



UNIVERSITY OF TM
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI

**AN INVESTIGATION INTO THE CHARACTERISTICS OF
ON-SITE FAECAL SLUDGE IN DURBAN IN A STUDY OF
VENTILATED IMPROVED PIT (VIP) LATRINES AND
URINE DIVERSION (UD) TOILETS**

Lungiswa Nokwazi Zuma

BSc Eng (Chemical) (UCT)

In fulfilment of the academic requirements for the degree of the Master of Science degree in Engineering in the School of Chemical Engineering at the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Durban, South Africa

Supervisor: Prof. C.A. Buckley

December 2016

PLAGIARISM DECLARATION

I, LUNGISWA NOKWAZI ZUMA declare that

- (i) The research reported in this dissertation, except where otherwise indicated, is my original work.
- (ii) This dissertation has not been submitted for any degree or examination at any other university.
- (iii) This dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
- (iv) This dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
 - a) their words have been re-written but the general information attributed to them has been referenced;
 - b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced.
- (v) Where I have reproduced a publication of which I am an author, co-author or editor, I have indicated in detail which part of the publication was actually written by myself alone and have fully referenced such publications.
- (vi) This dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the References sections.

Signed:

Date:

ACKNOWLEDGEMENTS

I would like to acknowledge and express my gratitude to the following people for their support during the course of this project:

The Bill and Melinda Gates Foundation for the funding to conduct this project.

My supervisors Prof Chris Buckley and Dr Tina Velkushanova, thank you for the guidance throughout the project.

The PRG laboratory staff, especially Merlien Reddy Marisa Rajan, for taking time to train me in all the laboratory techniques and for their assistance with the pit emptying and laboratory analyses.

For their emotional support and love, my family: Mme, Anti, Noksie and Sipha. My friends: Danna, Nomonde, Ntokozo; and Scelo Biyela.

ABSTRACT

Provision of sanitation services is a topical issue in South Africa and around the world and on-site sanitation systems have been the preferred approach over waterborne sanitation to providing services. However sanitation does not only mean the provision of a toilet, it includes the designing and providing the appropriate toilets for the local context and the management of the sludge which emanates from the toilets. On-site sanitation in eThekini Municipality is provided in the form of Ventilated Improved Pit latrines and Urine Diversion (UD) toilets. The knowledge of the characteristics of faecal sludge from these toilets and how they change with time and toilet conditions is important for the design of new toilet systems and faecal sludge treatment technologies after the toilets have been emptied.

In this study 30 on-site sanitation facilities (20 VIP latrines and 10 UD toilets) were emptied and faecal sludge samples were selected from the front and back section at different depths for VIP latrines and from the active and standing vaults at different depths for UD toilets. The samples were analysed for total solids, moisture content, volatile solids, ash content, total chemical oxygen demand (COD), pH, total Kjeldahl nitrogen (TKN), ammonia, thermal conductivity and calorific value.

In the UD toilets, only 3 of the active vaults were found to be diverting urine, in the other toilets evidence of urine was found in the active vaults. The laboratory results from the faecal sludge from the vaults where urine diversion was occurring showed that the sludge had moisture content lower than the average fresh faeces moisture content, a pH of below 7 and zero ammonia content.

Three different types of VIP latrines were found during this study, their classification was based on the faecal sludge surface during the emptying of the pit. The sludge surfaces were cone (*dry VIP latrines*), flat un-crusted (*Wet VIP latrines Type I*) and crusted (*Wet VIP latrines Type II*). There was no statistical significant difference found on the faecal sludge characteristics between the 3 types of VIP latrines. In both types of wet VIP latrines, it was found that the sampling method used in this study was not appropriate for these pits as it did not allow for representative sampling.

Table of Contents

PLAGIARISM DECLARATION	iii
ACKNOWLEDGEMENTS	iv
ABSTRACT	v
List of Figures	x
List of Tables	xiv
Abbreviations	xv
1 INTRODUCTION.....	1
1.1 Objectives.....	5
1.2 Hypotheses.....	5
1.3 Outline of the thesis.....	5
2 LITERATURE REVIEW	7
2.1 On-site sanitation.....	7
2.2 Components of VIP and UD toilets	8
2.2.1 Pits and vaults.....	9
2.2.2 Superstructure	9
2.3 On-site sanitation in eThekweni Municipality (Durban).....	10
2.4 Inputs into VIPs and UD toilets	11
2.4.1 Faeces	11
2.4.2 Urine	11
2.4.3 Household waste	12
2.5 Filling rates of VIP latrines and UD toilet vaults	12
2.5.1 Sludge age and depth relationship	13
2.6 Factors affecting faecal sludge characteristics	14
2.6.1 Processes in pit and vaults.....	14
2.6.2 Moisture	15
2.6.3 Temperature	16
2.6.4 pH	17

2.6.5	Surrounding soil conditions	17
2.6.6	Storage period	18
2.7	End use of faecal sludge	18
2.7.1	Nitrogen	18
2.7.2	Calorific value	19
2.7.3	Thermal conductivity	20
2.8	Faecal sludge management in eThekwini	20
2.8.1	Emptying	20
2.8.2	Transport	22
2.8.3	Treatment	22
2.8.4	Disposal and/or end use	23
2.8.5	FSM Costs	24
2.9	Faecal sludge characteristics in eThekwini	24
2.10	Innovations in sanitation – the need for data.....	27
2.11	Summary.....	28
3	MATERIALS AND METHODS	29
3.1	Description of sampling site areas	29
3.2	Sludge emptying and sampling.....	29
3.2.1	VIPs	30
3.2.2	UD toilets	32
3.3	Pit and vault content characterisation.....	33
3.4	Experimental methods.....	34
3.4.1	Method for laboratory analysis	34
3.4.2	Sample preparation.....	34
3.4.3	Thermal conductivity and calorific value analysis	34
3.5	Laboratory analysis	35
4	RESULTS AND DISCUSSION.....	37
4.1	Data consistency check.....	37
4.1.1	Volatile solids	38

4.1.2	COD.....	38
4.1.3	pH	39
4.1.4	Ammonia.....	40
4.1.5	TKN.....	40
4.1.6	Thermal conductivity	41
4.1.7	Calorific value	41
4.1.8	Discussion.....	43
4.2	UD toilets	44
4.2.1	Status of UD toilets	44
4.2.2	Moisture content	46
4.2.3	Volatile solids	47
4.2.4	COD.....	48
4.2.5	pH	49
4.2.6	Ammonia.....	50
4.2.7	TKN.....	50
4.2.8	Thermal conductivity	51
4.2.9	Calorific value	52
4.2.10	Discussion.....	52
4.3	VIPs	57
4.3.1	Dry vs wet VIP analysis.....	58
4.4	Dry VIP latrines.....	60
4.4.1	Moisture content	61
4.4.2	Volatile solids	63
4.4.3	COD.....	64
4.4.4	pH	65
4.4.5	Ammonia.....	66
4.4.6	TKN.....	67
4.4.7	Thermal conductivity	69
4.4.8	Calorific value	70

4.4.9	Discussion.....	71
4.5	Sampling location for dry VIPs latrines	75
4.5.1	Faecal sludge property by front and back section.....	75
4.5.2	Faecal sludge characteristics by layers	76
4.5.3	Discussion.....	77
4.6	Wet VIP latrines	78
4.6.1	Differences in the 2 types of wet VIPs	79
4.6.2	Sampling in wet VIPs	79
4.6.3	Analysis results for wet VIP latrines	79
4.7	Pit and vault content characterisation.....	79
5	CONCLUSIONS.....	81
5.1	UD toilets	81
5.2	VIPs	82
6	RECOMMENDATIONS.....	83
7	REFERENCES.....	84
8	APPENDICES.....	A
	APPENDIX A - Data.....	A
	APPENDIX B – Graphs for wet VIP latrines.....	F
	APPENDIX C - Laboratory procedures.....	G
	APPENDIX D – Urine diversion toilet flyer	ZZ
	APPENDIX E – Chemical and thermal properties of VIP latrine sludge	AAA

List of Figures

Figure 2-1 Basic structure of a VIP (Buckley et al., 2008a).....	8
Figure 2-2 Schematic representation of a urine diversion toilet (Mnkeni et al., 2009) ...	9
Figure 2-3 Dissociation balance between ammonia/ammonium depending on pH and on temperature (Fricke et al., 2007)	19
Figure 2-4 The faecal sludge management (FSM) chain	20
Figure 2-5 Manual emptying a VIP latrine using a shovel	21
Figure 2-6 Transport of faecal sludge using 250L bins to the treatment site	22
Figure 2-7 Schematic of the LaDePa machine (Wilson et al., 2012)	23
Figure 2-8 Pelletised pasteurised faecal sludge from the LaDePa machine (Wilson et al., 2012)	23
Figure 2-9 Diagram of a pit latrine showing the different theoretical layers (i) fresh stool; (ii) partially degraded aerobic surface layer; (iii) Partially degraded anaerobic layer beneath surface; (iv) completely stabilised anaerobic layer. (Buckley et al., 2008a)....	25
Figure 3-1 (a) A typical household with a VIP latrine in Besters, (b) A typical household with a UD toilet in uMzinyathi	29
Figure 3-2 (a) Diagram of a VIP latrine showing the layers from which the samples were selected from the front and back sections (b) the depths (m) at which the samples were selected from the front and back sections of the VIP latrine.....	30
Figure 3-3 Pictures of the group of VIPs noted on the field during the pit emptying and sampling campaign.	32
Figure 3-4 Diagram of a UD toilet showing the layers from which the samples were selected in the active and standing vaults	32
Figure 3-5 Manual characterisation of faecal sludge from VIP latrines.....	33
Figure 4-1 Correlation of faecal sludge moisture content (g water/g wet mass) to volatile solids content (g VS/g TS) for VIP latrines and UD toilets.....	38
Figure 4-2 Correlation of faecal sludge moisture content (g water/g wet mass) to COD (g COD/g TS)	39
Figure 4-3 Correlation of faecal sludge moisture content (g water/g wet mass) to pH..	39
Figure 4-4 Correlation of faecal sludge moisture content (g water/g wet mass) to ammonia (mg NH ₃ -N/g TS).....	40

Figure 4-5 Correlation of faecal sludge moisture content (g water/g wet mass) to TKN (mg N/g TS).....	41
Figure 4-6 Correlation of faecal sludge moisture content (g water/g wet mass) to thermal conductivity (W/(m. K))	41
Figure 4-7 Correlation of sludge moisture content (g water/g wet mass) to calorific value (kJ/g TS)	42
Figure 4-8 Correlation of faecal sludge COD (g COD/g TS) to calorific value (kJ/g TS)	42
Figure 4-9 The visual appearance of the sludge during sampling from the different UD toilet vaults. Top left: well-functioning active vault (UD 6); top right: decomposing inactive vault (UD 2); bottom left: vault being used for storage (UD 7); bottom right: active vault where no separation was occurring (UD 10).	46
Figure 4-10 Moisture content (g water/g wet mass) for 9 UD toilet active vaults and 7 UD toilet standing vaults. Mean fresh faeces moisture content from (Rose et al., 2015)	47
Figure 4-11 Volatile solids (g VS/g TS) for 9 UD toilet active vaults and 7 UD toilet standing vaults. Mean fresh faeces moisture content from (Nwaneri, 2009)	48
Figure 4-12 COD (g COD/g TS) for 9 UD toilet active vaults and 7 UD toilet standing vaults. Mean fresh faeces COD from (Nwaneri, 2009).....	49
Figure 4-13 pH for 8 active UD toilet vaults and 6 UD toilet standing vaults	49
Figure 4-14 Ammonia content (mg NH ₃ -N/g TS) for 9 UD toilet active vaults and 7 UD toilet standing vaults.....	50
Figure 4-15 TKN (g N/g TS) for 9 UD toilet active vaults and 7 UD toilet standing vaults	51
Figure 4-16 Thermal Conductivity (W/(m.K)) for 8 active UD toilet vaults and 6 standing UD toilet vaults	51
Figure 4-17 Calorific Value (kJ/g TS) for 8 active UD toilet vaults and 6 standing UD toilet vaults	52
Figure 4-18 The different types of <i>wet VIP latrines</i> ; left: type I; middle: crust of type II; right: water layer beneath the dry crust of type II	57
Figure 4-19 Moisture content (g water/g wet mass) per pit for the 10 dry and 10 wet VIPs	58

Figure 4-20 Moisture content (g water/g wet mass) and water content (g water/g TS) for 1g of total solids and the moisture content of VIP latrines.....	59
Figure 4-21 Faecal sludge depth (m) and the representation of the different layers of the 10 dry VIP latrines that were emptied	61
Figure 4-22 Moisture content (g water/g wet mass) for 10 dry VIP latrines at average faecal sludge depths of the layers (m).....	62
Figure 4-23 Moisture content (g water/g wet mass) for the front and back sections of 10 dry VIP latrines at varying pit depths (m)	62
Figure 4-24 Volatile solids content (g VS/g TS) for 10 dry VIP latrines at average faecal sludge depths of the layers (m)	63
Figure 4-25 Volatile solids content (g VS/g TS) for the front and back sections of 10 dry VIP latrines at varying sludge depth (m)	64
Figure 4-26 COD (g COD/g TS) for 10 dry VIP latrines at average faecal sludge depths of the layers (m)	64
Figure 4-27 COD (g COD/g TS) for the front and back sections of 10 dry VIP latrines at varying faecal sludge depth (m).....	65
Figure 4-28 pH for 10 dry VIPs for 10 dry VIP latrines at average faecal sludge depths of the layers (m)	65
Figure 4-29 pH for 8 dry VIP latrines at varying layers of the range of pits sampled for the front and back sections of the pit.....	66
Figure 4-30 Ammonia (mg NH ₃ -N/g TS) for 10 dry VIP latrines at average sludge depths of the layers (m).....	67
Figure 4-31 Ammonia (mg NH ₃ -N/g TS) for the front and back sections of 9 dry VIPs at varying faecal sludge depth (m).....	67
Figure 4-32 TKN (g N/g TS) for 10 dry VIP latrines at average faecal sludge depths (m) of the layers.....	68
Figure 4-33 TKN (g N / g TS) for the front and back sections of 9 dry VIP latrines at varying faecal sludge depths (m).....	68
Figure 4-34 Thermal conductivity (W/(m. K)) for 10 dry VIP latrines at average faecal sludge depths of the layers (m)	69
Figure 4-35 Thermal conductivity (W/(m. K)) for the front and back sections of 9 dry VIP latrines at varying faecal sludge depths (m)	70

Figure 4-36 Calorific value (kJ/g TS) for 10 <i>dry VIP latrines</i> at average sludge depths of the layers (m)	70
Figure 4-37 Calorific value (kJ/g TS) for the front and back sections of 10 <i>dry VIP latrines</i> at varying faecal sludge depths (m)	71
Figure 5-1 Cumulative graphs for UD toilets active vaults (urine separation), active vaults (no urine separation) and standing vaults for moisture content, volatile solids, COD, pH, ammonia, TKN, thermal conductivity and calorific value.....	55
Figure 5-2 Cumulative graphs for <i>dry VIP latrine</i> and <i>wet VIP latrine</i> sludge for moisture content, volatile solids, COD, pH, ammonia, TKN, thermal conductivity and calorific value	73

List of Tables

Table 2-1 VIP latrine filling rates in the Durban area.....	13
Table 2-2 Ash mass, age and percent total mass of contents in each pit layer for VIP 1 and 2 (Wood, 2013).....	14
Table 2-3 Flows and contaminant loads for VIP latrines to groundwater (DWAF, 2003)	18
Table 2-4 Summary of VIP sludge contents at different layer within the pit. Data are presented as mean value \pm 95% conf. Interval, [min, max] (Bakare, 2011)	26
Table 2-5 Summary of properties of material taken from standing vaults (Buckley et al., 2008b).....	27
Table 2-6 Projects/technologies that require knowledge of the properties of faecal sludge and some of the properties required	27
Table 4-1 Laboratory procedures and the relevance of the properties	35
Table 4-2 Status of the 10 UD vaults at the time of emptying	44
Table 4-3 <i>p</i> -values for the properties of faecal sludge for dry and wet VIPs	60
Table 4-4 Student <i>t</i> -test results for faecal sludge characteristic properties between the front and the back sections of the pit	76
Table 4-5 Student <i>t</i> -test results comparing the characteristics in the different layers of the faecal sludge in dry VIP latrines	77
Table 4-6 Percentages of household waste and foreign objects found in pits and vaults	79
Table 5-1 Minimum, median and maximum values for the characteristics analysed for UD toilets active vaults (urine separation), active vaults (no urine separation) and standing vaults UD toilets.....	56
Table 5-2 Number of samples required per characteristics for the front and back sections of the pit	78
Table 5-3 Minimum, median and maximum values for the characteristics analysed for dry VIP latrines, wet VIP latrines Type I and wet VIP latrines Type II	74

Abbreviations

APHA	American Public Health Association
BMGF	Bill & Melinda Gates Foundation
BSF	Black Soldier Fly
COD	Chemical Oxygen Demand
DST	Department of Science and Technology
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EM	eThekwhini Municipality
EWS	eThekwhini Water and Sanitation
FSM	Faecal Sludge Management
GTZ	German Technical Corporation
LaDePa	Latrine Dehydration and Pasteurisation
MDG	Millenium Development Goals
MPFS	Mechanical Properties of Faecal Sludge
n	number of observations
p	probability
PRG	Pollution Research Group
RTTC	Re-invent the Toilet Challenge
SRFA	Sanitation Research Fund for Africa
SDG	Sustainable Development Goals
SOP	Standard Operating Procedures
TKN	Total Kjeldahl Nitrogen
TS	Total Solids
UD	Urine Diversion
UN	United Nations
VIP	Ventilated Improved Pit (latrine)
VS	Volatile Solids
WRC	Water Research Commission (of South Africa)

1 INTRODUCTION

Goal 7 of the Millennium Development Goals (MDGs) that were set in 2000 was *Ensuring environmental sustainability*; target 7c of this main goal was to: *Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation* (UN, 2015a). The MDG Report of 2015 states that 95 countries have achieved the sanitation target and worldwide 2.1 billion people have gained access to improved sanitation and the portion of people practising open defaecation has fallen almost by half. However, there are still 1 in 3 people (2.4 billion) that use unimproved sanitation facilities and thus the world has missed the MDG target (UN, 2015a).

In September 2015, a United Nations Development Summit was held for the adoption of Agenda 2030 and the Sustainable Development Goals (SDGs). In order to complete the work begun with the MDGs in 2000, there were 17 goals set. The new goals and targets will come into effect on 1 January 2016 and will guide the decisions taken over the next fifteen years. Goal 6 of the SDGs is to: *Ensure availability and sustainable management of water and sanitation for all*. Some of the targets of this goal are:

- *By 2030, achieve access to adequate and equitable **sanitation** and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations;*
- *By 2030, expand international cooperation and capacity-building support to developing countries in water and **sanitation** related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies;*
- *To support and strengthen the participation of local communities in improving water and **sanitation** management* (UN, 2015b).

The inclusion of sanitation in the SDGs illustrates its importance in the priorities of the UN Member States.

In February 2002, the South African Department of Water Affairs and Forestry (DWAF) defined sanitation as: *Any system that promotes sanitary or healthy living conditions... It includes systems that manage wastewater, storm water, solid waste and household refuse and it also includes ensuring that people have safe drinking water and enough water for washing. Sanitation includes both the ‘software’ of understanding why health problems exist and what steps people can take to address these problems; it also*

includes ‘hardware’ such as toilets, sewers and hand-washing facilities. Together, they combine to break the cycle of diseases that spread when human excreta and waste are not managed properly (DWAF, 2012).

In 2012, the government of South Africa set a target of achieving at least functional and adequate sanitation services by 2014. In 2012, approximately 11% of households still had to be provided with sanitation services (these households had never had a government supported sanitation intervention) and 28% of households had sanitation services which did not meet the standards due to lack of maintenance, inadequate water supply, or lack of pit emptying services (DWAF, 2012). Based on the 2011 pricing structure, it is estimated that a total of R50 billion is required to address this challenging situation (DWAF, 2012).

In May 2015, the Minister of Water and Sanitation in South African convened a Sanitation Indaba. The theme of the Indaba was: *It’s not all about flushing.* The purpose of the Indaba was to:

- *Showcase the practical demonstration of cutting-edge appropriate sanitation technologies that can be implemented in South Africa and Africa*
- *Provide an engagement space for communities on the feasibility of technology implementation as it pertains to their contexts*
- *Pool ideas and experiences to accelerate the adoption of world-class advanced technologies by both municipal and industrial water users*
- *Develop a roadmap for scaling up of technologies and solutions (DWS, 2015b)*

The focus was on dry and low water use sanitation systems particularly understanding the long term financial, environmental and institutional implications of operating and maintaining the various sanitation systems. In her Budget Vote Speech of the 2015/2016 financial year, the Minister allocated R 115 million to deliver 11 000 dry sanitation solution to rural areas and a further R 975 million to eradicate all bucket toilets by December 2015 (DWS, 2015a). Thus within the national government of South Africa, there has been a renewed focus in alternative sanitation solutions other than expensive and often unsustainable waterborne sanitation.

There recently has been a push towards funding of sanitation research and innovation in South Africa, Africa and worldwide. Two examples are:

- The partnership between the South African Department of Science and Technology (DST) together with the Bill & Melinda Gates Foundation (BMGF)

that have launched a partnership to demonstrate sanitation solutions in rural and peri-urban South Africa. The partnership funds the research, development, demonstration and manufacturing of sanitation technologies and solutions in South Africa, with the underlying objective of ensuring universal access to sanitation (DST, 2014).

- The Sanitation Research Fund for Africa (SRFA) is a collaboration between the Water Research Commission of South Africa (WRC) and the BMGF. This fund is aimed at improving sanitation research and innovation to improve the plight of millions of people without adequate sanitation and its purpose is to provide impetus for scientific-based knowledge and practical solutions for faecal sludge management (Pillay, 2014).

This call for innovation both locally and internationally is not only aimed at developing new sanitation systems, it is also aimed at ensuring that the existing systems are providing an adequate service to the people who use them. This includes investigating not only the toilet but the whole chain after the sludge has been removed.

Ventilated improved pit (VIP) latrines are the accepted basic sanitation delivery option and are the regulated minimum acceptable level of sanitation in South Africa (Buckley et al., 2008a). Other on-site sanitation systems available and being used in the country include urine diversion (UD) and low/pour flush toilets; all of these are regarded as accumulation systems where the excreta deposited is kept in the pit or vault until it has filled up and requires to be emptied (Tilley et al., 2008a). In the eThekweni Municipality, the minimum level of basic sanitation is a UD toilet (EWS, 2011), even though in some areas of the municipality VIP toilets are still being used – these are acceptable as a basic level of sanitation but will, overtime, be replaced either by waterborne sanitation or by a UD toilet.

Regardless of the type of on-site sanitation system, eventually any pit or vault will fill up. If there is no space to dig a replacement pit or vault, the existing one must be emptied (Eales, 2005). After the pit contents have been emptied, the faecal sludge needs to be treated and/or disposed; the choice of emptying device, treatment or disposal processes of the sludge that will be used will depend amongst other factors on the characteristics of the sludge.

There have been previous studies by the Pollution Research Group (PRG) in the University of KwaZulu-Natal on faecal sludge characteristics from VIP latrines in the eThekweni Municipality. Bakare et al. (2012) emptied and sampled 16 VIP latrines at

four depths and analysed the faecal sludge for moisture content, total and volatile solids content, chemical oxygen demand (COD) and aerobic biodegradability to determine the amount of biodegradable material present in each sample. The study was conducted in order to investigate the filling rates of VIPs and the efficacy of pit latrine additives. Wood (2013) analysed faecal sludge from VIP latrines for a wider selection of characteristics for samples collected at four depths of 2 VIP latrines, these tests included: pH; alkalinity; moisture content; volatile solids; COD; biodegradable COD; total Kjeldahl nitrogen (TKN); ammonia; total phosphorus and orthophosphate. The aim of this study was to model the degradation processes in a pit and to obtain a baseline understanding of the chemical transformations in the VIP.

This study extends on their work through a comprehensive sampling campaign of different on-site sanitation systems (VIP latrines and UD toilets). The faecal sludge was analysed for a wide range of characteristics thereby creating a more complete data set that can be used by sanitation practitioners worldwide. Since the installation of UD toilets in the eThekini Municipality, a few studies have been conducted to determine the faecal sludge characteristics in the vaults and the changes of the faecal matter with storage time. However, there has not been a structured study on the characteristics of the faecal sludge in UD vaults.

The PRG was awarded funding by the BMGF for a project titled Mechanical Properties of Faecal Sludge (MPFS). The aims were to provide properties and characteristics of sludge, it is anticipated that the data generated from MPFS will support the design and sizing of mechanical pit-emptying devices, transportation and processing systems for the excavated sludge, and the design of future on-site sanitation facilities (PRG, 2014c). A portion of the results from this study has been published: Chemical and thermal properties of VIP latrine sludge (Zuma et al., 2015), **see Appendix E**.

This study was part of the MPFS project and focused on obtaining faecal sludge properties of 20 VIP latrines and 10 UD toilets in the eThekini Municipality. The results from the laboratory analysis of the chemical and thermal characteristics of the faecal sludge were used to determine the appropriate emptying and sampling techniques and sampling positions in the pits for VIP latrines. The functioning of UD toilets was determined using the laboratory analysis results of the faecal sludge and visual observations in the field.

There have been studies in the PRG that have been conducted in parallel to this current study that deal with other characteristics of faecal sludge from VIP latrines;

these are *Thermal Properties and Drying Characteristics of Faecal Sludge and Rheology, Extrusion and Pelletisation of Faecal Sludges* (PRG, 2014b).

1.1 Objectives

The objective of the study was to:

- Obtain a baseline of UD faecal sludge characteristics in eThekwin UD toilets for both active and standing vaults.
- Conduct an extensive emptying and sampling campaign of VIP latrines and UD toilets in order to characterise the faecal sludge.

1.2 Hypotheses

The following hypotheses are tested in this study

- UD toilets in eThekwin are designed, constructed and used such that the sludge from the vaults is dry and non-objective.
- The determination of the faecal sludge properties can be used to assess if the UD toilet is being used as anticipated by the designers.
- General trends in UD toilet faecal sludge characteristics can be used to determine/predict corresponding faecal sludge properties.
- Faecal sludge samples at 4 different depths from the centre of the pit are adequate to describe the transformations of faecal sludge through the depth of VIP latrines.
- All the VIP latrines in eThekwin produce a similar faecal sludge and the same methods can be used throughout the municipality to empty the full pits.
- General trends in VIP latrine faecal sludge characteristics can be used to determine/predict corresponding faecal sludge characteristics.

1.3 Outline of the thesis

Chapter 1 discusses the background, and presents the hypotheses and objectives for the study.

Chapter 2 presents and critically reviews the literature that is relevant to this study. The gaps in the knowledge are identified and the way in which this study plans to address them is presented.

Chapter 3 details the materials and methods used to test the hypotheses and to fulfil the objectives of this study.

Chapter 4 presents and discusses the laboratory results from samples of faecal sludge.

Chapter 5 summarises the major conclusions from this study.

Chapter 6 lists the recommendations for further research that was not covered by this study.

2 LITERATURE REVIEW

This section reviews general on-site sanitation systems and in particular the ones used in the eThekini Municipality, the inputs into these systems, the filling rates of these systems and the factors that affect the sludge quality. Faecal sludge management in eThekini Municipality is reviewed along with the faecal sludge characteristics. Lastly, the innovations in sanitation are reviewed.

2.1 On-site sanitation

On-site sanitation system refers to a system where the excreta remain within the boundaries of the household or institution from which they emanate (Fawcett, 2010). In an effective on-site system such as in VIPs and UD toilets, the excreta are contained safely, in a well-designed, well-constructed and well-maintained pit or tank, without giving off unpleasant odours (Fawcett, 2010). The common feature in all on-site sanitation systems is the pit or vault that collects faeces, urine, anal cleansing material and all other household waste that may be disposed of by the users. The processes that occur in pits and vaults include (WRC, 2007):

- filling with faeces, urine, water and other material,
- water transfer into and out of the pit,
- biological transformation, and
- pathogen deactivation

After a certain time depending on the user habits, the pit and vaults will fill up and there will be a requirement for emptying. Shorter lifespans in pits due to bad user habits increase maintenance costs should the desludging of pits be required. This is expensive and becomes very difficult if the pits and superstructures are not designed to allow for desludging. Should desludging prove difficult, an alternative option is to build new VIPs, which is cost related and contributes to the sanitation backlog (Bhagwan et al., 2008a).

2.2 Components of VIP and UD toilets

The development of the VIP managed to substantially reduce two main disadvantages of traditionally unimproved pit latrines, namely the odour problem and the fly nuisance (GTZ, 2000).

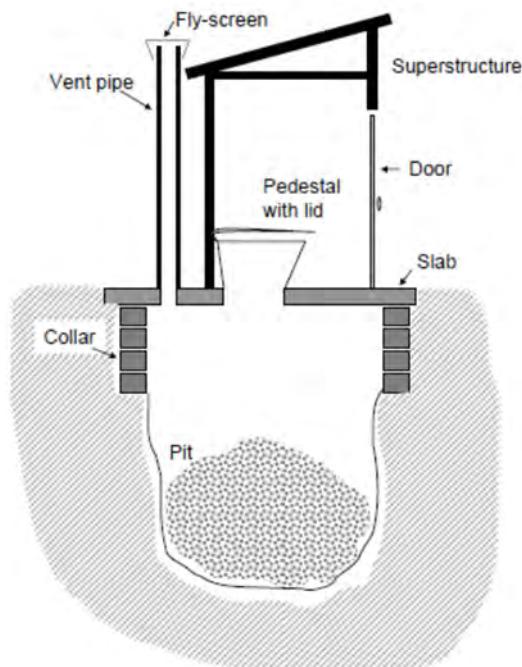


Figure 2-1 Basic structure of a VIP (Buckley et al., 2008a)

To qualify as a VIP, Buckley et al. (2008a) explains that the latrine must comply with certain requirements: (i) to provide hygienic separation of human waste from contact with people, (ii) to have a vent pipe fitted with a fly-screen to minimise odour and flies, (iii) to be built on a secure slab that will resist collapse of the superstructure, and (iv) to provide privacy and dignity for the user (**Figure 2-1**).

The basic design of the eThekweni Municipality UD toilet system is a double vault dry toilet with urine diversion to a soak-away located near the unit (**Figure 2-2**). A pedestal is located above one of the vaults into which faeces, anal cleansing material and a cover (e.g. soil) are dropped. Once the first vault is full, the pedestal is moved to the hole above the second vault and the first is sealed and allowed to stand. Once the second vault is full, which typically takes between 6 months and 1 year depending on the household size and diet type (Roma et al., 2013), the first vault is opened via the backplate and manually emptied by the householder or a contractor. The emptied contents are buried on the householder's property and the pedestal is then returned to its position above the first vault, the second vault is closed and is left to stand while the first refills (Buckley et al., 2008b).

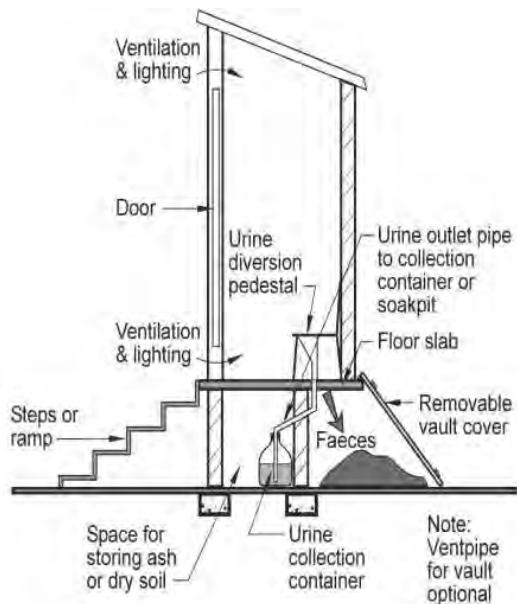


Figure 2-2 Schematic representation of a urine diversion toilet (Mnkeni et al., 2009)

2.2.1 Pits and vaults

Circular and rectangular pits are used for VIPs although round pits are more stable. Usually the pit of a VIP should be about 1 m in diameter and up to 3 m in depth. Pits can be lined to enhance the stability of the structure, but the lining should allow for flow of moisture and soluble components out of the pit into the surrounding soil (GTZ, 2000). Two essential processes occur as a result of the VIP use: the liquid excreta (mainly urine) infiltrate into the surrounding soil and the solid faeces are digested anaerobically or aerobically by bacterial activity (Mara, 1984).

In UD toilets, the volume of the material that requires handling is substantially less than in a VIP, thus the vault should have smaller capacity than a VIP pit (Buckley et al., 2008b). An accumulation rate of 70 litres per person per year is recommended by Austin (2006) for the design of UD vaults. Some of the other important aspects of UD vaults are: the vault lids should be made of lightweight material for ease of access for emptying, they should also fit tightly to prevent flies and vermin from gaining entry and there should be adequate storm water drainage around the vault (Austin, 2006).

2.2.2 Superstructure

The superstructure of a VIP is an important design step that is the major difference between the unimproved latrine and a VIP. The superstructure comprises of a vent pipe with a fly-screen which assists with keeping out the flies and controlling odours in the toilet (**Figure 2-1**). Wind passing over the vent pipe causes a flow of air from the pit

through the vent pipe to the atmosphere and a downdraught from the superstructure through the squat hole or seat into the pit. This continuous flow of air removes smells from the pit and vents the gases into the atmosphere at the top of the vent pipe rather than through the superstructure (Franceys et al., 1992). The drop hole on which the pedestal is mounted is not located in the centre of the pit.

For UD toilets, Austin (2006) explains that any suitable material may be used for the superstructure as long as it meets the criteria of strength, durability, weather resistance, and has good thermal (i.e. poor heat conducting) properties. In contrast to VIPs, which need to be partially darkened inside to assist with fly control, UD toilets may be light and airy as fly control is achieved by other ways e.g. covering faeces with ash, soil, etc.

2.3 On-site sanitation in eThekwini Municipality (Durban)

On-site sanitation in eThekwini Municipality is provided through VIP latrines and UD toilets. During the 1980s and 1990s, VIPs were the basic level of sanitation provided to areas without a waterborne sewage network (PRG, 2014a). VIPs were inherited by the municipality after its borders were expanded in December 2000 to include areas that had these systems installed by the previous government (Gounzen, 2008).

VIP latrines in eThekwini are single pit systems which collect both faeces and urine. There are an estimated 45 000 VIPs within the municipality, these are mostly located in the densely populated areas (Harrison et al., 2012).

Some areas that were previously unserved with basic sanitation were incorporated within the municipal boundary due to the extension. UD toilets were chosen to be the basic level of sanitation for these unserved areas. The development of UD toilets in the eThekwini Municipality began in 2002, the driving forces for the project were the prevention of further outbreaks of waterborne diseases among the population and the lowering of maintenance costs of sanitation systems for the municipality (Roma et al., 2011).

UD toilets comprise of 2 vaults – a specialised pedestal is placed over 1 pedestal at a time. The pedestal is designed to separate the urine and the faeces; the faeces go into the vault while the urine is diverted to a soakaway via a pipe. Cover material (ash, soil etc.) is to be poured over the faeces after each use to aid with the drying of the solids (EWS, 2003)

The vaults are used alternately, at initial use the first vault is used and once it is full the pedestal is switched over to the second vault while the first vault is closed off. It was estimated during design that the vault takes 1 year to fill up (Buckley et al., 2008b). When both vaults are full, the sludge in the first vault is deemed to be safe enough (dry and pathogen free) such that the householders can empty the vault themselves and bury the sludge in the open land adjacent to their dwelling. Approximately 81 000 UD toilets have been installed – this makes up 9% of the households in the municipality (PRG, 2014a).

2.4 Inputs into VIPs and UD toilets

The main inputs into VIPs and UD toilets are faeces and urine, but commonly households make use of the pit or vault for dumping of solid refuse. A large variety of other material such as newspaper, magazines, broken glass, bottles, rags, plastic bags and other waste materials can be found (Bakare et al., 2012) in pits and vaults. In households where there is no soak pit for household water, the toilet will often be used as a convenient disposal site for greywater (Still et al., 2012). All of these factors affect the functioning of the pits and vaults including their filling rate, biological and drying processes.

2.4.1 Faeces

The composition and characteristics of human faeces are influenced by the diet, health and age of individuals (Nwaneri, 2009). The median faecal wet mass value is 128 g/cap/day ($n=116$) with a range of between 51 and 796 g/cap/day (Rose et al., 2015); approximately 80-90% of faeces is organic matter which can degrade (Still et al., 2012). The nutrients content of faeces originates from the food consumed. It is estimated that the nutrients are distributed in the following proportions:

- 10-20% nitrogen (N),
- 20-50% phosphorus (P) and
- 10-20% potassium (K) (Niwagaba, 2009).

For well-functioning VIP or UD toilets, faeces should contribute the bulk of the solids in the pit or vault.

2.4.2 Urine

Liquid generation from humans is dependent on the water balance of individuals. The majority of the liquid fraction in pits is usually urine. Urine is 91 – 96% water, this is comprised of approximately:

- 1.4% inorganic electrolytes,

- 1.3% urea,
- 0.4% organics,
- 0.4% organic ammonia and the rest of it is water (Still et al., 2012).

The median volume of urine produced is 1.42 ℓ/cap/day (n=14) with a range of between 0.6 and 2.6 ℓ/cap/day (Rose et al., 2015).

2.4.3 Household waste

In communities where solid waste collection is not provided by the municipality, the pit latrine is often used for solid waste disposal. The drawbacks of using a toilet for solid waste disposal, however, is that it shortens the life of the pit, as most rubbish will not degrade and also can inhibit degradation of other waste, and rubbish in a pit makes it difficult or impossible to empty to the pit with a mechanised technology (Still et al., 2012). Items of household waste such as newspaper, magazines, broken glass, bottles, rags, plastic bags were found in VIP latrines emptied in Umlazi Q section in eThekweni (Bakare et al., 2012). It is estimated that while rubbish represents about 5-10% of the volume entering the pit and by the time the sludge has been in the pit for 10 years rubbish will constitute 25% of the volume (Still, 2002).

2.5 Filling rates of VIP latrines and UD toilet vaults

The filling rate of VIPs will determine how long it will take before the pit needs to be emptied, therefore keeping the filling rate as low as possible will extend the time that the pit will need to be emptied.

Pit filling times vary widely depending on factors such as numbers of users, soil type and pit lining methodology. The volume of the pit contents is a function of the moisture content of the sludge. Pits are also generally used for solid waste disposal, and this hastens the filling time (Still, 2002). In VIP latrines where anaerobic digestion is understood to be the predominant process in the deeper layers of the sludge there is a reduction in volume and mass due to the evaporation of moisture, production of gases, leaching of soluble substances, transport of insoluble material by surrounding liquids and the consolidation at the bottom of pits under the weight of superimposed solids and liquids (Franceys et al., 1992). It is also likely that the sludge build up rate decreases with time due to the gradual increase of natural anaerobic digestion processes in the latrine (Still, 2002).

There are varying ranges of pit filling rates reported throughout literature – these values vary widely even within the same community. **Table 2-1** presents the filling rates of pits measured around Durban.

Table 2-1 VIP latrine filling rates in the Durban area

Area	Filling rate (l/person·year)	Reference
Bester's Camp	69.4	(Still, 2002)
Ezimangweni	27±10	
Savana Park	31±21	(Foxon et al., 2011)
Folweni	44±46	

The variation in the filling rates can be attributed to the varying amount of household rubbish that each household throws away in the pit, because of its non-biodegradability – the household rubbish remains in the pit and does not decrease in mass. The accuracy of the number of people using the VIP as reported by the household members has also been questioned by researchers: Bakare (2011) and Still (2002). Citizens of Durban retain strong linkages to the rural areas of South Africa (most notably rural KwaZulu-Natal and Eastern Cape), with many residents identifying ‘home’ as their original home in the rural areas. This link creates a pattern of circular migration where people move between the rural areas and the city (Sutherland et al., 2013) – this may be one of the reasons of the uncertainty in the exact number of people using the VIP latrine.

Filling rates of UD toilets have not been studied. The eThekwin UD toilet vault was designed and estimated to fill up with 1 year of use for a 5 member household. This is based on faeces being deposited in the vault and no liquids. The UD vaults are lined with concrete on all sides and thus there is no contact between the sludge in the vault and the surrounding soil.

2.5.1 Sludge age and depth relationship

The extent of anaerobic digestion of the organic content in VIP latrines depends on the age of the content. A deeper sample is also an older sample which has had a longer residence time in which to undergo biological activity and whose characteristics may be affected by the mechanisms that occurred since the solids have been deposited in the pit (Buckley et al., 2008a). A study was conducted by Wood (2013) on the sludge age relationship in 2 VIP latrines it was found that in both VIPs: With time, a significant volume of excreta is no longer present in the pit through biological degradation, leaching of soluble components and dehydration. And thus the bottom layers are more compact and may vary greater in age than the surface layers (**Table 2-2**). The VIP latrines in the study had been in use for 14 years.

Table 2-2 Ash mass, age and percent total mass of contents in each pit layer for VIP 1 and 2 (Wood, 2013)

VIP 1				VIP2		
Layer	Depth [m]	Ash per slice [kg]	Time per slice [years]	Depth [m]	Ash per slice [kg]	Time per slice [years]
1	0 to 0.5	44	0.78	0 to 0.5	84	1.79
2	0.5 to 1.0	150	3.44	0.5 to 1.0	160	4.10
3	1.0 to 2.0	380	10.38	1.0 to 2.0	330	8.65
Total	0 to 2.0	574	14.60	0 to 2.0	574	14.54

2.6 Factors affecting faecal sludge characteristics

Faeces and urine that are added to the pits and vaults are transformed through processes that occur in the pits and vaults; these in turn will transform the characteristics. The decomposition process has been theorised to be dominantly anaerobic in the deeper levels of the pit, and aerobic close to the surface of the sludge (Buckley et al., 2008a). In UD vaults, the predominant process occurring is dehydration of the faeces. Some of the factors affecting the processes in the pits are: temperature, surrounding soil characteristics, moisture, pit dimensions, oxygen, storage time and inhibitory substances. Chaggu (2004) listed the following factors that could affect the dehydration of faeces in UD vaults as temperature, storage period and moisture content.

2.6.1 Processes in pit and vaults

The earliest documented studies on biological processes occurring in pits by Franceys et al. (1992) indicate that as soon as excreta are deposited in the pit they start to decompose, eventually becoming a stable material with no unpleasant smell and containing valuable plant nutrients. During decomposition, the following processes take place:

- Complex organic compounds, such as protein and urea are broken down to simpler and more stable forms
- Gases such as ammonia, methane, carbon dioxide and nitrogen are produced and released into the atmosphere
- Soluble material is produced which may leach into the underlying or surrounding soil

- Pathogens are destroyed or deactivated because they are unable to survive in the environment of the decomposing material

2.6.1.1 *Aerobic digestion*

Aerobic digestion is the consumption of biodegradable organic material in the presence of oxygen (Buckley, 2008). In aerobic digestion, the organic waste is mixed with large quantities of microorganisms and air. Microorganisms use the organic waste for food and use the oxygen in the air to burn a portion of this food to carbon dioxide and water for energy. Since these organisms obtain their energy from oxidation, their growth is rapid and a large portion of the organic waste is converted into new cells.

2.6.1.2 *Anaerobic digestion*

Anaerobic digestion is a multi-stage biological process whereby microorganisms in the absence of oxygen, decompose organic matter to carbon dioxide, methane and water (Ross, 1992). Unlike aerobic digestion, the anaerobic conversion to methane gas yields relatively little energy to the microorganisms and thus their rate of growth is slow and only a small portion of the waste is converted to new cells, the major portion of the degradable waste is converted to methane gas. Such conversion to methane gas represents waste stabilisation since this gas is insoluble (McCarty, 1964).

2.6.1.3 *Dehydration*

Dehydration is the net removal of moisture from a substance. The diversion of urine and the addition of cover material result in significant dehydration of faecal material in the UD vault (Chaggu, 2014). A simple model was developed to describe the drying of faecal material in a pit during the active phase. It showed that drying only occurs before material is covered, which results in a uniform moisture content throughout the mass (Brouckaert, 2009).

2.6.2 *Moisture*

In most of the pits that are not sealed, movement of moisture in and out of the pits depend on the type of soil/rock in which the pit is located, the presence and height of groundwater and the amount of water added to the pit (Buckley et al., 2008a). The rate and extent of stabilisation of the sludge is largely limited by chemical factors such as the amount of moisture available (Bhagwan et al., 2008).

Several studies done by Nwaneri (2009) and Bakare et al. (2012) where pit latrines were sampled at different depth profiles (surface, middle and bottom) and (surface, 0.5

m, 1 m and 1.5 m) respectively revealed that there is a general decrease of sludge moisture content with depth. This suggested that most of the pit latrines sampled were located in areas where most of the pit volume was above the ground water level and this implied that there was a net movement of water out of the pit. However, these studies only offer a one dimensional (vertical) view of the moisture movement in the pit which gives limitations. The addition of another dimension (horizontal) will extend the complex understanding of moisture movement in the pit.

If the amount of moisture available is a limiting factor to the rate and extent of the biological properties in the pit, the inverse is that adding moisture to the pit will lead to greater rates and extents of biological processes. However Couderc et al. (2008) concluded that addition of water did not improve gas production rates of VIP material from the lower part of the pit and addition of moisture had a negative effect on the rate of gas production. However, further experiments on fresher VIP material by Nwaneri (2009) revealed that increasing moisture content of VIP material had the potential to increase the rate of stabilisation of buried organic material in the pit. Thus there is no significant benefit of adding water to pits wherein the material is already well stabilised.

A model developed by Brouckaert et al. (2005) predicted that the moisture content during the filling phase of a UD toilet should remain approximately constant if the material entering the vault is also constant. Nevertheless this is not what is usually seen in practise because faecal material is erratically combined with cover material (sand, ash, etc.) forming a highly heterogeneous mixture in UD vaults (Buckley et al. 2008b). The loss of moisture in UD toilets occurs mainly via dehydration. The factors affecting the rate of dehydration in the vaults are temperature, wind, solar radiation and amount of moisture in faeces (Chaggu, 2004). The air circulation rate is important for achieving drying in inactive vaults (Buckley et al., 2008b).

2.6.3 Temperature

Temperature is an important factor affecting microbial growth and biological reactions; however there is little information available regarding temperature values in pit latrines. In anaerobic treatment processes, generally a rise in temperature leads to an increase in the rate of biochemical and enzymatic reactions within cells causing increased growth rates. However, above a specific temperature which is characteristic of each species, it causes inhibition and then mortality as the proteins and structural components of the cells become irreversibly denatured (Anderson et al., 2003). The most favourable temperature range for mesophilic digestion is from 32 to 37°C (Ross, 1992).

2.6.4 pH

Anaerobic microorganisms, especially methanogens exhibit a characteristic sensitivity to the extremes of pH. The best pH range appears to be around neutrality, while the range between 6.5 and 7.8 is generally believed to be optimal (Anderson et al., 2003), however Ross (1992) suggested a pH between 7.0 and 7.5 to encourage the methane producing stage in a wastewater digester. At pH values below 6.2, the efficiency drops rapidly and the acidic conditions produced can be toxic to the methane microorganisms (McCarty, 1964).

In UD toilet vaults where ash is added as a covering agent, Chaggu (2004) found that the pH of the sludge was above 9, this made the vault an unfavourable place for most pathogens, but on the other hand could not allow biological degradation of waste. If however the pH is brought back to neutral, it is still possible to initiate biological conversion. The pH of fresh faeces is reported as varying from 6.8 to 7.3 (Bockus, 1964).

2.6.5 Surrounding soil conditions

The surrounding soil conditions, more specifically, the type of soil and its permeability surrounding the pit affects the movement of moisture out of the pit. If the soil is of a clay nature, moisture and the soluble substances are likely to be retained within the pit, if the soil is sandy, there will be moisture movement out of the pit (Buckley, 2008). The presence and the height of the groundwater will affect the moisture movement in and out of the pit.

Groundwater can be contaminated by a sanitation system; therefore the risk should be assessed or the groundwater periodically monitored, particularly where this water is intended for human consumption. Generally, the susceptibility of a water source to pollution decreases quite sharply with increasing distance and depth from the source of pollution (Austin et al., 1998)

The contaminants associated with on-site sanitation are microbial (bacteria, viruses etc.) and chemical contaminants (human wastes, salts etc.). The rates of contamination for some of the contaminants from VIP latrines have been calculated and are shown in **Table 2-3**.

Table 2-3 Flows and contaminant loads for VIP latrines to groundwater (DWAF, 2003)

Parameter	Value
Flow (l/cap.d)	2
Total P (g P/cap.d)	0.6
Total N (g N/cap.d)	4.5
COD (g O ₂ /cap.d)	12

In UD toilets, the vaults are sealed and thus there no contact between the vault contents and the surrounding soil.

2.6.6 Storage period

In VIP latrines and in UD toilet vaults the sludge depth is usually correlated with the age of the sludge i.e. the deeper the sludge the older it is. Older sludge deeper in the pit is more stabilised than sludge closer to the surface (Buckley, 2008).

The eThekini UD toilet standing vaults are designed to have a drying period of 6 to 12 months while the active vaults are in use. It was assumed by Buckley et al. (2008b) that in this time period the contents become safer and not unpleasant to handle.

2.7 End use of faecal sludge

The downstream use of faecal sludge after it has been removed from the pit or vaults include it's as a fuel and in agriculture. However, the physical and chemical properties and the pathogen content of sludge coming out of pits affect its handling, processing and possible end use. Faecal sludge properties that are important to its end use as a fuel or in agriculture include the calorific value and the thermal conductivity (for use as a fuel) and N, P and K content (for use in agriculture).

2.7.1 Nitrogen

The biggest contributor to the nitrogen content of excreta is in the urine fraction, 93% to the total nitrogen concentration, 84% of which consists of urea-nitrogen which is readily converted to ammonia (Lentner, 1981). Nitrogen plays an important role in the anaerobic digestion processes: it contributes to the stabilisation of the pH value in digesters. However, ammonium in high concentrations may lead to the inhibition of the biological processes (Fricke et al., 2007).

Nitrogen can occur in a number of inorganic forms: ammonia (NH_3), nitrate (NO_3^-), nitrite (NO_2^-) and nitrogen gas (N_2). Ammonia is the most utilised of all the forms of inorganic nitrogen (Anderson et al., 2003). TKN is the sum of free ammonia and organic nitrogen compounds (APHA, 2012).

Ammonia is usually formed in anaerobic treatment from degradation of wastes containing proteins or urea. Ammonia may be present in the form of the ammonium ion (NH_4^+) or as dissolved ammonia gas (NH_3). These two forms are in equilibrium with each other, the relative concentration of each depending on the pH or the hydrogen ion concentration



At neutral pH values, most of the $\text{NH}_3\text{-N}$ will be present as NH_4^+ which is less toxic than dissolved ammonia. However, at pH values that are compatible with anaerobic digestion (pH 8), the equilibrium shifts to the more toxic free ammonia (Anderson et al., 2003). The relationship between the proportions of ammonia present in the system is dependent on pH and temperature and is represented in **Figure 2-3**.

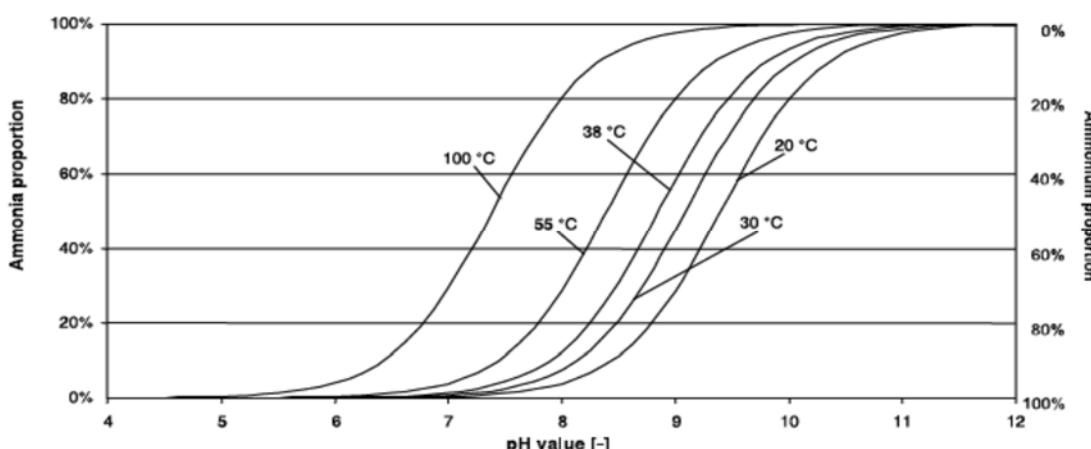


Figure 2-3 Dissociation balance between ammonia/ammonium depending on pH and on temperature (Fricke et al., 2007)

2.7.2 Calorific value

The calorific value of a material is the quantity of heat produced by its combustion. Moisture content affects the self-sustained combustibility and calorific value of a material. An increase in moisture content decreases the calorific value of a material due to the heat of vapourisation of water (Komilis et al., 2014) and therefore a material

is dried before calorific value test are conducted and the result is reported on a dry mass basis.

A study conducted by Nakato et al. (2012) on faecal sludge from different types of on-site sanitation facilities (septic tanks, unlined, partially lined and fully lined pit latrines) in Kampala, Dakar and Kumasi concluded that the calorific value did not vary significantly with the source of the sludge. The age and chemical oxygen demand (COD) content of the faecal sludge were found not to be a predictor for calorific value; however, the moisture of the sludge affects its net calorific value. There have not been any studies on the calorific value of faecal sludge from VIPs and UD toilets in South Africa.

2.7.3 Thermal conductivity

Composting refers to the process by which biodegradable components are biologically decomposed under aerobic conditions by microorganisms (mainly bacteria and fungi). Compost is a stable, inoffensive product that can be handled safely and used as a soil conditioner (Tilley et al., 2008b). Co-composting of faecal sludge allows recycling of nutrients into agriculture, thereby closing the nutrient loop (Cofie et al., 2009). The complex processes in composting include biological, heat transfer and mass transfer processes; the biological activities generate heat, leading to changes in moisture content and temperature conditions. Regarding heat transfers, thermal conductivity is a key role parameter (Huet et al., 2012). On a composting test done on organic solid waste by Huet et al. (2012), thermal conductivity was significantly influenced by moisture content.

2.8 Faecal sludge management in eThekwini

The on-site sanitation facilities that are installed in 13% of the 912,400 households (PRG, 2014a) in eThekwini fill up after a certain amount of time. The chain that deals with the emptying, transport, treatment and disposal and/or end use is called faecal sludge management (FSM) (**Figure 2-4**). This section describes the management of faecal sludge in eThekwini.



Figure 2-4 The faecal sludge management (FSM) chain

2.8.1 Emptying

An emptying service is offered free of charge by the eThekwini Municipality to all households with VIP toilets. This service is offered once in every 5 years (EWS, 2011).

The Municipality conducts this emptying program through hiring a managing contractor who manages a number of subcontractors (Wilson et al., 2012). Due to the nature of the sludge in the VIPs, the difficulty in accessing some areas due to the terrain and housing density, it was decided that manual emptying using shovels, rakes and forks would be the most economical method (Wilson et al., 2012). The sludge is emptied from the pits and placed in 250L bins from which it is transported.



Figure 2-5 Manual emptying a VIP latrine using a shovel

At the implementation stages of the UD toilets, the mandate was for the individual households to empty the vaults when they filled up and the contents have dehydrated. The faecal sludge was to be buried in the yard of the household and a tree planted over it. When the UD toilets were designed, it was assumed that the drying time will be sufficient for pathogen removal and thus the vault content would be safe for the members of the household to remove. However a study on the prevalence and die-off of Ascaris ova in urine diversion found that it is possible that previous studies underestimated helminth persistence and hence overestimated the safety of UD waste and similar waste residues (Buckley et al., 2008b). A study was conducted on the user perceptions of UD toilets a decade after implementation, the results showed that there are low levels of satisfaction with the facilities as well as an association between perceived smell in the toilets and malfunctioning of the pedestal, and low use of UDDTs when a pit latrine is present in the dwelling perimeter (Roma et al., 2013). These results have prompted the eThekweni Municipality to initiate an emptying service similar

to that of the VIP latrines for the UD toilets. This service will also be offered free of charge once in every 2 years. This new initiative will begin in 2016.

2.8.2 Transport

The 250L bins in which the faecal sludge from VIP latrines is placed are transported in trucks and vans to the treatment site. The transporting of the sludge is covered by the contractors responsible for the emptying of the pits.

Prior to the new initiative to offer free emptying for UD toilets; there was no transport component of the faecal sludge from UD toilets as it was buried in the yard of the household. After 2016, it is planned to empty the UD vaults and if spatial and social issues allow, the faecal sludge will be buried in the yard, if burying is not possible – it will be transported in 250L bins to a central processing site (Alcock, 2015)



Figure 2-6 Transport of faecal sludge using 250L bins to the treatment site

2.8.3 Treatment

Faecal sludge from VIP latrines is treated in the Latrine Dehydration and Pasteurisation (LaDePa) machine which is a machine that provides a containerized method of producing a nutrient-rich soil conditioner that is workable and improves sustainability on a number of fronts, by removing the detritus, pasteurizing and drying the sludge to beyond the sticky phase (Wilson et al., 2012). The detritus is separated from the sludge using a variable speed screw and extruded to a porous steel belt; the detritus is bagged and sent to landfill. The extruded faecal sludge is heated with the exhaust heat

from the Genset and with medium-wave infrared. The resultant product is pasteurised faecal sludge.

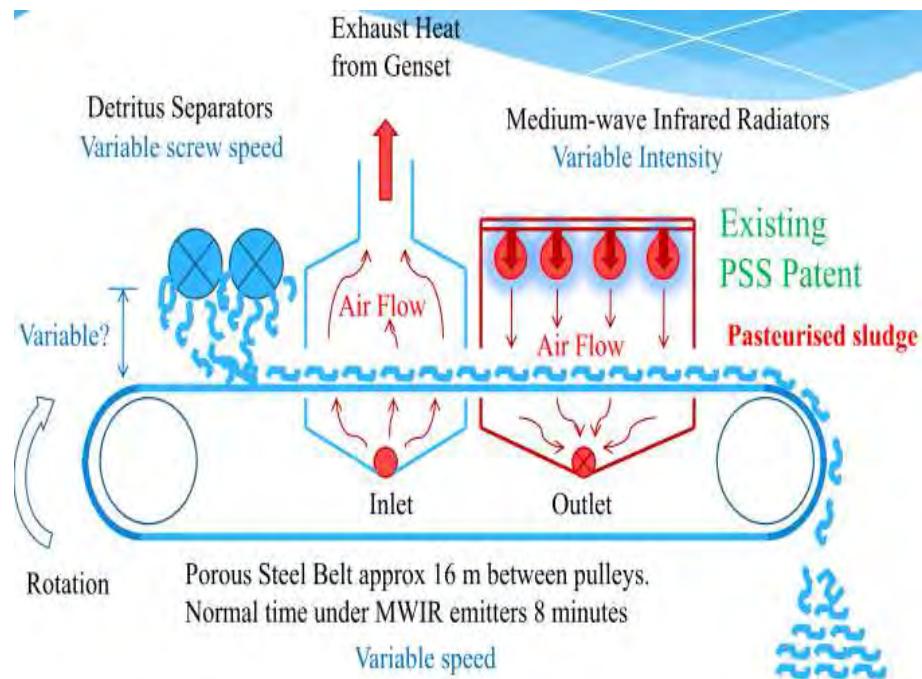


Figure 2-7 Schematic of the LaDePa machine (Wilson et al., 2012)

A UD faecal sludge processing plant is currently being built to test the Black Soldier Fly (BSF) technology for the processing of UD faecal sludge (Alcock, 2015)

2.8.4 Disposal and/or end use

The pasteurised sludge from the LaDePa machine is in the form of pellets. These pellets can be used as a soil conditioner (Harrison et al., 2012). The products from the BSF technology will be larvae for the livestock feed market, oil and soil residue all of which will be sold (Alcock, 2015).



Figure 2-8 Pelletised pasteurised faecal sludge from the LaDePa machine (Wilson et al., 2012)

2.8.5 FSM Costs

The eThekini Municipality is responsible for financing the entire FSM chain. The households are offered an emptying service for VIP latrines once every 5 years for free; any other emptying costs within that time frame are at the householder's expense. The cost to the municipality of emptying a pit is R 2008 (Salisbury et al., 2011) – this includes all the managing contractor's and sub contractor's costs associated with emptying and transport to the treatment site. An economic evaluation of faecal sludge disposal routes was conducted by PRG (2013) - the financial model developed showed that the cost of operating the LaDePa machine is 276 USD/VIP latrine emptied and the production costs for the pellets is 1226 USD/tonne. The machine is estimated to produce 2147 tonnes of pellets per annum.

The pellets are worth 48 USD/tonne based on their NPK nutrient content. In comparison, the maximum competitive selling price for the pellets, if they were to be used to fertilise a dry beans crop in place of an existing organic fertiliser, was 18 USD/tonne. It should be noted that this value is based on the NPK nutrient content of a very small number of pellet samples, and did not take into account micronutrients. On this basis however, the sale of pellets will not cover the cost of producing them.

2.9 Faecal sludge characteristics in eThekini

Various studies have been conducted on the physical and chemical characteristics of faecal sludge in eThekini. A general theory describing the processes that occur in a pit latrine was proposed by Buckley et al. (2008a). This theory describes the fate of the organic material that enters a pit latrine. It proposes four theoretical layers in a pit latrine as shown on **Figure 2-9**. It was hypothesised that the layers are as follows (i) all readily biodegradable originating from faeces is aerobically degraded by naturally occurring micro-organisms within a very short time of arriving on the surface of the pit; (ii) a significant portion of the remaining biodegradable material is aerobically degraded before being covered over by new pit contents; (iii) the remaining biodegradable material, including organic residual from dead cells from micro-organisms and from the original faeces are slowly converted to soluble products, methane gas and carbon dioxide in the buried layers of the pit contents (the fraction of the original organic material that is converted by this path is not large); and finally (iv) the material that remains at the bottom of the pit latrine or after a long residence time in the pit is largely non-degradable.

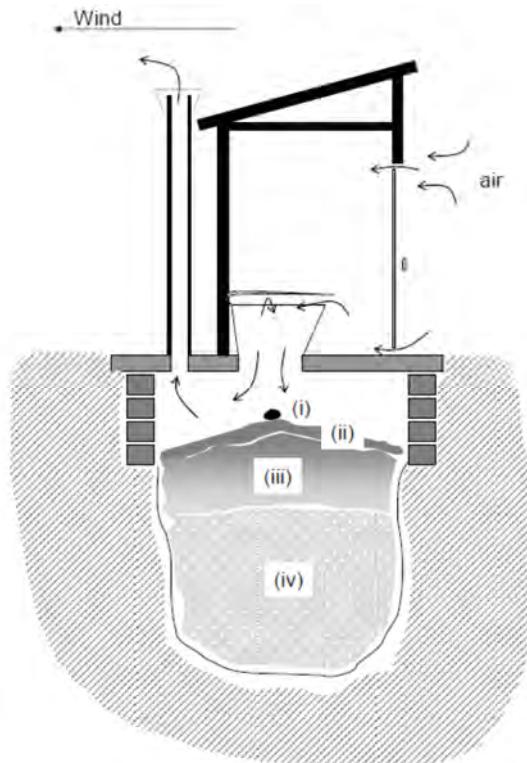


Figure 2-9 Diagram of a pit latrine showing the different theoretical layers (i) fresh stool; (ii) partially degraded aerobic surface layer; (iii) Partially degraded anaerobic layer beneath surface; (iv) completely stabilised anaerobic layer.
(Buckley et al., 2008a)

The subsequent studies of VIP latrines in eThekweni followed this general theory during the sampling of faecal sludge from VIP latrines. A study was conducted by (Bakare, 2011) to determine the COD, moisture content, organic solids and inorganic solids content of faecal sludge samples from 16 pits at 4 different depth levels (0m, 0.5m, 1m and 1.5m). The results showed that there appears to be a regular decrease in, COD content, moisture content and organic solids fraction with increase in the depth of pit contents and there were large variations in the physical and chemical composition both within a pit and from different pits. The results from this characterisation are reported in **Table 2-4**.

Table 2-4 Summary of VIP sludge contents at different layer within the pit. Data are presented as mean value \pm 95% conf. Interval, [min, max] (Bakare, 2011)

Parameters	Units	Surface Layer	0.5 m depth	1m depth	1.5m depth
Moisture	%	76.88 \pm 1.22 [57.58, 85.71]	71.63 \pm 2.58 [30.06, 86.06]	64.60 \pm 2.98 [30.72, 84.83]	67.22 \pm 3.07 [34.71, 87.48]
COD	g/gdrysample	0.603 \pm 0.06 [0.10, 1.23]	0.382 \pm 0.034 [0.05, 0.76]	0.251 \pm 0.030 [0.10, 0.59]	0.244 \pm 0.032 [0.09, 0.49]
VS	%gVS/gTS	57.89 \pm 3.370 [23.60, 94.64]	47.74 \pm 3.90 [3.67, 75.62]	33.95 \pm 4.04 [4.89, 73.57]	36.57 \pm 4.32 [3.94, 74.46]
Biodegrad.	%	52.46 \pm 10.92 [35, 68]	41.35 \pm 9.38 [27, 56]	24.08 \pm 7.73 [7, 44]	16.55 \pm 6.25 [8, 35]

In a study by (Wood, 2013) on modelling the filling rates of pit latrines, 2 VIP latrines were emptied and the faecal sludge sampled as per the (Buckley et al., 2008a) theory. The samples were analysed for pH, alkalinity, moisture content, volatile solids, COD, biodegradable COD, total Kjeldahl nitrogen (TKN), ammonia, total phosphorus and orthophosphate. The results of this study showed that phosphorous, total solids and COD have a decreasing trend with pit depth. Water, nitrogen and alkalinity are not showing to be strongly correlated with depth in the two sampled pits. With regards to the filling rate of VIP latrines, it was found that the presence of rubbish reduces the pit volume and decreases the lifetime of the pit. Many components affect VIP performance; however reducing rubbish will have a significant impact on the pit lifetime. The rubbish content decreases available volume from the pit by existing as a permanent unbiodegradable presence which in essence decreases the years of use before emptying is necessary.

Faecal sludge samples (15) were selected from 11 standing UD vaults were analysed for moisture content, volatile solids content, ash content and COD with the aim to characterise the process of biodegradation in the pits using the anaerobic serum bottle test. The aim of the project was not met as the serum bottle technique proved to be unsuitable for applying to UD waste because the quantities of gas evolved were too low and erratic for meaningful conclusions to be drawn from them. Although the data are insufficient to provide a clear picture of the processes occurring in the vault, it does give a good idea of what will be encountered when emptying a vault that has been through a standing phase. The results of the characterisation are shown in **Table 2-5**.

Table 2-5 Summary of properties of material taken from standing vaults (Buckley et al., 2008b)

Property (% mass)	Range	Average
Moisture	7 – 31	14
Total solids	69 – 93	86
Inorganic solids	58 – 92	82
Organic solids	1.5 – 11	4
COD (g/g)	0.006 – 0.028	0.07

These studies show that the examination of pit latrine contents can assist in understanding the processes that occur in the pits and the conditions of some of the pits in eThekweni. This can enable the municipality to better structure their emptying cycles, educational programs etc. in order to ensure that these facilities are providing an adequate service to the people using them.

2.10 Innovations in sanitation – the need for data

There are several projects/technologies where novel ways of processing faecal sludge while it is in the pit and after it has been removed are being investigated. These projects/technologies are in different stages of development, the one entity they have in common is the knowledge of various properties of faecal sludge in order to design the systems. Some of the projects/technologies have been summarised in and the various properties of faecal sludge that was/will be required to design them are listed.

Table 2-6 Projects/technologies that require knowledge of the properties of faecal sludge and some of the properties required

Project/technology	Company/university	Properties required	Reference
Omni-processor	Janicki Industries	<ul style="list-style-type: none"> • Calorific value • Moisture content • Volatile solids 	(BMGF, 2014)
The excavator	North Caroline State University	<ul style="list-style-type: none"> • Moisture content • Viscosity • Penetrometer 	

Faecal sludge omnivore ingestor	AGI Engineering Beaumont Design DCI Automation Synapse Product Development	<ul style="list-style-type: none"> • Moisture content • Household waste in the pit • Thermal conductivity • Viscosity
The disinfection of latrine FS with ammonia naturally present in excreta	University of California Berkeley	<ul style="list-style-type: none"> • Ammonia content • pH <p>(Ogunyoku et al., 2012)</p>
Black Soldier Fly Technology	EWS/BMGF	<ul style="list-style-type: none"> • Organic content • Inorganic content • Moisture Content • Household waste in the pit • Amount of sludge in the vault <p>(Alcock, 2015)</p>

2.11 Summary

There are 2 different types of on-site sanitation that are provided in eThekweni Municipality, the inputs to these systems vary in composition and quantity as does the location in which they are built – this contributes to the heterogeneity of the contents in these systems. The faecal sludge that emanates from these systems needs to be managed sustainably and efficiently to ensure the systems continue to provide an adequate service to the population. Many innovations in sanitation are currently underway; along with the design of emptying equipment, treatment and/or disposal technologies for existing systems; all these require the properties of the faecal sludge to be known.

3 MATERIALS AND METHODS

The emptying and sampling of 30 on-site sanitation systems consisting of 20 VIP latrines and 10 UD toilets (active and standing vaults) was conducted as part of this project. All the VIP latrines were from Besters (-29.722881, 30.977874) while the UD toilets were from uMzinyathi ([29.690556, 30.905327](#)) both areas are located in the eThekwin Municipality. The faecal sludge emptying was undertaken by a pit emptying contractor employed by the eThekwin Municipality. The laboratory analysis of the faecal sludge samples was conducted at the PRG laboratory at UKZN.

3.1 Description of sampling site areas

The area of eThekwin Municipality, the local authority of Durban, is approximately 2 297 km², with an estimated population of 3 517 157. A survey identified the presence of just over 945 910 households within the municipality consisting of formal houses (55%); informal settlements including backyard shacks (34%); and rural households (11%) (EM, 2014). There are approximately 81 000 UD toilets and 35 000 VIP latrines installed in the eThekwin Municipality, the typical households that have the different types on on-site sanitation systems are shown in **Figure 3-1**.

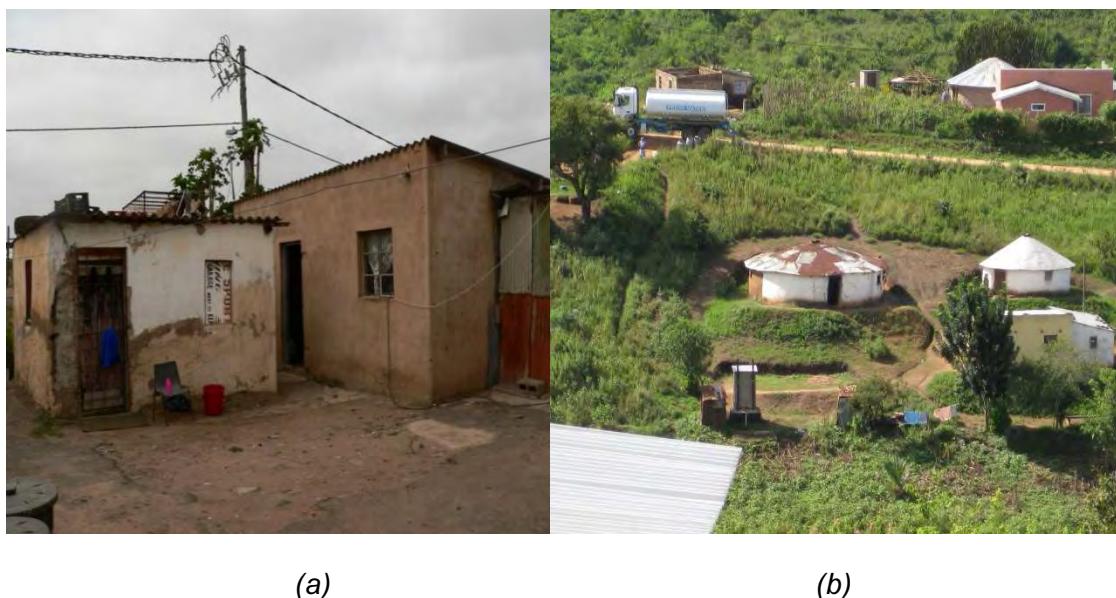


Figure 3-1 (a) A typical household with a VIP latrine in Besters, (b) A typical household with a UD toilet in uMzinyathi

3.2 Sludge emptying and sampling

The selection of the on-site sanitation systems to be sampled was through random selection within Besters and uMzinyathi. The pit and vaul emptying for all the different on-site sanitation facilities was performed manually using shovels and long-handle

forks. A vacuum tanker was occasionally used to extract the liquid from the some of the VIP latrines after the floating solids had been emptied manually.

3.2.1 VIPs

During the emptying process, faecal sludge samples were selected for laboratory analysis. The selection of samples for the VIP latrines was based on the conceptual approach proposed by Buckley et al. (2008a) described in §2.9. This approach was used in the sampling campaign for this study. When the VIP latrine emptying campaign started, different types of VIPs were noted in the field; these different types of VIP latrines required different emptying methods and different number of samples could be selected from the pits. The pits were able to be classified into 3 distinct groups (**Figure 3-2**). Depending on the type of emptying method that was applicable to the VIP latrine; either 8, 3 or 4 samples were selected from each pit.

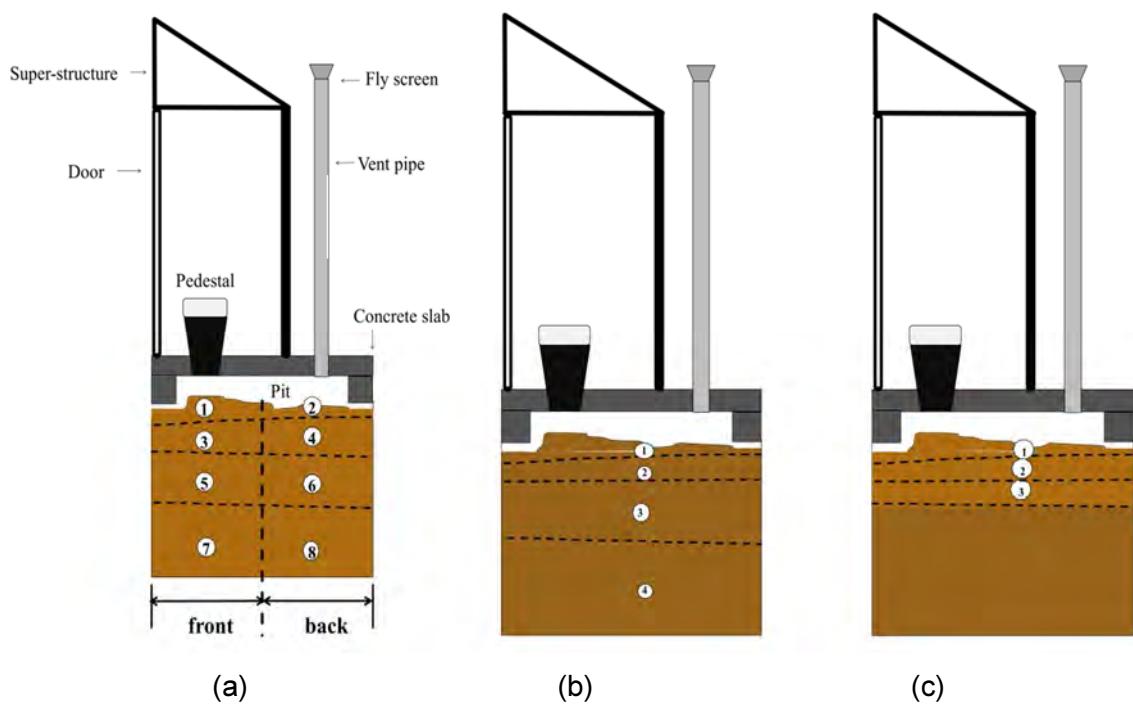


Figure 3-2 (a) Diagram of a VIP latrine showing the layers from which the samples were selected from the front and back sections (b) the depths (m) at which the samples were selected from the front and back sections of the VIP latrine

In the first group (**Figure 3-2 a**), the pit was conceptually divided into 2 sub-sections: a back section (not more than 200 mm from the back wall of the pit) and front section (under the pedestal). Samples were selected from the front and the back sections at 4 depths, therefore a total of 8 samples were selected from each pit.

In the second group (**Figure 3-2 b**), the crust of faecal sludge was sampled at 3 or 4 different depths dependent on the sludge depth. Once the sampling was completed, a vacuum tanker was used to drain the liquid portion of the pit. Samples of the thickened faecal sludge at the bottom of the pit were not taken. The liquid portion of the faecal sludge was transported to a wastewater treatment plant.

In the third group of VIP latrines (**Figure 3-2 c**), the emptying method was similar to that of the first group; with the only difference being that these pits was not divided into the front and back sections. Therefore only 4 samples were selected at 4 different depths. The liquid portion of the faecal sludge was transported to a wastewater treatment plant.

The VIP larine sampling was carried out manually using long-handled spades and forks to remove the faecal sludge from the pit into bins for disposal. Once the concrete back slabs of the pit had been removed (**Figure 3-2**), a long handled fork and a tape measure were used to measure the depth of the faecal sludge in the pit. This was important as not all of the pits that were emptied contained the same depth of faecal sludge. Faecal sludge samples were taken at predetermined depths for laboratory analysis. The faecal sludge samples were selected purposely to exclude any household waste found within the pit, i.e., only faecal sludge samples were taken for laboratory analysis.

In the emptying and sample selection process, surface layer samples were the first to be selected (to a depth of 50 mm) from the front and the back of the pit for the first group of VIP latrines and from the middle of the length for the other 2 types of VIP latrines. In order to reach the second layer, a sludge thickness layer of between 200 and 300 mm was taken out of the pit and disposed. The second layer samples were then taken from the appropriate position for each group of VIP latrines. The middle layer samples varied in depth for the different pits because of the varying faecal sludge depths. For each pit, the middle layer came from the halfway mark of the sludge depth. Therefore, if the faecal sludge depth was 1 000 mm, the middle layer was taken from the 500 mm mark. The bottom layer sample was taken from the last shovel of faecal sludge that was removed from the pit. A single sample was selected from each layer and approximately 1 ℥ of faecal sludge was placed in a plastic bag within a plastic bucket. After filling, the neck of the bag was knotted and then the bucket lid was pressed closed. The 1 ℥ faecal sludge samples were transported to the laboratory and stored at 4°C until analysis. The remains of the pit contents (faecal sludge portion)

were removed by the contractor for treatment in the latrine dehydration and pasteurisation (LaDePa) plant (Harrison et al., 2012).

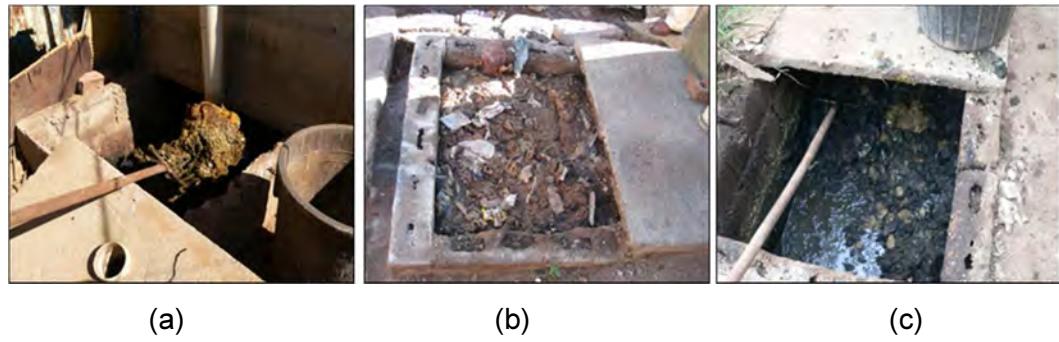


Figure 3-3 Pictures of the group of VIPs noted on the field during the pit emptying and sampling campaign.

3.2.2 UD toilets

UD toilets were emptied and the faecal sludge was sampled in a similar manner as described for VIP latrines §3.2.1. 4 samples were selected at different depths for the active and the standing vaults where possible (**Figure 3-4**). After the vaults had been emptied, a hole was dug next to the toilet and the sludge was buried as per UD toilet procedure for the households.

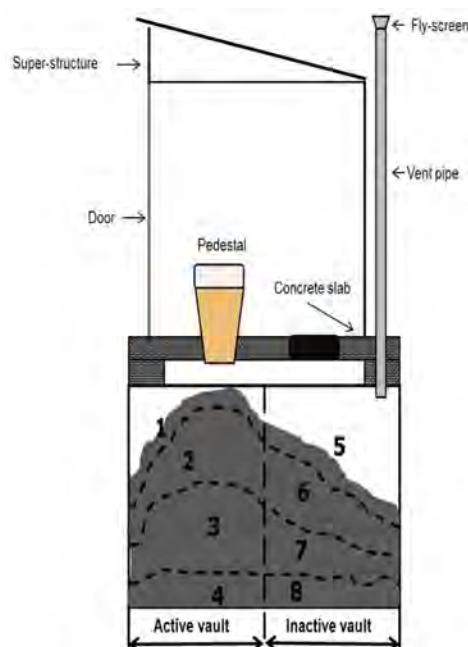


Figure 3-4 Diagram of a UD toilet showing the layers from which the samples were selected in the active and standing vaults

3.3 Pit and vault content characterisation

Two VIP latrines and 1 UD toilet active and standing vaults were randomly chosen so to categorise the contents. The pit content categorisation was carried out manually. Each bin full of sludge was emptied out onto plastic sheeting and the household waste separated by category. Thereafter the sludge and the categories of household waste were weighed. The contents were sorted into the following categories:

- Sludge
- Textiles
- Feminine products
- Lightweight plastics
- Paper
- Stiff plastics
- Metals
- Wood
- Hair
- Glass



Figure 3-5 Manual characterisation of faecal sludge from VIP latrines

The sorting was carried out at the Tongaat Wastewater Treatment Plant – this is the site where the VIP latrine faecal sludge emptied out from eThekwin Municipality is stored in heaps prior to being processed in the LaDePa machine.

3.4 Experimental methods

The laboratory methods used to determine the properties of faecal sludge from the pits and vaults are described in this section.

3.4.1 Method for laboratory analysis

The Standard Methods for the Examination of Water and Wastewater APHA (2012) were used for the following analyses: total solids, moisture content, volatile solids, ash content, total COD, pH, TKN and ammonia. These methods can be found in **Appendix C**.

3.4.2 Sample preparation

Where the analysis required samples in liquid form (COD, TKN and ammonia), faecal sludge dilutions were prepared by weighing a representative mass of the sample of between 1.8 and 2.0 g and making it up to 1 l using distilled water. The solution was mixed in a Waring™ blender for 30 s and then stored in a plastic bottle in a cold room at 4°C until required. The solutions were stored for an average of 1 week before the analyses were conducted. Samples were removed from the cold room and allowed to come to room temperature ($20 \pm 5^\circ\text{C}$) before any analysis was conducted.

3.4.3 Thermal conductivity and calorific value analysis

The thermal conductivity was measured using the C-Therm TCI™ - this apparatus measures thermal conductivity directly. The calorific value of the sludge was measured using a Parr 6200 Oxygen Bomb Calorimeter™ and a 1180P Oxygen Combustion Bomb™, for this apparatus a dry powder sample of the faecal sludge was prepared for measurement. The SOP methods for these analyses can be found in **Appendix C**.

3.5 Laboratory analysis

The faecal sludge samples from the pits and vaults were analysed in the laboratory for the following properties:

- Solids Content: Total solids, Volatile solids
- Moisture content
- Total COD
- pH
- Nitrogen: TKN, Ammonia
- Thermal conductivity
- Calorific value

The relevance of each of the identified properties in the pits and vaults of VIP latrines and UD toilets are listed in **Table 3-1**.

Table 3-1 Laboratory procedures and the relevance of the properties

Laboratory procedure	Relevance
Total solids / moisture content	Water transports the soluble components throughout the pit and is an important factor in biological processes in the pit. It is the largest contributor to the pit volume and determines pit emptying techniques.
Volatile solids / ash	Volatile solids represent the organic solids in the sludge and can be used to determine the degree of stabilisation of the sludge. The ash is the remaining, unchanging portion of the solids (fixed solids). Volatile solids are determined by igniting a total solids sample at 550°C
Total COD	COD is a measure of the organic material in of the sludge and can also be used to determine the degree of stabilisation of the sludge.
pH	pH is one of the environmental factors that influences the rate of anaerobic digestion in pits and can be one of the inhibition factors in the anaerobic digestion process.
Nitrogen: TKN and Ammonia	Nitrogen in various forms is found in the protein fraction of faecal matter and urea in urine. TKN is the sum of organic N compounds, free ammonia (NH_3) and ammonium ion (NH_4^+).

Laboratory procedure	Relevance
	<p>Ammonia in the form of free ammonia and ammonium ion are important in the pH balance in anaerobic digestion.</p> <p>Nitrogen in its various forms also contributes to the nutritional value of sludge and its possible use in agriculture.</p>
Calorific Value	<p>The calorific value of a material is the quantity of heat produced by its combustion. Determining the calorific value of sludge can be used to determine its appropriate use as a fuel.</p>
Thermal Conductivity	<p>Thermal conductivity is the ability of a material to conduct heat, it is important to understanding drying processes of sludge.</p>

4 RESULTS AND DISCUSSION

During the emptying of VIP latrines and UD toilets faecal sludge samples were selected from the front and back sections of VIP latrines at different sludge depths and from different sludge depths of active and standing UD vaults. The selected samples were analysed in the laboratory for the following properties: moisture content, volatile solids, total COD, pH, TKN, ammonia, thermal conductivity and calorific value.

In this chapter, the results from the emptying, sample selection and laboratory analysis are presented and discussed. The relevance of each property analysed is discussed. The data is checked for consistency using correlations to the faecal sludge moisture content. The results of the UD toilets are interpreted: the status of the toilets during sampling and each property is presented for the active and standing vaults of UD toilets.

The VIP latrine results are presented through an analysis of the types of VIP latrines noted during the pit emptying. The results for each property are presented for the front and back sections and the different layers. The sampling locations of the VIP latrines are analysed using statistics and the results from the characterisation of the pit and vault contents are presented and discussed.

4.1 Data consistency check

Due to prior knowledge and conceptual theories developed for the processes that occur in VIP latrines and UD toilet vaults it is possible to draw inferences on how the characteristics of faecal sludge are meant to vary in relation to another faecal sludge characteristic. In this section, all the faecal sludge data from the laboratory analysis is plotted against the moisture content as water forms the largest volume in pits and vaults. The COD and calorific value of the sludge is plotted against each other as these 2 characteristics are related. This data consistency check will assist in identifying any outliers or unexpected trends.

The Pearson's product moment correlation (r) gives a measure of how close the relationship between two types of variables is to a straight line. There is no convention as to which r -values should be described as a strong or weak correlation. However, as a guide, the following can be used (Townend, 2012):

r-value	± 1	\longleftrightarrow	± 0.9	\longleftrightarrow	± 0.6	\longleftrightarrow	0
Correlation	STRONG		WEAK		LITTLE OR NONE		

4.1.1 Volatile solids

There is a positive correlation expected between faecal sludge moisture content and volatile solids in VIP latrines. The longer the time that the sludge is in the pit, the volatile solids decrease due to anaerobic processes occurring and the moisture content is lost through leaching/draining and compaction (Buckley et al., 2008a). The operation of UD toilets requires that users add cover material after each use of the vault. This cover material may be sand, soil, ash etc. and thus has varying volatile solids content, the quantity of cover material added is also not known. Therefore, there are no expectations of the correlation between moisture content and volatile solids content in UD toilets.

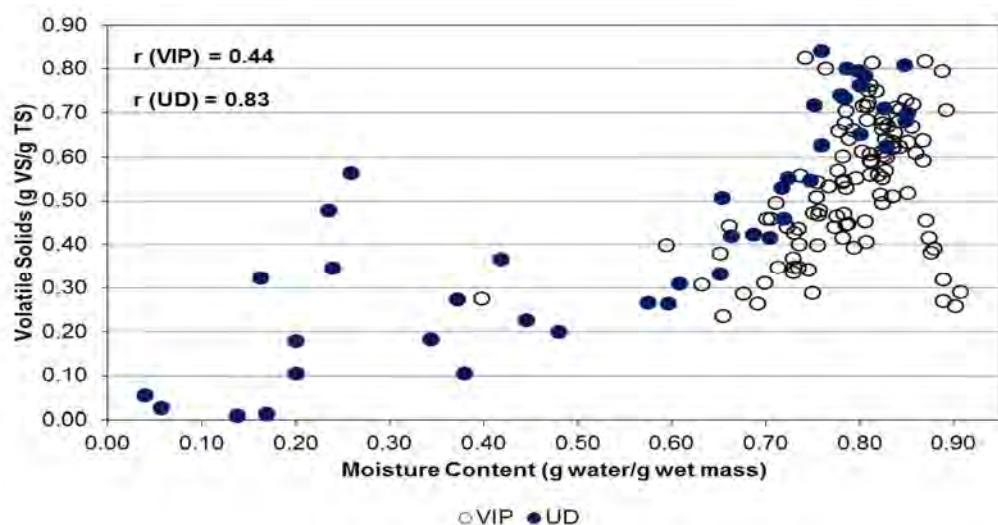


Figure 4-1 Correlation of faecal sludge moisture content (g water/g wet mass) to volatile solids content (g VS/g TS) for VIP latrines and UD toilets

There is a little or no correlation between faecal sludge moisture content and volatile solids in VIP latrines ($r = 0.44$), while there is a weak positive correlation in UD toilets ($r = 0.83$) (Figure 4-1). The sludge from UD toilets has a stronger correlation than VIP latrine faecal sludge. There are outliers in both sets of data; there is UD sludge of low moisture content but high volatile solids and VIP latrine faecal sludge of high moisture content but low volatile solids.

4.1.2 COD

Similar to volatile solids, there is a positive correlation expected between the COD and moisture content of faecal sludge from VIP latrines. The r -value of 0.45 shows that there is little or no correlation between the moisture content and COD in VIP latrine faecal sludge (Figure 4-2). UD toilet faecal sludge had a weak correlation between

moisture content and COD ($r=0.87$). The outliers are mainly from VIP latrine faecal sludge; there are faecal sludge samples with high moisture content but a low COD.

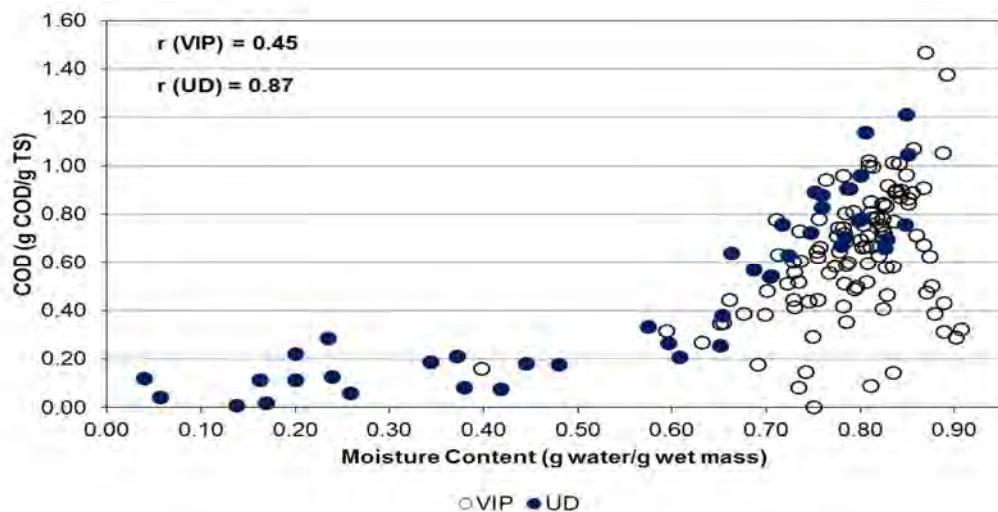


Figure 4-2 Correlation of faecal sludge moisture content (g water/g wet mass) to COD (g COD/g TS)

4.1.3 pH

There is little or no correlation between the pH and moisture content in VIP latrine faecal sludge ($r = 0.16$), in UD toilet faecal sludge there is a weak correlation between the properties ($r=0.60$). UD toilet faecal sludge with low moisture content is mainly acidic to neutral; VIP latrine faecal sludge that is acidic to neutral has high moisture content (**Figure 4-3**).

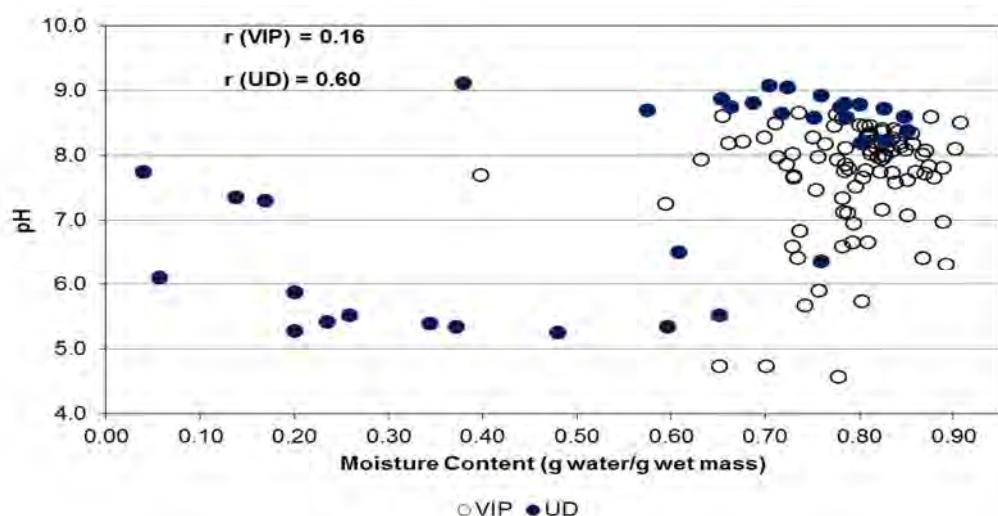


Figure 4-3 Correlation of faecal sludge moisture content (g water/g wet mass) to pH

4.1.4 Ammonia

There is a positive correlation between the moisture content and ammonia for UD toilet faecal sludge (**Figure 4-4**); the correlation in UD toilet faecal sludge is weak ($r=0.74$) while there is little or no correlation ($r=0.36$) for VIP latrine faecal sludge. There are a number of faecal sludge samples with low ammonia content however; the moisture content of the samples varies widely. For the VIP latrine faecal sludge, the samples with the highest ammonia content also had high moisture content.

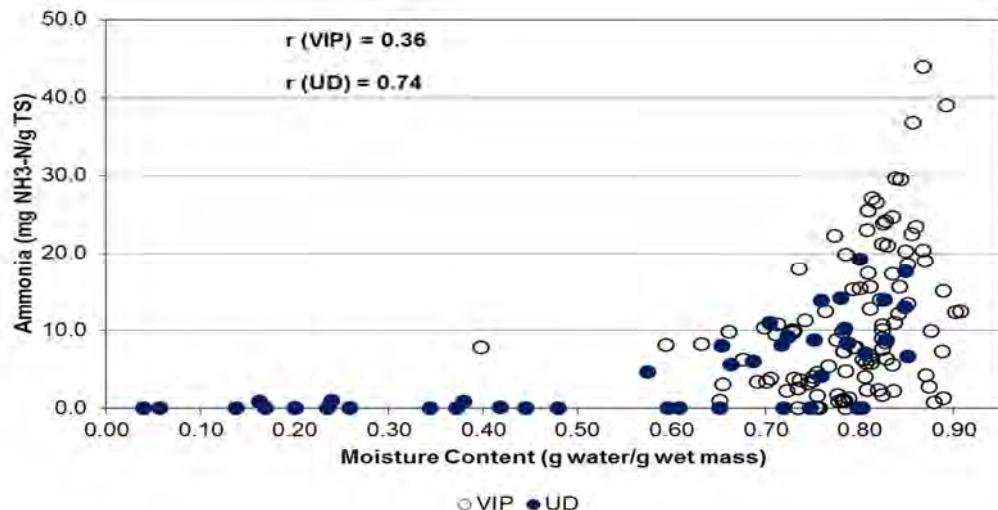


Figure 4-4 Correlation of faecal sludge moisture content (g water/g wet mass) to ammonia (mg NH₃-N/g TS)

4.1.5 TKN

The correlation between moisture content and TKN is positive for both VIP latrine and UD toilet faecal sludge (**Figure 4-5**); the correlation in UD toilet faecal sludge is weak ($r=0.80$) while there is little or no correlation ($r=0.34$) for VIP latrine faecal sludge. As the moisture content increases, so does the variation in TKN between the sludge samples. The samples with minimal TKN content vary in their moisture content.

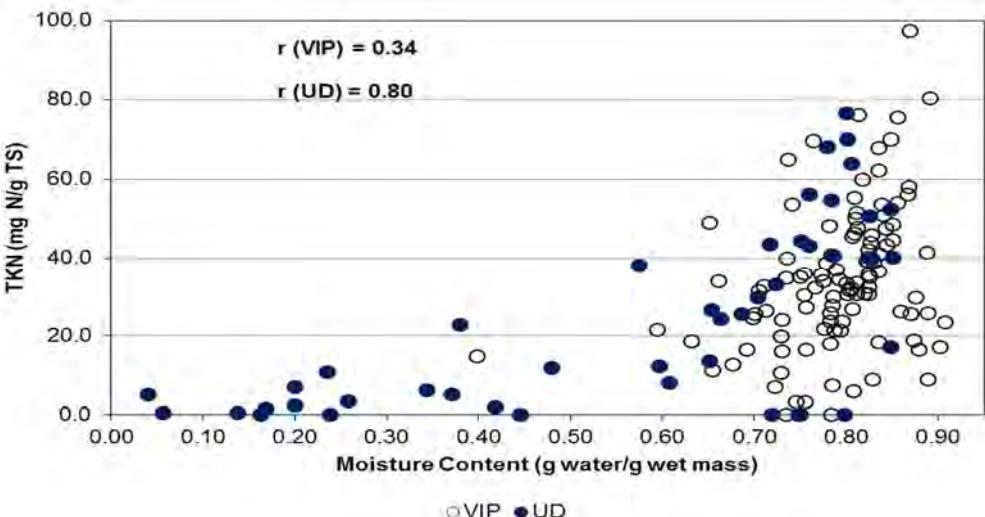


Figure 4-5 Correlation of faecal sludge moisture content (g water/g wet mass) to TKN (mg N/g TS)

4.1.6 Thermal conductivity

The correlation between thermal conductivity and moisture content is negative for VIP latrine faecal sludge ($r=-0.36$) and positive for UD toilet faecal sludge ($r=0.51$). There is little variation in the thermal conductivity at faecal sludge moisture content of between 0.63 to 0.91 g water/g wet mass (**Figure 4-6**). The outliers are mostly UD toilet faecal sludge samples which have thermal conductivity of lower than 0.40 W/(m. K).

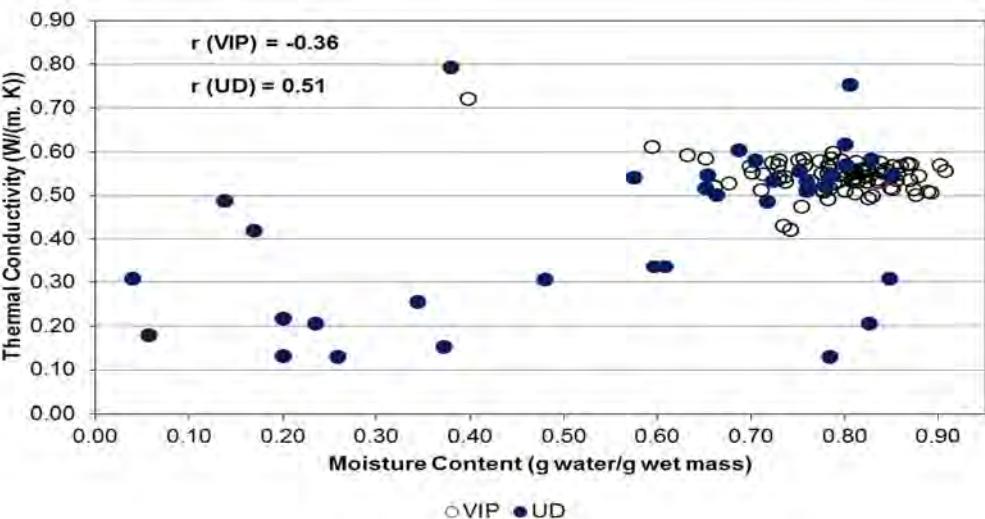


Figure 4-6 Correlation of faecal sludge moisture content (g water/g wet mass) to thermal conductivity (W/(m. K))

4.1.7 Calorific value

There is little or no correlation between the calorific value and the moisture content of the faecal sludge ($r=0.55$) from VIP latrines (**Figure 4-7**); there is weak positive

correlation between the calorific value and the moisture content in UD toilet faecal sludge ($r=0.70$). There are VIP latrine faecal sludge samples with a high moisture content, but low calorific value. There are samples from UD toilet faecal sludge with a low moisture content, however they have a high calorific value.

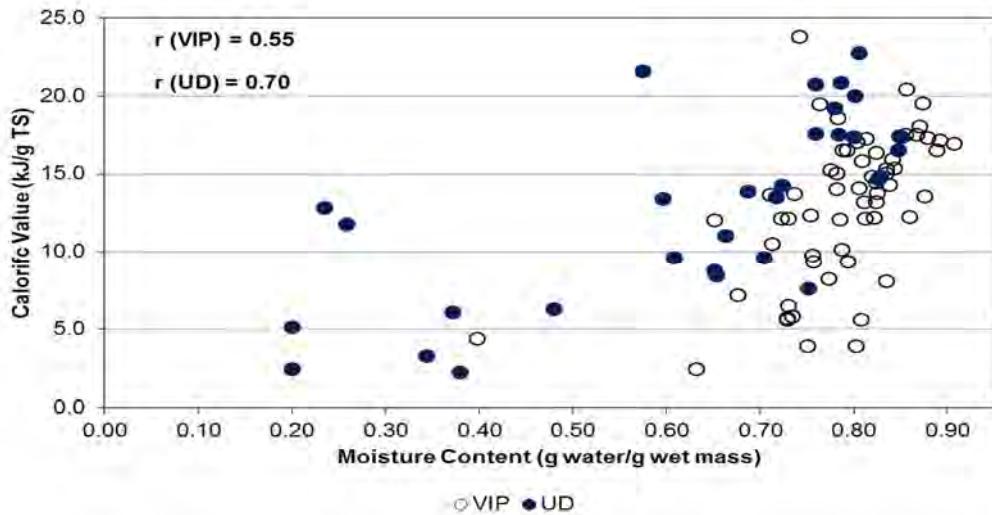


Figure 4-7 Correlation of sludge moisture content (g water/g wet mass) to calorific value (kJ/g TS)

A positive correlation is expected between the calorific value and COD of faecal sludge as they are both measures of the amount of organic content in faecal sludge. The results show that there is little or no correlation between the calorific value and the COD of the sludge for VIP latrine ($r = 0.42$) and UD toilet faecal sludge ($r = 0.49$) (Figure 4-8).

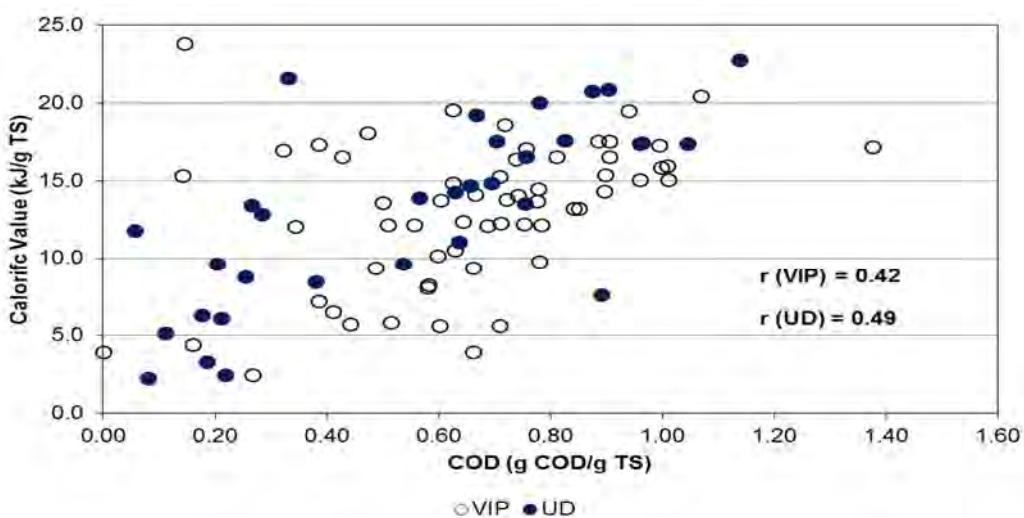


Figure 4-8 Correlation of faecal sludge COD (g COD/g TS) to calorific value (kJ/g TS)

4.1.8 Discussion

The characteristics of UD toilet faecal sludge correlated better to the moisture content than those of VIP latrine faecal sludge. There were strong correlations for UD toilet faecal sludge between the moisture content and volatile solids, COD and TKN. There were little or no correlations between moisture content and thermal conductivity and between COD and calorific value.

In VIP latrine faecal sludge, there was little or no correlation between the moisture content and the characteristics analysed. The higher r-values were for calorific value, volatile solids and COD, all these characteristics are indicators for organic content of the sludge. The faecal sludge characteristics with the lowest correlations were pH and TKN. Thermal conductivity was found to have a negative correlation to VIP latrine sludge; this is the only characteristic that displayed a negative correlation.

The VIP latrines in this study were classified into 3 categories (see §4.3.1) based on visual observation of the shape of the sludge surface in the pit as well as the emptying method used to evacuate the sludge from the pit. Upon further analysis of the correlation data, and plotting each VIP latrine data separately, it was found that for 1 type of VIP latrine has higher r-values for volatile solids and COD correlated with moisture content. In the other 2 types of VIPs, the r-values were close to zero and in some cases they were negative; this in turn decreased the overall r-value for the VIP latrine correlations for volatile solids and COD correlated with moisture content. In the 2 types of VIP latrines with small and negative r-values, the sludge in the pit was well mixed due to the presence of excess water and thus the sludge depth was not an indicator of the sludge age.

The range of faecal sludge moisture content varies for UD and VIP toilets; the UD toilet faecal sludge moisture content varies from 0.04 to 0.85 g water/g wet mass; whereas that of VIP latrine faecal sludge varies from 0.40 to 0.91 g water/g wet mass. The number of samples for correlated for UD toilet faecal sludge is on average half of that correlated for VIP latrine faecal sludge for the different characteristics. Both these factors can affect the resultant r-value for the correlations. Thus, this can make it appear that the moisture of VIP latrine faecal sludge has weaker correlation to the other characteristics than that of UD toilet faecal sludge.

Studies on faecal sludge calorific value by (Nakato et al., 2012) showed that faecal sludge COD was not a predictor for its calorific value. This has been shown as well with the results from this study (**Figure 4-8**), where there is little or no correlation between

faecal sludge and COD for both VIP latrine and UD toilet faecal sludge. This may be due to the calorific value being able to measure a wider range of organic molecules which may not be oxidised in the COD measurement.

4.2 UD toilets

The results from the sampling (**Section 3.2.2**) and the laboratory analysis (**Section 3.4**) of sludge from UD toilets are presented in this section. The status of each UD toilet during emptying is discussed. The results from the laboratory analysis are presented for the active and standing vaults.

Hypotheses

- UD toilets are being used by the households according to the procedure provided by eThekweni Water & Sanitation (**§2.3 and Appendix D**).
- The UD toilet active vault contents are dry as urine is diverted to the soakaway.
- The UD toilet standing vault contents are dry, decomposed, non-objectionable and are acceptable to the household to handle.

4.2.1 Status of UD toilets

Ten UD toilets were included in the vault emptying and sludge sampling campaign for this study, these were chosen randomly in order to get a sense of how the UD toilets were being utilised by the communities in which they are installed. **Table 4-1** shows the status of each of the toilets' active and standing vaults. The UD toilets are numbered in the order that they were emptied. The active and standing vaults will be denoted by the letters A and S respectively, thus A1 and S1 are the active and standing vaults of UD 1.

Table 4-1 Status of the 10 UD vaults at the time of emptying

UD	Active Vault	Standing Vault
UD 1	No urine separation	Decomposing
UD 2	Not being used	Decomposing
UD 3	No urine separation	Emptied, there is still some sludge in the vault
UD 4	No urine separation	Decomposing
UD 5	Urine separation occurring	Emptied, there is still some sludge in the vault
UD 6	Urine separation occurring	Empty
UD 7	Urine separation occurring	Used for storage
UD 8	No urine separation	Decomposing
UD 9	No urine separation	Not being used
UD 10	No urine separation	Not decomposed

*Note: All toilets are assumed to be in use except where indicated

For the active vaults, no urine separation means that the visual observation showed that the faecal sludge was wet and there was strong evidence of urine in the sludge. Urine separation occurring means that the faecal sludge looked dry and there was no evidence of urine present in the vault. For the standing vaults, decomposing means that the sludge looked dry and not decomposing means that the faecal sludge in the vault was similar to that of the no urine separation active vaults (**Figure 4-9**).

The observations while emptying the vaults showed that 3 out of the 10 UD active vaults were being used properly (UD 5, 6 and 7). There were 6 where it was visible that there was no urine separation occurring i.e. both urine and faeces were present in the vault (UD 1, 3, 4, 8, 9, 10). UD 2 was not being used as the household had installed a flushing toilet in the house; 4 contained faecal sludge that was decomposing (UD 1, 2, 4, 8); 2 were empty (UD 6, 7), of those 1 was being used as a storage space. 2 had been emptied; however there was still faecal sludge left over that could be sampled (UD 3, 5). 1 standing vault had faecal sludge that had not decomposed (UD 10).

The standing vaults that were sampled had been standing (not being used) for various lengths of time, the exact dates of the changing over of the pedestal by the users could not be established. It is unknown the way in which these standing vaults were operating when they were active. It can be hypothesised that if the UD toilet had an improper functioning active vault at the time of the visual observation, the standing vaults were functioning improperly as well during their active phase.

From the results of the status of UD toilet vaults, data from the following UD toilets will be presented; active vaults: 1, 3, 4, 5, 6, 7, 8, 9 and 10, standing vaults: 1, 2, 3, 4, 5, 8, 10.



Figure 4-9 The visual appearance of the sludge during sampling from the different UD toilet vaults. Top left: well-functioning active vault (UD 6); top right: decomposing inactive vault (UD 2); bottom left: vault being used for storage (UD 7); bottom right: active vault where no separation was occurring (UD 10).

4.2.2 Moisture content

The moisture content data for the active vaults (A1 – A10) and the standing vaults (S1 – S10) are presented in **Figure 4-10**. There is a wide variation of sludge moisture content in the active vaults – the overall range is from 0.20 to 0.85 g water/g wet mass. The faecal sludge from the 3 UD toilet vaults that were deemed by visual observation to be functioning properly i.e. urine separation was occurring (A5, A6, A7), has the lowest moisture content. From the UD toilet vaults where no urine separation was not occurring (A1, A3, A4, A8, A9 and A10), the moisture content of the faecal sludge ranges from 0.38 to 0.85 g water / g wet mass. The moisture content of faeces has a mean value of 0.746 g water/g wet mass ($n=47$) with a range of 0.630 to 0.860 g water/g wet mass (Rose et al., 2015). It follows that in vaults where the moisture content of the faecal sludge was higher than 0.746 g water/g wet mass; separation was not occurring.

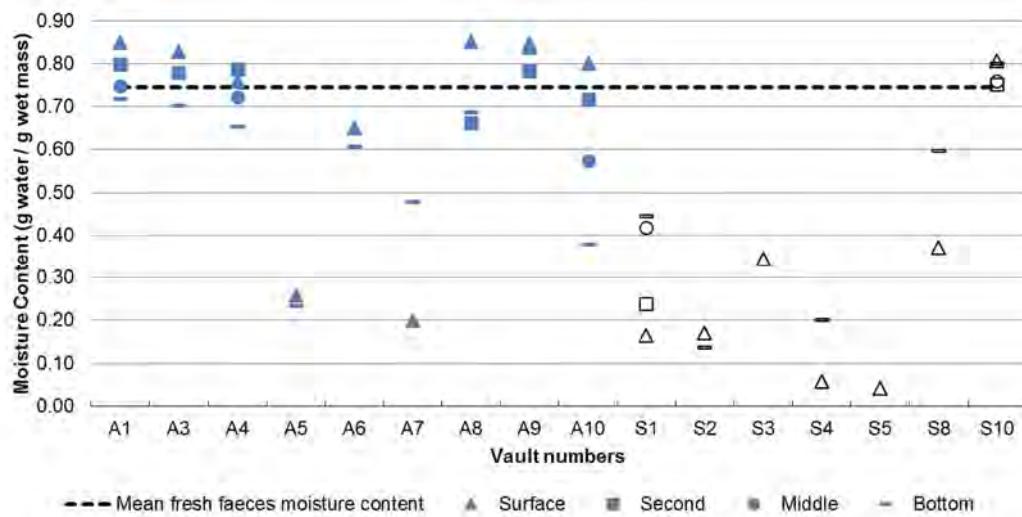


Figure 4-10 Moisture content (g water/g wet mass) for 9 UD toilet active vaults and 7 UD toilet standing vaults. Mean fresh faeces moisture content from (Rose et al., 2015)

The faecal sludge in the standing vault S10 which was visually determined not to have decomposed had the highest moisture content; this ranged from 0.75 to 0.81 g water/g wet mass; this is similar to the moisture content of its active vault and higher than the mean moisture content of faeces. The faecal sludge in the decomposing standing vaults has a moisture content which ranges from 0.04 to 0.60 g water/g wet mass with a mean of 0.27 g water/g wet mass.

4.2.3 Volatile solids

The volatile solids content in the faecal sludge ranges from 0.10 to 0.84 g VS/g TS in the active UD vaults (**Figure 4-11**). There is a wide variation of volatile solids content between the UD toilets; in the use of UD toilets it is advised that a cover material (e.g. sand, ash etc.) be used to cover the solids in the vault after each use. The organic content in the cover material that is used is unknown. The amount and frequency that each household uses the cover material has an effect on the volatile solids content of the faecal sludge. The average volatile solids content for fresh faeces is 0.84 g VS/gTS (Nwaneri, 2009); all of the faecal sludge samples have volatile solids content of less than the mean for fresh faeces.

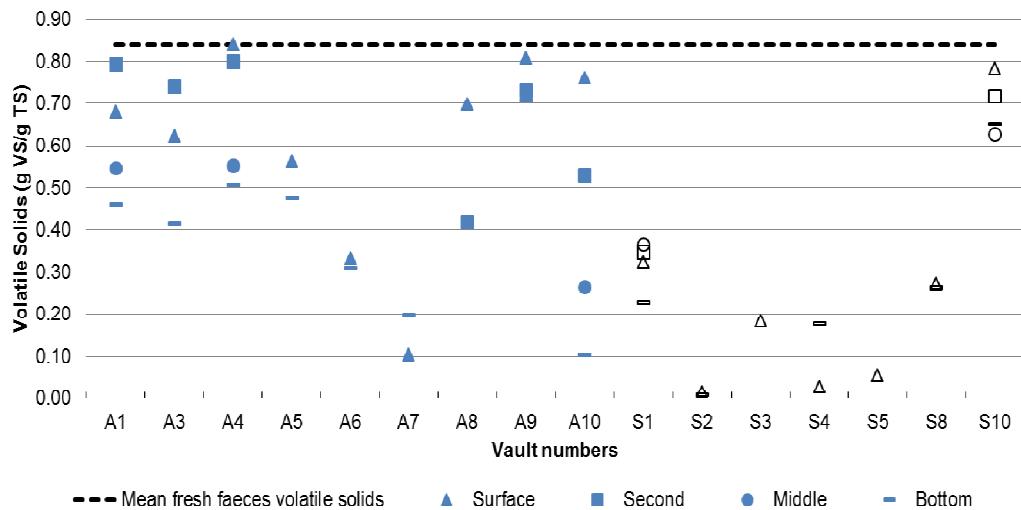


Figure 4-11 Volatile solids (g VS/g TS) for 9 UD toilet active vaults and 7 UD toilet standing vaults. Mean fresh faeces moisture content from (Nwaneri, 2009)

The faecal sludge in the standing vaults has low volatile solids except for S10 which in the visual observation was seen not to be decomposed. The volatile solids content of the sludge in S10 is comparable to the sludge in the active vaults. The volatile solids in the standing vaults range from 9.4×10^{-3} to 0.78 g VS/g TS. In the standing vaults S2, S4 and S5 – the faecal sludge has low volatile solids content; this is in line with a low organic content cover material used in UD vaults like sand.

The volatile solids content of the faecal sludge in S10 is higher than that of A10. Visual observation of S10 showed that the sludge was not decomposed and thus is expected to have a high volatile solids content and moisture content as see in **Figure 4-10**. This could be attributed to a change in the UD toilet user behaviour in the current active vault i.e. urine is being diverted and sand is being added to the vault after use.

4.2.4 COD

The COD content of the faecal sludge in the active vaults varies between the UD toilets, the range is from 0.10 to 1.78 g COD/g VS (**Figure 4-12**), the mean COD for fresh faeces was reported to be 1.31 g COD/g VS (n=11) (Nwaneri, 2009). The most of the sludge samples have a COD content of less than that of fresh faeces. There was no noticeable trend in the COD of the faecal sludge from the surface to the bottom layers of the standing vaults.

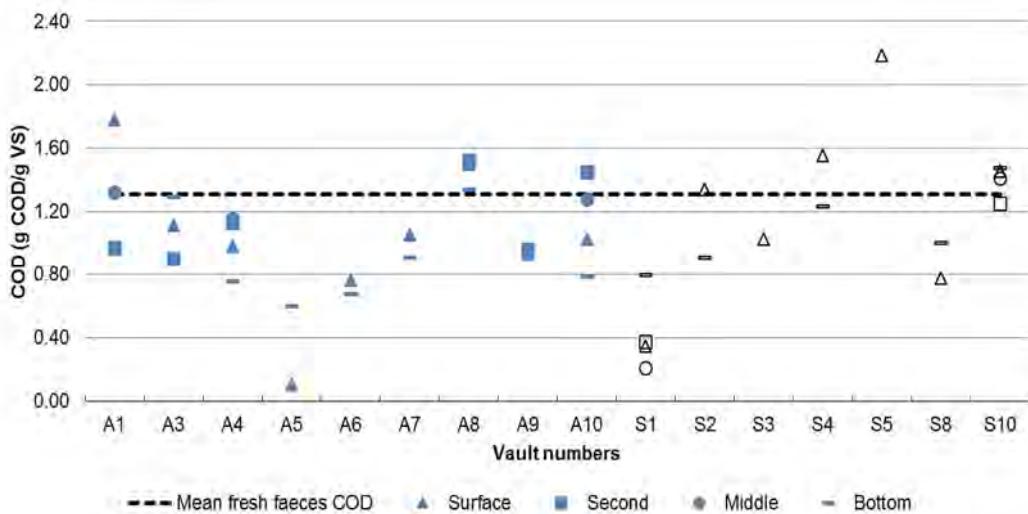


Figure 4-12 COD (g COD/g TS) for 9 UD toilet active vaults and 7 UD toilet standing vaults. Mean fresh faeces COD from (Nwaneri, 2009)

The COD in the standing vaults ranges from 0.21 to 2.18 g COD/g VS. The sludge from S10 has a high COD content which is comparable to that of the active vaults. Faecal sludge from the standing vaults S1 had low COD values which is consistent with decomposed material.

4.2.5 pH

The faecal sludge from the active vaults of the UD toilets that were deemed to not separating urine mostly has a pH of above 8 (Figure 4-13). The median pH of fresh faeces is 6.64 (Rose et al., 2015). The faecal sludge from A5, A6 and A7 had pH of mostly less than 6. The pH in the active vaults ranged from 5.3 to 9.1.

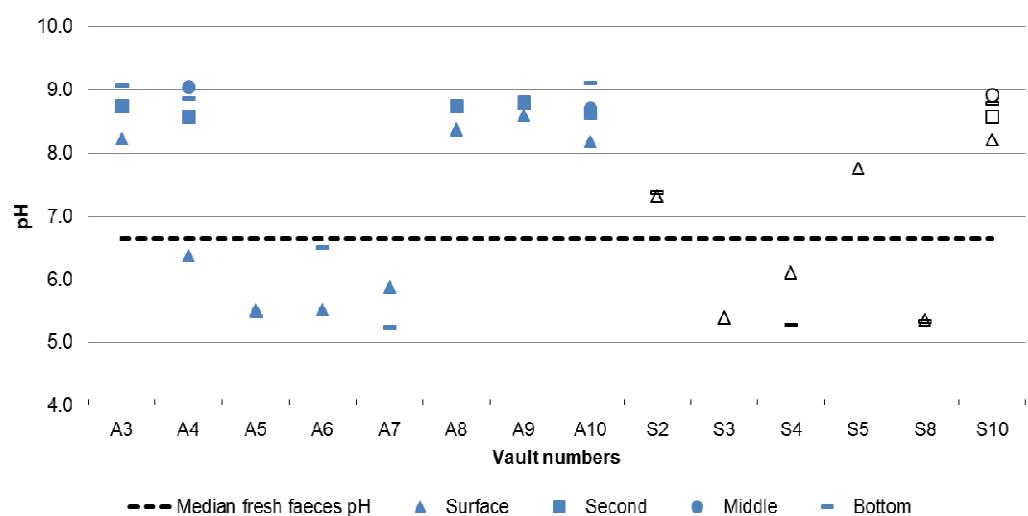


Figure 4-13 pH for 8 active UD toilet vaults and 6 UD toilet standing vaults

The pH of the faecal sludge in the inactive vaults ranges from 5.3 to 8.9. The pH of sludge in S10 is between 8.2 and 8.9.

4.2.6 Ammonia

In excreta, the majority of the ammonia is contributed through the urine component, therefore in faecal sludge from UD vaults there should be no ammonia present. In the active vaults, the faecal sludge from A5, A6 and A7 has 0 ammonia content; these were the vaults which were deemed to have separation occurring from the visual observations. The remainder of the UD active vaults had ammonia content ranges from 4.9 to 27 mg NH₃-N/g VS (**Figure 4-14**).

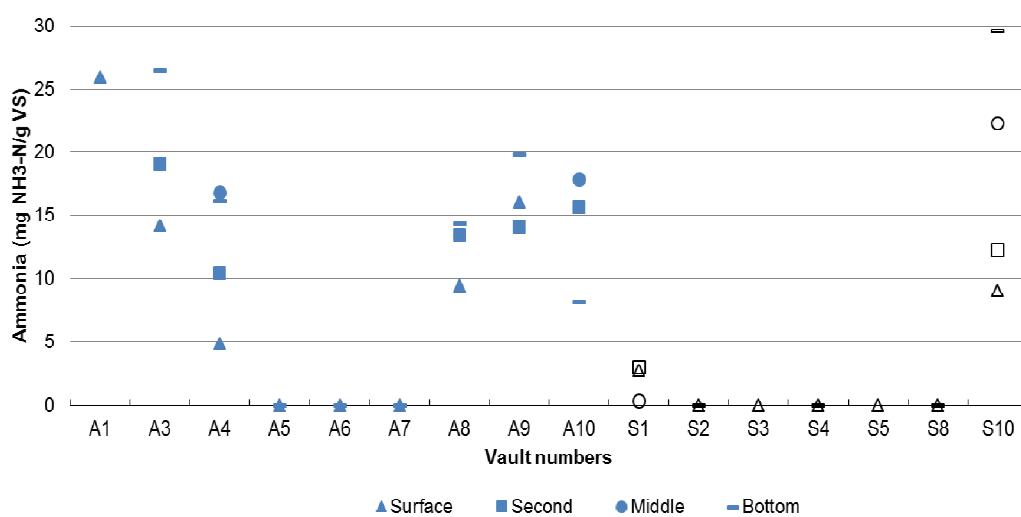


Figure 4-14 Ammonia content (mg NH₃-N/g VS) for 9 UD toilet active vaults and 7 UD toilet standing vaults

There are low levels of ammonia in the faecal sludge from the standing vaults which were decomposing with a number of samples having 0 ammonia content. The only vault having some amount of ammonia was S10; the ammonia content in the vault ranged from 9.0 to 30 mg NH₃-N/g VS.

4.2.7 TKN

The TKN in the faecal sludge in the active vaults ranges from 6.2 to 220 mg N/g VS (**Figure 4-15**). The TKN varies through the UD toilets with faecal sludge from A5, A6 and A7 having the lowest TKN content which is comparable to the standing vaults TKN content.

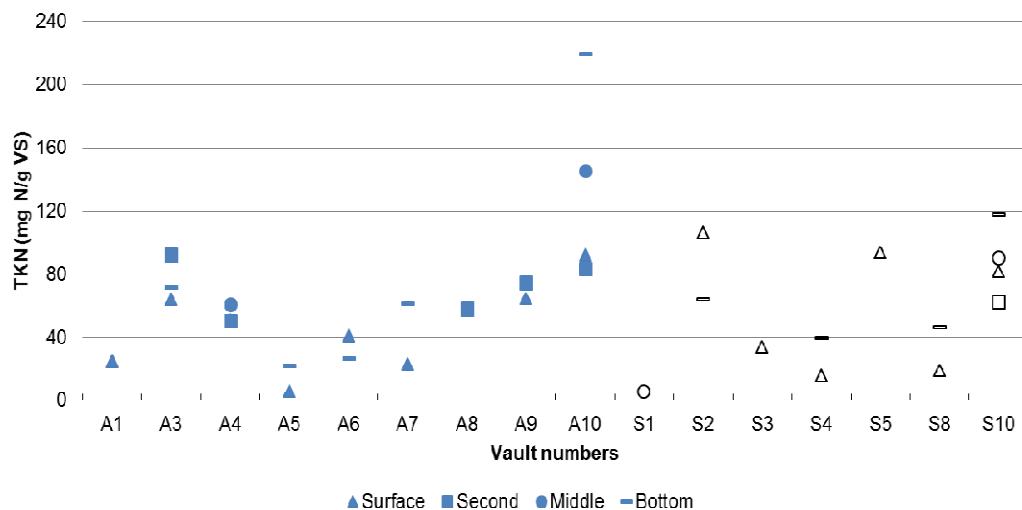


Figure 4-15 TKN (g N/g VS) for 9 UD toilet active vaults and 7 UD toilet standing vaults

The faecal sludge from S10 standing vault has the highest TKN content which is comparable to that of the active vaults; this is due to the sludge in this vault having volatile solids values comparable to that of the faecal sludge in the active vaults. The remainder of the standing vaults have a low TKN content. The TKN content of the standing vaults ranges from 5.7 to 118 mg N/g VS.

4.2.8 Thermal conductivity

In active vaults there is no distinguishable difference between the thermal conductivity of the UD toilets where separation was occurring to the ones where separation was not occurring (**Figure 4-16**). The thermal conductivity of the faecal sludge ranges from 0.13 to 0.79 W/(m.K).

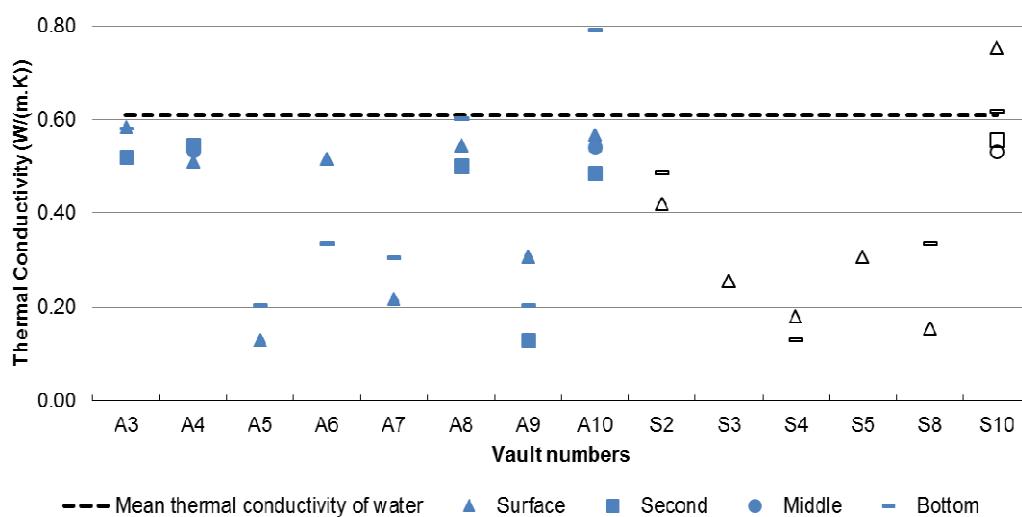


Figure 4-16 Thermal Conductivity (W/(m.K)) for 8 active UD toilet vaults and 6 standing UD toilet vaults

The thermal conductivity of the faecal sludge in the standing vaults is comparable to that of the active vaults. The thermal conductivity in the standing vaults ranges from 0.13 to 0.75 W/(m.K).

4.2.9 Calorific value

The calorific value of the faecal sludge in the active vault ranges from 21 to 83 kJ/g VS (**Figure 4-17**). There is no difference between the UD vaults where urine separation occurred and those where urine separation did not occur.

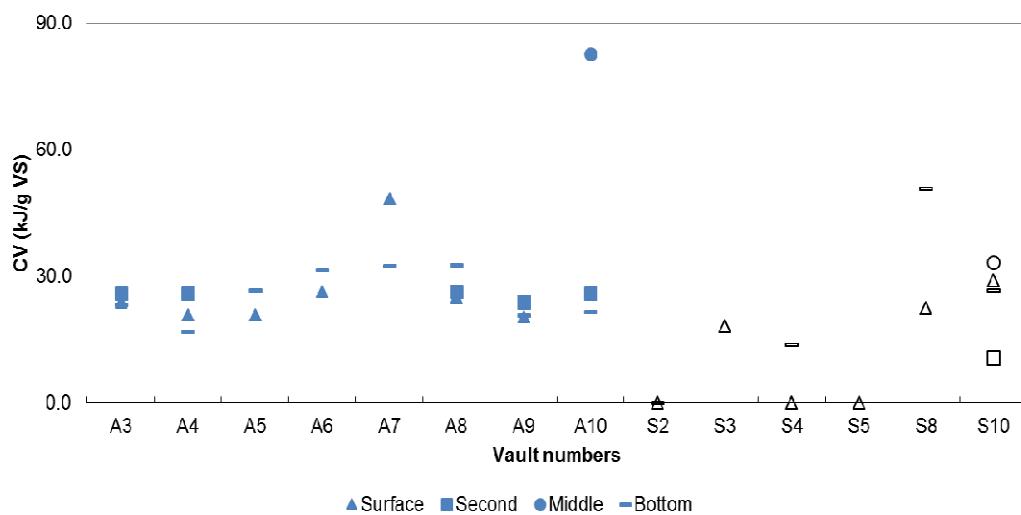


Figure 4-17 Calorific Value (kJ/g VS) for 8 active UD toilet vaults and 6 standing UD toilet vaults

In the standing vaults, there is a variation in the faecal sludge calorific value, S8 and S10 had the highest calorific value while the other vaults had lower values. There were some faecal sludge samples with a 0 calorific value; this is not expected of faecal sludge; this could be a combination between excess of cover material e.g. sand and a sample that has been decomposed.

4.2.10 Discussion

The status of the UD toilets in this study showed that there are low levels of proper use of the toilets in this study sample. Through the visual observations in the field – it was very clear to see faecal sludge which consisted of only faeces and that which consisted of both faeces and urine (**Figure 4-9** and **Table 4-1**). This is an important result for the treatment of sludge from UD toilets; the design of the treatment technology (e.g. BSF plant) should take into account that the sludge might contain more moisture than anticipated.

In well-constructed and properly functioning UD toilets, the largest contributor of moisture in the vault is the faecal material that is deposited. If the mean moisture content of faeces is used, the moisture content of the sludge in UD toilet vaults should be below 0.746 g water/g wet mass (Rose, 2015). **Figure 4-10** shows the moisture content of sludge for the different vaults at the various layers sampled and it can be seen that only 3 UD toilet active vaults (UD 5, 6 and 7) have sludge with moisture content less than that of fresh faeces.

Following that if UD toilets are operated in a proper manner, there should not be any urine present in the vault and thus there should not be any ammonia present in the faecal sludge. The presence of ammonia in the faecal sludge is due to the urine component of excreta. The pH of urine once urine is excreted rises to 9 – 9.3 due to urea degradation in the presence of urease (Niwagaba, 2009); the median pH of faeces is 6.64 (Rose, 2015). The faecal sludge from vaults A5, A6 and A7 was ammonia free. This is in agreement with the moisture content analysis of these UD toilet vaults as well as the visual observations. In this study, it was found that the pH of the faecal sludge in UD 5, 6 and 7 had values of approximately 6. The other active UD toilet vaults had pH levels of above 8. Thus pH can be used as an indicator of the functioning of a UD toilet vault.

Faecal sludge ammonia content is a more definitive characteristic property than moisture content in the determining of the functioning of UD toilets because the moisture content of faeces varies, however in terms of expense and time; moisture content is the better property and can be further supported by visual observation of the faecal sludge in the vault.

The length of time which the standing vaults had been in the standing phase could not be ascertained as the householders were not sure of the dates at which the pedestal had been changed to the now active vault. From the visual observations, it was seen that most of the standing vaults were in the decomposition phase i.e. the faecal sludge looked dry. This visual observation is supported by the faecal sludge analysis data; the characteristics of the faecal sludge from the standing vaults is comparable to the faecal sludge from the correctly functioning active vaults in all the properties except volatile solids and calorific value. The standing vault S10 was deemed to be not decomposed during the visual observations; this is supported by the characterisation results from that vault which are in most cases as high as the faecal sludge characteristics of the improper functioning active vaults.

Comparisons of faecal sludge properties in UD toilet vaults to fresh faeces characteristics can assist to show how the vaults are operating or were operating during the active phase. For active vaults, the vaults where urine separation was occurring had lower properties than that of fresh faeces for all the characteristics. The active vaults where no urine separation was occurring mostly had higher values than fresh faeces for moisture content, pH and ammonia. For the standing vaults, the characteristics of the faecal sludge in vault S10 were consistently higher than that of the other standing vaults especially in the case of the moisture content, volatile solids and thermal conductivity.

There were not enough samples of the faecal sludge in the standing vaults to be able to support the hypothesis that if the UD toilet had an improper functioning active vault at the time of the visual observation, the standing vaults were functioning improperly as well during their active phase. However, the data showed that UD 10 was not functioning properly.

The range of characteristics for UD toilet faecal sludge is shown in **Figure 4-18** and **Table 4-2**, it is separated into the faecal sludge from the urine separating active vaults, the no urine separating active vaults and the standing vaults.

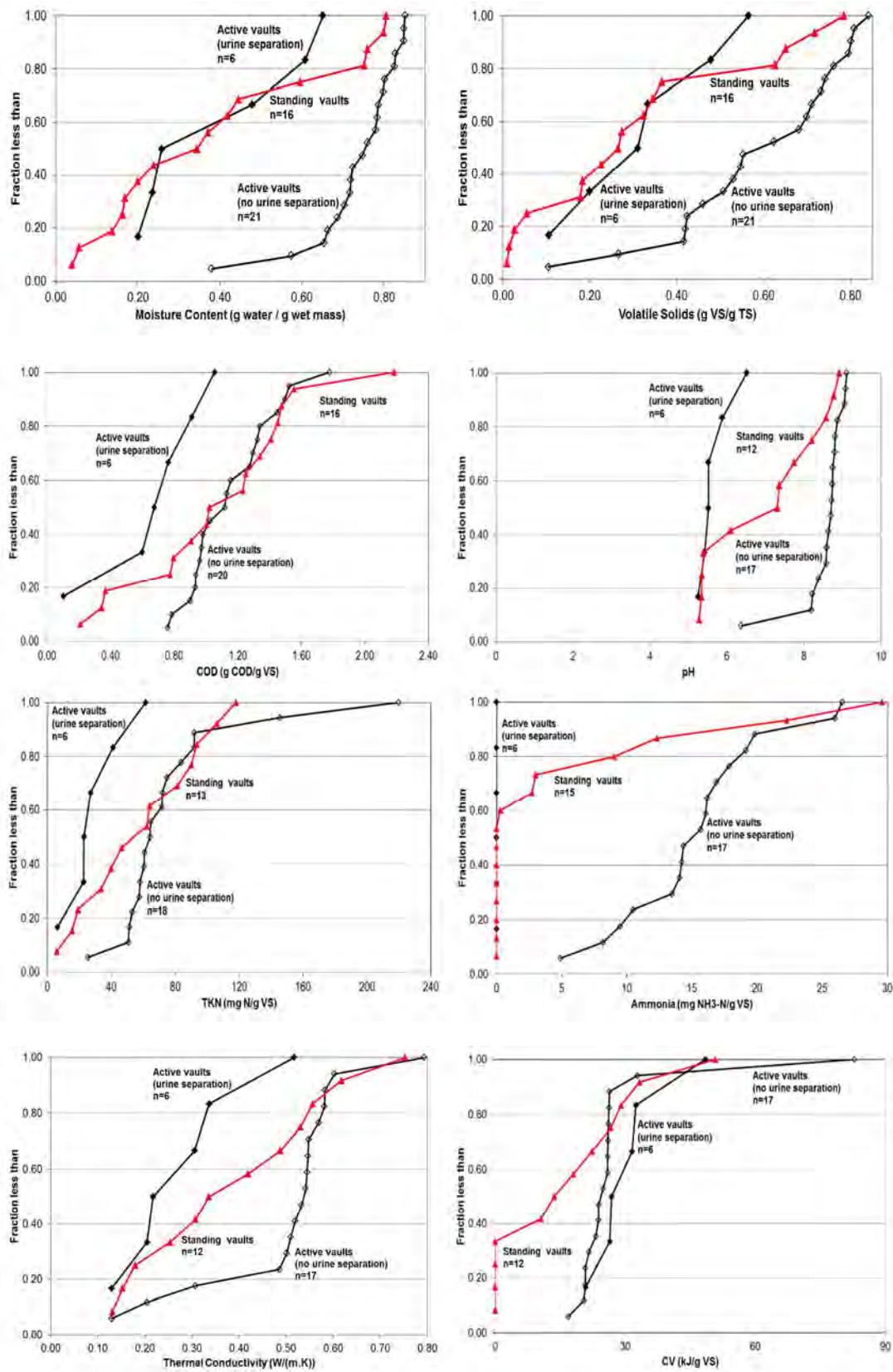


Figure 4-18 Cumulative graphs for UD toilets active vaults (urine separation), active vaults (no urine separation) and standing vaults for moisture content, volatile solids, COD, pH, ammonia, TKN, thermal conductivity and calorific value

Table 4-2 Minimum, median and maximum values for the characteristics analysed for UD toilets active vaults (urine separation), active vaults (no urine separation) and standing vaults UD toilets

Characteristic	Vault	Min	Median	Max
Moisture Content (g water/g wet mass)	Active vaults (urine separation)	0.20	0.37	0.65
	Active vaults (no urine separation)	0.38	0.76	0.85
	Standing vaults	0.04	0.36	0.81
Volatile Solids (g VS/g TS)	Active vaults (urine separation)	0.11	0.32	0.56
	Active vaults (no urine separation)	0.10	0.62	0.84
	Standing vaults	0.01	0.27	0.78
COD (g COD/g VS)	Active vaults (urine separation)	0.10	0.72	1.05
	Active vaults (no urine separation)	0.76	1.12	1.78
	Standing vaults	0.21	1.13	2.18
pH	Active vaults (urine separation)	5.3	5.5	5.9
	Active vaults (no urine separation)	6.4	8.7	9.1
	Standing vaults	5.3	7.3	8.9
TKN (mg N/g VS)	Active vaults (urine separation)	6.2	25	61
	Active vaults (no urine separation)	25	64	220
	Standing vaults	5.7	62	118
Ammonia (mg NH3-N/g VS)	Active vaults (urine separation)	0	0	0
	Active vaults (no urine separation)	4.9	16	27
	Standing vaults	0	0	30
Thermal Conductivity (W/(m.K))	Active vaults (urine separation)	0.13	0.26	0.52
	Active vaults (no urine separation)	0.13	0.54	0.79
	Standing vaults	0.13	0.38	0.75
Calorific Value (kJ/g VS)	Active vaults (urine separation)	21	29	48
	Active vaults (no urine separation)	17	25	83
	Standing vaults	0	16	51

4.3 VIPs

During the emptying and sampling campaign for this study, it was noted that there are 3 types of faecal sludge in VIP latrines in the study area. This classification was based on a visual observation of the faecal sludge in the pit: 3 types of faecal sludge surfaces were noted; one where the faecal sludge forms a ‘cone’ shape under the pedestal, the second where the faecal sludge is flat and the third where the faecal sludge surface is flat but with a crusted surface. The flat surface VIP latrines had regions of visually different moisture content faecal sludge across the width and the depth of the pit. The crusted surface VIP latrine had a faecal sludge crust floating on top of a liquid layer (**Figure 4-19**).

Another practical differentiating feature between the categories was the pit emptying method. In the ‘cone’ shape VIP latrines, the faecal sludge could be moved using a spade and a fork, the faecal sludge would not fall off; the pit could be fully emptied using manual methods. During the emptying of flat surface VIP latrines, the faecal sludge did not stay on the fork during emptying. In the crusted VIP latrines after the manual emptying was completed, a vacuum truck was used to completely empty the liquid portion. For simplification, the different types will be referred to as the following in the subsequent chapters:

- ‘Cone’ faecal sludge surface = *Dry VIP latrine*
- Flat un-crusted faecal sludge surface = *Wet VIP latrine Type I*
- Crusted surface faecal sludge = *Wet VIP latrine Type II*



Figure 4-19 The different types of wet VIP latrines; left: type I; middle: crust of type II; right: water layer beneath the dry crust of type II

4.3.1 Dry vs wet VIP analysis

All the moisture content data for all the *wet* and *dry VIP latrines* has been plotted on one graph (**Figure 4-20**). The 3 types of VIPs have been given short codes:

- Dry VIP (D1 – D10)
- Wet VIP Type I (W1 – W6)
- Wet VIP Type II (W7 – W10)

The numbering of the VIPs is according to the order in which they were emptied. There is no observable change in the moisture content of the VIPs. W9 presents a low moisture content which is due to a very dry crust. The moisture content of the faecal sludge in the *dry VIP latrines* range from 0.65 to 0.89 g water / g wet mass with an average of 0.79 g water / g wet mass. For the *wet VIP latrines Type I*, the faecal sludge moisture content ranges from 0.66 to 0.91 g water / g wet mass with an average of 0.80 g water / g wet mass; for the *wet VIP latrines Type II* the range is from 0.40 to 0.91 g water / g wet mass with an average of 0.75 g water / g wet mass. The maximum faecal sludge moisture content is similar for all the types of pits. The faecal sludge from *dry VIP latrines* and *wet VIP latrines Type I* is similar in the moisture content while the faecal sludge from *wet VIP latrines Type II* has lower moisture content.

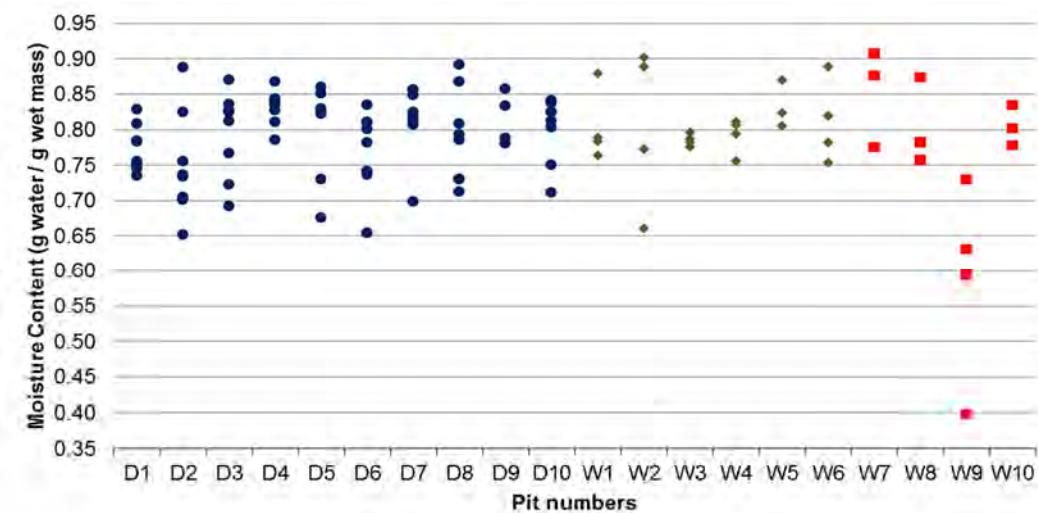


Figure 4-20 Moisture content (g water/g wet mass) per pit for the 10 dry and 10 wet VIPs

A student t-test was used to determine if there was a significant difference between the moisture content of the three types of pits at a 95% confidence level. There was no significant difference found ($p>0.05$) in the moisture content of the faecal sludge from the categories of VIPs; *dry VIP* vs *wet VIP Type I* ($p=0.42$); *dry VIP latrines* vs *wet VIP latrines Type I* ($p=0.28$); *wet VIP latrines Type I* vs *wet VIP latrines Type II* ($p=0.19$).

The results from **Figure 4-20** show that there was not a clear distinction between the 3 types of VIP latrines based on the moisture content. These results can be explained by **Figure 4-21** which illustrates the relationship between moisture content on a wet basis and water content on a dry basis. On a basis of 1g of total solids, if water is added to this gram of TS, the moisture content of the total mass (wet mass) increases. As the moisture content increases, this difference becomes more evident as the amount of water added increases and the moisture content is approaching 1. At a moisture content of 0.75 g water/g wet mass, the amount of water added to the solid is 3.66 g, for a moisture content of 0.85 g water/g wet mass; the amount of water added is 7.09 g. Thus when comparing the moisture content of 2 faecal sludge samples, this cannot be done on a linear basis especially at high moisture contents.

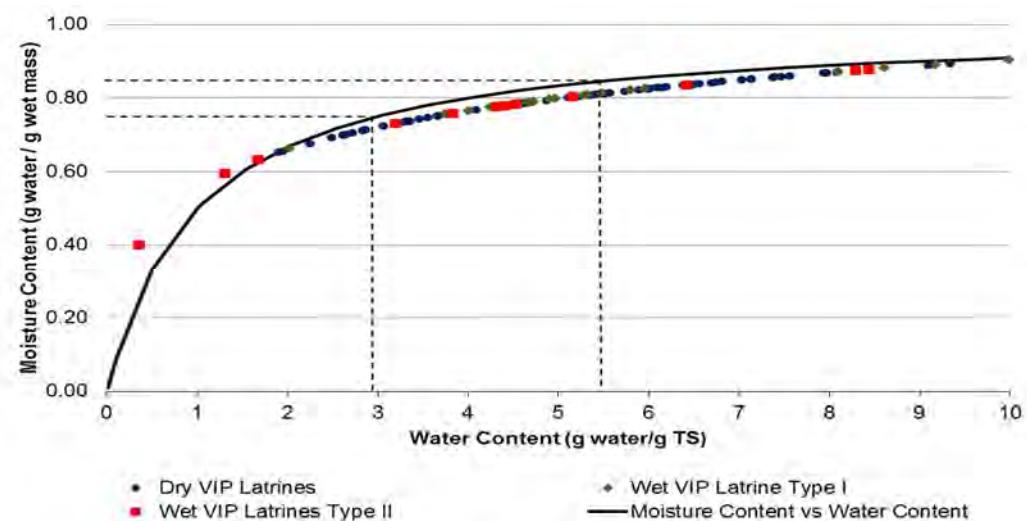


Figure 4-21 Moisture content (g water/g wet mass) and water content (g water/g TS) for 1g of total solids and the moisture content of VIP latrines

The faecal sludge volatile solids, COD, TKN, ammonia and calorific value are expressed per gram total solids.

The *p*-values for the other characteristics properties of faecal sludge are shown in **Table 4-3** – there was a significant difference ($p<0.05$) found in the ammonia content between the sludge of *dry VIP latrines* vs *wet VIP latrines Type I* and *dry VIP latrines* and *wet VIP latrines Type II*. From these results, at a 95% significance level, the characteristic properties of the faecal sludge from the different types of VIP latrines are not significantly different. However, due to the differences in the different emptying techniques required for the *dry* and *wet VIP latrines* during the emptying and sampling process and the visual differences of the faecal sludge – the results of the *dry VIP latrines* and the *wet VIP latrines* will be presented separately.

Table 4-3 p-values for the properties of faecal sludge for dry and wet VIPs

Property	Dry VIP latrine	Dry VIP latrine	Wet VIP latrine
	Wet VIP latrine	Wet VIP latrine Type II	Type I
	Type I		Wet VIP latrine
Moisture Content (g water / g wet mass)	0.42	0.28	0.19
Volatile solids (g VS / g TS)	0.51	0.14	0.25
COD (g COD / g TS)	0.88	0.39	0.35
TKN (g N / g TS)	0.22	0.10	0.41
Ammonia (g NH ₃ -N / g TS)	0.01	0.02	0.71
Thermal conductivity (W / (m. K))	0.71	0.17	0.25
Calorific value (kJ / g TS)	0.27	0.23	0.07

4.4 Dry VIP latrines

Different localities within the VIP latrines are exposed to different conditions during the lifetime of the pit. During emptying and sampling, the pit was conceptually divided into two sections (front and back) and in 4 layers (surface, second, middle and bottom). These results will be presented as raw data for all 10 pits at the average faecal sludge depths from the surface to the bottom. The average of all the 10 pits is calculated and plotted for the front and back sections of the pit. For the characteristics that are affected_by the dominant process in the pit, anaerobic digestion (moisture content, volatile solids, COD and calorific value) the average data is linear regressed as there is an expectation for these properties to decrease linearly with depth.

The VIP latrines that were emptied had varying faecal sludge depth; **Figure 4-22** shows the faecal sludge depths for the 10 dry VIP latrines and the depth of the layers for each pit. For the graphs in this chapter, the average depth for each layer of the 10 pits is calculated and the minimum and maximum depths for each layers are shown as error bars on the x-axis.

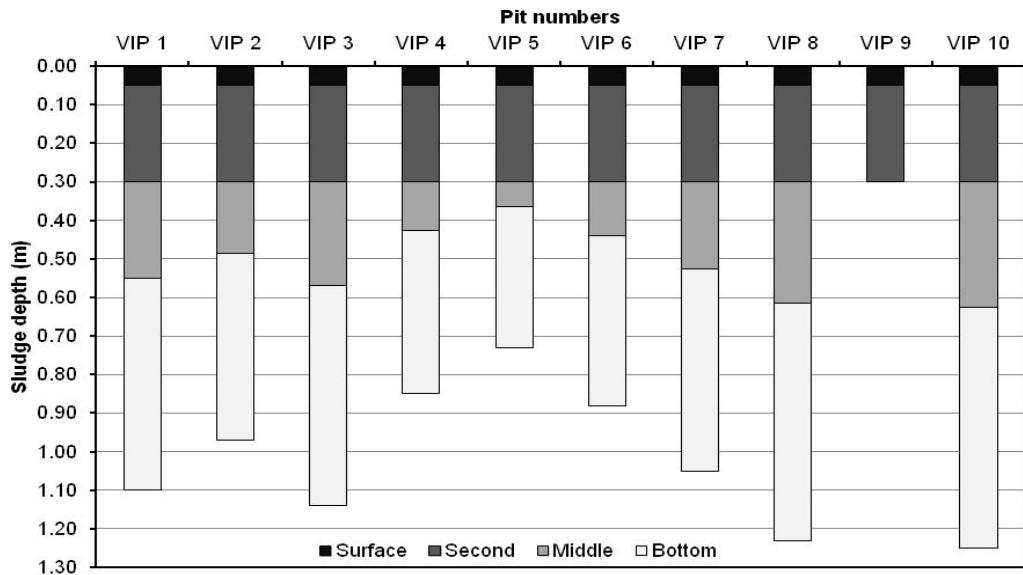


Figure 4-22 Faecal sludge depth (m) and the representation of the different layers of the 10 dry VIP latrines that were emptied

Hypotheses

- Due to the constant addition of material through the pedestal into the front section of the pit; there are differences in the faecal sludge characteristics between the front and back section of the pit.
- Faecal sludge moisture content, volatile solids, COD and calorific value can be accurately predicted at certain faecal sludge depths in the pit

4.4.1 Moisture content

The moisture content raw data of each of the 10 pits is shown on **Figure 4-23** for the front and back sections of the pit. At the surface (0 m), there is little distinction between the 2 sections; as the depth increases the back section has lower moisture content than the front section. The bottom layer has the widest variation of moisture content through the 2 sections; the middle layer has the narrowest variation.

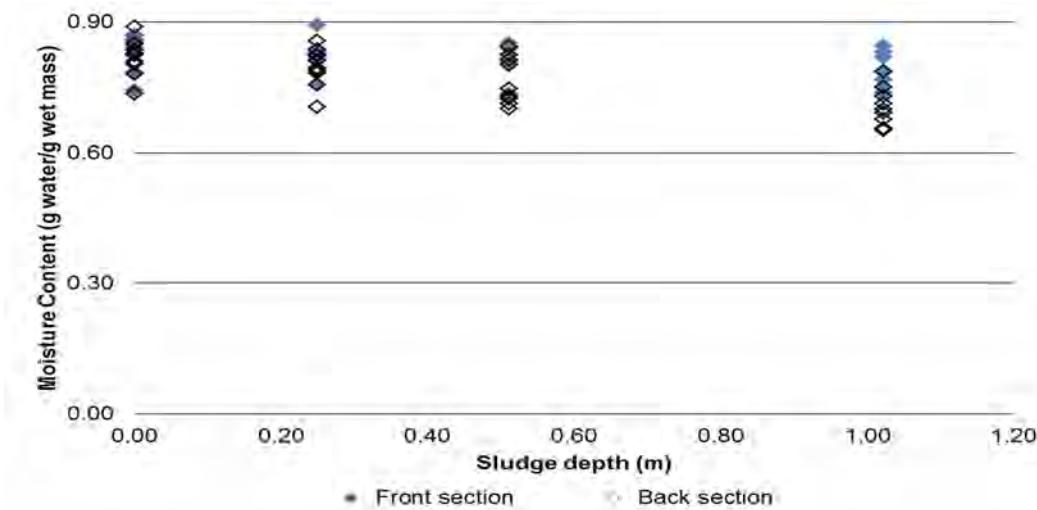


Figure 4-23 Moisture content (g water/g wet mass) for 10 dry VIP latrines at average faecal sludge depths of the layers (m)

On average, there is a moisture decrease in the faecal sludge with increasing depth in both sections of the pit (**Figure 4-24**). A linear regression of the average moisture data shows a very close fit of the data to the line. The back section of the pit has a closer fit than the front section. The decrease in moisture between the layers is steeper in the back section (slope = -0.1137) of the pit than in the front section (slope = -0.0542). The difference in moisture content for the same layers in the different section increases with increasing depth; it increases from 0.01 g water/g wet mass in the surface layer to 0.08 g water/g wet mass in the bottom layer.

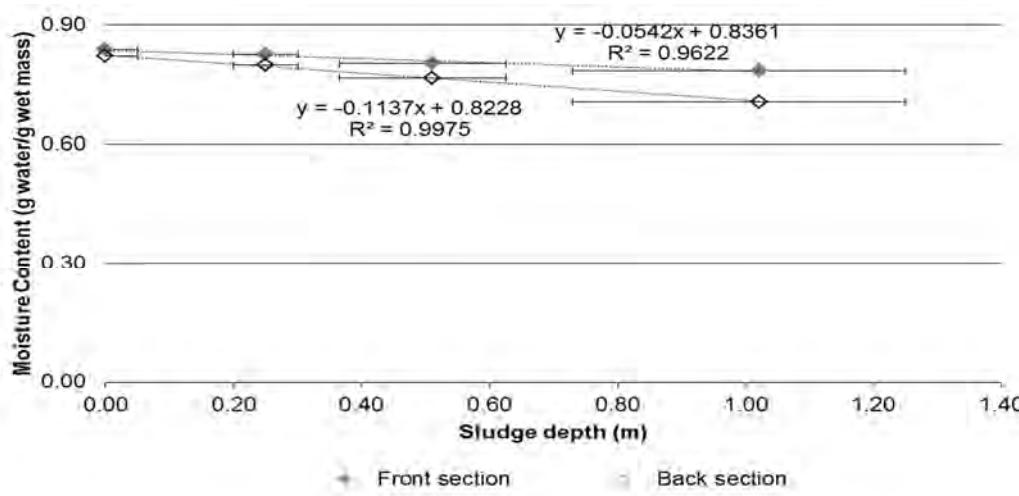


Figure 4-24 Moisture content (g water/g wet mass) for the front and back sections of 10 dry VIP latrines at varying pit depths (m)

4.4.2 Volatile solids

The volatile solids content and the remainder of the characteristics are presented on a total solids basis in order to remove the influence of varying moisture contents of the sludge depth, see **Section 4.3.1**. The volatile solids content in the faecal sludge is expected to decrease with faecal sludge depth due to the anaerobic processes occurring within the pit which degrade the organic material.

The surface (0 m) and middle layers (0.51 m) show little distinction between the volatile solids of the front and back sections (**Figure 4-25**). The bottom layer (1.02 m) has the widest variation of volatile solids content.

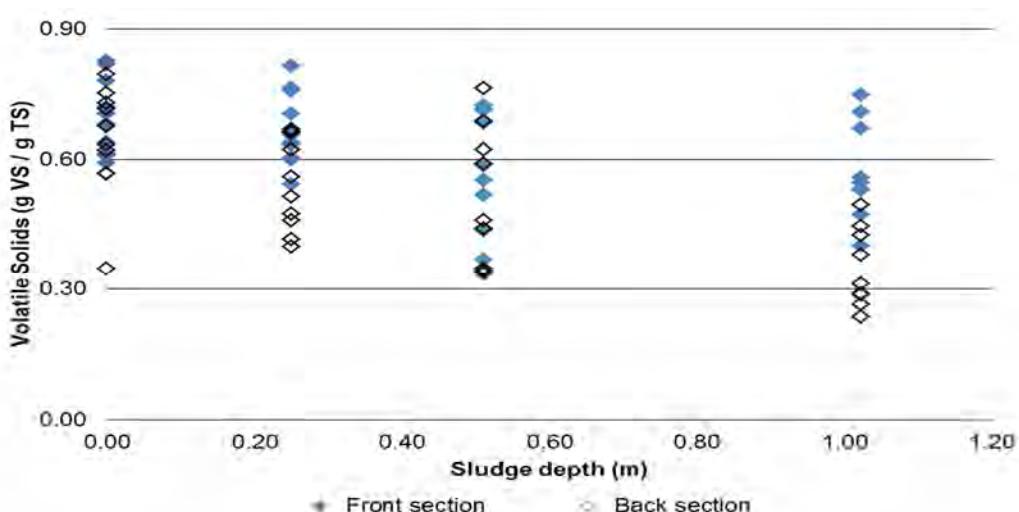


Figure 4-25 Volatile solids content (g VS/g TS) for 10 dry VIP latrines at average faecal sludge depths of the layers (m)

On average, there is a decrease in the volatile solids content from the surface to the bottom of the pit at the front and back sections of the pit (**Figure 4-26**). In the back section, the volatile solids content decreases more steeply (slope = -0.3076) than in the front section of the pit (slope = -0.1433). The back section has a bigger difference in moisture content between adjacent layers than the front section. The difference in volatile solids content for the same layers in the different section increases with increasing depth; it increases from 0.04 g VS/g TS in the surface layer to 0.23 g VS/g TS in the bottom layer. A linear regression of the average volatile solids content data shows a very close fit of the data to the line. The back section of the pit has a closer fit than the front section.

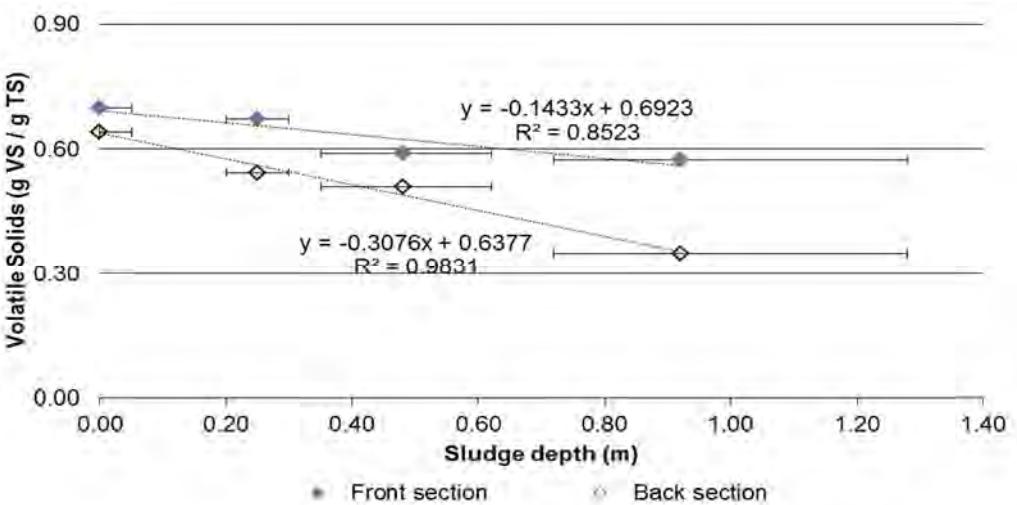


Figure 4-26 Volatile solids content (g VS/g TS) for the front and back sections of 10 dry VIP latrines at varying sludge depth (m)

4.4.3 COD

There is no distinct difference in the COD between the front section and the back section (**Figure 4-27**). The surface layer (0 m) shows the most variation in COD, this may be due to the varying 'freshness' of the top material during the time of sampling. If sampling occurred immediately after the toilet was used, a high COD is expected, if some time had passed since the last used, a lower COD is expected.

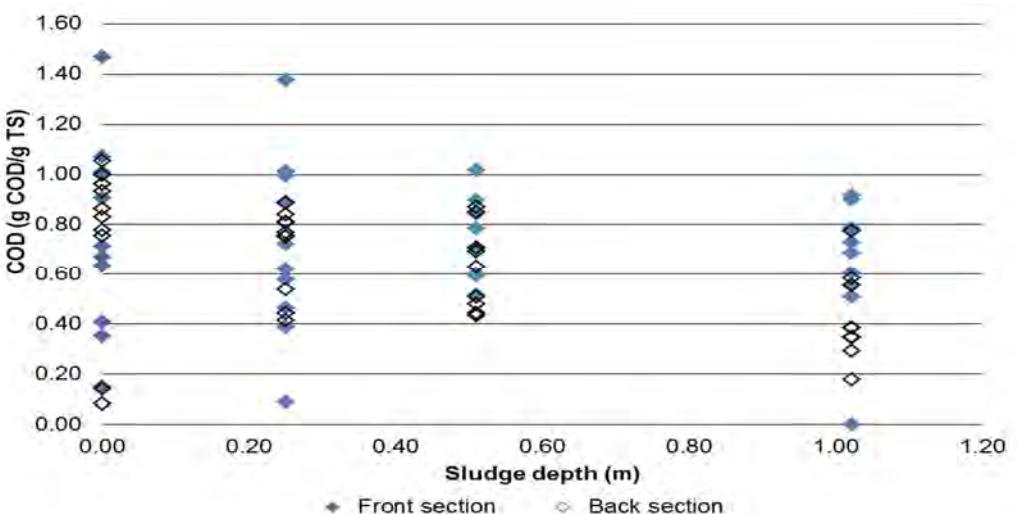


Figure 4-27 COD (g COD/g TS) for 10 dry VIP latrines at average faecal sludge depths of the layers (m)

The average COD of the first 2 layers are similar between the layers and the sections (**Figure 4-28**). The difference in the COD between the layers in the different sections increases with increasing depth; it increases from 0.03 g COD / g TS in the surface layer to 0.20 g COD / g TS in the bottom layer. A linear regression of the average COD

data has a good linear fit for the back section of the pit, while the front section fit can be overestimated at a certain faecal sludge depths. The COD in the back section of the pit changes more steeply (slope = -0.3494) than the front section of the pit (slope = -0.1058).

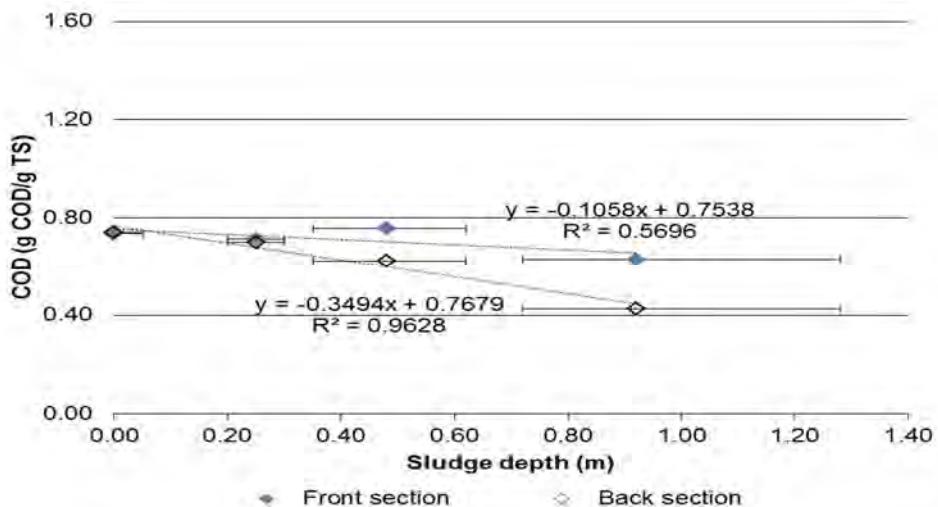


Figure 4-28 COD (g COD/g TS) for the front and back sections of 10 dry VIP latrines at varying faecal sludge depth (m)

4.4.4 pH

There is no distinct difference in the pH of the sections of the pit (**Figure 4-29**). The lowest pH in the pit is from the back section of the pit at 4.74. 70% of the sludge pH is above 8.

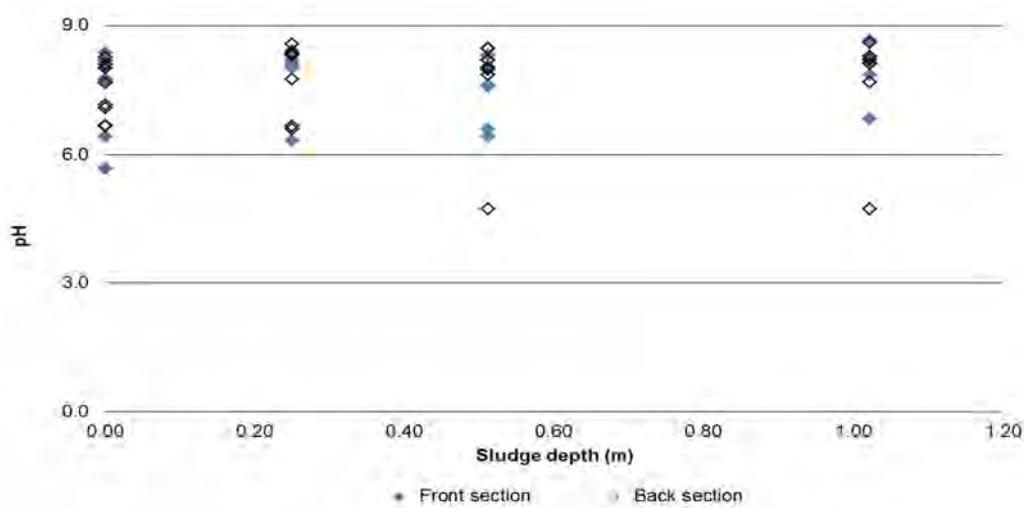


Figure 4-29 pH for 10 dry VIPs for 10 dry VIP latrines at average faecal sludge depths of the layers (m)

There is mostly an increasing trend in the pH from the surface to the bottom layers of the faecal sludge for the front and back sections of the pit. In the front sections of the pit, the pH ranges from 5.7 to 8.7 while in the back section of the pit, the range is from 4.7 to 8.6 (**Figure 4-30**).

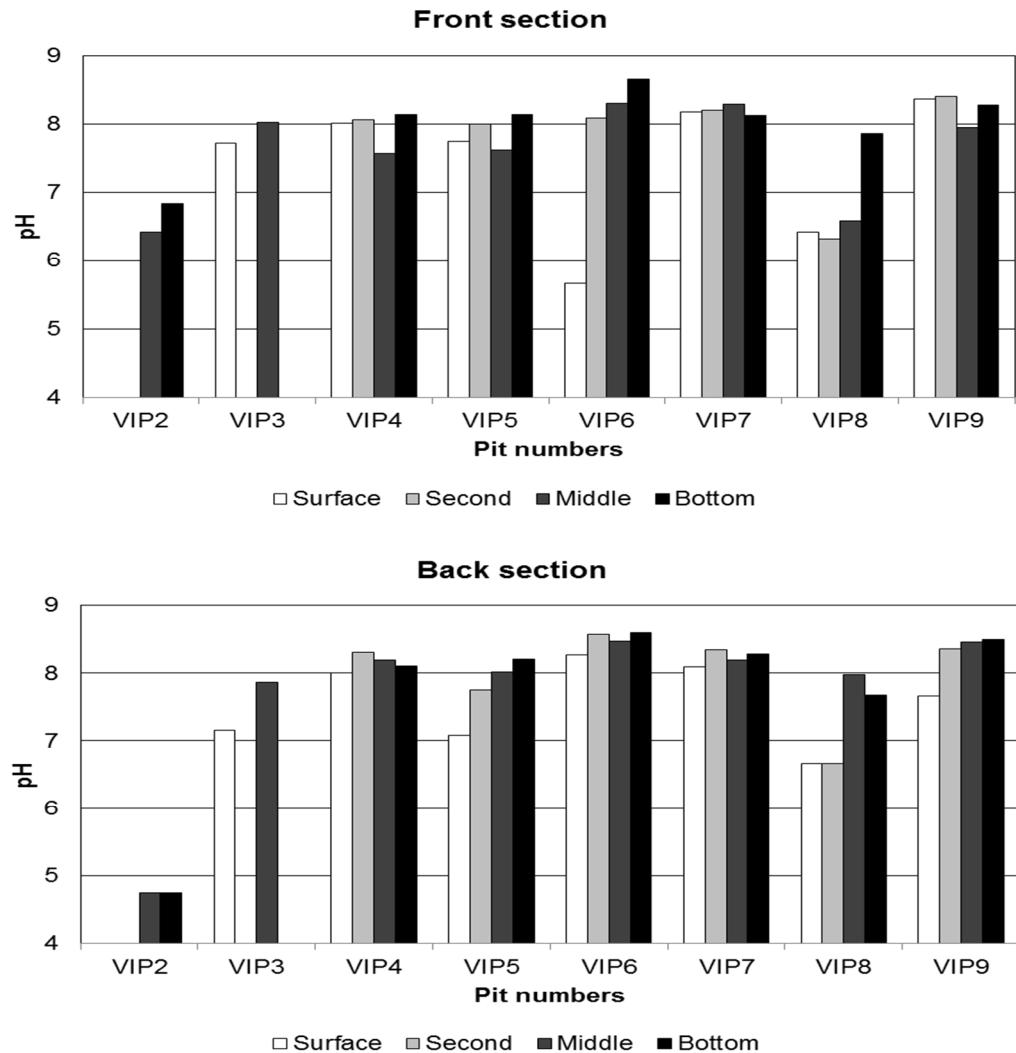


Figure 4-30 pH for 8 dry VIP latrines at varying layers of the range of pits sampled for the front and back sections of the pit

4.4.5 Ammonia

The ammonia content of the faecal sludge is lower at the back section than in the front section, especially for the middle and bottom layers of the pit (**Figure 4-31**). The front section of the pit has a wider variation of ammonia content than the back section. The bottom layer in the back section has the lowest ammonia content overall and the lowest variation.

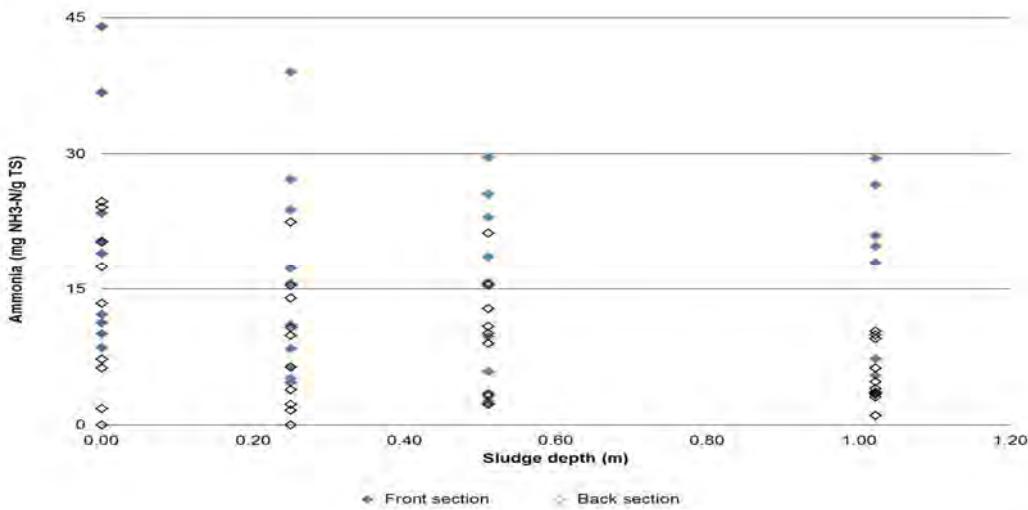


Figure 4-31 Ammonia (mg NH₃-N/g TS) for 10 dry VIP latrines at average sludge depths of the layers (m)

There is an overall decrease of ammonia from the surface layer to the bottom layer of the pit in both sections of the pit. In the front section, the middle and bottom layers have similar average ammonia content (**Figure 4-32**). The bottom layer has the biggest difference in ammonia content between the different sections.

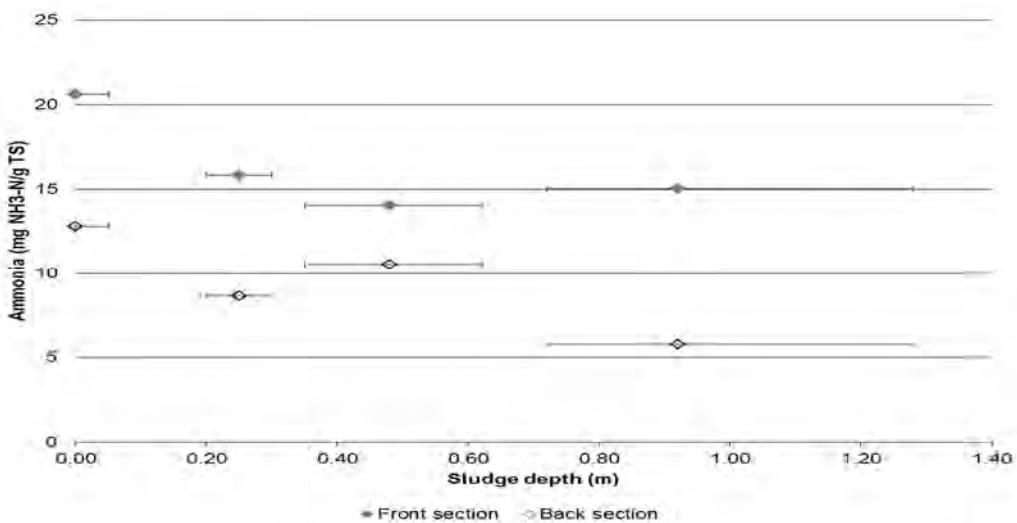


Figure 4-32 Ammonia (mg NH₃-N/g TS) for the front and back sections of 9 dry VIPs at varying faecal sludge depth (m)

4.4.6 TKN

There are distinct differences in the TKN in the different sections of the pit in the second, middle and bottom layers (**Figure 4-33**). The back section has mostly lower TKN values than the front section.

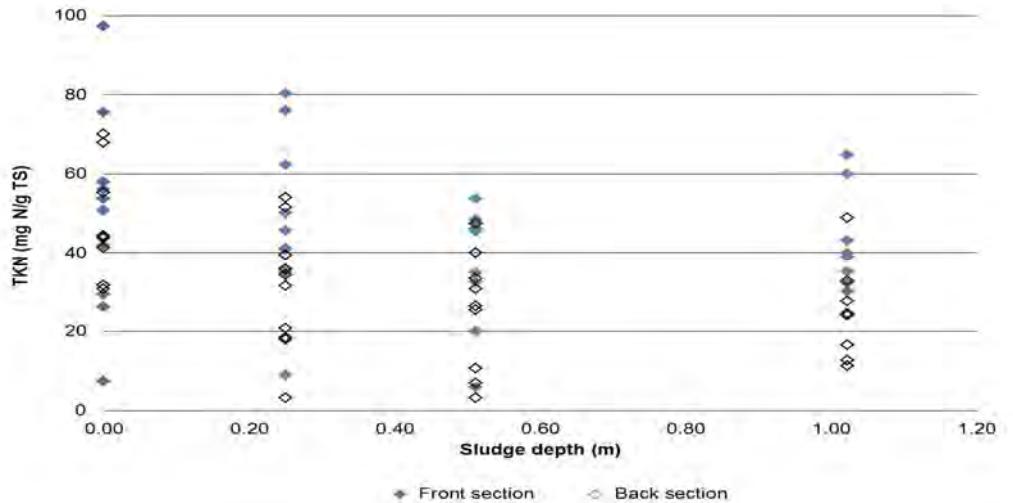


Figure 4-33 TKN (g N/g TS) for 10 dry VIP latrines at average faecal sludge depths (m) of the layers

On average, the TKN decreases in the first 3 layers of the pit in both sections, there is a slight increase in the bottom layer of the front section of the pit (**Figure 4-34**), while the middle and bottom layer at the back of the pit have the same average TKN. The surface layer of the different section has the smallest difference in TKN at 3.73×10^{-3} g N/g TS; however the surface layer in the front section has the largest variation of TKN.

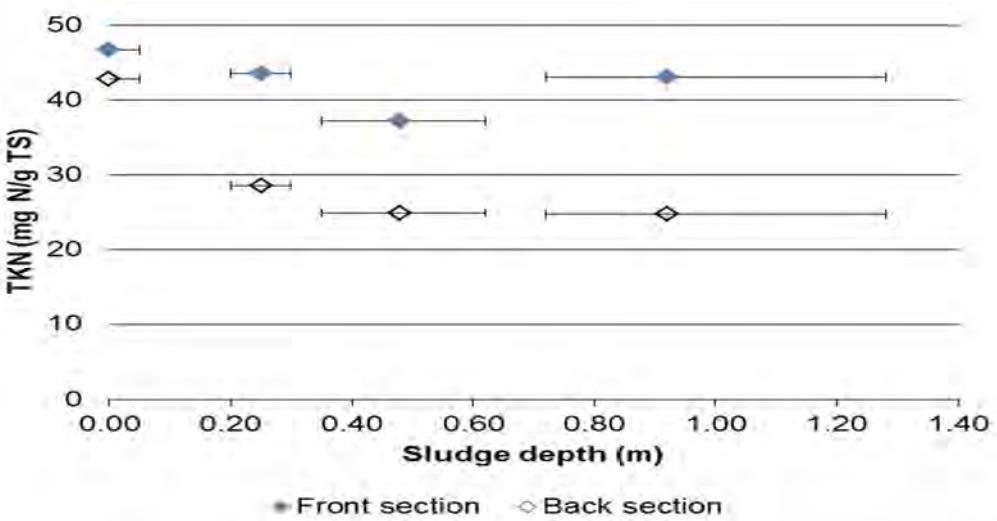


Figure 4-34 TKN (g N / g TS) for the front and back sections of 9 dry VIP latrines at varying faecal sludge depths (m)

4.4.7 Thermal conductivity

For the second and middle layers, there is a distinct difference between the faecal sludge thermal conductivity in the different sections (**Figure 4-35**). The thermal conductivity of the faecal sludge is less than that of water. A low value of 0.43 W/(m.K) was measured for one of the samples from the surface layer, this value can be considered an outlier as all other sludge thermal conductivity values are within 0.48 and 0.59 W/(m.K). The thermal conductivity of water is 0.61 W/(m.K) (Pandarum, 2013).

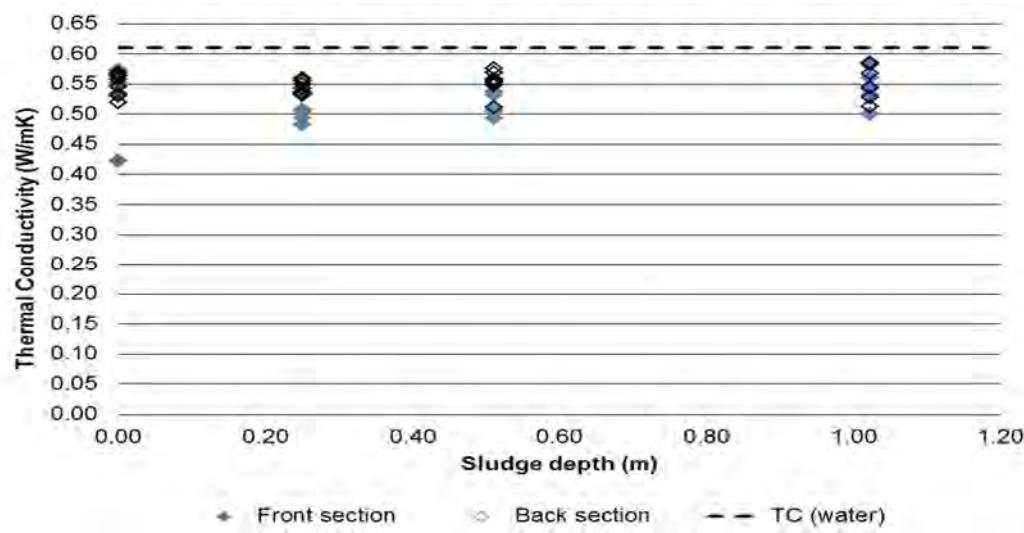


Figure 4-35 Thermal conductivity (W/(m. K)) for 10 dry VIP latrines at average faecal sludge depths of the layers (m)

The thermal conductivity of the faecal sludge in the pit does not vary greatly through the layers of the pit and between the sections (**Figure 4-36**). On average, the back section of the pit has higher thermal conductivity than the front section. In the front section of the pit, the thermal conductivity decreases over the first 3 layers and increased between the middle and the bottom layer. In the back section of the pit, the average thermal conductivity remains relatively similar through the pit depth. The surface and bottom layers of the difference sections have similar thermal conductivities.

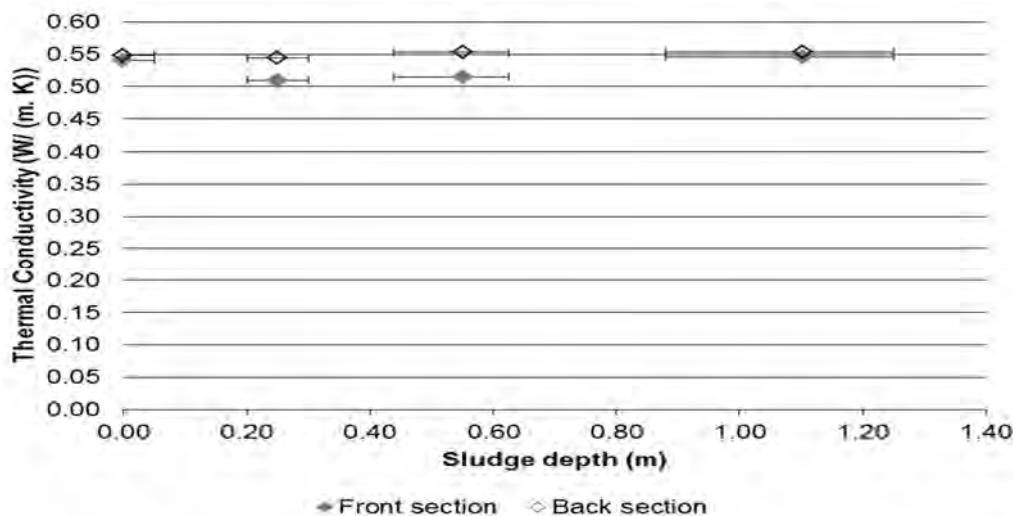


Figure 4-36 Thermal conductivity ($\text{W}/(\text{m. K})$) for the front and back sections of 9 dry VIP latrines at varying faecal sludge depths (m)

4.4.8 Calorific value

There is no distinct difference in the calorific value of the faecal sludge between the sections (**Figure 4-37**). There is a larger variation in the calorific value in the front section of the pit than in the back section. The second layer has the least variation of faecal sludge calorific value.

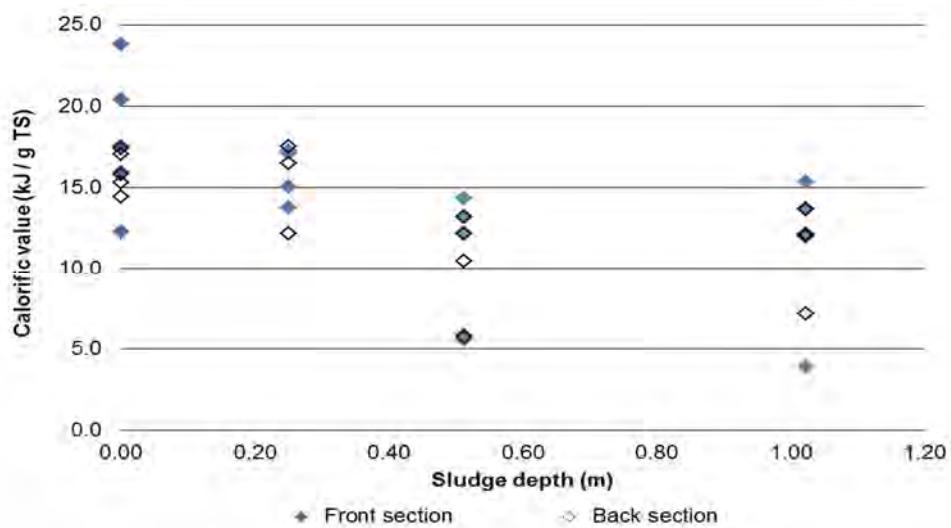


Figure 4-37 Calorific value (kJ/g TS) for 10 dry VIP latrines at average sludge depths of the layers (m)

In both sections of the pit, there is a decrease in the calorific value from the surface to the bottom layers (**Figure 4-38**). The average calorific value of the bottom layer from the front and back section is similar. The faecal sludge calorific value in the back section of the pit changes more steeply (slope = -5.8871) than the front section of the

pit (slope = -7.914). A linear regression for both the sections is poor; the fitted lines underestimate and overestimate the calorific value at certain depths.

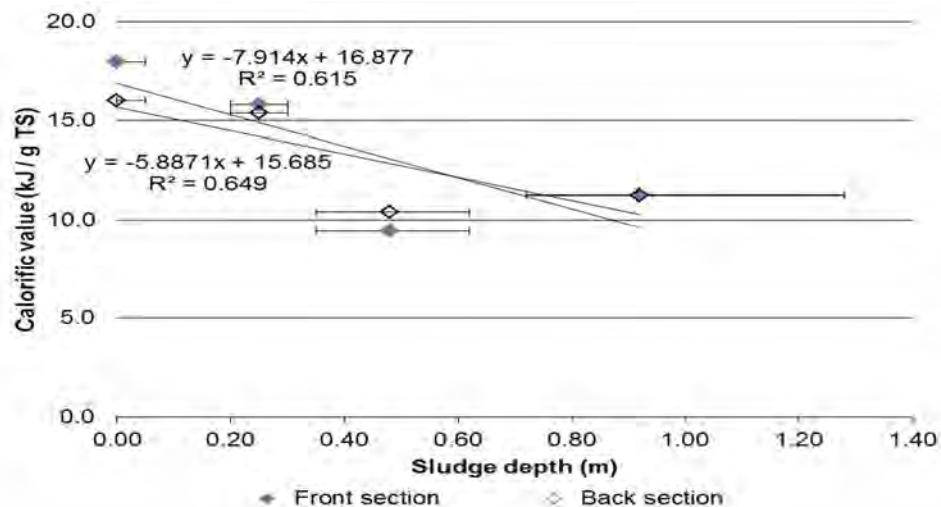


Figure 4-38 Calorific value (kJ/g TS) for the front and back sections of 10 dry VIP latrines at varying faecal sludge depths (m)

4.4.9 Discussion

The faecal sludge in the front section of the pit had higher values of the characteristic analysed than the faecal sludge in the back section of the pit in all the properties except for thermal conductivity. There was mostly a decreasing trend of the properties analysed from the surface to the bottom layer. The faecal sludge in the front and back sections had on average similar characteristics in the upper layers of the pit, however the difference between the same layers from the front and back sections of the pit increased with increasing depth for the moisture content, volatile solids, COD and TKN.

The addition of new material on top of the heap and degradation of older organic material results in the compaction of pit material at the bottom of the pit. This may also cause moisture to be squeezed out of the pit contents (Buckley et al., 2008a). The surface layers in the front and back section (Figure 4-24) showed similar average moisture content (0.84 and 0.82 g water / g wet mass respectively). It can be assumed that the material in the front section under the pedestal is fresher than the material in the surface layer of the back section of the pit. This result of similar moisture content shows that the surface layer in the back section has not lost a large amount of moisture; this illustrates that faecal sludge compaction is one of the dominant contributors to loss of moisture in the sludge.

The linear regression of the average moisture content, volatile solids data and COD in the back section of the pit showed a good fit. These can be used confidently to predict these faecal sludge characteristics for *dry VIP latrines* exposed to the similar conditions as those in this study. The thermal conductivity in the back section of the pit and the calorific value of the sludge cannot be predicted using linear regression in the study.

The range of characteristics obtained in this study for *dry VIP latrines* and *wet VIP latrines* is shown in **Figure 4-39** and **Table 4-4**.

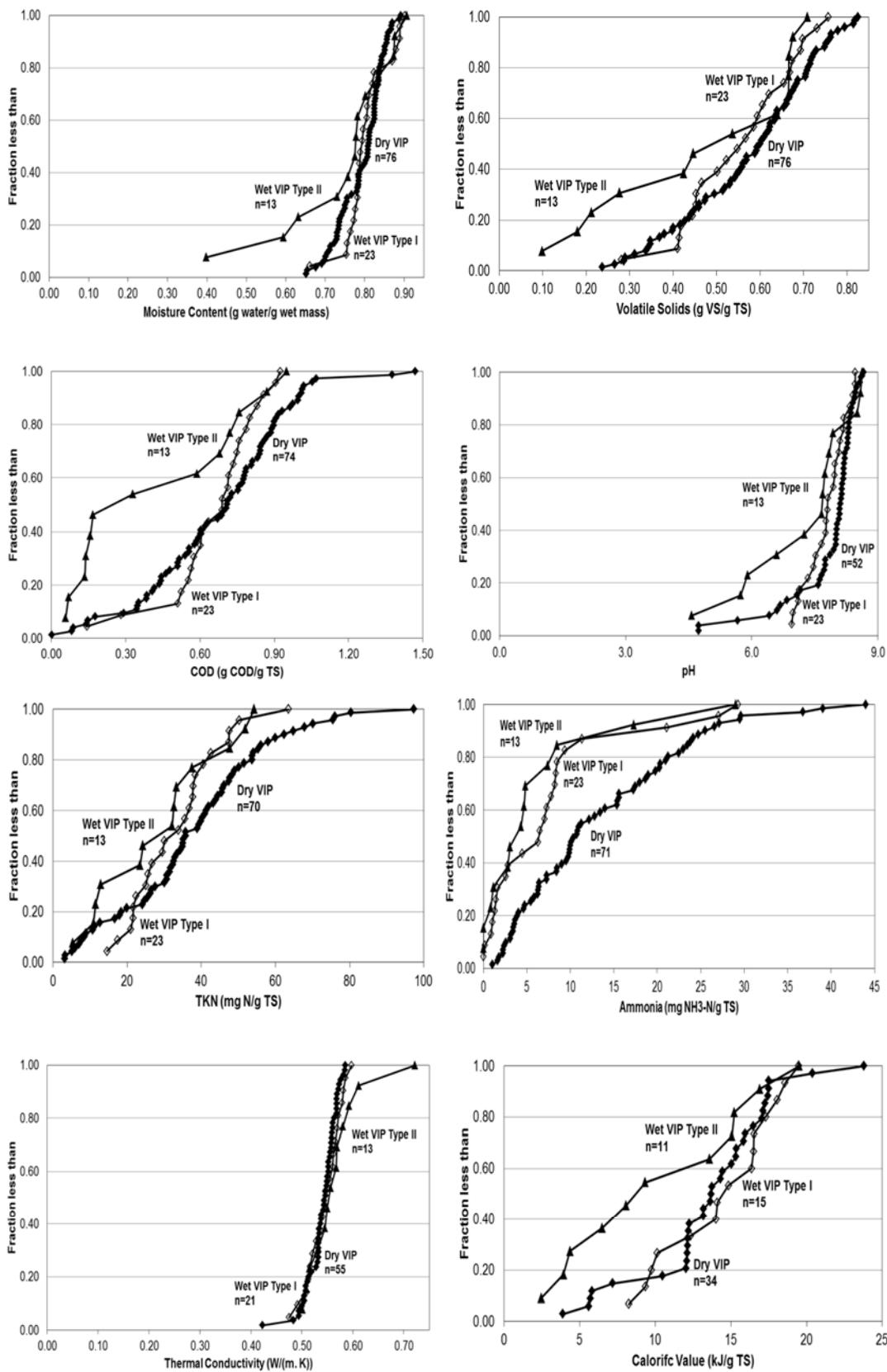


Figure 4-39 Cumulative graphs for dry VIP latrine and wet VIP latrine sludge for moisture content, volatile solids, COD, pH, ammonia, TKN, thermal conductivity and calorific value

Table 4-4 Minimum, median and maximum values for the characteristics analysed for dry VIP latrines, wet VIP latrines Type I and wet VIP latrines Type II

Characteristic	VIP latrine type	Min	Median	Max
Moisture Content (g water/g wet mass)	Dry VIP latrines	0.65	0.81	0.89
	Wet VIP latrines Type I	0.66	0.79	0.90
	Wet VIP latrines Type II	0.40	0.78	0.91
Volatile Solids (g VS/g TS)	Dry VIP latrines	0.24	0.60	0.82
	Wet VIP latrines Type I	0.28	0.57	0.76
	Wet VIP latrines Type II	0.10	0.54	0.71
COD (g COD/g TS)	Dry VIP latrines	0.00	0.71	1.5
	Wet VIP latrines Type I	0.14	0.69	0.92
	Wet VIP latrines Type II	0.06	0.33	0.95
pH	Dry VIP latrines	4.7	8.1	8.7
	Wet VIP latrines Type I	7.0	7.8	8.5
	Wet VIP latrines Type II	4.6	7.7	8.6
TKN (mg N/g TS)	Dry VIP latrines	3.2	36	97
	Wet VIP latrines Type I	15	34	64
	Wet VIP latrines Type II	5.3	32	54
Ammonia (mg NH ₃ -N/g TS)	Dry VIP latrines	0	11	44
	Wet VIP latrines Type I	0	6.5	29
	Wet VIP latrines Type II	0	4.3	29
Thermal Conductivity (W/(m. K))	Dry VIP latrines	0.42	0.55	0.59
	Wet VIP latrines Type I	0.47	0.55	0.60
	Wet VIP latrines Type II	0.50	0.56	0.72
Calorific Value (kJ/g TS)	Dry VIP latrines	3.9	14	24
	Wet VIP latrines Type I	8.2	15	19
	Wet VIP latrines Type II	2.5	9.3	20

4.5 Sampling location for dry VIPs latrines

This section examines the sampling of *dry VIPs latrines* and analyses sampling depths based on available resources and applicability to the needs. Numerous data can be obtained from sampling *dry VIP latrines* in a particular area; however the amount of data obtained has to be balanced with the availability of resources such as time, finances, laboratory equipment and personnel.

Based on the data from this study, the ideal sampling depth will be determined for the properties of sludge that were analysed and presented in **Section 4.4**.

Hypotheses

- There is a significant difference between the faecal sludge in the front and back sections of *dry VIP latrines*.
- Faecal sludge in *dry VIP latrines* can be sampled in 4 layers or less to describe the change of the faecal sludge with depth.

4.5.1 Faecal sludge property by front and back section

The *dry VIP latrines* sampled in this study had an average length of 2.5 m from front to back. Across the length of the pit, the faecal sludge is subjected to different conditions. The greatest differences in properties were assumed to be under the pedestal and at the back of the pit. In the front section of the pit under the pedestal, faeces and urine are constantly added; the back section of the pit is minimally interrupted once the faeces and urine have been deposited. Samples were selected at different depths from the front and back sections as described in §3.2.1.

From the **Section 4.4**, it was observed that for each characteristic except for thermal conductivity, on average, the front section had consistently higher values than the back section for the same layers. A student t-test was conducted to test if the mean values of each characteristic in the front section are significantly different to the back section at a 95% confidence level ($p<0.05$). The results from the test are shown in **Table 4-5**, all the values in bold are significantly different. All the statistical analyses were conducted in STATA11®.

Table 4-5 Student *t*-test results for faecal sludge characteristic properties between the front and the back sections of the pit

Faecal sludge characteristic	p - value
Moisture Content	0.0029
Volatile Solids	0.0001
COD	0.0001
TKN	0.0001
Ammonia	0.0001
Thermal Conductivity	0.0975
Calorific Value	0.0001

*Note: the characteristics and values in **bold** are significantly different at a 95% confidence level

4.5.2 Faecal sludge characteristics by layers

To further investigate the data for each of the layers, a student *t*-test was conducted to determine if the means of the characteristics of the faecal sludge were significantly different between the layers.

From **Section 4.5.1**, the results from the student *t*-test showed that the characteristics except for thermal conductivity are significantly different in the front and back sections of the pit. Further student *t*-tests were conducted for the characteristics by layer of the pits (in the sections for those found to be significantly different, and for the whole pit for those found not to be significantly different) to determine if there are significant differences in the means of the characteristics by faecal sludge layer.

The layers that were compared were: surface and second layer, second and middle and middle and bottom. The results from the *t*-tests with the number of observations are shown in **Table 4-6**; only those layers found to be significantly different are shown ($p<0.05$).

Table 4-6 Student *t*-test results comparing the characteristics in the different layers of the faecal sludge in dry VIP latrines

Section	Layers	p-value
Moisture Content		
Front	Second v Middle	0.0469
Back	Surface v Second	0.0389
	Second v Middle	0.0479
	Middle v Bottom	0.0001
Volatile solids		
Front	Second v Middle	0.0016
Back	Surface v Second	0.0001
	Middle v Bottom	0.0044
COD		
Back	Surface v Second	0.0029
	Middle v Bottom	0.0001
Ammonia		
Front	Surface v Second	0.0019
TKN		
Front	Second v Middle	0.0154
Calorific Value		
Front	Second v Middle	0.0004
Back	Second v Middle	0.0028

4.5.3 Discussion

Except for thermal conductivity, all the sludge characteristics are significantly different from the front section to the back section of the pit. This shows that the different conditions in the pit have an effect on the sludge quality and contribute to the non-homogeneous nature of faecal sludge from *dry VIP latrines*.

Through the faecal sludge depth, in the front section of the pit, the comparison between the second and middle layers show significant difference in moisture content, volatile solids, TKN and calorific value. In the back section of the pit, it is the moisture content and characteristics that are directly related to the organic content of the sludge (volatile solids, COD and calorific value) that exhibit significant changes through the pit.

Therefore at the front section of the pit, dividing the depth of the pit in 2 layers is sufficient. Samples taken from the second layer (0.25 – 0.30 cm below the surface) and

from the middle layer (half way through the sludge depth) are adequate. At the back section of the pit, the depth should be divided into 4 sections as done in the study if the moisture content and the characteristics that are indicators for organic content are required. The bottom layer for this study was too large (there was a significant difference between the middle and bottom layers for the moisture content, volatile solids content, COD) – it is recommended to divide the bottom layer in the back section of the pit even further. In all other cases, 1 sample can be selected to represent the whole back section of the pit.

The number of samples required from a VIP latrine to adequately describe each characteristic can be found in **Table 4-7**.

Table 4-7 Number of samples required per characteristics for the front and back sections of the pit

Characteristic	Number of samples – front section of the pit	Number of samples – back section of the pit
Moisture content	2	4
Volatile solids	2	4
COD	1	4
TKN	2	1
Ammonia	3	1
Thermal conductivity	1	
Calorific value	2	2

4.6 Wet VIP latrines

There were two types of *wet VIP latrines* noted during the emptying and sampling campaign of this study. These types were distinguished by the nature of the faecal sludge surface: un-crusted or crusted. Further descriptions of these 2 different types have been explained in **§4.3**. The 2 types were named *Type I* for the un-crusted surface and *Type II* for the crusted surface. The graphs for the results of the faecal sludge laboratory analysis can be found in **§4.3.1** and in **Appendix B**.

4.6.1 Differences in the 2 types of wet VIPs

The source of excessive water in wet pits is thought to be either from the users adding water into the pit or from a high water table in the area that causes ingress of water into the pit. However, the mechanism that causes these 2 distinct types of *wet VIP latrines* that were noted in this study is not known.

4.6.2 Sampling in wet VIPs

Faecal Sludge sampling in *wet VIP latrines* was conducted using shovels and long handle forks. During the sampling of *Type I wet VIP latrines* at different depths; there was a degree of mixing that occurred when the shovel and long handle forks were inserted into the faecal sludge to remove it from the pit - this means that the layers became mixed and were not as distinct as in the *dry VIP latrines*. This method of sampling was not suitable for sampling and faecal sludge analysis *wet VIP latrines* requiring distinct layers to study the processes that happen in *wet VIP latrines* with faecal sludge depth.

4.6.3 Analysis results for wet VIP latrines

The results from the student t-test showed that there are no significant differences in the faecal sludge from the *Type I* and *Type II wet VIP latrines* for all the properties analysed (**Section 4.3.1**). An appropriate sampling method can change some of the results from this study and further support the 2 categories of VIP latrines statistically and not by observation only.

4.7 Pit and vault content characterisation

Two *dry VIP latrines* and 1 UD toilet were sorted in order to determine the proportions of household waste and foreign objects found in the pits. The results from the manual sorting are shown in **Table 4-8**.

Table 4-8 Percentages (by mass) of household waste and foreign objects found in pits and vaults

Category (% mass)	Dry VIP latrine 1	Dry VIP latrine 2	UD toilet 1 (active vault)	UD toilet 1 (standing vault)
Faecal sludge	86	87	86	93
Paper	8.4	3.8	6.8	-
Synthetic hair	1.2	-	-	0.82
Light plastics	0.74	3.4	0.98	0.94
Stiff plastics	0.32	0.96	0.39	0.32
Textiles	1.1	1.3	2.2	1.6
Feminine products	0.42	2.5	1.3	1.4

Category (% mass)	Dry VIP latrine 1	Dry VIP latrine 2	UD toilet 1 (active vault)	UD toilet 1 (standing vault)
Glass	0.56	-	-	0.29
Metals	0.19		0.73	-
Wood	0.27	0.77	0.41	0.32
Stones	0.71		1.72	0.49

The types of household waste found in *dry VIP latrines* varied depending on the habits of the users, the demographics of the household and the type of cleansing material used. The results show that sludge forms the majority of pit and vault content (approximately 87%) followed by paper. In the inactive vault of UD1, the paper and sludge were mixed such that it was difficult to separate these two; therefore the 93% includes sludge and paper. The differences in the paper content of the two pits could be because of the use of toilet paper versus the use of newspaper which takes longer to degrade.

The types of foreign objects found in pits and vaults varies per household, the characterisation of these objects is important for the design of pit emptying equipment. Textiles were found to be a prominent foreign object found in the pit followed by feminine hygiene products and in most cases plastics. The use of the pits and vaults as rubbish bins shortens the lifespan of the pits and vaults because the materials are not biodegradable and they accumulate (Wood, 2013)

It has been assumed by (Still et al., 2012) that in *VIP latrines*, household waste represent 5 – 10% of pit contents and by the time the sludge has been in the pit for 10 years rubbish will constitute 25% of the volume. In this study, the pits have been filling up for 5 years or less (the exact time of last emptying is not known, but the eThekweni Municipality emptying programme is such that each pit is empties once every 5 years). The household waste represents 13 – 14% of the pit. The length of time that the UD toilet active vault had been used was unknown and thus it cannot be concluded if this value of household waste is higher or lower than what was reported in previous studies.

5 CONCLUSIONS

There were 10 dry VIP latrines, 10 wet VIP latrines, 9 active UD toilet vaults and 7 inactive UD toilet vaults that were emptied and sampled as detailed in **Chapter 3**. The results of the laboratory tests of these on site sanitation systems have been presented, interpreted and discussed in **Chapter 4**. The conclusions from these results are detailed in this chapter.

5.1 UD toilets

The characteristics of the sludge in UD toilet active vaults were different to what is expected – it was moist and had an objectionable smell (**§4.2.10**); the sludge showed that in some UD toilets, urine was not being diverted to the soakaway into the ground but was landing up in the vault which is meant to collect only faecal matter.

The separation of urine (to the soakaway) and faeces (into the vault) in UD toilets means that the vault contents will contain mainly faecal matter. This means that the characteristics of the material in the vault can be predicted because it contains mainly faecal material and thus it is possible to determine whether a UD toilet is being used accordingly as prescribed by the designers through visual observation of the sludge in the active vault on site. The faecal sludge from the UD vaults can be tested for characteristics that are associated with urine more than faeces such as moisture content, ammonia and pH to determine whether the faecal sludge from the vault contains urine.

The moisture content of UD toilet faecal sludge is a good indicator of the volatile solids, COD and TKN concentrations and thus can be used as a surrogate measurement for these characteristics.

5.2 VIPs

There are at least 3 types of sludge found within the VIP latrines in eThekwin – and they can be differentiated from each other by the shape of the sludge surface:

- ‘Cone’ sludge surface = *Dry VIP latrine*
- Flat un-crusted sludge surface = *Wet VIP latrine Type I*
- Crusted surface sludge = *Wet VIP latrine Type II*

The sludge moisture content and volatile solids in *dry VIP latrines* can be accurately predicted using sludge depth and linear regressions developed in this study for estimating faecal sludge characteristics in pits that are exposed to similar conditions as this study (**Figure 4-24**, **Figure 4-26** and **Figure 4-28**).

In *dry VIP latrines*, the household waste accounts for 13-14% of total *dry VIP latrines* contents after 5 years of use.

Except for thermal conductivity, sludge properties in *dry VIP latrines* are significantly different (at a 95% confidence level) between the front and back sections of the pit for all properties analysed in this study (**Table 4-5**).

Different numbers of samples can be taken for the front and back section of the pit for the faecal sludge characteristics to describe the sludge in the pit (**Table 4-7**).

The manual sampling method using spades and long handle forks used for *wet VIP latrines* in this study was not appropriate for sampling as it did not allow for representative sampling.

6 RECOMMENDATIONS

From the conclusions of this study, the following can be recommended for further research into VIP latrines and UD toilets:

- With the methods developed in this study, it was challenging to obtain a representative sludge sample from *wet VIP latrines*. Thus a sampling method/equipment for representative sampling *wet VIP latrines* is required; one that does not disturb the faecal sludge around the sample.
- Better design, construction of UD toilets and further education on the use of UD toilets to ensure that the urine separation is possible; this ensures that an adequate sanitation service is provided to the users.
- It is possible to ascertain the operation of a UD toilet by visual observation of the sludge. Therefore, in future studies requiring correctly constructed and operated UD toilets, visual observations of the faecal sludge should be done before it is sampled and analysed in the laboratory.
- Different on-site sanitation systems in eThekwin have different quality of faecal sludge which requires different types of treatment and emptying methods.
- Quantities and categories of household waste in VIP latrines and UD toilets need to be taken into consideration in the design of emptying technologies.

7 REFERENCES

- ALCOCK N. (2015). *Urine Diversion Toilet Waste Removal in eThekini Municipality Business Partnership Modeling* In: Proceedings of the 3rd International Faecal Sludge Management Conference, 19 - 21 January 2015 2015, Hanoi, Vietnam.
- ANDERSON K., SALLIS P. and UYANIK S. (2003). *Anaerobic treatment processes*. In: MARA D. & HORAN N. (eds.) *Handbook of Water and Wastewater Microbiology*. Academic Press, London, UK.
- APHA (2012). *Standard methods for the examination of water and wastewater*. American Public Health Association, Washington DC, USA.
- AUSTIN A. and BIERMANN S. (1998). *Guidelines for Human Settlement Planning and Design*. Pretoria, South Africa.
- AUSTIN L. (2006). *Guidelines for the design, operation and maintenance of urine diversion sanitation systems. TT 275/06*, Pretoria, South Africa.
- BAKARE B. (2011). *Scientific and management support for ventilated improved pit latrines (VIP) sludge content*. PhD thesis, University of KwaZulu-Natal.
- BAKARE B., FOXON K., BROUCKAERT C. and BUCKLEY C. (2012). *Variation in VIP latrine sludge contents*. Water SA, **38** (4) 479-486.
- BHAGWAN J., STILL D., BUCKLEY C. and FOXON K. (2008). *Challenges with upscaling dry sanitation technologies*. Water Science and Technology, **58** (1) 21-27.
- BMGF (2014). *Reinvent the toilet fair: India - Technical Guides*. Seattle, USA.
- BROUCKAERT C., FOXON K., RIDGEWAY T., RODDA N. and BUCKLEY C. (2005). *A mathematical analysis of the drying of faeces in a urine diversion toilet - a sensitivity analysis*. In: Proceedings of the 3rd International Conference on Ecological Sanitation, 23-26 May 2005, Durban.
- BUCKLEY C., FOXON K., BROUCKAERT C., RODDA N., NWANERI C., BALBONI E., COUDERC A. and MAGAGNA D. (2008a). *Scientific Support for the Design and*

Operation of Ventilated Improved Pit Latrines (VIPS) and The Efficacy of Pit Latrine Additives. TT/357/08, Pretoria, South Africa.

BUCKLEY C., FOXON K., RODDA N., BROUCKAERT C., MANTOVANELLI S. and MNGUNI M. (2008b). *Research into urine diversion, ventilated improved double pit toilets (UD/VIDP) in eThekwin. Part A: Physical and health-related characteristics of UD/VIDP vault contents.* 1629/1/08, Pretoria, South Africa.

CHAGGU E. (2004). *Sustainable environmental protection using modified pit-latrines.* Ph.D thesis, Wageningen University.

COFIE O., KONE D., ROTENBERGER S., MOSER D. and ZUBRUEGG C. (2009). *Co-composting of faecal sludge and organic solid waste for agriculture: Process dynamics.* IWA Water Research, **43** (18) 4665-4675.

COUDERC A., FOXON K., BUCKLEY C., NWANERI C., BAKARE B., GOUNDEN T. and BATTIMELLI A. (2008). *The effect of moisture content and alkalinity on the anaerobic biodegradation of pit latrine sludge.* Water Science & Technology, **58** (7) 1461 - 1466.

DST (2014). SA: *Statement by the Department of Trade and Industry, DST and the Bill and Melinda Gates Foundation to partner on sanitation innovation solutions for South Africa.* [Online]. Available: <http://www.polity.org.za/article/sa-statement-by-the-department-of-trade-and-industry-dst-and-the-bill-and-melinda-gates-foundation-to-partner-on-sanitation-innovation-solutions-for-south-africa-24032014-2014-03-24> [Accessed 01 October 2014 2014].

DWAF (2003). *A protocol to manage the potential of groundwater contamination from on site sanitation.* Pretoria, South Africa.

DWAF (2012). *Sanitation Services – Quality of Sanitation in South Africa Report on the Status of sanitation services in South Africa.* Pretoria, South Africa.

DWS (2015a). *Address by the Minister of Water and Sanitation. Ms Nomvula Mokonyane, on the occasion of Budget Vote number 38.* In: SANITATION D.o.W.a. (ed.). Cape Town, South Africa.

DWS (2015b). *Synthesis Report - 2015 National Sanitation Indaba*. Pretoria, South Africa.

EALES K. (2005). *Bringing pit emptying out of the darkness: A comparison of approaches in Durban, South Africa, and Kibera, Kenya*.

EM (2014). *eThekwini Municipality Draft Integrated Development Plan 5 Year Plan: 2012/12 to 2016/17*. Durban, South Africa.

EWS (2003). *eThekwini Water Services Facilitator Training Manual for the basic level water and sanitation programme*. Durban, South Africa.

EWS (2011). *Water Services Development Plan for the eThekwini Municipality*. Durban.

FAWCETT B. (2010). *Master of integrated water management program: Learning Guide WATR7400, Water Supply and Sanitation*. Brisbane, Australia.

FOXON K., BUCKLEY C., BROUCKAERT C., BAKARE B., STILL D. and SALISBURY F. (2011). *How fast do pits and septic tanks fill up? Implications for design and maintenance*. In: Proceedings of the 1st Faecal Sludge Management Seminar, 14 - 15 March 2011, Durban, South Africa.

FRANCEYS R., PICKFORD J. and REED R. (1992). *A guide to the development of on-site sanitation*. World Health Organization.

FRICKE K., SANTEN H., WALLMANN R., HÜTTNER A. and DICHTL N. (2007). *Operating problems in anaerobic digestion plants resulting from nitrogen in MSW*. Waste management, **27** (1) 30-43.

GOUNDEN T. (2008). *Sustainable Sanitation in the eThekwini Municipality*.

GTZ (2000). *Basic sanitation and human excreta disposal in latrines*. Frankfurt, Germany.

- HARRISON J. and WILSON D. (2012). *Towards sustainable pit latrine management through LaDePa*. In: Proceedings of the Second International Faecal Sludge Management Conference 29 - 31 October 2012, Durban.
- HUET J., DRUILHE C. and DEBENEST G. (2012). *Study of thermal conductivity in organic solid wastes before composting*. In: Proceedings of the ORBIT2012 Conference 2012, Rennes, France.
- KOMILIS D., KISSAS K. and SYMEONIDIS A. (2014). *Effect of organic matter and moisture on the calorific value of solid wastes: An update of the Tanner diagram*. Waste management, **34** (2) 249-255.
- LENTNER C. (1981). *Geigy Scientific tables. Vol. 1, Units of measurement, body fluids, composition of the body, nutrition*. Ciba-Geigy Basel, Switzerland.
- MARA D.D. (1984). *The design of ventilated improved pit latrines TAG Technical Note*. Washington DC, USA.
- MNKENI P. and AUSTIN L. (2009). *Fertiliser value of human manure from pilot urine-diversion toilets*. Water SA, **35** (1) 133-138.
- NAKATO T., STRANDE L., NIWAGABA C., DIONE H., BAAWUAH N. and MURRAY A. (2012). *Fuel potential of faecal sludge: Calorific value results from Uganda, Ghana and Senegal*. In: Proceedings of the Second Faecal Sludge Management Conference, 2012 2012, Durban, South Africa.
- NIWAGABA C.B. (2009). *Treatment technologies for human faeces and urine*. Doctoral Thesis thesis, Makerere University & Swedish University of Agricultural Sciences.
- NWANERI C. (2009). *Physico-chemical characteristics and biodegradability of contents of ventilated improved pit latrines (VIPs) in eThekweni Municipality*. MSc thesis, University of KwaZulu-Natal.
- OGUNYOKU T. and NELSON K. (2012). *The disinfection of latrine faecal sludge with ammonia naturally present in excreta* In: Proceedings of the Second International Faecal Sludge Management Conference, 29 - 31 October 2012, Durban, South Africa.

PILLAY S. (2014). *Bill and Melinda Gates Foundation and WRC collaborate for improved sanitation in Africa.* [Online]. Pretoria, South Africa. Available: <http://www.wrc.org.za/News/Pages/BillandMelindaGatesFoundationandWRCCollaborationforimprovedsanitationinAfrica.aspx> [Accessed July 14 2015].

PRG (2013). *Economic Evaluation of Faecal Sludge Disposal Routes.* Durban, South Africa.

PRG (2014a). *City Partnerships for Urban Sanitation Services in eThekwini Municipality South Africa: Institutional Analysis of the eThekwini Municipality.* Durban, South Africa.

PRG (2014b). *Data acquisition and field support for sanitation projects.* Durban, South Africa.

PRG (2014c). *Mechanical Properties of Faecal Sludge.* [Online]. Available: <http://prg.ukzn.ac.za/projects/current-projects/mechanical-properties-of-faecal-sludge> [Accessed May 30 2015].

ROMA E., HOLZWARTH S. and BUCKLEY C. (2011). *Case study of SuSanA projects: Large-scale peri-urban and rural sanitation with UDDTs in eThekwini.* www.susana.org.

ROMA E., PHILP K., BUCKLEY C., XULU S. and SCOTT D. (2013). *User perceptions of urine diversion dehydration toilets: Experiences from a cross-sectional study in eThekwini Municipality.* Water SA, **39** (2) 305-312.

ROSE C., PARKER A., JEFFERSON B. and CARTMELL E. (2015). *The Characterisation of Faeces and Urine; A Review of the Literature to Inform Treatment Technology.* Critical reviews in environmental science and technology, **41** (17) 1827-1879.

ROSS W. (1992). *Anaerobic Digestion of Waste-Water Sludge: Operating Guide.* TT55/92, Pretoria, South Africa.

SALISBURY F. and SALISBURY H. (2011). *Costs of faecal sludge management: on-site system emptying, sludge transport and disposal* **1745**, Pretoria, South Africa.

STILL D. (2002). *After the pit latrine is full.... What then? Effective options for pit latrine management.* In: Proceedings of the WISA Biennial Conference, 19 - 23 May 2002, Durban, South Africa.

STILL D. and FOXON K. (2012). *Tackling the challenges of full pit latrines: How fast do pit toilets fill up? A scientific understanding of sludge build up and accumulation in pit latrines* **1745/1/12**, Pretoria, South Africa.

SUTHERLAND C., ROBBINS G., SCOTT D. and SIM V. (2013). *Durban City Report EU: Chance2Sustain.* Durban, South Africa.

TILLEY E., LUETHI C., MOREL A., ZUBRUEGG C. and SCHERTENLEIB R. (2008a). *Compendium of Sanitation Systems and Technologies.* Dubendorf, Switzerland.

TILLEY E., LUETHI C., MOREL A., ZURBRUGG C. and SCHERTENLEIB R. (2008b). *Compendium of Sanitation Systems and Technologies.* Dubendorf, Switzerland.

TOWNEND J. (2012). *Practical statistics for environmental and biological scientists.* John Wiley & Sons.

UN (2015a). *The Millennium Development Goals Report.* New York, USA.

UN (2015b). *Resolution adopted by the General Assembly on 25 September 2015.* New York, USA.

WILSON D. and HARRISON J. (2012). *eThekweni pit latrine emptying program the contract the pitfalls and the solutions.* In: Proceedings of the Second International Faecal Sludge Management Conference 29 - 31 October 2012, Durban, South Africa.

WOOD K. (2013). *Transformation of faecal sludge in VIPs: Modelling fill rate with an unsteady-state mass balance.* MScEng thesis, University of KwaZulu-Natal.

WRC (2007). *Design and operating requirements to optimize the life span of VIP toilets.* Pretoria, South Africa.

ZUMA L., VELKUSHANOVA K. and BUCKLEY C. (2015). *Chemical and thermal properties of VIP latrine sludge.* Water SA, **41** (4) 534-540.

A**8 APPENDICES****APPENDIX A - Data****Dry and wet VIPs**

Moisture Content (g water/g wet mass)	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Front - Surface	0.78	0.82	0.87	0.87	0.86	0.74	0.86	0.87	0.86	0.84
Front - Second	0.83	0.75	0.83	0.83	0.83	0.81	0.81	0.89	0.83	0.84
Front - Middle	0.81	0.73	0.81	0.84	0.85	0.81	0.81	0.73		0.82
Front - Bottom	0.78	0.74	0.77	0.84	0.83	0.74	0.82	0.79		0.75
Back - Surface	0.73	0.89	0.82	0.83	0.85	0.83	0.85	0.81	0.78	0.80
Back - Second	0.76	0.71	0.84	0.81	0.82	0.78	0.86	0.79	0.79	0.82
Back - Middle	0.75	0.70	0.72	0.84	0.73	0.80	0.82	0.71		0.81
Back - Bottom	0.75	0.65	0.69	0.79	0.68	0.65	0.70	0.73		0.71
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Surface	0.76	0.89	0.78	0.81	0.82	0.82	0.78	0.76	0.40	0.80
Second	0.78	0.77	0.80	0.76	0.87	0.78	0.88	0.78	0.63	0.84
Middle	0.79	0.90	0.78	0.81	0.81	0.89	0.91	0.87	0.59	0.78
Bottom	0.88	0.66	0.79	0.79		0.75			0.73	
Volatile Solids (g VS/g TS)	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Front - Surface	0.70	0.61	0.82	0.59	0.61	0.82	0.72	0.64	0.78	0.68
Front - Second	0.60	0.54	0.64	0.63	0.60	0.76	0.81	0.71	0.76	0.65
Front - Middle	0.68	0.44	0.59	0.71	0.52	0.72	0.72	0.37		0.55
Front - Bottom	0.55	0.56	0.53	0.71	0.67	0.40	0.75	0.53		0.47
Back - Surface	0.35	0.79	0.68	0.57	0.63	0.62	0.73	0.75	0.57	0.72
Back - Second	0.40	0.46	0.62	0.56	0.51	0.42	0.67	0.66	0.48	0.66
Back - Middle	0.34	0.46	0.44	0.62	0.34	0.76	0.69	0.35		0.59
Back - Bottom	0.29	0.38	0.27	0.45	0.29	0.24	0.31	0.43		0.50
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Surface	0.73	0.62	0.55	0.69	0.61	0.67	0.45	0.42	0.10	0.67
Second	0.67	0.42	0.59	0.41	0.76	0.59	0.67	0.54	0.18	0.67
Middle	0.65	0.57	0.47	0.45	0.50	0.52	0.68	0.71	0.21	0.64
Bottom	0.70	0.28	0.45	0.41		0.44			0.28	
COD (g COD/g TS)	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Front - Surface	0.35	0.41	1.47	0.67	0.71	0.15	1.07	0.91	0.97	1.01
Front - Second	0.46	0.62	0.58	1.01	0.72	0.09	0.99	1.38		0.89
Front - Middle	0.59	0.52	0.78	0.90	0.84	1.02	0.71	0.60		0.84
Front - Bottom	0.51	0.60	0.56	0.90	0.92	0.73	0.79	0.69		0.00
Back - Surface	0.08	1.05	0.78	0.83	0.86	0.14	0.96	1.00	0.93	0.76
Back - Second	0.44	0.54	0.77	0.81	0.75	0.42	0.89	0.81		0.84
Back - Middle	0.44	0.48	0.51	0.87	0.44	0.69	0.71	0.63		0.85
Back - Bottom	0.29	0.34	0.18	0.59	0.39	0.35	0.38	0.56		0.78
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Surface	0.86	0.83	0.72	0.76	0.90	0.75	0.68	0.59	0.06	0.72
Second	0.80	0.55	0.52	0.69	0.79	0.73	0.87	0.95	0.16	0.76
Middle	0.92	0.63	0.71	0.58	0.14	0.60	0.07	0.13	0.17	0.14
Bottom	0.69	0.28	0.61	0.51		0.56			0.33	

B

pH	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Front - Surface			7.72	8.01	7.75	5.67	8.18	6.42	8.20	8.37
Front - Second				8.07	8.00	8.09	8.21	6.32	8.15	8.41
Front - Middle		6.42	8.03	7.58	7.62	8.31	8.30	6.59		7.95
Front - Bottom		6.84		8.14	8.14	8.66	8.13	7.86		8.28
Back - Surface			7.16	8.00	7.08	8.27	8.09	6.66	6.68	7.66
Back - Second				8.31	7.75	8.57	8.34	6.66	6.60	8.36
Back - Middle		4.74	7.86	8.19	8.02	8.47	8.19	7.98		8.46
Back - Bottom		4.74		8.11	8.21	8.60	8.28	7.68		8.49
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Surface	8.18	7.81	7.94	8.34	8.41	7.98	8.63	5.90	7.69	5.74
Second	7.76	8.46	7.52	7.97	8.07	7.34	8.59	6.59	7.93	7.74
Middle	7.80	8.10	7.13	7.77	8.46	6.98	8.51	7.84	7.25	4.57
Bottom	7.66	8.19	7.11	6.95		7.47			7.66	
TKN (mg N/g TS)	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Front - Surface		41.9	97.3	56.1	26.3	53.7	75.5	58.0	8.47	7.59
Front - Second	8.88	35.8	45.7	62.3	35.0	50.1	76.0	80.4	5.09	40.9
Front - Middle	5.92	34.9	47.7	53.7	48.4	46.2	45.4	19.9		32.5
Front - Bottom		64.9	32.3	43.2	38.9	39.9	60.0	30.1		35.1
Back - Surface		41.3	30.7	43.8	44.4	67.8	70.1	55.3		31.6
Back - Second	3.17	31.5	18.4	51.5	39.4	17.9	54.0	34.4		35.7
Back - Middle	3.24	25.5	6.98	47.4	10.7	33.4	40.1	26.4		30.7
Back - Bottom		49.0	16.6	27.6	12.6	11.3	24.6	24.1		32.8
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Surface	63.5	50.2	21.0	38.4	47.5	36.8	32.6	24.2	5.30	33.3
Second	40.5	33.8	25.1	14.5	42.5	47.5	51.8	23.5	10.9	47.6
Middle	37.8	37.7	25.6	30.0	35.6	17.4	54.2	32.1	11.5	37.5
Bottom	29.5	21.6	21.6	22.4		26.6			12.8	
Ammonia (mg NH3-N/g TS)	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Front - Surface		10.0	19.0	20.3	23.4	11.3	36.8	44.0	8.47	12.2
Front - Second	6.37	4.62	8.43	17.3	23.8	15.6	27.1	39.0		11.0
Front - Middle	2.35	2.58	5.82	29.6	18.6	25.5	23.0	9.75		9.00
Front - Bottom	7.28	3.65	5.46	29.5	21.0	17.9	26.6	19.8		4.01
Back - Surface	0.00	7.26	1.77	24.1	13.4	24.7	20.2	17.4		6.28
Back - Second	1.62	3.86	2.24	6.40	14.0	9.88	22.5	15.4		10.7
Back - Middle	3.18	3.43	2.27	15.6	10.1	15.4	21.3	10.8		12.8
Back - Bottom	3.55	1.01	3.38	4.74	6.24	3.08	10.3	9.93		9.52
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Surface	11.4	29.3	1.64	7.79	9.37	2.82	8.47	0.00	2.79	0.00
Second	1.02	21.1	8.32	0.00	7.03	0.89	17.3	1.13	4.83	7.38
Middle	1.30	27.0	7.26	6.49	4.46	2.58	29.0	4.67	4.32	0.83
Bottom	1.43	6.26	8.47	8.21		0.17			3.06	

C

Thermal Conductivity (W/(m·K))	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Front - Surface			0.53	0.57	0.57	0.42	0.55	0.57	0.56	0.55
Front - Second			0.54	0.49	0.50	0.53	0.51	0.48		
Front - Middle			0.54	0.49	0.50	0.53	0.51			
Front - Bottom		0.53		0.56	0.50	0.54	0.56	0.55		0.58
Back - Surface			0.53	0.55	0.57	0.56	0.52	0.53	0.57	0.56
Back - Second			0.55	0.54	0.55	0.53	0.53	0.54	0.56	
Back - Middle		0.55	0.58	0.55	0.57	0.51	0.56	0.55		0.56
Back - Bottom		0.58		0.59	0.53		0.57	0.54		0.51
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Surface	0.5	0.5	0.51	0.54	0.56	0.55	0.55	0.57	0.72	0.55
Second	0.52	0.6	0.58	0.59	0.57	0.49	0.5	0.57	0.59	0.53
Middle	0.53	0.6	0.57	0.55	0.56	0.47	0.6	0.51	0.61	0.51
Bottom	0.54	0.52	0.60						0.58	
Calorific Value (kJ/g TS)	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Front - Surface					12.25	23.78	20.38	17.51		15.94
Front - Second				15.04	13.75		17.25	17.11		
Front - Middle	5.82	12.15	14.30			5.60				13.17
Front - Bottom	13.69		15.34					12.09		3.89
Back - Surface		14.45			15.32	17.43	15.83			17.05
Back - Second				12.19		17.51	16.48			
Back - Middle		12.15		5.72			10.48			13.17
Back - Bottom	12.03			7.19			12.11			13.65
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Surface	19.5	16.5			16.36	14.83	15.22	9.33	4.37	3.93
Second		8.2		9.74	18.06	14.01	13.6	15.06	2.47	8.05
Middle	16.53		18.57		14.10	16.9	19.51		6.49	
Bottom	17.30		10.13	9.35		12.33				

UD Toilets

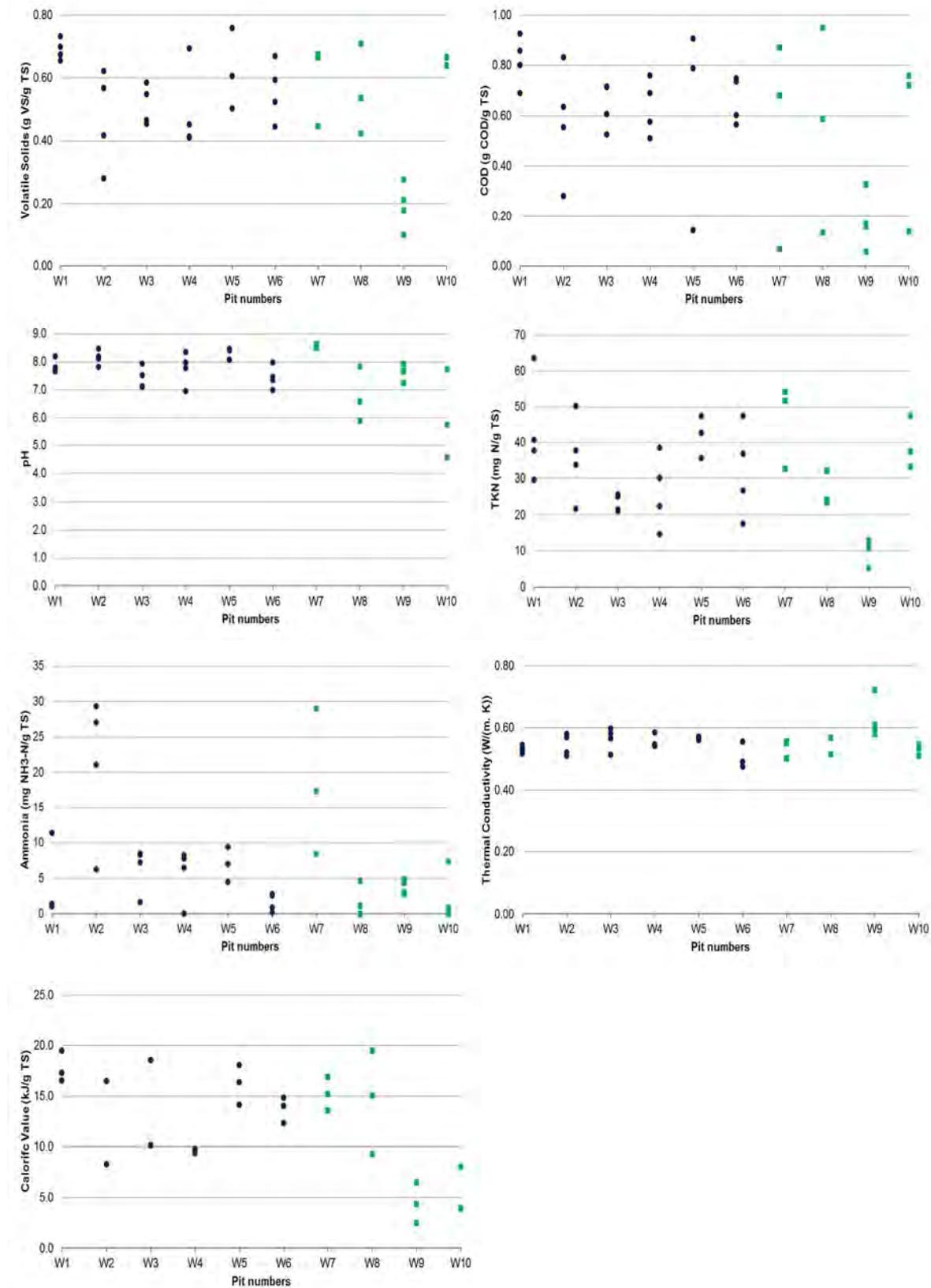
D

COD (g COD/g TS)	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Surface	0.72		0.54	0.38	0.06	0.21	0.11	0.57	0.66	0.08
Second	0.77		0.67	0.63	0.29	0.25	0.18	0.64	0.70	0.33
Middle	1.21		0.69	0.83				1.05	0.76	0.76
Bottom				0.90						0.78
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Surface	0.08	0.01	0.19	0.04	0.13			0.21		0.88
Second	0.11	0.02		0.22				0.27		0.89
Middle	0.13									0.96
Bottom	0.18									1.14
pH	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Surface			8.22	6.37	5.42	5.52	5.25	8.38	8.59	8.19
Second			8.74	8.58	5.52	6.51	5.88	8.75	8.72	8.64
Middle			9.08	8.87				8.81	8.8	8.7
Bottom			9.05							9.11
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Surface		7.31	5.39	5.28	7.75			5.34		8.21
Second		7.36		6.10				5.35		8.58
Middle										8.78
Bottom										8.92
TKN (mg N/g TS)	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Surface	17.1		29.8	26.6	3.51	8.18	2.41	24.2	50.6	22.8
Second			39.9	33.1	10.8	13.6	11.9	25.5	52.3	37.9
Middle			68.1	40.5				40.1	54.7	43.5
Bottom			43.0							70.0
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Surface	2.07	0.61	6.16	0.41	5.12			5.21		44.4
Second		1.53		7.12				12.3		56.1
Middle										63.9
Bottom										76.6
Ammonia (mg NH3-N/g TS)	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Surface	17.7		8.84	4.15	0	0	0	6.63	13.0	
Second			14.2	8.38				5.63	10.3	8.18
Middle			9.17							4.65
Bottom			11.0	8.08	0	0	0	6.07	14.0	0.85
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Surface	0.88	0	0	0	0			0		7.07
Second	1.04									8.78
Middle	0.11									13.9
Bottom	0		0					0		19.2
Thermal Conductivity (W/(m.K))	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Surface			0.58	0.51	0.13	0.52	0.22	0.54	0.31	0.57
Second			0.52	0.55				0.50	0.13	0.49
Middle			0.53							0.54
Bottom			0.58	0.55	0.20	0.34	0.31	0.60	0.20	0.79
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Surface		0.42	0.25	0.18	0.31			0.15		0.75
Second										0.56
Middle										0.53
Bottom		0.49		0.13				0.34		0.62

E

Calorific Value (kJ/g TS)	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Surface			14.8	17.5	11.8	8.79	5.10	17.4	16.5	20.0
Second			19.2	20.8				11.0	17.5	13.5
Middle				14.2						21.6
Bottom			9.61	8.45	12.8	9.59	6.29	13.9	14.6	2.25
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Surface		0	3.30	0	0			6.10		22.7
Second										7.58
Middle										20.7
Bottom		0		2.42				13.4		17.4

APPENDIX B – Graphs for wet VIP latrines



Wet VIP latrine data from sludge analysis for volatile solids, COD, pH, ammonia, TKN, thermal conductivity and calorific value

APPENDIX C - Laboratory procedures

Total solids / Moisture content

 <small>UNIVERSITY OF KWAZULU-NATAL</small>	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version: 001
		Reviewed by/Date: <small></small>	
SOP_Chem_004 Chemical Analysis_Solids			Page #: 1 of 11

Standard Operation Procedure -Solids

Introduction

Solids refer to matter suspended or dissolved in water or wastewater. Solids may affect water or effluent quality adversely in a number of ways. Solids analyses are important in the control of biological and physical wastewater treatment processes and for assessing compliance with regulatory agency wastewater effluent limitations.

Total Solids is the term applied to material residue left in the vessel after evaporation of a sample and its subsequent drying in an oven at a defined temperature. Total solids includes total suspended solids, the portion of solids retained by a filter and total dissolved solids, the portion that passes through the filter of 2.0um or smaller. Fixed Solids, is the term applied to residue of total, suspended or dissolved solids after heating to dryness for a specified time at a specified temperature. The weight loss on ignition is called volatile solids.

Total Solids Dried at 103-105°C

1. Scope and Field of Application

Total Solids are determined in a wide variety of liquid and semi-liquid materials. These include portable waters, domestic and industrial waters, polluted waters and sludge produced from treatment processes. It is of particular importance for the efficient operation of a treatment plant.

2. Principle

A known volume of well-mixed sample is evaporated to dryness in a porcelain crucible in a hot air oven at 105°C, the solids remaining are cooled and weighed. The residual material in the crucible is classified as total solids, and may consist of organic, inorganic, dissolved, suspended or volatile matter.

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
		Reviewed by/Date:	
SOP_Chem_004 Chemical Analysis_Solids		Page #: 2 of 11	

3. Interferences

- Highly mineralized water with a significant concentration of calcium, magnesium, chloride and sulphate may be hygroscopic and require prolonged drying, proper desiccation and rapid weighing.
- Exclude large, floating particles from the sample if it is determined that their inclusion is not desired in the final result.
- Disperse visible floating oil and grease with a blender before withdrawing sample portion for analysis. Because excessive residue in the dish may form a water-trapping crust.

4. Sampling

- Mix the sample well to suspend solids uniformly.
- Remove the test portion rapidly before any settling of solid matter occurs.
- Use a measuring cylinder and not a pipette for sludge and wastewater samples.
- Use a crucible for feces.
- Use a volume or mass of sample to ensure a measurable residue- limit sample to no more than 200mg residue
- Suitable aliquots: Liquid samples – 100ml, Sludges -30ml, feces 10-20g.

5. Safety Precautions

- Always use safety goggles, gloves and laboratory coat while working in laboratory
- Wear gloves suitable for withstanding high temperatures when removing crucibles from the oven.
- After the analysis clean bottles and beakers with clear water keep it for drying

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version: 001
		Reviewed by/Date:	
SOP_Chem_004 Chemical Analysis_Solids			Page #: 3 of 11

- Dispose the used gloves after completion of analysis
- Clean the hands using antiseptic soap
- Disinfect hands after washing with soap
- Avoid spillage and contact with skin. In the latter case use copious washings with cold water and call for medical attention.

6. Apparatus

- 50ml capacity evaporating porcelain crucibles
- Desiccator
- Drying oven
- Four – place Analytical Balance

7. Reagents

- Nil.

8. Calibration

- Check the temperature throughout the oven area by placing a calibrated thermometer on each shelf, after 30mins, check temperature at each level against oven setting.
- Adjust oven setting if necessary.
- If temperatures are uneven on the shelves, check insulation.

9. Procedure

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version: 001
		Reviewed by/Date:	
SOP_Chem_004 Chemical Analysis_Solids		Page #: 4 of 11	

Prepare Crucible

- If volatile solids are to be measured ignite clean crucible at 550°C for 1hr in the furnace. If only total solids are to be measured, heat clean crucible to 103-105°C for 1h. Store and cool dish in a desiccator until needed. Weigh immediately before use.....**W1g**

Sample Analysis

- Measure out appropriate volume (30ml) /mass (10-20g) that will yield a residue between 2.5 and 200mg of a well mixed sample using correct volume measuring cylinder or analytical balance.....**Vml...Wg**. Transfer quantitatively to the weighed crucible, rinsing the cylinder with small volumes of distilled water to dislodge heavy particles. Add washings to the crucible.
- Place in hot oven at 103-105°C for 24hrs
- Dry sample for at least 1hr in an oven 103-105°C, to dish in desiccator to balance temperature and weigh. Repeat cycle of drying, cooling , desiccating and weighing until a constant weight is obtained, or until weight change is less than 4% of previous weight or 0.5mg, whichever is less.*
- Remove the next day and cool for 15 minutes and weigh.....**W2g**

10. Calculation

$$\text{Total Solids in Sample (mg/l)} = \frac{(W_2 - W_1)g \times 100\,000}{V_{sample} \text{ (ml)}}$$

$$\text{Total Solids in Wet Sample (g/g)} = \frac{(W_2 - W_1)g}{W_{sample} \text{ (g)}}$$

$$\text{Moisture Content (g)} = W_{sample} \text{ (g)} - [(W_2 - W_1)]g$$

Volatile Solids

	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version: 001
Reviewed by/Date:			
SOP_Chem_004 Chemical Analysis_Solids			Page #: 9 of 11

W_1 = weight of filter paper before oven (105°C) (g)

W_2 = weight of residue + filter paper after oven(105°C) (g)

DF = Dilution Factor

Fixed and Volatile Solids Ignited at 550°C

1. Principle

The residue from the above methods is ignited to constant weight at 550°C . The remaining solids represent the fixed total, dissolved or suspended solids while the weight lost on ignition is the volatile solids. The determination is useful in control of wastewater treatment plant operation because it offers a rough estimate of the amount of organic matter present in the solid fraction of wastewater, activated sludge and industrial wastes.

2. Interferences

- Negative errors in the volatile solids may be produced by loss of volatile matter during the drying.

3. Apparatus

- Muffle Furnace
- As above



Standard Operating Procedure Pollution Research Group

Effective Date: **20 June 2013** Version: **001**

Reviewed by/Date:

Page #: **10 of 11**

SOP_Chem_004 Chemical Analysis_Solids

4. Procedure

- Ignite residue from the total solids to constant weight in a muffle furnace at a temperature of 550°C.
- Have furnace up to temperature before inserting sample.
- Usually 2 hr for VIP and sludge samples, 15-20min for waste water(200mg residue)
- Let the crucible cool partially in air until most of the heat has dissipated
- Transfer to a desiccator for final cooling. Do no overload the desiccator
- Weigh dish as soon as it has cooled to balance temperature.

5. Calculation

$$\text{Volatile Solids in Wet Sample (g/g)} = \frac{(B - C)}{W_{\text{sample}}(\text{g})}$$

$$\text{Volatile Solids in Dry Sample (g/g)} = \frac{VS_{\text{wet sample}}}{\text{Total Solids(g/g)}}$$

$$\text{Fixed Solids in Wet Sample(g/g)} = \frac{(C - D)}{W_{\text{sample}}(\text{g})}$$

$$\text{Fixed Solids in Dry Sample(g/g)} = \frac{FS_{\text{wet sample}}}{\text{Total Solids(g/g)}}$$

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version: 001
		Reviewed by/Date:	
SOP_Chem_004 Chemical Analysis_Solids		Page #: 11 of 11	

B = weight of residue + crucible before ignition - 550°C (g)

C = weight of residue + crucible after ignition -550°C (g)

D = weight of crucible (g)

6. Precision and Accuracy

mg Total Solids/L

%SD

%Error

APPROVAL OF STANDARD OPERATING PROCEDURE

PRG Head: Prof Buckley

Signature:

Date:

Author Merlien Reddy:

Signature:

Date:

COD

	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version: 001
Reviewed by/Date:			
SOP_Chem_003 Chemical Analysis_ Chemical Oxygen Demand			Page #: 1 of 7

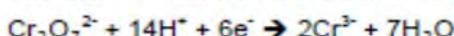
**Standard Operation Procedure – Chemical Oxygen Demand Closed Reflux,
Titrimetric Method****1. Scope and Application**

- The Chemical Oxygen Demand (C.O.D) measures the oxygen equivalent of that portion of the organic matter in a sample that is easily oxidized by a strong chemical oxidant.
- It is an important and rapidly measured parameter to measure the amount of organic compounds in stream and industrial waste studies, and in operational control of waste water treatment plants. It is also applicable for measurements on human excreta.
- This procedure described hereafter is applicable to COD values 40-400mg/L.

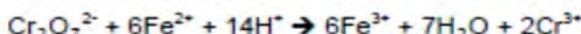
2. Summary

The sample is digested for 2hours in a strongly acidic dichromate solution, using silver sulphate as a catalyst and mercuric sulphate as a masking agent to prevent chloride interference. The dichromate is partially reduced by the oxidizable material present in the sample. The excess dichromate is titrated with ammonium iron (II) sulphate and the COD value calculated from the amount of dichromate.

The half reaction for the reduction of dichromate is:



The remaining dichromate is titrated with a standard ammonium iron(II) sulphate solution:



 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version: 001
	Reviewed by/Date:		
SOP_Chem_003 Chemical Analysis_ Chemical Oxygen Demand		Page #: 2 of 7	

The equivalence point is indicated by the sharp colour change from blue-green to red as the ferroin indicator undergoes reduction from iron (III) to the iron (II) complex.

3. Interferences

- Difficulties caused by the presence of chlorides in the sample are overcome by the addition of mercuric sulphate to samples before digesting. The chloride ion is then eliminated from the reaction by forming a soluble mercuric chloride complex.
- A catalyst must be used to include some organic compounds (e.g. acetic acid), while other biological compounds (eg cellulose), which are not important, are included in the determination. Pyridine is not oxidized even in the presence of the catalyst.

4. Sampling

- Preferably collect samples in glass bottles.
- Test unstable samples without delay.
- Preserve samples by acidifying with concentrated sulphuric acid to pH 2.
- Determine COD on well shaken samples. Settled samples may also be analysed if requested.
- 5ml pipette to measure out sample.

5. Safety Precautions

- Handle concentrated sulphuric acid with care.
- Always use safety goggles, gloves and laboratory coat while working in laboratory
- Wear face shield and protect hands from heat produced when contents of the vessels are mixed.
- After the analysis clean bottles and beakers with water then dry
- Dispose the used gloves after completion of analysis

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version: 001
		Reviewed by/Date: 	
SOP_Chem_003 Chemical Analysis_ Chemical Oxygen Demand		Page #: 3 of 7	

- Clean the hands using antiseptic soap
- Avoid spillage and contact with skin. In the latter case use copious washings with cold water and call for medical attention.

6. Apparatus

- Carousal of 10 teflon vessels
- 100 ml Erlenmeyer flasks
- 5ml pipette
- 10ml and 5ml automatic bottle top dispensers

7. Sample Preparation –Fecal Sludge

- Weigh out between 1.8g and 2g of well mixed fecal sludge sample.
- Place the weighed out sample into a blender with 250ml of distilled water.
- Blend for 30 seconds.
- Transfer the blended mixture into a volumetric flask and top up to 1L with distilled water.
- Transfer the 1L solution to a plastic bottle and store in the cold room.

8. Reagents

Standard Potassium Dichromate $K_2Cr_2O_7$ Digestion Solution: 0.0167M

Add to about 500ml distilled water **4.913g $K_2Cr_2O_7$** , previously dried at 105 °C for 2hrs.

Add **167ml concentrated Sulphuric acid H_2SO_4** and **13.3g Mercuric Sulphate $HgSO_4$** .

Dissolve and cool to room temperature before diluting to 1L.

Sulphuric Acid H_2SO_4 /Silver Sulphate Reagent Ag_2SO_4 (COD Reagent)

Q

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
	Reviewed by/Date:		
SOP_Chem_003 Chemical Analysis_ Chemical Oxygen Demand		Page #:	4 of 7

Add 26g of silver sulphate crystals or powder to 2.5L of concentrated sulphuric acid using a magnetic stirrer. Shake well and leave for 2days for dissolution.

Ferroin Indicator 2 drops

Dissolve 1.485g 1:10 phenentroline monohydrate and 0.695g ferrous sulphate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) in distilled water and dilute to100ml.

Ferrous Ammonium Sulphate $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$: 0.10M

Dissolve 39.2g $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$ in distilled water.

Add 20ml concentrated Sulphuric acid H_2SO_4 and dilute to 1L.

Standardize daily against Standard Potassium Dichromate $\text{K}_2\text{Cr}_2\text{O}_7$ Digestion Solution

9. Calibration

- Prepare a standard $\text{K}_2\text{Cr}_2\text{O}_7$ solution daily to correct any variation in the concentration of the Ferrous Ammonium Sulphate.
- Prepare a blank with each set of samples consisting of 5 ml distilled water in place of sample together with all the reagents and digest together with samples.
- **Standard Preparation**
- Add 3ml of standard $\text{K}_2\text{Cr}_2\text{O}_7$ digestion solution to 5 ml of distilled water. Add 7ml COD reagent and cool it down. Titrate with FAS titrant using 2 drops of ferroin indicator.
- **Quality Control: Potassium hydrogen Phthalate (KHP)**
Lightly crush and then dry out KHP to a constant weight at 120°C . Dissolve 0.0425g in distilled water and then dilute to 250ml. This solution has a theoretical COD of 200mg/L.
Solution is stable if refrigerated, for a period of 3 months in the absence of biological growth.

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version: 001
		Reviewed by/Date:	
SOP_Chem_003 Chemical Analysis_ Chemical Oxygen Demand		Page #: 5 of 7	

10. Procedure

Sample Preparation

- Add 5ml sample to each teflon vessel.
- Add 5ml distilled water to another vessel (blank).
- Add 3ml potassium dichromate digestion solution into each vessel.
- Add 7ml sulphuric acid reagent (with silver sulphate) in each vessel.
- The acid must be poured down the wall of the flask while flask is tilted. If sample is too concentrated it will turn green, and a higher dilution of sample must be used.

Digestion

- Place teflon vessels into the rotor, with the temperature probe placed into the teflon vessel labeled 1.
- Switch on the microwave and select COD METHOD:
- 15min ramping time to 150 °C, 30min digestion at 150°C and 1hr cooling to 50 °C.
- Transfer contents from teflon vessels into 100ml flasks for titrating.

Titration

- Titrate the excess dichromate in the digest mixture with standard ferrous ammonium sulphate using 2 drops of ferroin indicator.
- Titrate from a sharp green/orange to red brown end point.
- Take reading.

Calculation

$$COD \text{ (mg O}_2/\text{L}) = \frac{(Blank - Titration) \times \text{molarity of FAS} \times 8000}{\text{Sample (ml)}}$$

Where:

8000 = milliequivalent weight of oxygen × 1000 ml/L

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version: 001
		Reviewed by/Date:	
SOP_Chem_003 Chemical Analysis_ Chemical Oxygen Demand		Page #:	6 of 7

$$\text{Molarity of FAS} = \frac{\text{Volume } 0.0167M \text{ } K_2Cr_2O_7 \text{ Solution Titrated (ml)}}{\text{Volume FAS used in titration (ml)}} \times 0.10$$

$$\text{COD (mg O}_2/\text{L}) = \frac{(\text{Blank} - \text{Titration}) \times \text{molarity of FAS} \times 8000}{\text{Sample (ml)}} \times \frac{V}{M}$$

$$\text{COD in Wet Sample (g O}_2/\text{g}) = \frac{\text{COD (mg O}_2/\text{L})}{1000}$$

$$\text{COD in Dry Sample (g O}_2/\text{g}) = \frac{\text{COD in Wet Sample (g O}_2/\text{g})}{\text{Total Solids (g/g)}}$$

Where:

V = Total volume (L)

M = Mass of sludge used in sample preparation (g)

11. Precision and Accuracy

mg COD/L

%SD

%Error

pH

 UNIVERSITY OF KWAZULU-NATAL	<i>Standard Operating Procedure</i> Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
		Reviewed by/Date:	
SOP_Chem_015 pH Analysis			Page #: 1 of 3

Standard Operation Procedure - pH of Faecal Sludge

1. Scope and Field of Application

This method is an electrometric procedure for measuring pH in soils and waste samples. Wastes may be solids, sludges, or non-aqueous liquids. If water is present, it must constitute less than 20% of the total volume of the sample.

2. Interferences

Samples with very low or very high pH may give incorrect readings on the meter. For samples with a true pH of >10, the measured pH may be incorrectly low. This error can be minimized by using a low-sodium-error electrode. Strong acid solutions, with a true pH of <1, may give incorrectly high pH measurements.

Errors will occur when the electrodes become coated. If an electrode becomes coated with an oily material that will not rinse free, the electrode can (1) be cleaned with an ultrasonic bath, or (2) be washed with detergent, rinsed several times with water, placed in 1:10 HCl so that the lower third of the electrode is submerged, and then thoroughly rinsed with water, or (3) be cleaned per the manufacturer's instructions.

3. Safety Precautions

- Always use safety goggles, gloves and laboratory coat while working in laboratory
- After the analysis clean bottles and beakers with clear water keep it for drying
- Dispose the used gloves after completion of analysis
- Clean the hands using antiseptic soap
- Disinfect hands after washing with soap

 UNIVERSITY OF KWAZULU-NATAL	<i>Standard Operating Procedure</i> Pollution Research Group	Effective Date: 20 June 2013	Version: 001
		Reviewed by/Date:	
SOP_Chem_015 pH Analysis		Page #: 2 of 3	

- Avoid spillage and contact with skin. In the latter case use copious washings with cold water and call for medical attention.

4. Apparatus

- pH meter with means for temperature compensation.
- Glass electrode.
- Reference electrode -- A silver-silver chloride or other reference electrode of constant potential may be used.
- 50 ml beaker
- Thermometer and/or temperature sensor for automatic compensation.
- Analytical balance -- capable of weighing 0.1 g.

5. Procedure

Sample Preparation

- To 20 g of waste sample in a 50 ml beaker, add 20 ml of distilled water, cover, and continuously stir the suspension for 5 min. Additional dilutions are allowed if working with hygroscopic wastes and salts or other problematic matrices.
- Let the waste suspension stand for about 15 min to allow most of the suspended waste to settle out from the suspension or filter or centrifuge off aqueous phase for pH measurement.

NOTE: If the waste is hygroscopic and absorbs all the reagent water, begin the experiment again using 20 g of waste and 40 ml of reagent water.

NOTE: If the supernatant is multiphasic, decant the oily phase and measure the pH of the aqueous phase. The electrode may need to be cleaned if it becomes coated with an oily material.

Measurement of pH

 UNIVERSITY OF KWAZULU-NATAL	<i>Standard Operating Procedure</i> Pollution Research Group	Effective Date: 20 June 2013	Version: 001
		Reviewed by/Date:	
SOP_Chem_015 pH Analysis		Page #: 3 of 3	

Adjust the electrodes in the clamps of the electrode holder so that, upon lowering the electrodes into the beaker, the glass electrode will be immersed just deep enough into the clear supernatant to establish good electrical contact through the ground glass joint or the fiber-capillary hole.

Insert the electrode into the sample solution in this manner. For combination electrodes, immerse just below the suspension.

If the sample temperature differs by more than 2 °C from the buffer solution, the measured pH values must be corrected.

6. Results

Report the results as "waste pH measured in water at ___°C" where "___°C" is the temperature at which the test was conducted.

7. References

<http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/9045d.pdf>

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
		Reviewed:	
SOP_Chem_002 Chemical Analysis_ Total Kjeldahl Nitrogen		Page #: 1 of 7	

Standard Operation Procedure – Total Kjeldahl Nitrogen

1. Scope and Application

- This Kjeldahl method determines nitrogen in the tri-negative state. This fails to account for nitrogen in the form of ozide, azine, azo, hydrazone, nitrate, nitrite, nitro.
- Kjeldahl nitrogen is the sum of organic nitrogen and ammonia nitrogen. Organic nitrogen includes proteins, peptides, nucleic acids and urea.
- Typical organic nitrogen concentrations vary from a few hundred mg/L in some lakes to more than 20mg/L in raw sewage.
- This macro- Kjeldahl method is applicable for samples containing either low or high concentrations of organic nitrogen but requires but requires a relatively large sample volume for low concentrations.

2. Summary

- In the presence of sulphuric acid, potassium sulfate, and cupric sulphate catalyst, amino nitrogen of many organic materials is converted to ammonium.
- Free ammonia is also converted to ammonium.
- After addition of base, the ammonia is distilled from an alkaline medium and absorbed in boric or sulphuric acid.
- The ammonia may be determined colorimetrically, by ammonia selective electrode or by titration with a standard mineral acid.
- The titrimetric and selective electrode methods of measuring ammonia in the distillate are suitable for determining a wide range of organic nitrogen concentrations.

Y

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
	Reviewed:		
SOP_Chem_002 Chemical Analysis_ Total Kjeldahl Nitrogen		Page #: 2 of 7	

4. Sampling

- Nitrate: During Kjeldahl digestion, nitrate in excess of 10mg/L can oxidize a portion of the ammonia released from the digested organic nitrogen, producing N₂O, resulting in a negative interference.
- Inorganic salts and solids: The acid and salt content of the Kjeldahl digestion reagent is intended to produce a digestion temperature of about 380°C.
- If the sample contains a very large quantity of salts or inorganic solids the temperature may rise to 400°C during digestion at which point pyrolytic loss of nitrogen occurs. To prevent this increase in temperature add more sulphuric acid to maintain an acid-salt balance.

3. Interferences

- The most reliable results are obtained on fresh samples.
- If an immediate analysis is not possible, preserve samples for Kjeldahl digestion by acidifying to pH 1.5 to 2.0 with concentrated sulphuric acid and storing at 4°C.
- Do not use HgCl₂ because it will interfere with ammonia removal.

5. Safety Precautions

- Handle concentrated sulphuric acid with care.
- Always use safety goggles, gloves and laboratory coat while working in laboratory
- After the analysis clean bottles and beakers with clear water keep it for drying
- Dispose the used gloves after completion of analysis
- Clean the hands using antiseptic soap
- Disinfect hands after washing with soap
- Avoid spillage and contact with skin. In the latter case use copious washings with cold water and call for medical attention.

AA

	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
	Reviewed:		
SOP_Chem_002 Chemical Analysis_ Total Kjeldahl Nitrogen			Page #: 3 of 7

6. Apparatus

- Velp Digestion apparatus: DK 20 slim. F30100181, S/N 214130 .
- SMS Scrubber F307C0199
- JP recirculating water pump F30620198
- Kjeldahl flasks with a total capacity of 800ml yield the best results. Digest over a heating device adjusted so that 250ml water at an initial temperature of 25°C can be heated to a rolling boil in about 5 min. The temperature range should be 375 to 385°C for effective digestion.
- Distillation apparatus: UDK 127 Distilling Unit F30200183 s/N 126145
- 300ml TKN flasks.

7. Sampling Preparation – Fecal Sludge

- Weigh out between 1.8g and 2g of well mixed fecal sludge sample.
- Place the weighed out sample into a blender with 250ml of distilled water.
- Blend for 30 seconds.
- Transfer the blended mixture into a volumetric flask and top up to 1L with distilled water.
- Transfer the 1L solution to a plastic bottle and store in the cold room.

8. Reagents

Digestion Reagent:

Kjeldahl tablets or powder: Free of Hg, Se.

3.5g K₂SO₄ and 0.5g CuSO₄

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
	Reviewed:		
SOP_Chem_002 Chemical Analysis_ Total Kjeldahl Nitrogen		Page #:	4 of 7

Boric Acid – 4 %

Dissolve 40g of Boric acid into 1L of distilled water.

Concentrated Sulphuric acid**Sulphuric acid – 0.1N**

Dissolve 2.8ml of concentrated sulphuric acid into 1L of distilled water

Sodium Hydroxide – 35%

Dissolve 350g of NaOH into 1L of distilled water

Mixed Indicator

Mix methyl red (20mg) and bromocresol green indicator (100mg) top up to 100ml ethanol. Make up every month.

Standard

A solution of 30mg/N is prepared by weighing 0.1607g glycine dissolving in distilled water and diluting to 1L in a volumetric flask.

Waste water / Sludge	20-100ml (70ml)	15-20 TKN
Final effluent	140ml	
Outfalls	100ml	4-5 TKN

9. Procedure**Sample Preparation**

- Weigh out between 1.8g and 2g of well mixed fecal sludge sample.
- Place the weighed out sample into a blender with 250ml of distilled water.
- Blend for 30 seconds.

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
		Reviewed:	
SOP_Chem_002 Chemical Analysis_ Total Kjeldahl Nitrogen		Page #: 5 of 7	

- Transfer the blended mixture into a volumetric flask and top up to 1L with distilled water.
- Transfer the 1L solution to a plastic bottle and store in the cold room.

Heating Block

- Place 50ml of mixed diluted sample into 300ml Kjeldahl flask for raw or primary sewage, wastewater or 140ml for ponds, rivers or final effluents.
- Add a glass rod to the tube, and 5 boiling stones.
- Add slowly 10ml of concentrated sulphuric acid, 1kjeltab (or 2 spatulas powder), swirl to dissolve- wait approx 15min or overnight if sample has a high organic/fat content and then place onto digestion unit.
- Add 1000ml of 32% NaOH into reagent bottle 2, screw in bottle (clockwise) and push the bubbling tube to the bottom.
- Temperature range is set, follow program 1: 380 °C for 60min,
- Place suction cap onto tubes and open tap until a steady flow of water is reached (2L/min).
- Set pump to Mode A, air flow No: 4 until temperature of heating block reaches 200 °C.
- Then set pump to Mode B: air flow No: 4 until end of digestion.
- Reactivate Mode B -100 % of the maximum air flow – if SO₂ gas emission is too much.
- Boil briskly at 380°C until dense fumes of SO₂ are evolved and a pale green color is obtained.
- The required temperature i.e. 380°C is usually reached after an hour.
- Keep pump running for 30min after samples are fully digested and heating block is switched off.
- If sample is too little before fully digested, add 10ml concentrated sulphuric acid and remember to increase the vol of sodium hydroxide used during the distillation.
- Digestion takes about 3 hrs – colour changes from blue to dark green to black to colorless/pale green.
- Switch off the heating block, pump and the water supply.
- Replace water in the water bath and replace the NaOH in reagent bottle 2.

EE

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version: 001
	Reviewed:		
SOP_Chem_002 Chemical Analysis_ Total Kjeldahl Nitrogen		Page #: 6 of 7	

- Wait for samples to cool then distill samples.

Distillation

- Prepare absorption solution by placing 25ml of 4% boric acid in a 250ml conical flask and insert under the condenser outlet with the tip below the surface of boric acid.
- Lower collected distillate free from contact with the condenser tip and continue distillation for 1 or 2 minutes to cleanse the condenser.
- Enter distillation programme as follows:

Vol of water	Add 50ml to tube manually
Phenolphthalein indicator	10 drops to tube manually
Vol of NaOH	50ml (if 10ml sulphuric acid used in digestion) 200ml (if 30ml sulphuric acid used in digestion)

Distillation time 3min

Sample in tube turns purple with addition of NaOH - above pH 11 before distillation

Distillate in flask should reach around pH 8 before titrating.

Titration

Titrate distillate against 0.1N sulphuric acid with mixed methyl red (0.02g) bromocresol green indicator (0.1g) top up to 100ml ethanol.

Colour change: from blue to pale pink

Calculation

$$\text{Nitrogen (mg/L)} = \frac{(Titration - Blank)(0.1)(14)(1000)}{\text{Sample Volume (ml)}}$$

0.1 - Concentration of sulphuric acid used in titration

14 - Atomic weight of Nitrogen

1000 - Conversion of g to mg

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
		Reviewed:	
SOP_Chem_002 Chemical Analysis_ Total Kjeldahl Nitrogen			Page #: 7 of 7

$$\text{Nitrogen in Wet Sample (mg/g)} = \frac{(Titration - Blank)(0.1)(14)(1000)}{\text{Sample Volume (ml)}} \times \frac{V}{M}$$

$$\text{Nitrogen in Wet Sample (g/g)} = \frac{\text{Nitrogen in Wet Sample (mg/g)}}{1000}$$

$$\text{Nitrogen in Dry Sample (g/g)} = \frac{\text{Nitrogen in Wet Sample (g/g)}}{\text{Total Solids (g/g)}}$$

Where:

V = Volume of dilution (L)

M = mass of sludge used in sample preparation (g)

10. Precision and Accuracy

mg TKN/L	%SD	%Error
----------	-----	--------

APPROVAL OF STANDARD OPERATING PROCEDURE

PRG Head: Prof Buckley

Signature:

Date:

Author Merlien Reddy:

Signature:

Date:

Ammonia

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version: 001
		Reviewed by/Date:	
SOP_Chem_001 Chemical Analysis_Nitrogen, Ammonia		Page #: 1 of 6	

Standard Operation Procedure – Nitrogen, Ammonia**1. Scope and Application**

- Ammonia is naturally present in surface and wastewaters.
- It is produced largely by the deamination of waters and wastewaters the forms of nitrogen of the greatest interest are, in order of decreasing oxidation state, nitrate, nitrite, ammonia and organic nitrogen.
- All these forms of nitrogen as well as nitrogen gas are biochemically interconvertible and are components of the nitrogen cycle.
- The method covers the range from about 10 to 25mg/L for titrimetric procedure.

2. Summary

- The sample is buffered at pH 9.5 with a borate buffer to decrease hydrolysis of cyanates and organic nitrogen compounds.
- It is distilled into a solution of boric acid when titration is to be used.
- The ammonia in the distillate is determined titrimetrically with standard sulphuric acid and a mixed indicator together with a pH meter.

3. Interferences

- Glycine, urea, glutamic acid, cyanates and acetamide hydrolyze very slowly in solution on standing but of these only urea and cyanates hydrolyze on distillation at pH 9.5.

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version: 001
SOP_Chem_001 Chemical Analysis_Nitrogen, Ammonia			Reviewed by/Date: Page #: 2 of 6

4. Sampling

- Most reliable results are obtained on fresh samples
- Destroy residual chlorine immediately after sample collection to prevent its reaction with ammonia.
- If an immediate analysis is not possible, preserve samples by acidifying to pH between 1.5 and 2.0 with 0.8 ml conc H₂SO₄/L and store at 4°C.
- If acid preservation is used, neutralize samples with NaOH or KOH immediately before making the determination.

5. Safety Precautions

- Always use safety goggles, gloves and laboratory coat while working in laboratory
- Use eye and hand protection when preparing acid or handling color reagent
- Prepare and keep color reagent in fume hood

6. Apparatus

- VELP Distillation unit
- HANNA pH meter

7. Reagents

- Ammonia Free Water

Eliminate traces of ammonia in distilled water by adding 0.1ml sulphuric acid to 1L distilled water and redistilled. Alternately treat distilled water with enough bromine or chlorine water to produce a free halogen residue of 2-5 mg/L and redistill after standing for 1 hr.

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version: 001
		Reviewed by/Date:	
SOP_Chem_001 Chemical Analysis_Nitrogen, Ammonia		Page #: 3 of 6	

- 0.1N NaOH

Dissolve 4g NaOH in 1L distilled water.

- 1N NaOH

Dissolve 40g NaOH in 1 ammonia free distilled water.

- Borate Buffer Solution

Add 88mL of 0.1N NaOH solution to 500ml of 0.025M di-sodium tetra borate-hydrous ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$) solution – (9.5g $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ hydrous per liter) or (5.0g $\text{Na}_2\text{B}_4\text{O}_7$ anhydrous per liter) and dilute to 1L.

- Mixed indicator Solution

Dissolve 200mg methyl red indicator in 100ml 95% ethyl or isopropyl alcohol or ethanol. Dissolve 100mg methylene blue in 50ml 95% ethyl or isopropyl alcohol or ethanol. Combine solutions. Prepare monthly.

- Indicating Boric acid Solution

Dissolve 20g H_3BO_3 in ammonia free distilled water, add 10ml mixed indicator solution and dilute to 1L. Prepare monthly.

- Standard Sulphuric acid Titrant, 0.02N

Dissolve 0.5ml conc sulphuric acid in distilled water and dilute to 1liter.

Weigh out about 1.325g anhydrous Sodium Carbonate, previously dried at 270 °C. Dissolve in distilled water and make up to 250ml in a volumetric flask- this is 0.10N. Do not keep longer than 1 week.

Titrate the sulphuric acid solution against 25ml of sodium carbonate solution using bromocresol green-methyl red mixed indicator. Calculate the normality of the sulphuric acid.

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version: 001
SOP_Chem_001 Chemical Analysis_Nitrogen, Ammonia			Reviewed by/Date: Page #: 4 of 6

Error! Bookmark not defined. Normality of H_2SO_4 Solution = $\frac{25 \times 0.1}{\text{Vol } H_2SO_4 \text{ used}}$

Error! Bookmark not defined. Error! Bookmark not defined.

8. Sample Preparation – Fecal Sludge

- Weigh out between 1.8g and 2g of well mixed fecal sludge sample.
- Place the weighed out sample into a blender with 250ml of distilled water.
- Blend for 30 seconds.
- Transfer the blended mixture into a volumetric flask and top up to 1L with distilled water.
- Transfer the 1L solution to a plastic bottle and store in the cold room.

9. Procedure

- Preparation of Equipment

Add 500ml ammonia – free water and 20 ml borate buffer to a distillation flask and adjust pH to 9.5 with 6N NaOH solution. Add a few glass beads and use this mixture to steam out the distillation apparatus until distillate shows no traces of ammonia.

Ammonia Nitrogen	Sample
In Sample	Volume
Mg/L	mL
5-10	250
10-20	100
20-50	50.0
50-100	25.0

LL

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
Reviewed by/Date:			
SOP_Chem_001 Chemical Analysis_Nitrogen, Ammonia			Page #: 5 of 6

- Add 70ml of sample to distillation flask.
- Add 20ml borate buffer to distillation flask.
- Distill for 5min and collect 100ml distillate into the 50 ml indicating boric acid solution.
- Titrate ammonia in distillate with standard 0.02N sulphuric acid, titrate until indicator turns a pale lavender.
- Carry a blank through all steps of the procedure and apply the necessary correction to the results.

Calculation:

$$NH_3 \text{ (mg/L)} = \frac{(A - B) \times 280}{\text{Sample (ml)}}$$

Where:

A = volume of H_2SO_4 , titrated for sample, ml

B = Volume of H_2SO_4 , titrated for blank, ml

Sulphuric acid : Standard solution(0.02N, 1mL=0.28mg NH3-N) 1L=280mg NH3- N

Concentration = mass/Molar mass

$$NH_3 \text{ in Wet Sample (mg/g)} = \frac{(A - B) \times 280}{\text{Sample (ml)}} \times \frac{V}{M}$$

$$NH_3 \text{ in Wet Sample (g/g)} = \frac{NH_3 \text{ in Wet Sample (mg/g)}}{1000}$$

$$NH_3 \text{ in Dry Sample (g/g)} = \frac{NH_3 \text{ in Wet Sample (g/g)}}{Total Solids (g/g)}$$

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version: 001
		Reviewed by/Date:	
SOP_Chem_001 Chemical Analysis_Nitrogen, Ammonia		Page #: 6 of 6	

Where:

M = mass of sludge used in sample preparation (g)

V = Volume of dilution (L)

Quality control:

- Ammonium chloride, stock solution: 1.0mL=1.0mg NH₃-N. Dissolve 3.819g NH₄Cl in distilled water and bring volume to 1L with distilled water in a volumetric flask.
- Ammonium chloride, STD solution: 1.0mL = 0.01mg. Dilute 10.0mL of stock solution to 1Liter in a volumetric flask to give a concentration of 10mg/L NH₃-N.

10. Precision and Accuracy

mg NH ₃ -N/L	%SD	%Error
-------------------------	-----	--------

APPROVAL OF STANDARD OPERATING PROCEDURE

PRG Head: Prof Buckley

Signature:

Date:

Author Merlien Reddy:

Signature:

Date:

Thermal Conductivity

 UNIVERSITY OF KWAZULU-NATAL	<i>Standard Operating Procedure</i> Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
		Reviewed by/Date:	
SOP_MP_005 Thermal Conductivity Testing			Page #: 1 of 7

Standard Operation Procedure – Thermal Conductivity Testing**1. Scope and Application**

- This document provides instructions on testing minimal volumes of powder, liquids, feces, pit latrine(VIP) samples using TCi small volume test kit(SVTK).
- Testing with the C-Therm TCi can directly measure thermal conductivity and thermal effusivity.
- It can indirectly measure diffusivity, heat capacity, the R-value or depth of penetration.

2. Summary

The SVTK was developed for testing minimal volumes of liquid volumes of fluid material. Reducing the volume of sample material required for an effective thermal conductivity measurement is extremely important in the testing of energetic materials whereby larger samples pose a significant safety concern. The use of the accessory has also been applied widely in the testing of various materials that are doped with extremely expensive filters(gold, diamonds etc.) that are in limited supply.

3. Interferences

- If any cell is red , the measurement is not valid. Repeat the measurement.
- Check the R^2 value for each measurement. If the R^2 value is less than 0.995, the measurement is not valid.
- An orange cell means that the thermal conductivity or thermal effusivity value is outside of the calibration range of that material group.
- To enter density:

 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
		Reviewed by/Date:	
SOP_MP_005 Thermal Conductivity Testing		Page #: 2 of 7	

- Click on material, add, density value, save.

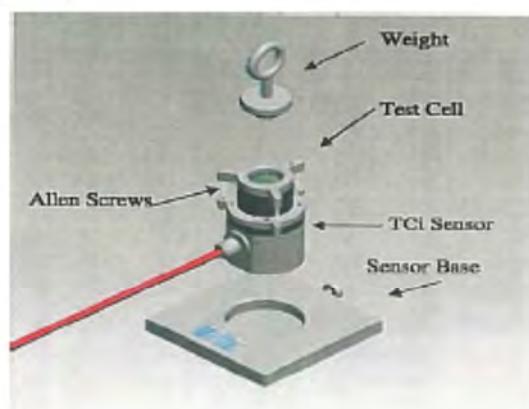
4. Sampling

5. Safety Precautions

6. Apparatus

SVTK P/N:

- Weight
- Test Cell, Allen screws,
- TCi sensor
- Sensor Base
- Measuring spoons(1/8 and 1/4)



 UNIVERSITY OF KWAZULU-NATAL	<i>Standard Operating Procedure</i> Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
		Reviewed by/Date:	
SOP_MP_005 Thermal Conductivity Testing		Page #: 3 of 7	

7. Reagents

8. Calibration

9. Procedure

DENSITY:

SOLID TESTING:

- Fill the 1/8 teaspoon (0.63ml) with the sample to be investigated.
- Level off the excess sample by scraping off the excess with a spatula by making a horizontal movement.
- Care must be taken to prevent compaction of the sample in the teaspoon (e.g. Vibrations, rearranging sample with spatula, and tapping on the teaspoon).
- The sample remaining in the teaspoon is the specimen.
- Transfer the sample to a weighing dish.
- Repeat the above steps 3 times for a total volume of specimen of approximately 3/8 teaspoon or 1.8ml.
- Place the weight onto the sample so that it seats on the rim of the test cell.NB:If the sample to be measured weighs more than 150g,omit the weight.
- Monitor the sensor temperature via the TCi software until it is stable and the sensor , sample and environment have all reached a state of thermal equilibrium.

 UNIVERSITY OF KWAZULU-NATAL	<i>Standard Operating Procedure</i> Pollution Research Group	Effective Date: 20 June 2013	Version: 001
		Reviewed by/Date:	
SOP_MP_005 Thermal Conductivity Testing			Page #: 4 of 7

- Initiate the test sequence within the TCi software.



CLEANING:

- Pour out the contents of the sample from the test cell or remove it with a paper towel.
 - Place sensor upside down and remove the test cell by gradually unfastening the three screws in a sequenced manner. Use a 3/32 Allen wrench.
 - Remove the sensor test and clean with either soap and water, water or propyl alcohol.
 - To test again place the test cell on the sensor and place upside down in order to have easy access to the screws.
 - Tighten gradually and in sequence until the test cell seats perfectly flat against the sensor housing surface.

LIQUID TESTING:

- Measure 1.25ml(1/4 tsp) of total liquid volume of specimen.
 - Transfer this volume directly to the test cell.
 - Place the quick clamp cap on the test cell.

 UNIVERSITY OF KWAZULU-NATAL	<i>Standard Operating Procedure</i> Pollution Research Group	Effective Date:	Version.:
		20 June 2013	001
		Reviewed by/ Date:	
	SOP_MP_005 Thermal Conductivity Testing		Page #: 5 of 7

-
- Use of the cap is optional but will prevent any undesirable evaporation of the liquid from the cell.
 - Monitor the sensor temperature via the TCi software until it is stable and the sensor, sample and environment have all reached a state of equilibrium.
 - Initiate the test sequence within the TCi software.



 UNIVERSITY OF KWAZULU-NATAL	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
		Reviewed by/Date:	
SOP_MP_005 Thermal Conductivity Testing			Page #: 6 of 7

TCi Quick Card

For technical support call 1-506-462-7204 or email support@ctherm.com

Material Type	Minimum Thickness	Sample Preparation	Contact Agent
Liquids	1 mm	Fill 50 mL beaker to 35 mL mark. Place sensor in beaker.	None
Powders	1 mm	Fill 50 mL beaker to 30 mL mark. Place sensor in beaker.	
Foams	2 mm	Place sample on sensor. Place weight on sample.	
Polymers	5 mm	Place contact agent on sensor.	-20°C to 5°C: 3 drops of glycol
Ceramics	5 mm	Place sample on sensor. Place weight on sample.	5°C to 70°C: 3 drops of water
Metals	5-12 mm		70°C to 200°C: Wakefield 120 Thermal Joint Compound

Testing: General Procedure

- Step 1 Prepare the materials to be tested. Inspect surface for dirt/damage.
- Step 2 Position the material on the sensor. Place weight if applicable.
- Step 3 Click the New Test button on the toolbar.
- Step 4 Select the project.
- Step 5 Click the Next button.
- Step 6 Select the test method to be used.
- Step 7 Select the material group and material to be used. If no suitable record exists, click the New button, enter the name of the group or material, and click the Save button.
- Step 8 Click the Next button.
- Step 9 Select the instrument.
- Step 10 Select the sensors.
- Step 11 Select the contact agent.
- Step 12 Click the Start Test button.

Testing Tips

- Wear gloves while handling samples to avoid thermal contamination.
- When using a thermal chamber, allow samples and sensor to equilibrate to temperature for 2 hours prior to testing and for 10 minutes every time the door is opened.

Importing Files

- Step 1 Select the type of record to import from the Tools menu.
- Step 2 Select the file to import.
- Step 3 All records contained in the file are displayed.
- Step 4 Click the Import button.



 POLLUTION RESEARCH GROUP	Standard Operating Procedure Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
		Reviewed by/Date:	
SOP_MP_005 Thermal Conductivity Testing		Page #: 7 of 7	

Exporting Files

Test results, user calibration results, calibration methods, and test methods can be exported and imported. All records with the exception of notes are exported and imported with the test results, user calibration results, calibration methods, or test methods.

- Step 1 Select the type of file to export from the Tools menu.
- Step 2 Enter keywords in the parameter fields.
- Step 3 Click the Search button or press the Enter key.
- Step 4 Select the records to export from the displayed list.
- Step 5 Click the Next button.
- Step 6 Select a destination for the export file.
- Step 7 Click the Export button.

Creating a Test Method

- Step 1 Open the test method table.
- Step 2 Click the Add button.
- Step 3 Enter a name for the test method.
- Step 4 Select a project.
- Step 5 Select a calibration method.
- Step 6 Enter the delay before the first measurement (optional).
- Step 7 Enter the minimum measurement period (optional).
- Step 8 Enter the number of measurements to be taken. If zero is entered, measurements will be taken until the test is stopped by the user.
- Step 9 Enter the number of sensors to be used. If zero is entered, any number of sensors can be selected when beginning a test.
- Step 10 Enter the number of samples per sensor per measurement. This is the number of times the sensor fires during a single measurement interval.

- Step 11 Select the prompts to be displayed.
- Step 12 Click the Save button.

Changing Units

Step 1 Select Change Units of Measure from the Tools menu.

- Step 2 Select the units.
- Step 3 Click the OK button.
- Step 4 Logout and restart the software.

Reference Material Tests

Calibration Material Group	Reference Material
Liquids and Powders	Distilled Water
Foams	LAF 6720*
Polymers	Pyrex
Ceramics	Pyroceram
Metals	Phosphor Bronze*

- Step 1 Prepare the reference material and sensor.
- Step 2 Click Reference Material Test from the Tools menu.
- Step 3 Click the Next button.
- Step 4 Select an Instrument.
- Step 5 Select the calibration method.
- Step 6 Select the sensor(s) to be used.
- Step 7 Click the Next button.
- Step 8 Select the reference material bin (Foam and Metal).
- Step 9 Confirm the ambient temperature.
- Step 10 Click the Update button (if temperature was incorrect).
- Step 11 Click the Get Sample button. All results should be within 5% of the displayed predicted value.
- Step 12 Click the Finish button.

C-THERM
TECHNOLOGIES®

Calorific Value

	<i>Standard Operating Procedure</i> Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
		Reviewed by/Date:	
SOP_MP_001 Calorimetric Analysis			Page #: 1 of 4

Standard Operation Procedure – Calorimetric Tests**1. Scope and Application**

Heats of combustion as determined in an oxygen bomb calorimeter are measured by a substitution procedure in which the heat obtained from the sample is compared with the heat obtained from combustion of a similar amount of benzoic acid or other standardizing material whose calorific value is known. These measurements are obtained by burning a representative sample in a high pressure oxygen atmosphere within a bomb. The energy released by this combustion is absorbed within the calorimeter and the resulting temperature change within the absorbing medium is noted. The heat of combustion of the sample is then calculated by multiplying the temperature rise in the calorimeter by the previously determined energy equivalent or heat capacity determined from a standardizing material.

2. Summary

Calorimetry is the science of measuring quantities of heat, as distinct from temperature. The instruments used for such measurements are known as calorimeters. The oxygen bomb calorimeters, which are the standard instruments for measuring calorific values of liquid and solid combustible samples.

The calorific value (heat of combustion) of a sample may be broadly defined as the number of heat units liberated by a unit mass of a sample when burned with oxygen in an enclosure of constant volume.

3. Sampling

- Dry sample for 24 hours @ 105 °C in a crucible.
- Grind dried sample to a powder form.
- Weigh out a gram of sample into the sample vial.

 Standard Operating Procedure Pollution Research Group	Effective Date:	Version.:
	20 June 2013	001
	Reviewed by/Date:	
SOP_MP_001 Calorimetric Analysis	Page #:	2 of 4

- The bomb should never be charged with a sample which will release more than 8000 calories when burned in oxygen, and the initial oxygen pressure should never exceed 40 atmospheres (590psi).
- Never charge the bomb with more than 1g of combustible material.

4. Safety Precautions

- Do not use too much sample. The standard bomb 1108 cannot be expected to withstand the effects of combustible charges which liberate more than 8000 calories frequently. This generally limits the total weight of combustible material (sample plus combustion aid) to not more than 1.1gram.
- Do not charge the bomb with more oxygen than is necessary to obtain complete combustion. It is best to use the lowest gas pressure that will give complete combustion. Lower gas pressure permit higher gas temperatures and greater turbulence, both of which help to secure better combustion. The range is 20-35 atmospheres.
- Keep all parts of the bomb-especially the o-rings, insulated electrode assemblies and valves- in good repair at all times.
- Do not fire the bomb if gas bubbles are leaking from the bomb when it is submerged in water.
- Stand back from the calorimeter for at least 15 seconds after firing and keep clear of the top of the calorimeter. If the bomb should explode, it is likely that the force of the explosion will be directly upward.

5. Apparatus

- Parr 6200 Oxygen Bomb Calorimeter
- 1180P Oxygen Combustion Bomb

 UNIVERSITY OF KWAZULU-NATAL	<i>Standard Operating Procedure</i> Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
		Reviewed by/Date:	
SOP_MP_001 Calorimetric Analysis		Page #: 3 of 4	

6. Reagents

- Benzoic acid tablets for standardization.

7. Calibration

8. Procedure

1. Open oxygen gas cylinder, flow rate is already set to (400kPa), do not alter.
2. Check that distilled water chamber is filled to the mark.
3. Turn on the calorimeter and activate the pump and heater. Allow at least 20 minutes for the calorimeter to warm up and the jacket temperature to stabilize at 29 °C.
4. The calorimeter is ready to begin testing. The START key will be available at this time.
5. Fill the calorimeter bucket with 2L of distilled water. Set the bucket in the calorimeter.
6. SAMPLE PREP:
 - 1 g 24hr @105 °C dried blended sample into capsule. Tie cotton tread which is used as a fuse to ignite the sample onto heat wire in the bomb.
 - When contact is made through the heating wire, the tread will ignite, drop into the sample cup and ignite the sample.
7. Care must be taken when moving the bomb head from the support stand to the bomb cylinder.
8. Check the sealing ring to be sure it is in good condition and moisten it with a bit of water so it will slide freely into the cylinder and push it as far down as it can go.
9. Close the bomb and pressurize with oxygen. The pressure connection to the bomb is made with a slip connector on the oxygen hose.
10. Slide the connector onto the inlet valve body and push it as far as it can go.

 UNIVERSITY OF KWAZULU-NATAL	<i>Standard Operating Procedure</i> Pollution Research Group	Effective Date: 20 June 2013	Version.: 001
		Reviewed by/Date:	
SOP_MP_001 Calorimetric Analysis		Page #: 4 of 4	

11. Press the O2 FILL button and Step back until bomb is filled. Takes 1min.
12. Remove the gas connection and attach the lifting handle to the two holes in the side of the screw cap and lower the bomb into the water partially. Press the banana plugs onto the two ignition wires firmly into the terminal sockets on the bomb head before the head is completely immersed in water.
13. Note: If bubbles continue to rise from the bomb after the air in the screw cap has escaped the test must be stopped. Do not fire the bomb until the leak has been corrected.
14. Close the calorimeter cover. This lowers the stirrer and thermistor probe into the bucket. Make sure that the bucket thermistor does not touch the bucket or the bomb when the lid is lowered.
15. Select determination under OPERATING MODE.
16. After pressing the START key, the calorimeter will prompt the operator for BOMB ID number, sample ID number, sample weight and spike weight.
17. The calorimeter will now take over and conduct the test.
18. During the time it is establishing the initial equilibrium, the status bar will display PREPERIOD.
19. Just before it fires the bomb, at about 12min, it will sound a series of short beeps to warn the user to move away from the calorimeter.
20. Once the bomb has been fired the status bar will display POSTPERIOD.
21. Read of calorific value from screen.
22. Remove the bomb from the chamber after 3 minutes and depressurize bomb by opening the valve knob slowly. After all the pressure has been released, unscrew the cap and lift the head straight out to avoid sticking.
23. Remove the chamber containing the ash
24. Wipe the inside of the bomb clean and proceed with next sample.

APPENDIX D – Urine diversion toilet flyer



KEEP YOUR TOILET WORKING HEALTHILY AND HYGIENICALLY.



1. Faeces are deposited into the back of the toilet bowl, and ladies urinate into the front part.



2. Do not defacate into the front of the toilet.



3. Ash or sand is thrown over faeces after each use. Do not pour water into the pit.



4. Males must not urinate into the back of the toilet, use the separate urinal.



5. Men and boys must use the separate urinal.



6. Do not throw rubbish into the pit.



7. Clean the urinal with fresh water. Do not use disinfectants.



8. Keep the lid of the toilet closed to keep flies out of the pit.



9. Always wash your hands after using the toilet.

APPENDIX E – Chemical and thermal properties of VIP latrine sludge

Chemical and thermal properties of VIP latrine sludge

Lungi Zuma^{1*}, Konstantina Velkushanova¹ and Chris Buckley¹

¹Pollution Research Group, Department of Chemical Engineering, University of KwaZulu-Natal, Durban, 4000, South Africa

ABSTRACT

This study investigated the chemical and thermal properties of faecal sludge from 10 dry VIP latrines in Bester's Camp in the eThekini Municipality, Durban, South Africa. Faecal sludge samples were selected at different depths and from the front and back sections of 10 VIP latrines during a manual emptying process. The samples were analysed for: moisture content; volatile solids; chemical oxygen demand; ammonia; total Kjeldahl nitrogen; pH; orthophosphate; thermal conductivity; calorific value and heat capacity. These properties will facilitate the design of faecal sludge emptying and treatment equipment. A manual sorting of the pit contents was carried out to determine the categories and amounts of household waste present. There was a significant difference in the moisture, volatile solids, chemical oxygen demand, ammonia, total Kjeldahl nitrogen and orthophosphate content of the faecal sludge between the front and back sections of the pit. There was minimal change in the thermal properties within the pit. The median values through the pit of each property analysed were: moisture content – 0.81 g water/g wet mass; volatile solids – 1.5 g VS/g ash; COD – 1.7 g COD/g ash; ammonia nitrogen – 10 mg NH₃-N/g dry mass; TKN – 39 mg N/g dry mass; pH – 8.03; orthophosphate – 0.06 mg PO₄/g dry mass; thermal conductivity – 0.55 W/m K; calorific value – 14 kJ/g dry mass; heat capacity – 2.4x10³ kJ/kg K. On average, 87% of pit content is faecal sludge; the remainder consists of wastes such as paper, plastics and textiles.

Keywords: faecal sludge, VIP latrines, chemical properties, thermal properties

INTRODUCTION

In South Africa, 31.3% of households have their sanitation needs met by a pit latrine; 12.5% are ventilated improved pit (VIP) latrines while 18.8% are pit latrines without ventilation (StatisticsSA, 2011). VIPs are on-site sanitation systems; the excreta is stored on site prior to being emptied and disposed. The material that is emptied from the pits is known as faecal sludge. In the eThekini Municipality there are an estimated 40 000 VIP latrines. Because the toilet is a permanent structure, the pits need to be emptied when they become full. The municipality empties the pits on a 5-year cycle at no cost to the household (EWS, 2011); this faecal sludge requires treatment and/or disposal in a responsible manner. Technology development for collection, transport, treatment and disposal of faecal sludge requires

BBB

detailed knowledge of the properties of the faecal sludge that is emptied. The processes occurring in a VIP are: filling (with faecal matter, water and other material); water transfer in and out of the pit; biological transformation; and pathogen deactivation (Buckley et al., 2008a). These processes affect the properties of the faecal sludge within the pit.

The amount of urine and faeces excreted by an individual varies widely, even locally, depending on water consumption, diet, and occupation (Thye et al., 2011); this will affect the properties of the faecal sludge collected in the pit latrine. The properties of the faecal sludge will determine the emptying techniques (pumping, vacuum evacuation or manual emptying with spades, forks and buckets), transportation (tankers or skips), processing (anaerobic digestion, composting, drying or incineration) and final disposal (burial, incineration or agriculture) (Heinss et al., 1999, Harrison et al., 2012); (Radford et al., 2011). The properties can also inform the design of future sanitation facilities.

There are previous studies which have been conducted around the sampling and analysing of pit latrine sludge in the eThekweni Municipality for specific investigations. The first study, conducted by Bakare et al. (2012), involved sampling 16 VIP latrines at 4 depths and analysing the faecal sludge for moisture content, total and volatile solids content, chemical oxygen demand (COD) and aerobic biodegradability to determine the amount of biodegradable material present in each sample. The study was conducted in order to investigate the filling rates of VIPs and the efficacy of pit latrine additives. The second study, by Wood (2013), analysed for a wider selection of properties for samples collected at 4 depths of 2 VIP latrines – these tests included pH, alkalinity, moisture content, volatile solids, COD, biodegradable COD, total Kjeldahl nitrogen (TKN), ammonia, total phosphorus and orthophosphate, in order to model the degradation processes in a pit and to obtain a baseline understanding of the chemical transformations in the VIP.

This study formed part of a wider study funded by the Bill & Melinda Gates Foundation (BMGF) to characterise the contents of VIPs. The techniques developed will be applied to VIPs in other parts of Africa in order to assess the wider variability due to differences in the environment.

A difference was noted between the front and the back section of the pit; in the front section excreta are continually added through the use of the VIP latrine while no new material is added to the back section. Therefore this study extends the sample selection by conceptually dividing the pit into 2 sections (front and back) and selecting 4 samples from each section at 4 sludge depth levels; therefore 8 samples are collected from each pit. The average properties of the whole pit can be calculated by the volume-averaged mean of the properties of the 8 samples. The objective of the sampling campaign was to investigate the properties of faecal sludge along the pit depth and the two sections of the pit.

METHODOLOGY

Location

The VIPs were all located in the peri-urban area of Bester's Camp ($-29.723189, 30.977874$) in the eThekweni Municipality, Durban, South Africa. The records of when the pits were last emptied could not be located. It is reasonable to assume they were all emptied at the same time since the municipality sweeps through the city emptying all the pits once in every 5 years, regardless of the amount of sludge in an individual pit. The type and size of the brick dwellings were similar and were all built at the same time. The population is homogeneous in terms of their income level and diet.

VIP latrine emptying

The sampling programme entailed manually emptying 10 purposefully selected VIPs. The emptying was done by Fukamela Contractors, a contractor employed by eThekweni Municipality to empty VIP latrines.

The same conceptual approach (Buckley et al., 2008a) used by Bakare (2011) and Wood (2013), which describes the fate of the organic material that enters a pit latrine, was used in this study. The approach proposes 4 layers in a pit latrine as shown in Figure 40.

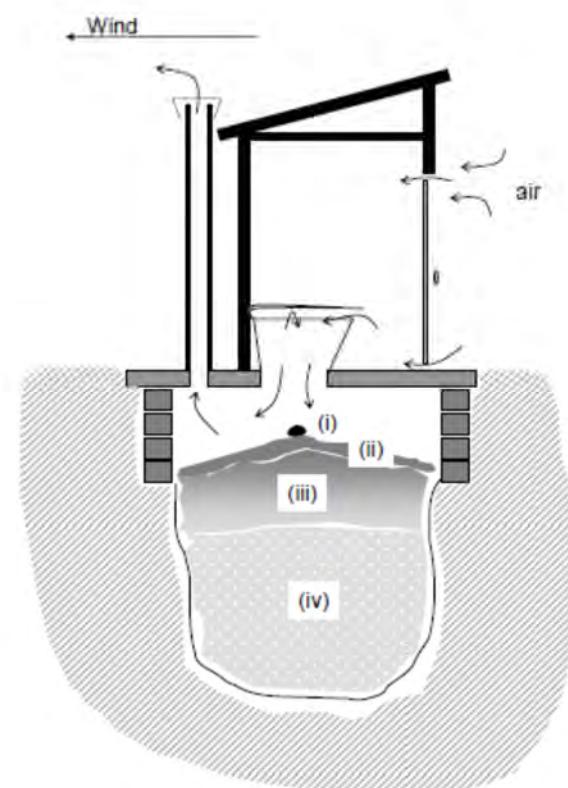


Figure 40

Diagram of a pit latrine showing the different conceptual layers (i) fresh stool; (ii) partially degraded aerobic surface layer; (iii) partially degraded anaerobic layer beneath surface; (iv) completely stabilised anaerobic layer(Buckley et al., 2008a)

This approach was used and further developed in the sampling campaign; this was conceptually achieved by dividing the pit into 2 sub-sections: a back section (not more than 200 mm from the back wall of the pit) and front section (under the pedestal). Samples were selected in these 2 sections based on Figure 3-2; therefore a total of 8 samples were selected from each pit.

Sludge sampling

The VIP sampling was carried out manually using long-handled spades and forks to remove the sludge from the pit into bins for disposal. Once the concrete back slabs of the pit had been removed (Figure 3-2), a long handled fork was used to measure the depth of the sludge in the pit. This was important as not all of the pits that were emptied contained the same depth of sludge. A measuring stick was used to measure the sludge depth. Faecal sludge samples were taken at predetermined depths for laboratory analysis. The faecal sludge samples were selected purposely to exclude any household waste found within the pit, i.e., only faecal sludge samples were taken for laboratory analysis.

Figure 3-2 and 3 depict the various depths that were sampled within each section of the pits. A single sample was selected from each layer and approximately 1 ℥ was placed in a plastic bag within a plastic bucket. After filling, the neck of the bag was knotted and then the bucket lid was pressed closed. Surface layer samples (to a depth of 50 mm) were taken from the front and the back of the pit. In order to reach the second layer, a sludge thickness layer of between 200 and 300 mm was taken out of the pit and disposed. The second layer samples were then taken from the front and the back of the pit. The middle layer samples varied in depth for the different pits because of the varying sludge heights. For each pit, the middle layer came from the halfway mark of the sludge depth. Therefore, if the sludge depth was 1 000 mm, the middle layer was taken from the 500 mm mark. The bottom layer sample was taken from the last shovel of sludge that was removed from the pit. The 1 ℥ sludge samples were transported to the laboratory and stored at 4°C until analysis. Samples were analysed within 2 weeks, with the exception of the analysis of thermal properties which was conducted 6 months later on a limited number of samples. The remains of the pit contents were removed by the contractor for treatment in the latrine dehydration and pasteurisation (LaDePa) plant (Harrison et al., 2012).

EEE

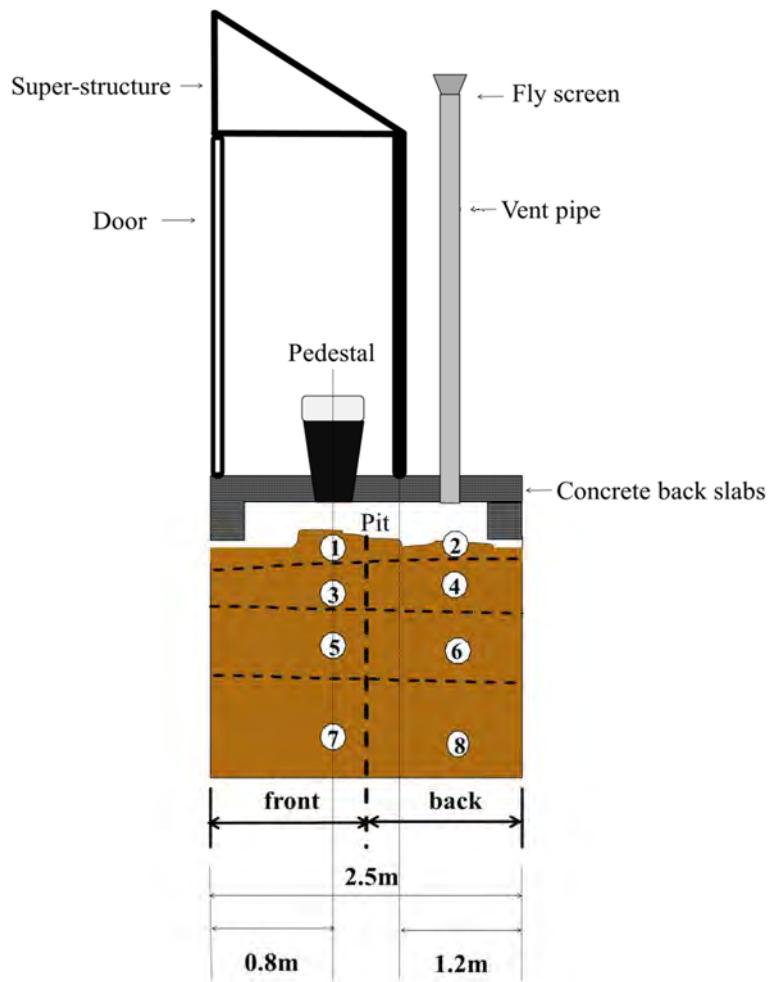


Figure 41

Diagram of a VIP latrine showing the layers from which the samples were selected in the front and back sections

Figure 42 illustrates the depths of the layers of the pits that were emptied and sampled.

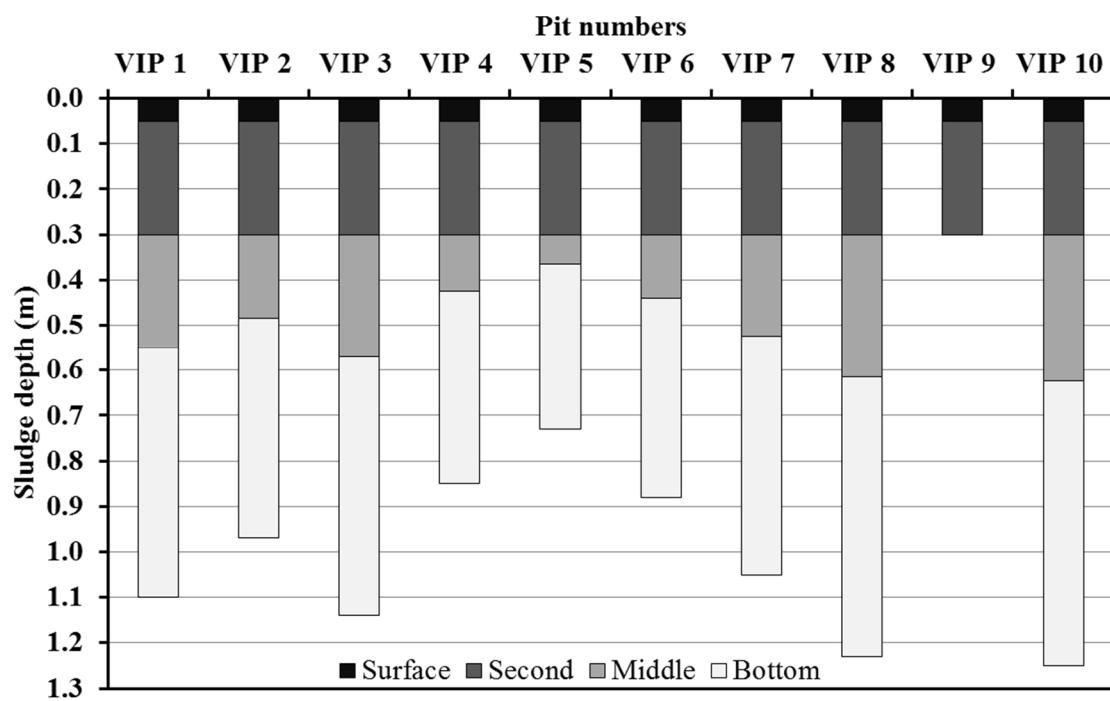
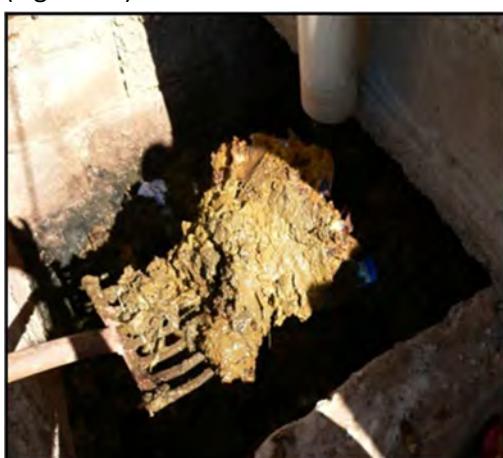


Figure 42

Sludge depths (m) of the layers sampled in each VIP latrine. For VIP 9, due to the structure of the pit, only the surface and second layers were sampled.

The faecal sludge from the different sections and layers was visually different – faecal sludge from the upper layers was a lighter brown colour as compared to the lower layers which was black and did not have an offensive odour – the stabilisation of the sludge is evident visually (Figure 43).



(a)



(b)

Figure 43

A range of faecal sludge from various points in VIP latrines: (a) second layer at the front section – VIP 5, (b) bottom layer at the back section – VIP 8 (Photo: Lungi Zuma, August 2012)

Laboratory analysis

Moisture content, volatile solids, COD, ammonia, TKN and pH analyses on the faecal sludge were carried out using Standard Methods for the Examination of Water and Wastewater (APHA, 2012). Where the analysis required samples in liquid form, faecal sludge dilutions were prepared by weighing a representative mass of the sample of between 1.8 and 2.0 g and making it up to 1 ℥ using distilled water. The solution was mixed in a Waring blender for 30 s and then stored in a plastic bottle in a cold room at 4°C until required. Samples were removed from the cold room and allowed to come to room temperature ($20 \pm 5^\circ\text{C}$) before any analysis was conducted.

Orthophosphate was analysed using a Spectroquant Category No. 1.14848 kit and a Merck spectrophotometer. Thermal conductivity and heat capacity tests were conducted on the C-Therm TCi instrument and calorific value tests were conducted on the Parr 6200 Oxygen Bomb Calorimeter. Moisture content is expressed on a wet mass basis. Volatile solids, COD and calorific value are expressed on an ash basis. The remainder of the properties, except pH, are expressed on a dry mass basis. The student t-tests were conducted in STATA 11.

Household waste sampling

All of the contents of VIP 1 and VIP 2 were set aside after the pits were emptied so that they could be sorted. The sorting of the pit contents gives an indication of the ratio of sludge to household rubbish in the pits, although the amount of household rubbish in pits varies from household to household.

The pit sorting was carried out manually; each bin full of faecal sludge was emptied out onto plastic sheeting and the household waste separated into the different categories (Figure 44). The objects that were found in the pits were sorted in the following categories: sludge; textiles; feminine products; lightweight plastics; paper; stiff plastics; stone; metals; wood; hair; and glass. Thereafter the sludge and the categories of waste were weighed and expressed as fractions of the total mass.



Figure 44

Manual sorting of the contents of a VIP: (a) the sludge removed from a bin, (b) sorting through the sludge, (c) textiles separated from the sludge (Photo: Lungi Zuma, September 2012)

RESULTS AND DISCUSSION

Box and whisker plots were generated using the data from the laboratory analysis for each property in each layer of the pit. A student t-test was conducted to determine if the faecal sludge property in one part of the pit was significantly different to the same property in another section of the pit. The parts were divided by sections (front and back) and a pair-wise comparison of the different layers.

Moisture content

The trend in moisture content was as expected – decreasing mean values with increasing sludge depth (Figure 45). The surface layer in the front section had the faecal sludge with the highest moisture content; this is expected as this is the freshest material. Overall, through the sludge depth, 90% of the samples had moisture content of between 0.69 and 0.87 g water/g wet mass; the median moisture content of the faecal sludge was 0.81 g water/g wet mass. There was a significant difference in moisture content between the:

- Front vs. back section ($p = 0.0029$)
- Front second vs. front middle layer ($p = 0.0469$)
- Back surface vs. back second layer ($p = 0.0389$)
- Back second vs. back middle layer ($p = 0.0479$)
- Back middle vs. back bottom layer ($p = 0.0001$)

From its appearance during emptying, the faecal sludge with higher moisture content was less viscous than that with lower moisture content. Faecal sludge with higher moisture content could not be emptied using a fork with tines 100 mm apart, while faecal sludge with lower moisture content could be emptied easily with this fork.

Volatile solids

Overall, 90% of the faecal sludge had a volatile solids content of between 0.45 and 4.3 g VS/g ash and the median volatile solids content of the faecal sludge was 1.5 g VS/g ash (Figure 46). In both sections of the pit there was an overall decrease of volatile solids content with increasing pit depth; this was expected because the faecal sludge becomes more stabilised at the lower depths. There was a significant difference in volatile solids content between the:

- Front vs. back section ($p = 0.0001$)
- Front second vs. front middle layer ($p = 0.0016$)
- Back surface vs. back second layer ($p = 0.0001$)
- Back middle vs. back bottom layer ($p = 0.0044$)

Total COD

Overall, 90% of the total COD of the faecal sludge was between 0.30 and 4.4 g COD/g ash with a median of 1.7 g COD/g ash (Figure 47). Through the whole pit, there was a decrease in COD of the faecal sludge with increasing pit depth. There was a significant difference in COD between the:

- Front vs. back section ($p = 0.0001$)
- Back surface vs. second layer ($p = 0.0029$)
- Back middle vs. bottom layer ($p = 0.0001$)

Ammonia

90% of the faecal sludge samples analysed had ammonia content of between 1.2 and 30 mg NH₃-N/g dry mass; the median ammonia content of the sludge was 10 g NH₃-N/g dry mass (Figure 48). The ammonia content in the faecal sludge decreased with increasing sludge depth for both sections of the pit. There was a significant difference in ammonia content between the:

- Front vs. back section ($p = 0.0001$)
- Front surface vs. second layer ($p = 0.0019$)

TKN

90% of faecal sludge analysed had a TKN content of between 9.3 and 74 mg N/g dry mass, with a median of 39 mg N/g dry mass (Figure 49). There was a decrease in faecal sludge TKN content with increasing pit depth in both sections of the pit. There was a significant difference in TKN between the:

- Front vs. back sections ($p = 0.0001$)
- Front second vs. middle layer ($p = 0.0154$)
- Back surface vs. second layer ($p = 0.0032$)

pH

The pH range through the faecal sludge depth was between 4.7 and 8.6 (Figure 50). The optimal pH for biological activity is between 6.5 and 8, as anaerobic microorganisms, especially methanogens, exhibit a characteristic sensitivity to the extremes of pH (Bhagwan et al., 2008b) (Anderson et al., 2003).

Faecal pH is neutral with a median value of pH 6.64 and a range of pH 5.3–7.5 (Rose et al., 2015), while urine has a pH of 9.0–9.3 due to urea dissociation by bacterial enzymes after secretion (Jonsson et al., 2007). The aerobic and anaerobic processes that occur within the pit also contribute to pH changes in the faecal sludge; therefore the pH of faecal sludge is a complex property which is affected by many factors.

Orthophosphate

Overall throughout the pit, 90% of the orthophosphate content of the faecal sludge was between 0.035 and 4.5 mg PO₄³⁻/g dry mass with a median of 0.37 mg PO₄³⁻/g dry mass (Figure 51). There was a significant difference in orthophosphate content between:

- Front vs. back sections ($p = 0.0077$)
- Front second vs. middle layer ($p = 0.0154$)
- Front middle vs. bottom ($p = 0.0394$)

Thermal conductivity

90% of the thermal conductivity throughout the pit lay between 0.48 and 0.58 W/m K with a median of 0.55 W/m K (Figure 52) – this indicates a very narrow range for the thermal conductivity of faecal sludge. The thermal conductivity of water was measured to be 0.61 W/m K (Pandarum, 2013). There was no significant difference in thermal conductivity between the sections of the pit and between the pair-wise comparisons of the different layers.

Calorific value

90% of the faecal sludge samples analysed had a calorific value of between 9.5 and 91 kJ/g ash, with a median calorific value of 31 kJ/g ash (Figure 53). The calorific value of the faecal sludge decreased with increasing sludge depth in both sections of the pit; this was expected due to the decrease in organic matter in the lower layers of the pit. There was a significant difference in calorific value between the:

- Front vs. back sections ($p = 0.0001$)
- Front second vs. middle layer ($p = 0.0004$)
- Back second vs. middle layer ($p = 0.0028$)

Heat capacity

Throughout the whole pit, the heat capacity of the sludge was within a narrow range; 90% of the faecal sludge samples had a heat capacity of between 1 970 and 3 430 kJ/kg K and the median heat capacity was 2 430 kJ/kg K (Figure 54). There was no significant difference in heat capacity between the sections of the pit and between the pair-wise comparisons of the different layers.

Household waste

The types of household waste found in VIP pits varied depending on the habits of the users, the demographics of the household and the type of cleansing material used (Table 9). The differences in the paper content of the two pits could be because of the use of toilet paper

versus the use of newspaper which takes longer to degrade. These typical household wastes found in the pit need to be taken into account in the design of pit emptying devices.

Table 9 The distribution of pit contents in categories

Category	VIP 1 %	VIP 2 %
Sludge	86.2	87.3
Paper	8.4	3.8
Synthetic hair	1.2	-
Light plastics	0.74	3.4
Stiff plastics	0.32	0.96
Textiles	1.1	1.3
Feminine products	0.42	2.5
Glass	0.56	-
Metals	0.19	
Wood	0.27	0.77*
Stones	0.71	

*Combined value for metals, wood and stones

CONCLUSION

The addition of material to the front section of the pit has an effect on the chemical properties of the faecal sludge as there were significant differences in chemical properties of the faecal sludge between the front and back sections. However, the thermal properties of the sludge are unaffected.

VIP latrine emptying devices have to be designed to cater for the differences between the front and back section of the pit with regards to moisture content. It is recommended that the viscosity of the faecal sludge in the layers be determined; this was seen to be visually different during the pit emptying and will influence the design of pit emptying equipment.

The volatile solids content and COD can both be used to determine the organic matter content of the faecal sludge. The results from these two analyses were similar, in the 90% range, for both average and median values – therefore, if only the amount of organic material is required, the volatile solids test is preferred because it is simpler and cheaper than the COD test. The faecal sludge in the back section of the pit had undergone more stabilisation than that in the front section of the pit; this conclusion is based on the average volatile solids and COD in these sections.

There was minimal transformation in the thermal conductivity and heat capacity within the pit as there were no significant differences between the different sections of the pit or between the different layers of the faecal sludge. Thus any treatment technologies that are based on

faecal sludge thermal conductivity and heat capacity can be designed to cater for a narrower range than technologies based on chemical properties.

In future VIP latrine sampling to understand transformation within the pit, it is recommended that the pit be divided into front and back sections for the analysis of chemical properties. In terms of understanding the stabilisation within the pit, the bottom layer for this study was too large (there was a significant difference in the volatile solids content, COD) – it is recommended to divide the bottom layer even further, especially in the back section of the pit. Sampling of faecal sludge for thermal conductivity and heat capacity analysis does not require many layers and it is unnecessary to sample in sections; thus a composite sample of the layers and sections can be analysed for thermal conductivity and heat capacity and used as the average for the whole pit.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Bill & Melinda Gates Foundation for the funding to complete this research.

REFERENCES

- ANDERSON K, SALLIS P and UYANIK S (2003) Anaerobic treatment processes. In: Mara D and Horan N (eds.) *Handbook of Water and Wastewater Microbiology*. Academic Press, London.
- APHA (2012) *Standard Methods for the Examination of Water and Wastewater*. American Public Health Association, Washington DC.
- BAKARE B (2011) Scientific and management support for ventilated improved pit latrines (VIP) sludge content. PhD thesis, University of KwaZulu-Natal.
- BHAGWAN JN, STILL D, BUCKLEY C and FOXON K (2008) Challenges with up-scaling dry sanitation technologies. *Water Sci. Technol.* **58** (1) 21–27.
- BUCKLEY C, FOXON K, BROUckaert C, RODDA N, NWANERI C, BALBONI E, COUDERC A and MAGAGNA D (2008) Scientific support for the design and operation of ventilated improved pit latrines (VIPs) and the efficacy of pit latrine additives. WRC Report No. TT/357/08. Water Research Commission, Pretoria.
- EWS (ETHEKWINI WATER & SANITATION) (2011) Water Services Development Plan for the eThekwin Municipality. EWS, Durban.
- HARRISON J and WILSON D (2012) Towards sustainable pit latrine management through LaDePa. In: *Proceedings of the Second International Faecal Sludge Management Conference (FSM2)*, 29–31 October 2012, Durban.
- HEINSS U, LARMIE S and STRAUSS M (1999) Characteristics of faecal sludges and their solids-liquids separation. EAWAG/SANDEC, Duebendorf.
- JONSSON H and VINNERAS B (2007) Experiences and suggestions for collection systems for source separated urine and faeces. *Water Sci. Technol.* **56** (5) 71–76.
- PANDARUM S (2013) Determination of the thermal conductivity of waste. Unpublished Chem Eng IV project report, University of KwaZulu-Natal, Durban.

MMM

- RADFORD J, COFFEY M and FENNER R (2011) Developing a synthetic pit latrine sludge and a process for its fluidisation. In: *Proceedings of the EWB-UK National Research & Education Conference*, 4 March 2011, London.
- ROSE C, PARKER A, JEFFERSON B and CARTMELL E (2015) The characterisation of faeces and urine; a review of the literature to inform treatment technology. *Crit. Rev. Environ. Sci. Technol.* **45** (17) 1827–1879.
- STATISTICS SA (2011) General Household Survey Series, Volume III, Water and Sanitation, 2002-2010. Stat SA Report No. 03-18-02. Statistics SA, Pretoria.
- THYE Y, TEMPLETON M and ALI M (2011) A critical review of technologies for pit latrine emptying in developing countries. *Crit. Rev. Environ. Sci. Technol.* **41** (20) 1793–1819.
- WOOD K (2013) Transformation of faecal sludge in VIPs: Modelling fill rate with an unsteady-state mass balance. MScEng thesis, University of KwaZulu-Natal.

Figures

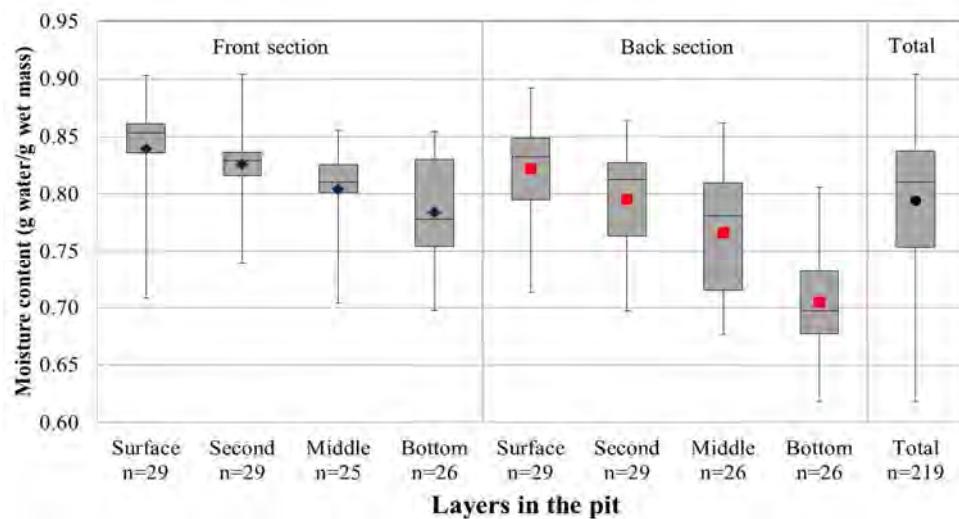


Figure 45

Box and whisker plot for the moisture content (g water/g wet mass) for the different layers of 10 dry VIPs. The extremes of the whisker represent the maximum and minimum values respectively. The outline of the box represents the 3rd and 1st quartile, the line in the box represents the median and the symbols represent the mean. The value in brackets below the graph represents the number of analyses.

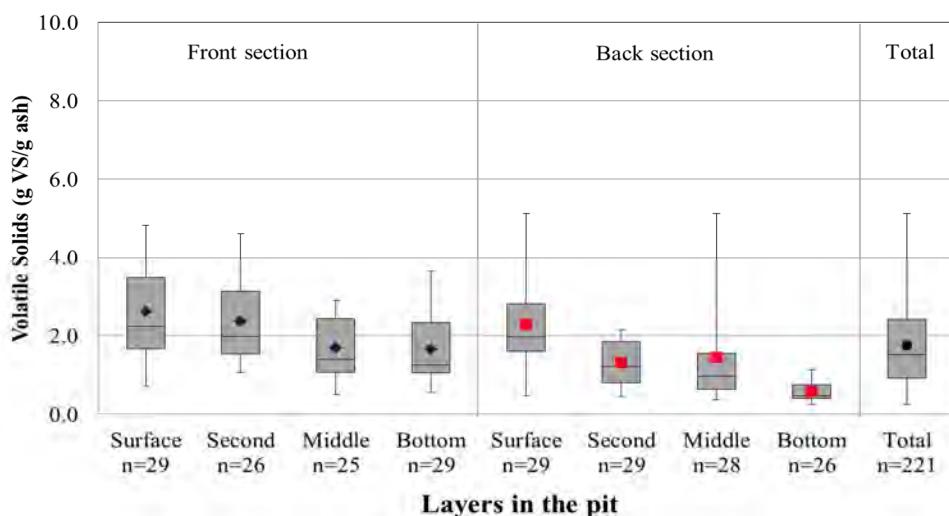
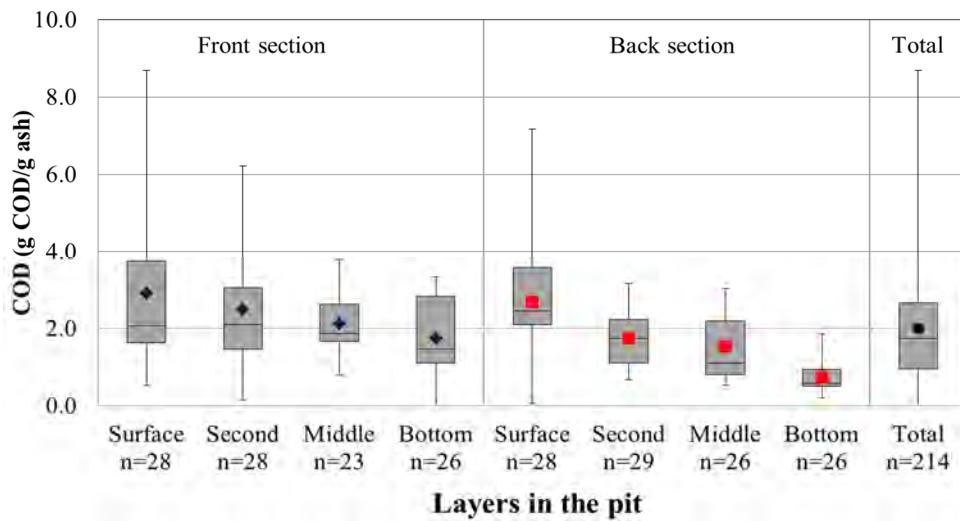
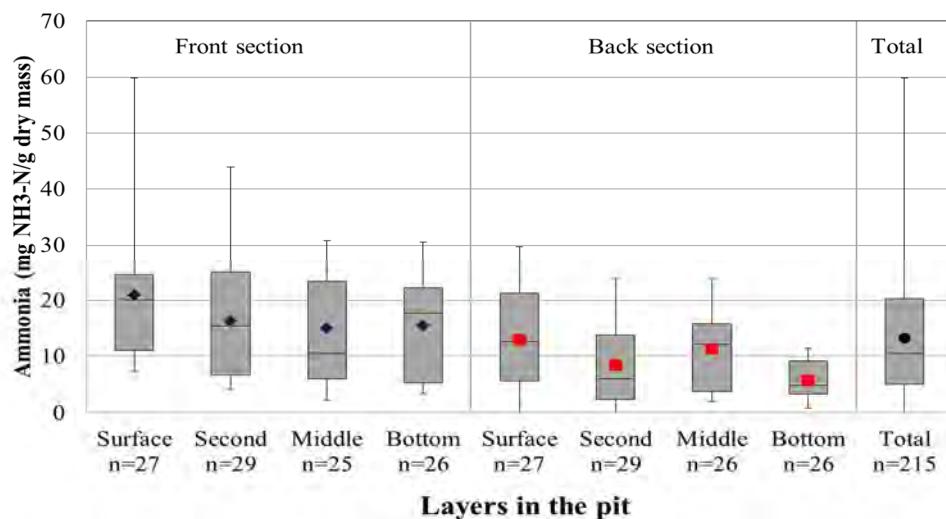


Figure 46

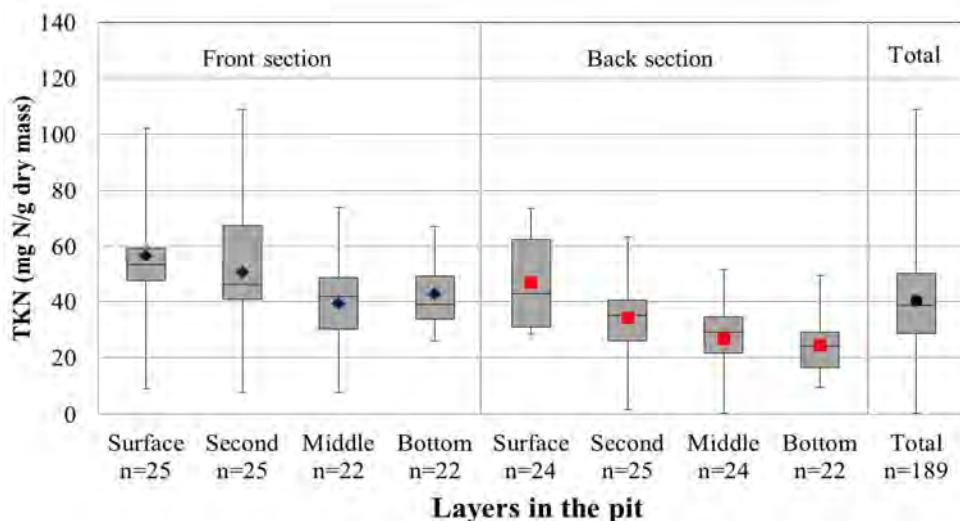
Box and whisker plot for the volatile solids (g VS/g ash) for the different layers of 10 dry VIPs

**Figure 47**

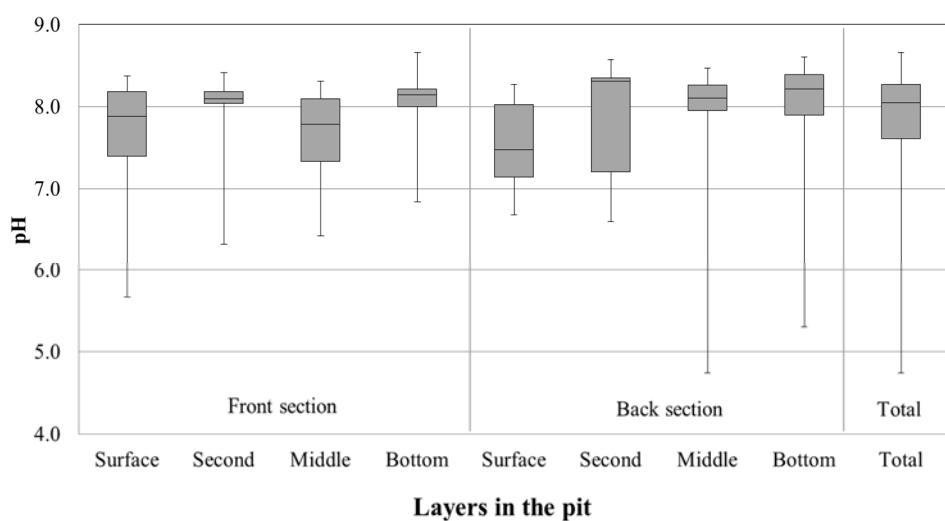
Box and whisker plot for the total COD (g COD/g ash) for the different layers of 10 dry VIPs

**Figure 48**

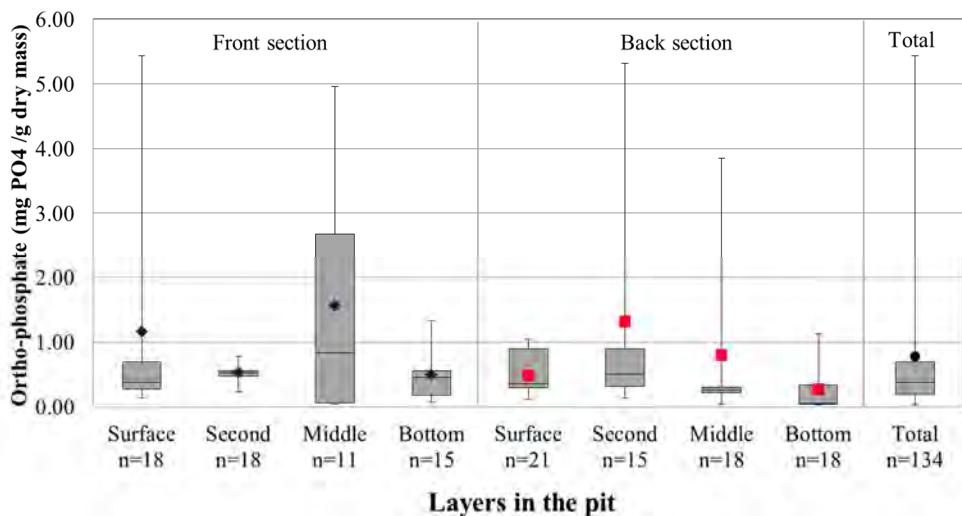
Box and whisker plot for the ammonia (mg NH₃/g dry mass) content for the different layers of 10 dry VIPs

**Figure 49**

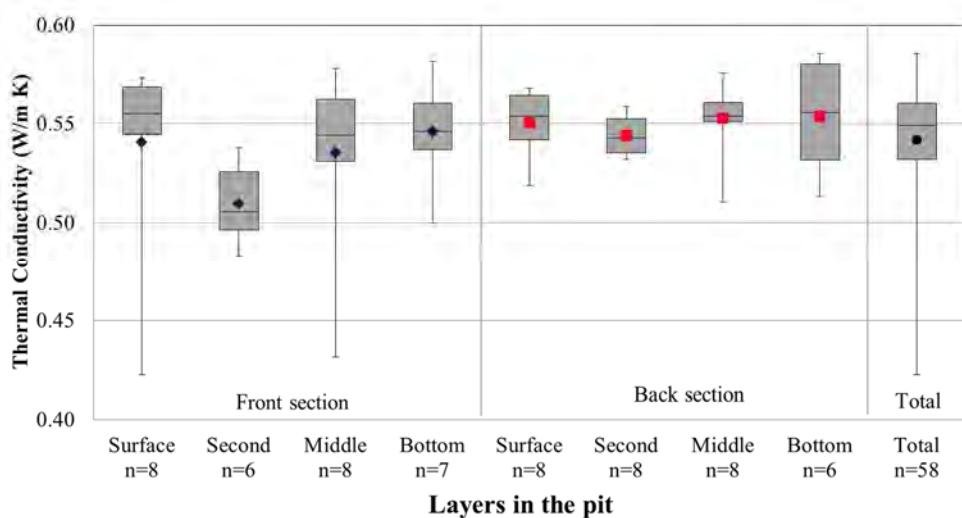
Box and whisker plot for the TKN (mg N/g dry mass) for the different layers of 10 dry VIPs

**Figure 50**

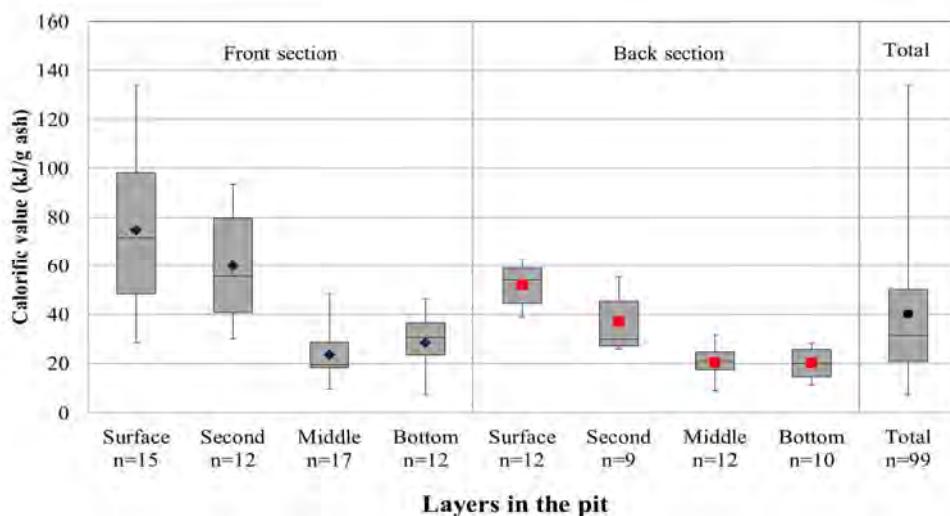
Box and whisker plot for the pH for the different layers of 10 dry VIPs

**Figure 51**

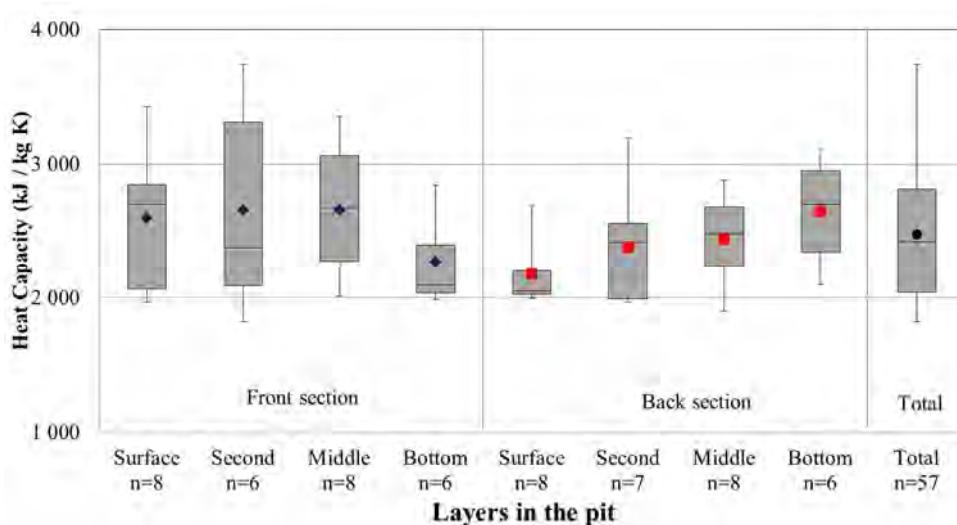
Box and whisker plot for the orthophosphate (mg PO₄/g dry mass) content for the different layers of 10 dry VIPs

**Figure 52**

Box and whisker plot for the thermal conductivity (W/(m·K)) for the different layers of 10 dry VIPs

**Figure 53**

Box and whisker plot for the calorific value (kJ/g ash) for the different layers of 10 dry VIPs

**Figure 54**

Box and whisker plot for the heat capacity (kJ/(kg·K)) for the different layers of 10 dry VIPs