increase from the surface layer to the bottom layer is observed.



**Figure 4 Organic solids distribution for faecal sludge sampled from different layers within the same pit and sampled from different pits**

The moisture content results are presented in **Figure 5**. A decrease is observed while progressing from the surface to 1m layer and then a slight increase while approaching the bottom layer. This unexpected increase in moisture content at the bottom layer samples as opposed to that of the samples from 1 m depth can be as a result of water collecting at the pit bottom. However an unexpected gradual increase in the moisture content of pit materials from the surface layer to the bottom layer of the pit is observed with Pit 16. This might possibly be due to a nearby source of ingress water



**Figure 5 Moisture distribution for faecal sludge sampled from different layers within the same pit and sampled from different pits**

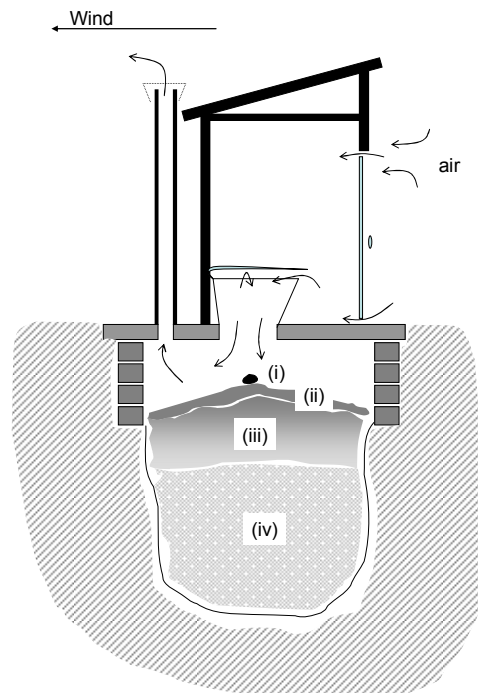
### Theory of processes occurring within the pit

Although COD and VS measurements only give an approximation of biodegradability test, the results obtained so far suggest that some possible changes take place in the biodegradable organic material of faecal sludge found in pit latrine with time. Biological activity has resulted in breakdown of some organic material. These results suggest that immediately after defecation, rapid degradation occur during which micro-organisms inherent in the faecal matter, and those present at topmost layer of the pit contents carry out a quick aerobic degradation of the readily biodegradable COD in fresh faeces(8). Consequently there is a loss of a large fraction of the biodegradable components in faeces through aerobic degradation while it is sitting at the topmost layer of the pit contents. Further, this significant aerobic biological activity occurs on the top surface of the pit, before the “fresh” is overlaid with new material. This layer is particularly too small to be

measured, since it eventually gets overlaid after a short while and thus cannot easily be sampled from. Once it is overlaid by new pit material, anaerobic degradation occurs at a far slower rate resulting in gradual reduction of organic material. In other words comparing COD value of fresh faeces to that of faecal sludge at the surface layer of the pit about half of the total fresh faeces have already been lost. The results of this study have shown this. Further reductions in COD values are seen with the other layers beyond the surface layer if compared to the surface layer.

Thus, based on these results a description of what the different layers occurring within a will comprise of is presented herewith, (8).

- i A first layer that is too small to be measured and comprised of fresh faeces where the readily biodegradable components are still unchanged.
- ii A second layer made up of the topmost aerobic part of the pit, whereby aerobic degradation of hydrolysable organic material takes place at a rate limited by the aerobic hydrolysis of large organic molecules into simpler compounds.
- iii A third layer that is anaerobic as a result of the elimination of oxygen by the covering material whereby anaerobic digestion of hydrolysable organic material takes place at a rate limited by the anaerobic hydrolysis of large organic molecules into simpler compounds.
- iv A bottom layer whereby no further stabilisation of organic material can occur, as materials are already stabilised.



**Figure 6:Diagram of a pit latrine showing the different theoretical layers**

#### Causes of variations within the different layers of the different pits

From the results that have been presented, it is deducible that although the VIPs that were sampled from within this study are located in similar hydro geological conditions, a significant variation in organic solids content; moisture content and COD concentration exists between samples from the same pits and samples from different pits. The variability in characteristics of pit contents is addressed here to be due to a number of possible causes.

### Ingress water

The presence or absence of ingress water will affect the moisture content of the pit materials. A possible explanation of the unexpected increased moisture content of pit materials that were sampled from the bottom layer was that there could have been a nearby source of ingress water. This can come from the location of the water table. If the water table is located somewhere above the pit bottom, infiltration may occur. Alternatively contents from pit latrine that are located on a steep and sandy area are most likely to have lower moisture content as water drains out through the pit walls (8).

### Inhibition

Furthermore, previous experiments that are part of the larger component of this study have shown that reduction of organic material is possible to some extent in the contents of some pit latrines under non-inhibiting conditions (8).

### User behavioural practices

User practices have also been observed to have an effect on the nature of pit latrine contents. This is because different users have different types of anal cleansing material, along with the practice of using the pit as a site for disposing solid waste in certain areas (8).

## CONCLUSIONS

From the results obtained, the following general conclusions can be made:

- There appears to be a regular decrease in, COD content, moisture content and organic solids fraction with increase in the depth of pit contents.
- A theory has been developed describing processes that have occurred in faecal sludge found within a pit latrine.
- Large variations exist in the physical and chemical composition both within a pit and from different pits.

## REFERENCES

1. World Health Organisation: Guidelines for drinking water quality, 3rd edition, Geneva: WHO. (2004)
2. Republic of South Africa White paper on reconstruction and Development Government Gazette (1994)
3. Republic of South Africa, National Water Act 36 of 1998, Government Gazette (1998)
4. African Economic Outlook, "South Africa" 978-92-64-025103 p 498 (2007).
5. Department of Water and Forestry: "Strategic framework for water services". (2003) <http://www.info.gov.za/2005/waterstrat.pdf> accessed . 12-08- 2005
6. K Eales, Sanitation Partnerships Series: Bringing pit emptying out of the darkness: A comparison of approaches in Durban, South Africa, and Kibera, Kenya (p 5-6) (2005)
7. D Mara, "The design of VIP", TAG Technical Note. World Bank Washington DC (1984)
8. K Foxon and CA Buckley, Scientific support for the design and operation of ventilated improved pit latrines. KS/1630/08. Water Research Commission in press (2008)

9. E.J Chaggu, "Sustainable Environmental Protection Using Modified Pit Latrines"; Wageningen University UNESCO-IHE, Delft, (2004)
10. M.A. Lopez Zavala N. Funamizu and T. Takakuwa, Characterization of faeces for describing the aerobic biodegradation of faeces. J. Environ. Syst. and Eng., JSCE 720/VII-25 99-105. (2002)
11. M.A. Lopez Zavala N. Funamizu and T. Takakuwa (2004) Temperature effect on aerobic biodegradation of faeces using sawdust as a matrix. Water research 38 0043-1354 2406-2416.
12. MC Almeida, D Butler and E Friedler, At-source domestic waste water quality. Journal of urban water. Vol. 1, pages 49-45. ,(1999):
13. A Nordin, Nitrogen based sanitation of source separated faecal matter M.Sc. thesis Department of Microbiology Swedish University of Agricultural Sciences ISSN 1101-8151 Uppsala ISRN SLU-MIKRO-EX-06/3-SE (2006)
14. APHA Standard Methods for the Examination of Water and Wastewater. 20th edition , American Public Health Association, (1998)
15. M C Wentzel, A Mbewe, M T Lakay and G A Ekama, Batch test for characterization of the carbonaceous materials in municipal wastewaters. Water SA Vol. 25 No. 3, (1999)
16. D Orhon, E.U Cokgör, COD fractionation in wastewater characterization- The state of the art. J. Chem. Tech. Biotechnol. 68: 283-269. (1997)
17. L Taljaard, A Venter and D Gorton, Evaluation of different commercial microbial or microbially-derived products for the treatment of organic waste in pit latrines. CSIR/Biotech/RN/03/1448/B. CSIR Bio/Chemtek (2003)