Characterisation of On-Site Sanitation Material and Products: VIP Latrines and Pour-Flush Toilets

VOLUME 1: CHARACTERISATION OF FAECAL SLUDGE FROM POUR-FLUSH LATRINES

Report to the
Water Research Commission

by

Pollution Research Group
University of KwaZulu-Natal

List of authors:
Ms. Aoife Byrne (M.Eng Student)
Ms. Anusha Singh (PhD Student)
Dr. Santiago Septien Stringel (Researcher)
Konstantina Velkushanova (Researcher)
Chris Buckley (Professor)

WRC Report No. 2137/1/18
ISBN 978-0-6392-0043-9

October 2018

Obtainable from:
Water Research Commission
Private Bag X03
GEZINA, 0031

The publication of this report emanates from a project entitled C*haracterisation of on-site sanitation material and products: VIP latrines and pour-flush toilets* (WRC Project No. K5/2137).

This report forms part of a series of two reports. The other report is *LaDePa* (WRC Report No. 2137/2/18).

Printed in the Republic of South Africa

EXECUTIVE SUMMARY

The Pour-Flush system is used extensively throughout South East Asia, where the system is designed with a squatting pan and the users are “washers”. It was considered that this type of on-site sanitation systems might be beneficial and well accepted in South Africa from user perspective as this is one step closer to the conventional flush toilet. The system was adapted to the South African context and culture by *Partners in Development* (PID). A sitting pedestal was designed which accommodated for the use of toilet paper rather than water for anal cleansing.

In the context of South Africa, the Pour-Flush system is viewed as an upgrade from the *Ventilated Improved Pit* latrine (VIP), which is the standard for basic sanitation in the country. For this reason, the performance and the user acceptance of the system are of interest. On the other hand, it is important to understand the characteristics of the sludge produced and stored in the leach pit to help understand the environmental impact of the system, mechanisms for emptying the pits once they are full and potential for reuse of the sludge, and how they compare to the VIP use and sludge characteristics.

PID successfully ran a pilot scheme involving the installation of approximately 25 Pour-Flush latrines in the greater Edendale area (Slangspruit, France and Azalea) outside of Pietermaritzburg in the province of KwaZulu-Natal, South Africa. The Pour-Flush systems installed in this area by PID were used for the basis of this research project. Sludge was sampled from selected pits repeatedly over a period of 11-months. The sludge was analysed chemically, physically and biologically to provide a base understanding of the sludge characteristics and possible mechanisms occurring in the pit. The filling rates of the pits were also monitored, as this is important information for planning future pit-emptying schemes and pit design.

It was found that the Pour-Flush and VIP sludge had minor differences in terms of the chemical composition. However, physically, the Pour-Flush sludge is more homogeneous with small amounts of non-faecal material in the pits. This means filling rates are slower as there is less non-degradable material in the sludge. Also, mechanical pit emptying is easier (provided the sludge is wet enough) without the presence of non-faecal material, which is often the cause for blockage or damage of pit emptying equipment.

It was thought that the concentration of ammonia in the sludge would be high enough to create a self-sanitising environment within the leach pit. However, it was determined early on that the concentration of ammonia in the sludge was too low to have a sanitising affect.

In order to ensure simplicity of understanding the research process and outcomes, the studies of both Pour Flush (Volume 1) and *Latrine Dehydration and Pasteurisation* (LaDePa) machine (Volume 2) are presented as two separate volumes within Research Project K5/2137. This report presents the former (Volume 1).

ACKNOWLEDGMENTS

- Water Research Commission (WRC) for its funding, special thanks to Mr. Jay Bhagwan (Chair: 2012-2013) and Dr. Sudhir Pillay (Chair: 2014-2015).

- eThekwini Water Services (EWS) for its support, special thanks to Mr. Teddy Gounden, Mr. Dave Wilson and Mr. John Harrison.

- Partners in Development (PID) for its support, special thanks to Mr. Dave Still.

- Reference Group Members for Research project K5/2137.

- Students involved in the research. A full list of researchers has been included in **Appendix I**.

- Technical and support staff from the Pollution Research Group (PRG) from the University of KwaZulu-Natal for its involvement, special thanks to Ms. Susan Mercer, Ms. Merlien Reddy and Mr. Kenneth Jack

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

Acronyms

COD	Chemical Oxygen Demand
COD_p	Particulate Chemical Oxygen Demand
COD_s	Soluble Chemical Oxygen Demand
COD_t	Total Chemical Oxygen Demand
CSTR	Continuously Stirred Tank Reactor
PID	Partners in Development
PRG	Pollution Research Group
TKN	Total Kjeldahl Nitrogen
TS	Total Solids
TSS	Total Suspended Solids
UKZN	University of KwaZulu-Natal
VIP	Ventilated Improved Pit
VS	Volatile Solids
WRC	Water Research Commission

Symbols

h	Penetration reading	m^{-2}
k	Drop cone factor	-
Q	Force of the cone	kN
S_{ur}	Shear strength	$kN.m^{-2}$

1. BACKGROUND

Partners in Development (PID), an engineering consultancy based in Pietermaritzburg, installed approximately 25 Pour-Flush toilets in the greater Edendale area, which are located in the uMsunduzi Municipality, KwaZulu-Natal Province. The toilets were installed between September 2010 and August 2012 as part of a pilot scheme to test the development of a Pour-Flush pedestal adapted from the standard Asian design to the South African user. To date, the pilot has been successful, with high user acceptance, limited odour issues and minimal operation and maintenance problems. Full details of the pilot can be found in a report produced for the WRC by PID [1].

The Pour-Flush system can be constructed with either one or two leach pits. The leach pits have internal dimensions 1 m by 0.8 m with 1.4 m depth. The two leach pits can either be constructed at the same time, when the entire system is being installed, or one leach pit can be constructed at the beginning and the second pit can be constructed when the owner can afford it or when the first pit has filled up. Where two pits are constructed, the underground sewer pipe is connected to one pit until it is full. When this pit is full the piped connection is diverted to the second pit, which then begins filling. The first pit is now out of use and the faecal sludge decomposes and the pathogens die off over time. A form of compost is produced that is safe to handle and dig out manually. It takes approximately 2 years for the sludge to become inert (see **Appendix A** for photographs).

If only one pit is constructed on site, it can either be emptied via a vacuum tanker or other appropriate mechanical emptying equipment. Alternatively, a second pit can be constructed when it is needed [1]. In the pilot, households were provided with a combination of one or two leach pits on site.

There is limited knowledge about the chemical, physical, and biological properties of the sludge produced from the Pour-Flush system, either from the Asian design or the newly implemented South African design. Hence, the aim of this part of the project was to begin building data about the chemical components of the sludge, how it behaves physically and mechanical and the process of degradation occurring inside the leach pit.

The main objectives of this project were to:

- Determine the filling rate of the Pour-Flush leach pit
- Characterise the Pour-Flush sludge chemically, physically and biologically
- Compare the contents of active and standing pit
- Compare the Pour-Flush system to the VIP latrine system
- Determine if the ammonia concentration is high enough to disinfectant the sludge
- Determine appropriate equipment for sludge sampling

Under this project (K5/2137: Volume 1), a number of deliverables were submitted in relation to the pour flush studies:

- Deliverable 5: Protocol for Assessing Pour-Flush Toilets
- Deliverable 7: Preliminary Data on Pour-Flush Toilets
- Deliverable 13: Preliminary Interpretive Report on Pour-Flush Latrines

In the next Chapter, the Materials and Methods used for experiments are presented.

2. MATERIALS AND METHODS

The chapter is divided into six sections: **section 2.1** presents information related to the site selection, **section 2.2** presents the sampling protocol; **section 2.3** presents the rheological analysis of the sludge, and **section 2.4** presents the biodegradability methodology.

2.1 SITE SELECTION

Of the 25 Pour-Flush toilets constructed by PID, four sites were selected for the purpose of this project with a total of 6 pits being sampled continuously over 11-months. The general site locations are shown below in **Figure 1**. One site is located in Azalea settlement and the remaining three are located in France settlement located close to Pietermaritzburg in the KwaZulu-Natal Province.

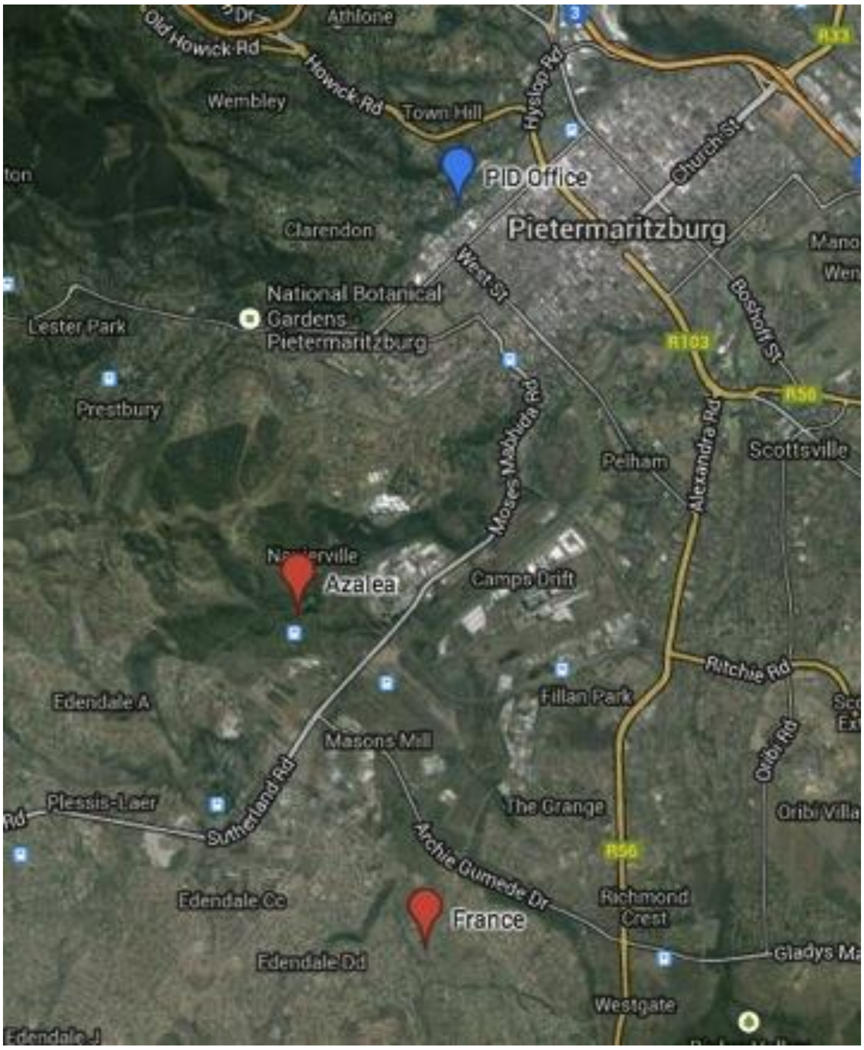


FIGURE 1. POUR-FLUSH SITE LOCATIONS AND PID OFFICE IN PIETERMARITZBURG, KWAZULU-NATAL

The following pit types were at the sites:

- Two households had a Pour-Flush system with one leach pit on site (single leach pit) and had been in use since January 2011.
- Two households had a Pour-Flush system with two leach pits on site (double leach pit). At both sites, one pit had been in use from January 2011 until December 2012. In December 2012, these pits where taken out of use (thereby becoming *inactive* or *standing*) by diverting

the pipes (and thus the toilet waste) to the second pit, which then became *active*. Both leach pits on site therefore contained sludge and were used for sampling.

The sites are referred to Site 1, Site 2, Site 3 and Site 4.

Site 1 and Site 2 have the double leach pits and Site 3 and 4 have the single leach pits. Samples were collected from these pits on 4 separate occasions over a period of 11 months. The aim of this was to identify changes in the sludge composition with time, particularly in the standing sumps. The first sampling campaign took place in May 2013, the next was 2 months later in July 2013 and then in November 2013 and finally in March 2014. The two single sumps were not sampled on the first campaign but were thereafter.

2.2 SAMPLING PROTOCOL & EQUIPMENT

Due to the lack of information regarding the conditions of the sludge in the Pour-Flush leach pit, a preliminary visit was made to the sites to assess the consistency of the sludge and how to retrieve the samples. An assumption was made that the leach pits would be similar to a septic tank – i.e. they would be relatively full and contain a lot of water. Sampling tools were chosen based on this assumption. However, conditions were not as expected once the leach pits were opened – a small volume of sludge was present and there was not an excess of water. The sludge in the standing pits were particularly dry.

Hence, a trial-and-error approach was used to determine the best equipment to retrieve sludge samples from the leach pits. The literature was studied to determine the different types of sampling equipment used on various soils, wastewater and faecal material to determine the best fit for sampling Pour-Flush sludge. Sampling equipment was designed and made at UKZN and tested on site for their ability to retrieve samples from the leach pit, with alterations made after each site visit to improve the equipment.

Samples were stored in a 2.5 ℓ plastic bucket with a lid and lined with a plastic bag. The samples were transported to and stored in a cold room below 4°C at the laboratory of the Pollution Research Group, Howard College, University of KwaZulu-Natal. The samples were kept in the cold room until all analysis was complete, after which they were safely disposed of following the standard laboratory protocol for the disposal of biological waste.

The sampling frequency was changed from the initial proposal; it was determined that weekly sampling was too frequent to discover any changes in the sludge composition from one week to the next. Hence, the first sampling campaign was conducted in May 2013 and the second campaign took place in July 2013. Upon conclusion of this report, it was suggested samples be taken between three- and four-month intervals for the remainder of the project.

2.3 CHEMICAL ANALYSIS

The sludge was analysed for total solids, moisture content, volatile solids, ash, suspended solids, COD (total, soluble and particulate), nitrogen species (TKN, ammonia, nitrate), phosphates (total and ortho-phosphate), sodium and potassium and pH. These were carried out according to Standard Methods for water and wastewater analysis [2].

COD, TKN, ammonia, nitrate, total and ortho-phosphate, sodium, potassium and suspended solids all required the sludge to be in liquid form for the analysis and hence samples were diluted with distilled water, either 1.8 to 2 g in a litre or 5.0 to 5.1 g in a litre, depending on the range of the test. The sludge was weighed on a mass balance to 4 decimal places, and then transferred to a blender with a small amount of distilled water. The sludge and water were homogenised for 30 seconds and then transferred to a graduated volumetric flask, along with the washings from the blender and topped up to a litre. The diluted samples were stored in labelled plastic bottles in a cold-room at 4°C until analysis was complete. Samples were taken out of the cold-room and allowed to adjust to room temperature of 20 ± 5°C before any analysis was conducted.

Nitrate, total phosphate, ortho-phosphate, sodium and potassium were analysed using the following Merck Spectroquant® test kits and a spectrophotometer, following the test procedure provided with the kits:

- Nitrate: Cat. No. 1.09713
- Total and ortho-phosphate: Cat. No. 1.14543
- Ortho-phosphate: Cat. No. 1.14848
- Sodium: Cat. No. 1.00885
- Potassium: Cat. No. 1.14562

2.4 RHEOLOGICAL ANALYSIS

This section has four subsections that deal with the methodology related to rheological analysis.

2.4.1 FLOW TABLE

The Flow Table Test is normally used in Civil Engineering to measure the flow of lime grouts and mortars. The test was used in this case to determine if it can be used to analysis the consistency and physical nature of the sludge and to provide a foundation to correlate the physical sludge properties to a selection of pit emptying equipment once the leach pits are full. The flow table test was conducted following the method stated in BS 4551: Part 1: 1998: Annex A1 (see **Appendix B**).

2.4.2 LIQUID LIMIT AND PLASTIC LIMIT

The liquid limit and plastic limit are tests normally used on soil in Civil Engineering to measure the range of water content over which a soil behaves plastically. They were adapted in this case to determine if they can be used to analysis the consistency and physical nature of the sludge and to form a basis to correlate the physical sludge properties to the selection of pit emptying equipment once the leach pits are full. The procedure described in BS1377-2: 1990 was followed for the liquid limit and plastic limit determination, in section 4.3 and 5.3 respectively. See **Appendix B** for images of the equipment in use.

2.4.3 SHEAR STRENGTH

The shear strength of sludge is useful to understand how the sludge behaves and how it will respond to different pit emptying methods. The shear strength of a material can be calculated using the penetration value recorded from the liquid limit test described in the previous sub section using the following formula:

$$S_{ur} = \frac{k \times Q}{h^2 \times 1000} \quad [kN/m^2]$$

Where,
k is the drop cone factor = 1.33
Q is the force of the cone = 0.785N
h is the penetration reading from the cone penetrometer
1000 is the conversion from N to kN

2.4.4 RHEOMETER MEASUREMENTS

Rheology tests were conducted on the sludge using the Anton Parr MCR51 Rheometer following the Standard Operating Procedure developed at the Pollution Research Group. Each sample was tested in triplicate and the average value was recorded for apparent viscosity, shear stress and yield stress. These parameters are useful for design and assessing the capability of pit emptying equipment. See **Appendix D** for images of the equipment.

2.5 BIODEGRADABILITY

Two methods were used to determine the biodegradability of Pour-Flush sludge; a continuously stirred tank reactor (CSTR) (**section 2.4.1**) and repeated COD (**section 2.4.2**).

2.5.1 CONTINUOUSLY STIRRED TANK REACTOR (CSTR)

A CSTR was used to determine the biodegradability of Pour-Flush sludge. The CSTR was modelled on the design of the small-scale 5-litre tank developed at Southampton University [3]. The tank was filled with 2.5kg of Pour-Flush sludge and 2.25l of distilled water, with a working volume of 4l. The sludge was too thick to be stirred without being diluted first. The heating coil was set at 35°C. A motor at 4 volts powered an asymmetrical bar stirrer (see **Appendix E**).

Normally, the organic material is inoculated with a substrate and the gas production is measured until it stops being produced. In this case, the activity of the Pour-Flush sludge was of interest. It was not inoculated with a substrate to determine the rate of gas production and hence degradability solely resulting from the sludge. This will give a more realistic depiction of the rate of degradation occurring naturally in the pit. However, the system is heated to 35° and the sludge is continuously stirred which will speed up the digestion process.

The gas produced by the sludge was measured using an inverted graduated cylinder, filled with water. The water displacement was monitored and reported as mℓ of gas produced. A webcam was setup with iSpy software to a computer to take and save photos of the gas measurement cylinder at regular intervals. This allowed the gas production of the system to be monitored continuously. See **0** for photos of the digester set-up.

2.5.2 REPEATED COD

The sludge was diluted to three different concentrations, 0.4 g, 1.0 g and 1.4 g each diluted to 500 mℓ. The samples were kept at room temperature. The COD was measured for each dilution on an interval of three to four days for two weeks and a final time, two weeks after that. The COD results versus time were plotted to determine the rate of degradation occurring in the Pour-Flush sludge.

3. RESULTS AND DISCUSSION

This chapter presents the findings of the physical, chemical and biological characterisation of Pour-Flush sludge. The chapter is divided into six sections: **section 3.1** presents background data for the Pour-Flush toilets, **section 3.2** presents the chemical analysis of the sludge; **section 3.3** presents the rheological analysis of the sludge, **section 3.4** presents the biodegradability analysis, **section 3.5** presents the pit filling rate data in comparison to literature, and **section 3.6** presents a comparison of Pour-Flush sludge with VIP latrine sludge.

3.1 BACKGROUND DATA

3.1.1 TIME PERIOD OF ACTIVE PITS

Figure 2 below shows the time frame each pit was active for, from the date of commissioning to the completion of this study. The pit IDs are explained in **section 2.1** and shown in **Appendix F**. Pit b at both Site 1 and 2 were active for almost 2 years (now "standing"), until the pits were switched, putting Pit a into use, from December 2012 until the present day. Site 3 and Site 4 have been in use consistently for approximately 4 years.

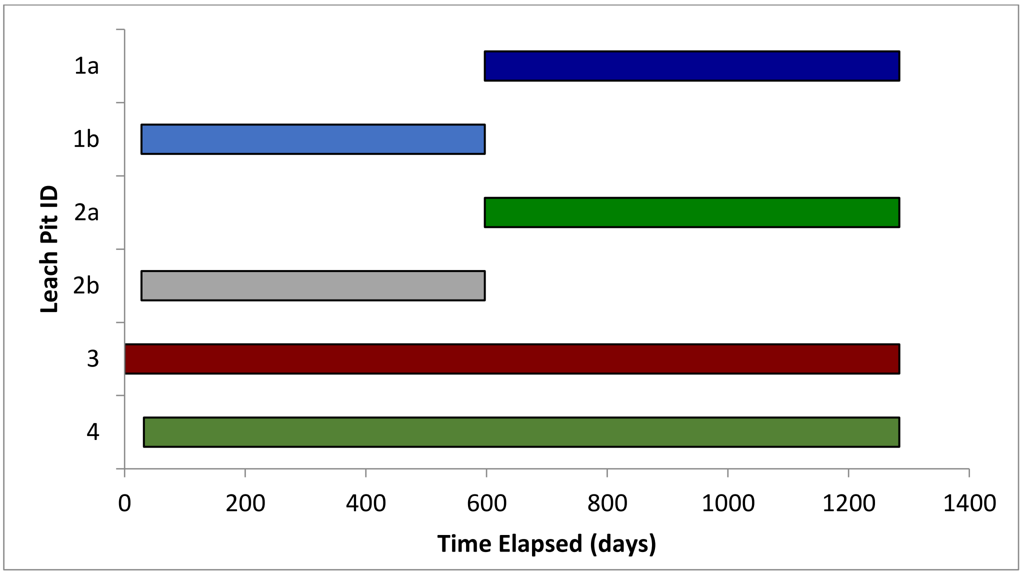


FIGURE 2. TIME PERIOD EACH PIT WAS ACTIVE FROM COMMISSIONING TO COMPLETION OF THIS STUDY

3.1.2 HOUSEHOLD SIZE

The average household size of the families included in the project is 5.75. Household size is not considered a reliable measurement of the number of users of a toilet. This number can change in the short-term due family members working away from home during the week and being home at the weekend and the frequency of visitors. The household number will also vary over a longer period of years as a family grows as children are born and gets smaller after they grow up and leave home. Table 1 shows the variation in estimated household size from the PID survey in July 2013 and the survey conducted within this project in March 2014. Additional data can be seen in **Appendix G**

TABLE 1. ESTIMATED HOUSEHOLD SIZE MEASURED BY PID IN 2013 AND FROM THIS PROJECT IN 2014

	Date	Site 1	Site 2	Site 3	Site 4
PID	July 2013	9	11	2	6
This project	March 2014	7	6	2	8

3.1.3 WEATHER DATA

Precipitation and temperature information was sourced for the period of the project. This information helps understand the sludge volumes recorded in the pits. It also helps with understanding the results from the chemical analysis performed on the sludge samples. It is important to know if a heavy rainfall or a particularly dry spell occurred in the days and weeks prior to each sampling campaign as it may affect composition of the sludge in the pits, such as water content and soluble chemicals like sodium and potassium. The shaded in bars in Figure 3 are the months when sampling campaigns occurred.

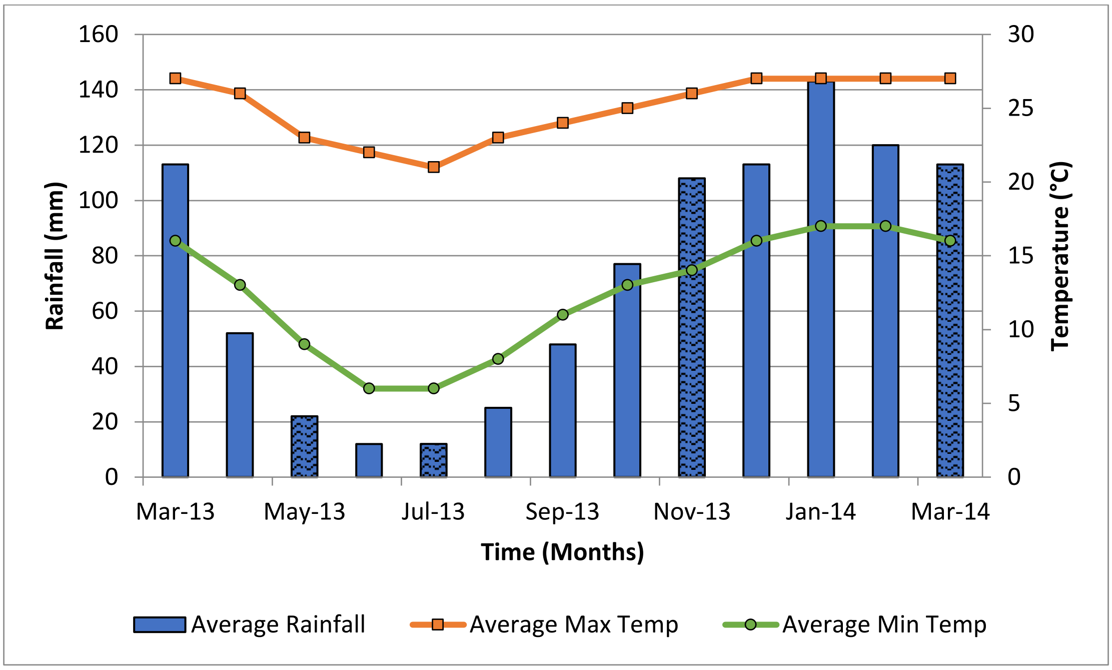


FIGURE 3. TIME PERIOD EACH PIT WAS ACTIVE FROM COMMISSIONING TO COMPLETION OF THIS STUDY

3.1.4 SAMPLING EQUIPMENT

Two pieces of sampling equipment were developed to suit the consistency of the sludge. The sludge consistency varied from each pit but it can be categorized into two general types – dry soil like sludge and wetter but still thick sludge. A bucket at the end of a long handle was used to scoop out wetter samples. A tube at the end of a long handle was used to take a ‘core’ sample of the drier, soil-like sludge. A plunger was built into the tube to push the sludge out of the tube and into the storage container. **Appendix H** contains images of the development of the sampling equipment and a table detailing issues encountered with the equipment variations.

3.1.5 LEACH PIT FILLING RATES

This section provides details of the sludge accumulation in the leach pits of the Pour-Flush units. There are two subsections; **section 3.1.5.1** which deals with sludge height measured over time and **section 3.1.5.2** which deals with the volume of sludge per pit latrine, respectively.

3.1.5.1 SLUDGE HEIGHT IN PITS

The depth of sludge was measured for each pit. The results are shown below in Figure 4. The two single pits show an increase in sludge depth over the time period with the fill-up in Site 4 (8-person household) being more pronounced than Site 3 (2-person household). The height of sludge in the standing pits show different trends; in the standing pit at Site 1 (1b in Figure 4), there is a gradual decrease in sludge height while the height in Site 2 (2b in Figure 4) remains relatively similar throughout the study period.

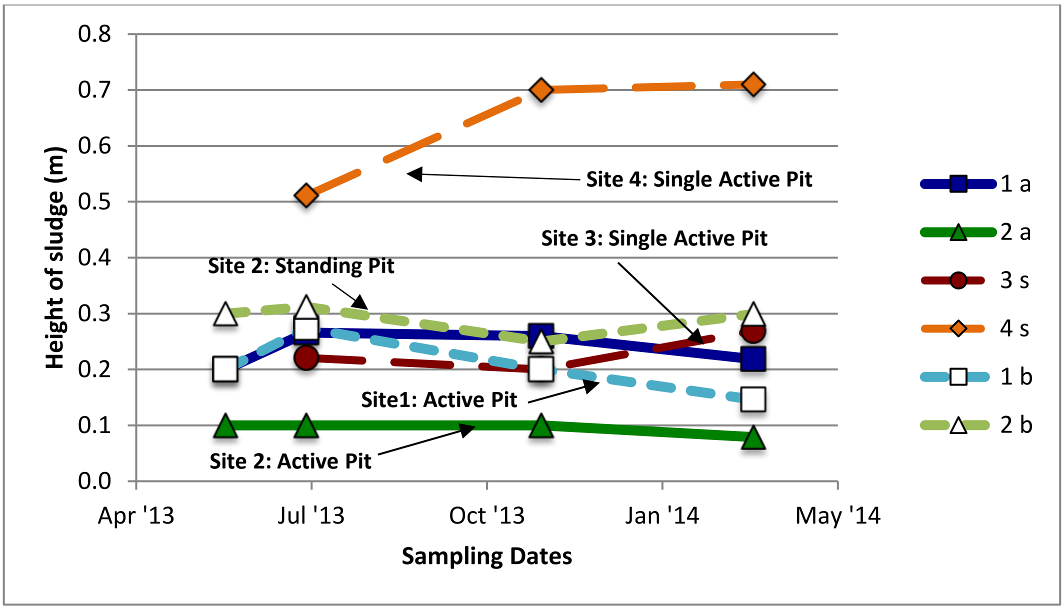


FIGURE 4. HEIGHT OF PITS MEASURED OVER TIME PERIOD OF THE PROJECT

The two pits that became active in December 2012, show an initial increase of sludge depth as material is being added to the system. At the end of sludge height sampling campaign, there is a decrease in sludge depth – this might be due to the development of bacteria in the system that have started breaking down the sludge and hence reducing the volume or leaching of the water contained into the sludge into surrounding soil [4].

Figure 5 shows the sludge depth measurements of the leach pits since their commissioning date (since they started filling). The active pits from Site 1 and Site 2 are closer to zero because they were put into use in December 2012, whereas the remaining pits were commissioned between December 2010 and January 2011 so the time elapsed since they started filling is greater. The pit at Site 4 has the highest sludge level; the household has 8 recorded users for the system and it seems this is reflected in the volume of sludge produced in the pit.

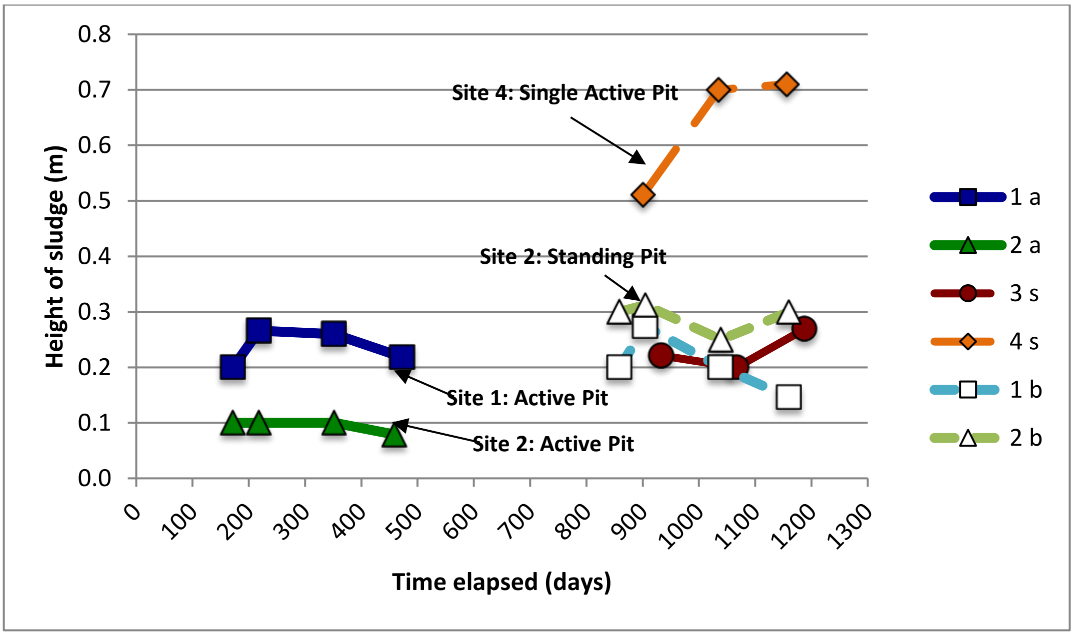


FIGURE 5. THE HEIGHT OF SLUDGE PER PIT GRAPHED SINCE LEACH PITS STARTED FILLING

3.1.5.2 VOLUME OF SLUDGE PER PIT

The rate at which the volume increases within each pit is displayed below in Figure 6 and Figure 7. The pits commissioned in 2010/11 were plotted separately to those commissioned in 2012, for ease of viewing. The dashed lines represent an average filling rate of 23 ℓ/person/year, recorded by PID in June/July 2013. Heights were recorded for each of the pits investigated in this project; these values were used to project a filling rate for each individual pit.

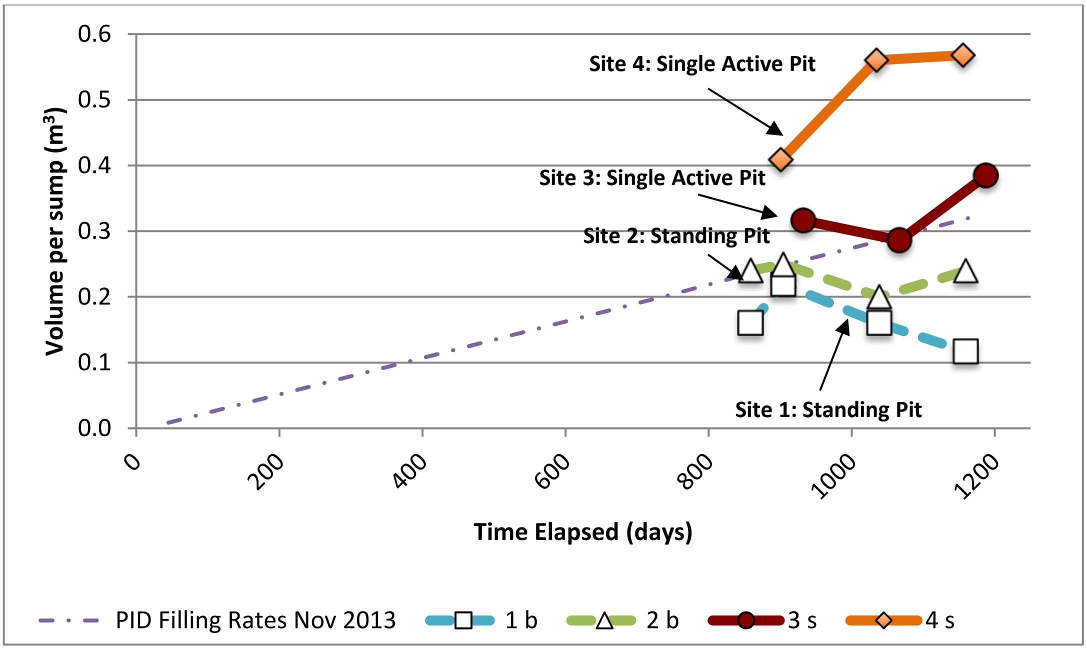


FIGURE 6. VOLUMETRIC FILLING RATE OF LEACH PITS COMMISSIONED IN DEC 2010 AND JAN 2011, OVERLAYING AVERAGE FILLING RATE RECORDED BY PID

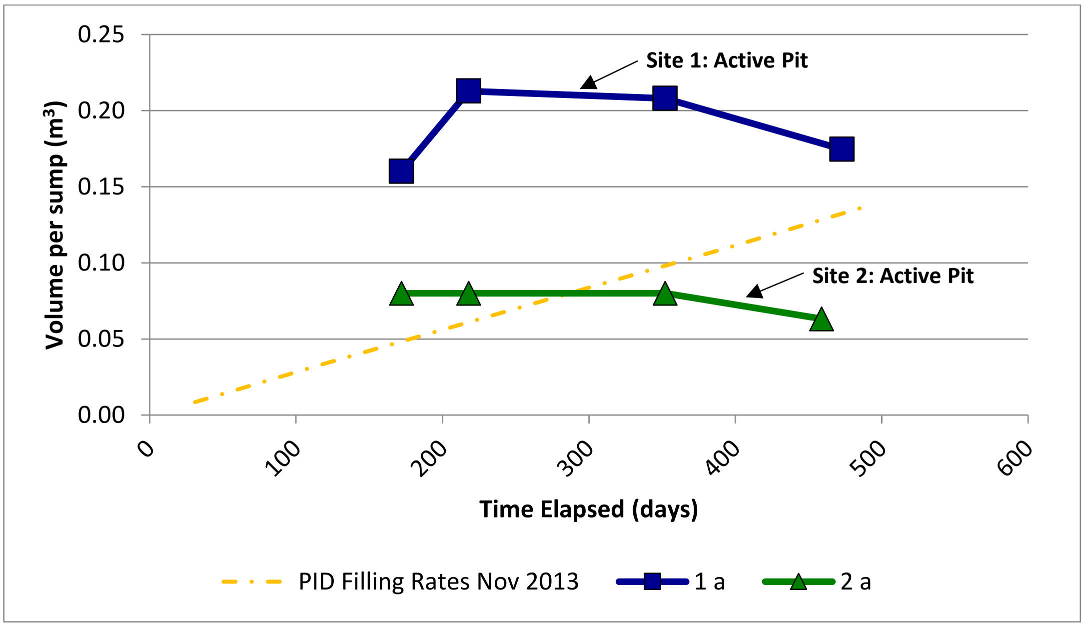


FIGURE 7. VOLUMETRIC FILLING RATES OF LEACH PITS COMMISSIONED IN DECEMBER 2012 OVERLAYING AVERAGE FILLING RATE RECORDED BY PID

The volume of sludge per pit was calculated using the heights measured on-site and the standard pit dimensions of 1.0 m by 0.8 m (length x breadth) and a total depth of 1.4 m. Hence, the trends seen in the sludge height graphs are repeated in the volume graph presentation. Site 3 is an exception however because PID did not construct the pit and so it does not have the standard Pour-Flush dimensions. A pit remained on this site from the previous sanitation system; it was adapted for use with the Pour-Flush toilet installed. This pit is 1.1 m by 1.3 m.

3.2 CHEMICAL ANALYSIS

The sludge underwent chemical analysis as detailed in **section 2.2**. The concentration of each parameter was measured and recorded as g/g of wet sample for total solids, volatile solids, ash and suspended solids and as mg/ℓ for COD_t, COD_s, COD_p, TKN, ammonia, nitrate, total and ortho phosphate, sodium and potassium. The mg/ℓ concentrations were then evaluated at on a wet, dry and ash basis by converting each from mg/ℓ to mg/g wet, mg/g dry and mg/g ash. After analysing the data in this form, it was decided that looking at each parameter in terms of its mass in the pit would provide more understanding of what the pit contained and how it was behaving. This method of representing the data took into account the volume of the pits contents.

3.2.1 MASS OF EACH COMPONENT IN THE PIT

3.2.1.1 SOLIDS (TS, VS, ASH, TSS)

A) TOTAL SOLIDS

The mass of total solids in the pit increases over time. The minimum mass of total solids is 0.006 kg and the maximum is 0.08 kg in the active pits (Figure 8). The mass of solids is greater in the two standing pits in comparison to the active pits. A range of 0.6 kg to 0.15 kg total solids is seen in the standing pits (Figure 9). The standing pits have no new material being added to them. The walls of the pits allow liquid to pass easily into the surrounding soil and so it can be assumed that liquid is leaching out, reducing the water content of the sludge and increasing the total solids present.

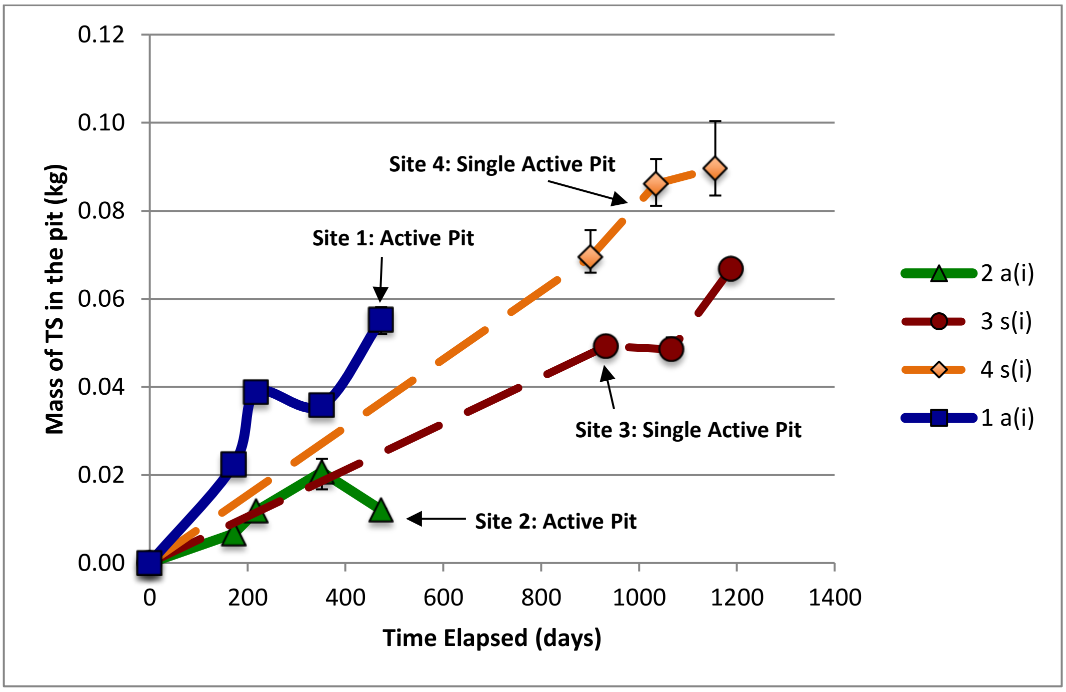


FIGURE 8. THE MASS OF TOTAL SOLIDS IN THE ACTIVE PITS SINCE START OF OPERATION

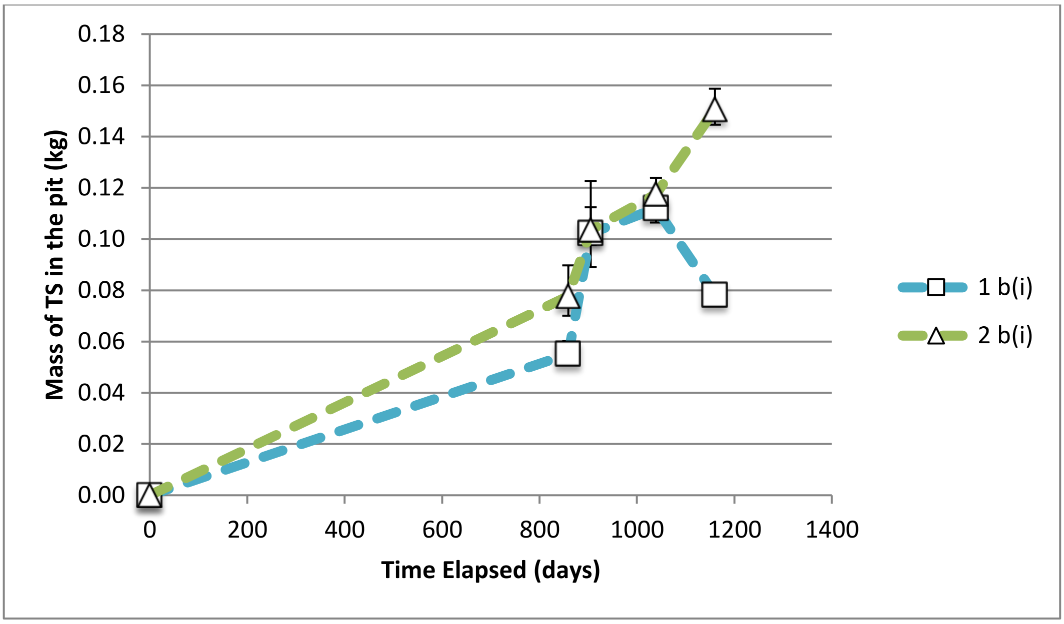


FIGURE 9. THE MASS OF TOTAL SOLIDS IN THE STANDING PITS SINCE START OF OPERATION

B) VOLATILE SOLIDS

Figure 10 shows the mass of volatile solids is increasing in the active pits at Site 3 and Site 4. Site 2 has an initial increase and then the mass of volatile solids remains relatively the same for the last two campaigns. The mass of volatile solids in the pit at Site 1 initially increases, followed by a decrease. These two pits were put into operation in December 2012 and are "young" in comparison to the other pits. The increase and subsequent decrease then stabilisation of the volatile solids mass could be a result of different processes beginning including the potential degradation of accumulated sludge. The linear increase observed in Site 4 could be potentially due to high number of toilet users in that household which results in accumulation of volatile solids.

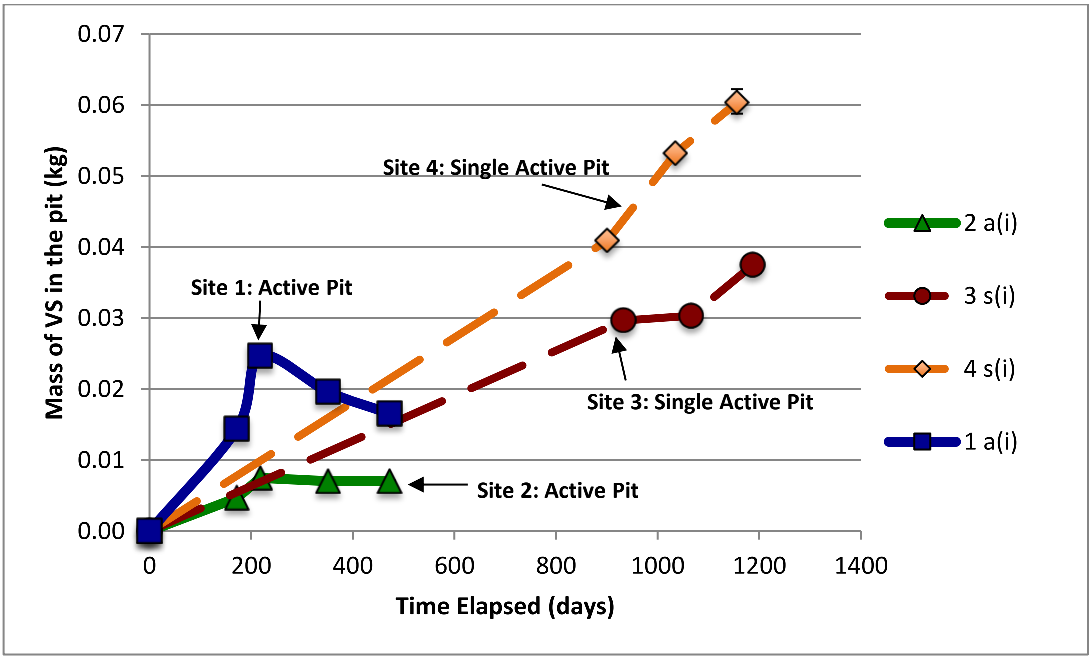


FIGURE 10. MASS OF VOLATILE SOLIDS IN THE ACTIVE PITS SINCE START OF OPERATION

Figure 11 displays the mass of volatile solids in the standing pits. A decrease in the mass of volatile solids happens after the initial measurements from the first two sampling campaigns. The sludge is degrading as it sits undisturbed in the pit; faecal matter breaking down as time passes. The reduction in volatile solids is probably a result of the age of the material and how degraded it is.

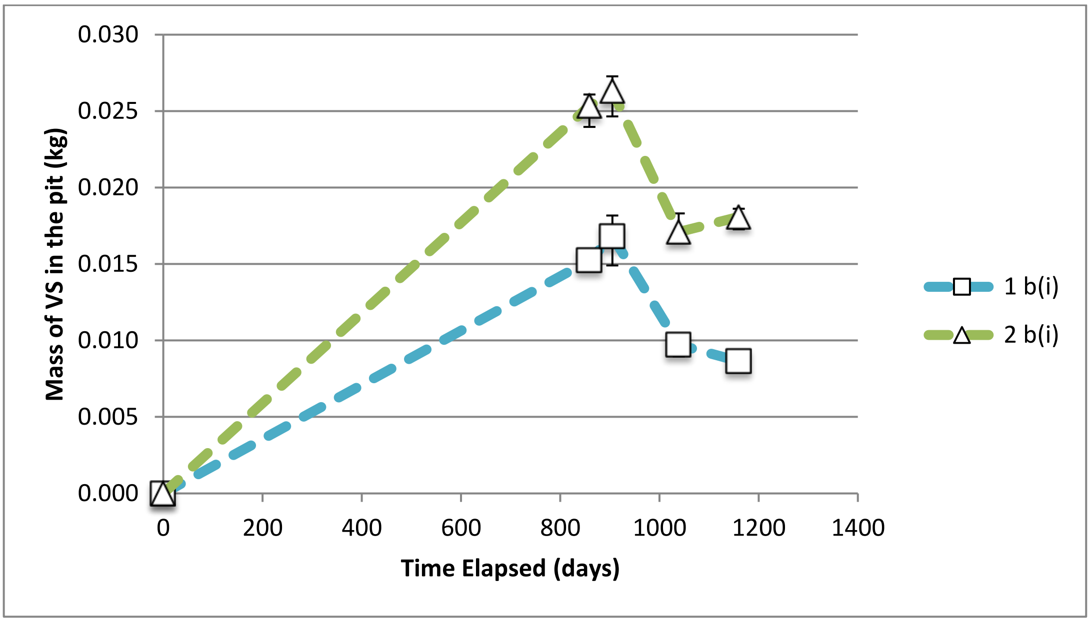


FIGURE 11. MASS OF VOLATILE SOLIDS IN THE STANDING PITS SINCE START OF OPERATION

C) ASH

The ash content generally increases in each active pit over time as can be Figure 12. The exception to this is the last data point for Site 2 of the active pit (2a in Figure 12) which also corresponds to decrease in total solids as seen in Figure 8.

The mass of ash in the standing pits in Figure 13 is increasing, excluding the last value for Site 1. The mass of ash is at least twice that seen in the active pits. This is possibly due as the sludge is degrades in the standing pit; material is being broken down and will either be released as gas (reducing the volatile solids) or will dissolve into the liquid in the pit and be transported with the leachate as it seeps out of the pit. What remains is the insoluble, non-biodegradable material – in other words – the insoluble ash. This cannot dissolve and be transported by the liquid portion of the pit contents and hence remains in the pit, slowly building up, which is shown by the increase of ash in Figure 13.

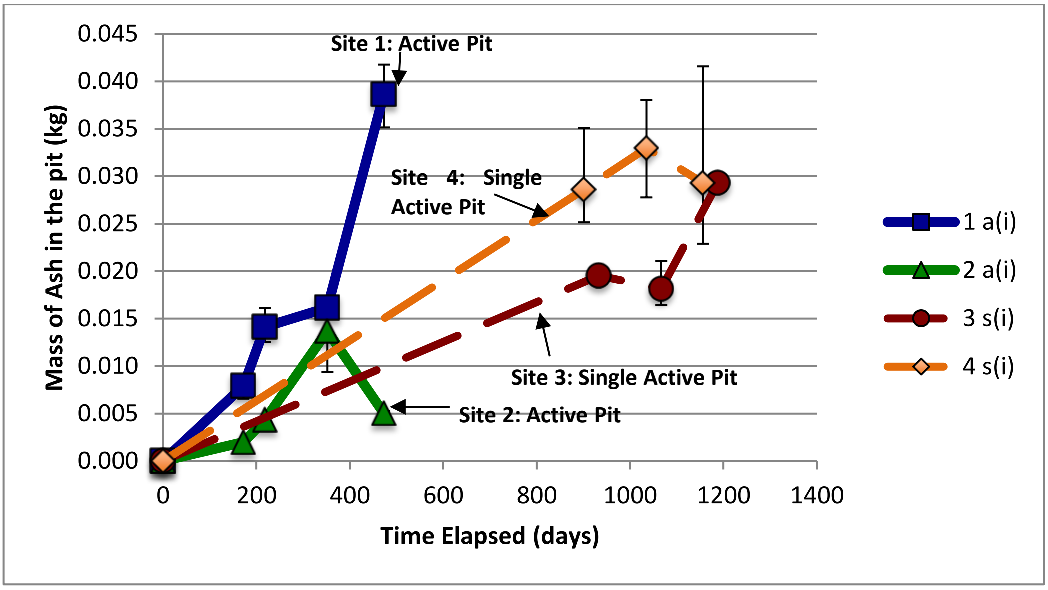


FIGURE 12. MASS OF ASH IN THE ACTIVE PITS SINCE START OF OPERATION

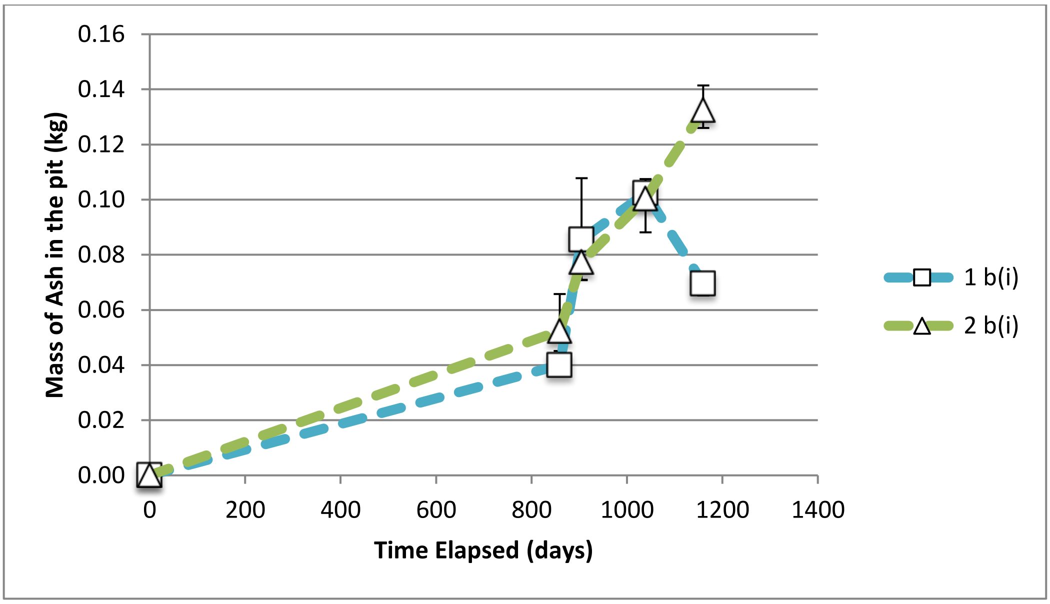


FIGURE 13. MASS OF ASH IN THE STANDING PITS SINCE START OF OPERATION

D) SUSPENDED SOLIDS

Total suspended solids (Figure 14 and Figure 15) were measured for the last two campaigns only. The mass of total suspended solids increases in the active pits. The material that is added to the pits, as well as the products of the sludge degradation process increase the quantity of soluble material in the pit, hence the mass of total suspended solids increases.

The mass of total suspended solids in the standing pits is lower than in the active pits. The mass decreases after the initial measurement. It is difficult with only two data points to predict if the mass of total suspended solids will continue to decrease, but this is the expected pattern, theoretically. As the leachate leaves the pit, it will take the suspended solids with it, reducing the mass remaining in the pit.

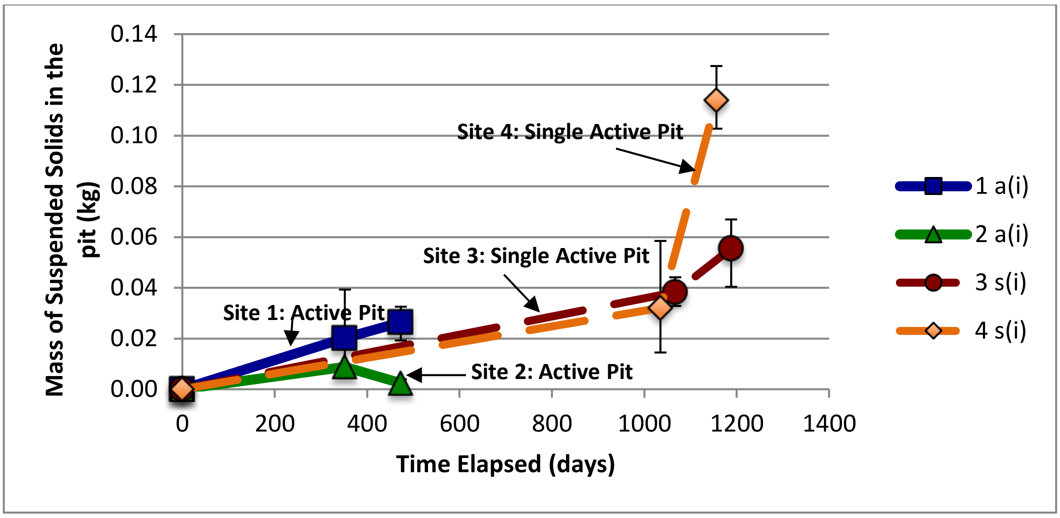


FIGURE 14. MASS OF TOTAL SUSPENDED SOLIDS IN THE **ACTIVE** PITS SINCE START OF OPERATION

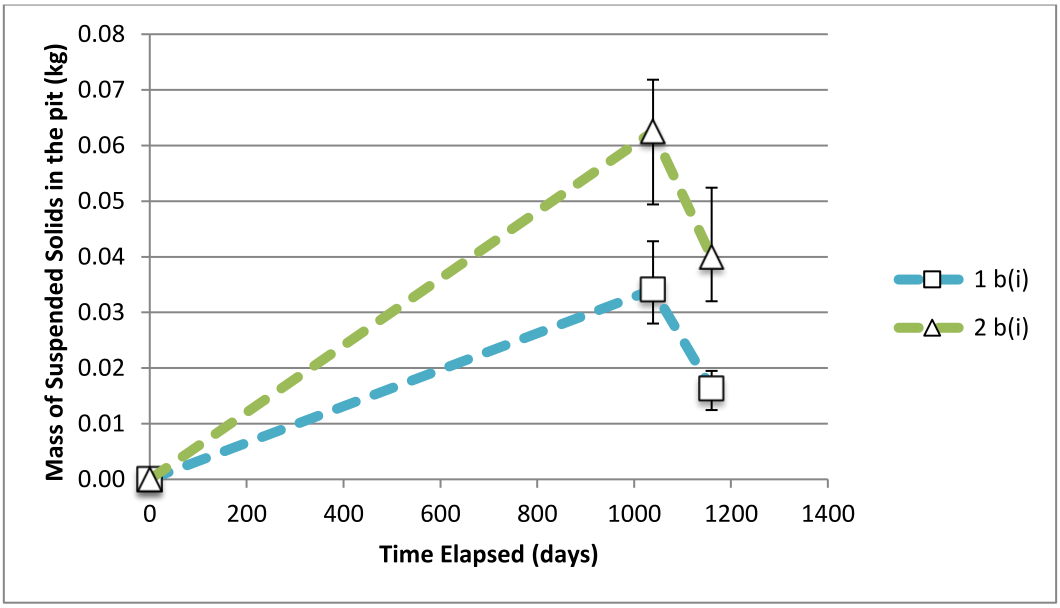


FIGURE 15. MASS OF TOTAL SUSPENDED SOLIDS IN THE **STANDING** PITS SINCE START OF OPERATION

E) MOISTURE CONTENT

The mass of water increases in the single active pits at Site 3 and Site 4, as seen in Figure 16. The mass of water in both Site 1 and Site 2 increase initially, but a decrease in the mass of water follows in campaign 3 and 4 for Site 1 and in campaign 2, 3 and 4 for Site 2. This may be for the same reasons mentioned for the decreases in total solids and volatile solids.

The mass of water in the standing pits decreases after the initial values. These pits do not have water and excreta being added to the system and the liquid is free to leach out of the pit, leading to a decrease in the mass of water. The mass of water in the standing pits is below 0.2 kg for the first two campaigns and reduces below 0.1 kg for the last two campaigns. These values are similar to the newly active pits, but smaller than the single pits, which had been in operation for over 2 years when this project began.

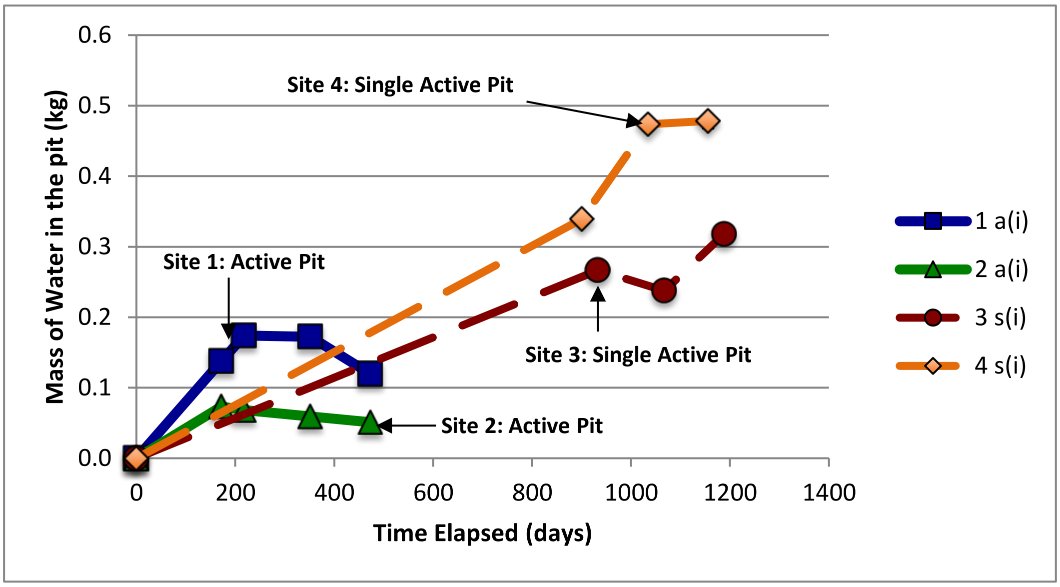


FIGURE 16. MASS OF WATER IN ACTIVE PITS SINCE START OF OPERATION

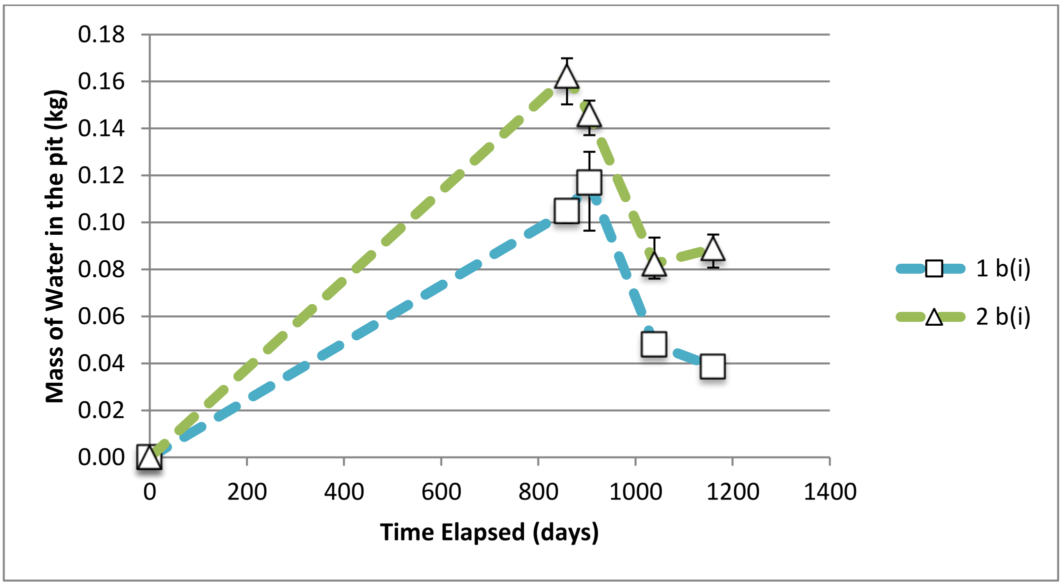


FIGURE 17. MASS OF WATER IN STANDING PITS SINCE START OF OPERATION

3.2.2 pH

The pH of the sludge was measured in the laboratory. The pH values range from 6.2 to 8.2 for the active pit (Figure 18) and 6.3 to 8.3 for the standing pits (Figure 19). It is recommended that the pH should be measured on site with a portable field pH meter for more accurate results.

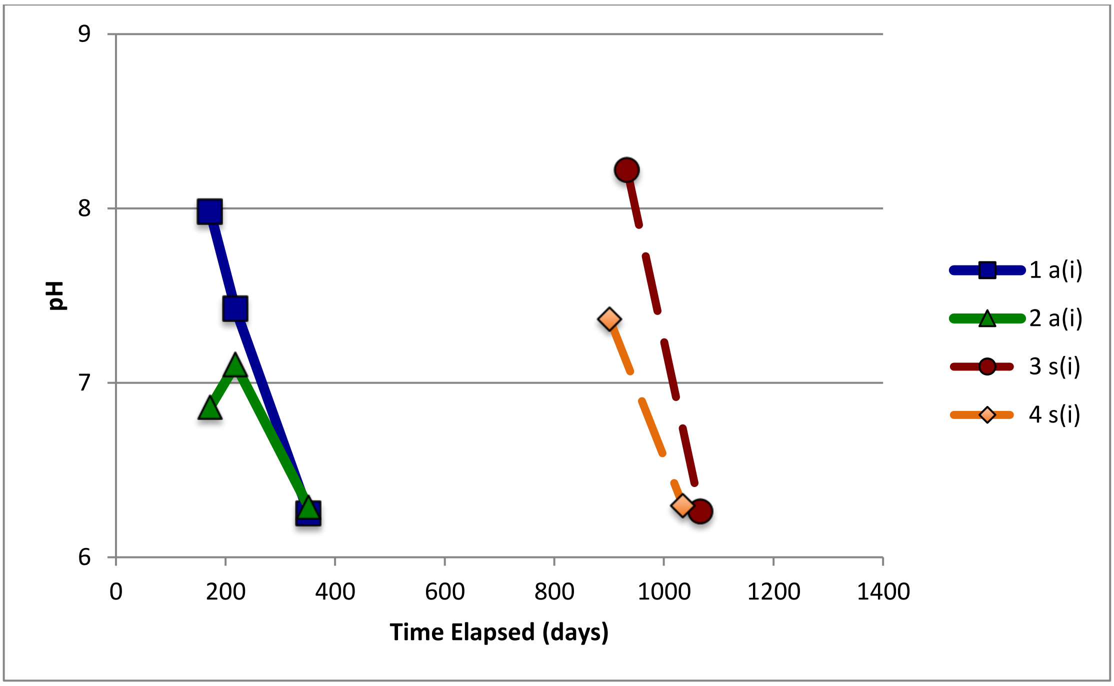


FIGURE 18. PH OF THE ACTIVE PITS SINCE START OF OPERATION

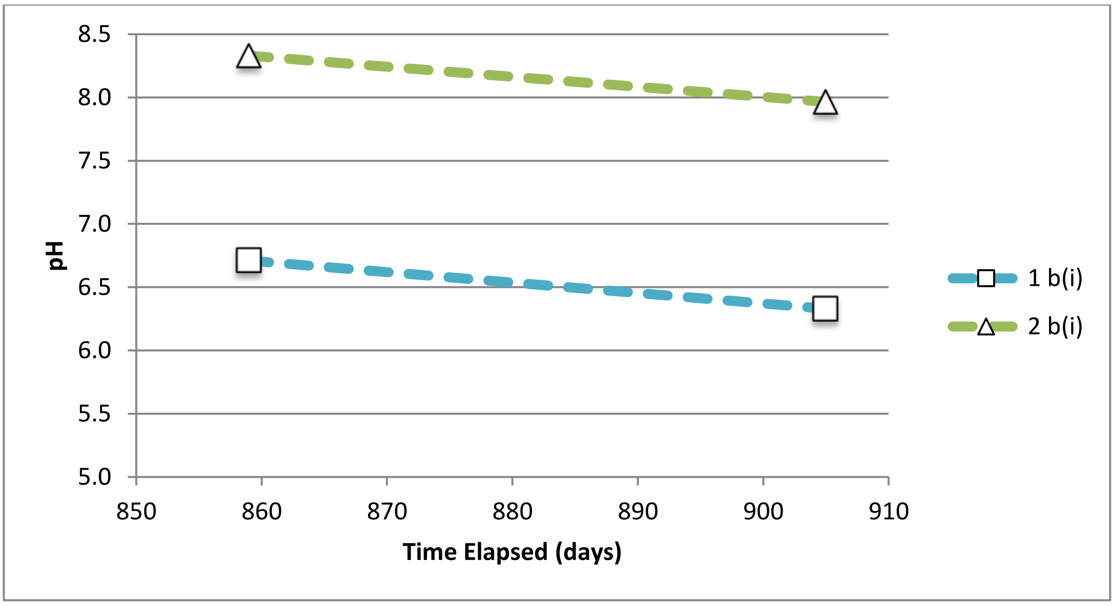


FIGURE 19. PH OF STANDING PITS SINCE START OF OPERATION

3.2.3 COD

This section has three sub-sections; the Total COD results are presented in **section 3.2.3.1**, the soluble COD results presented in **section 3.2.3.2** and the particulate COD results presented in **section 3.2.3.3**.

3.2.3.1 TOTAL COD

The mass of total COD in the active pits is increasing, although the values alternate up and down between the first and last campaigns (Figure 20). The mass of total COD is below 0.1 kg for all pits, with Site 2 containing the least amount, ranging from 0.006 kg to 0.01 kg.

The mass of total COD decreases in the standing pits as shown in Figure 21. The mass of total COD begins between 0.037 and 0.046 kg and reduces to around 0.005kg. As biodegradable material within the pit is broken down the COD will reduce as there is less material for the bacteria to breakdown and hence their population will decrease and die-off.

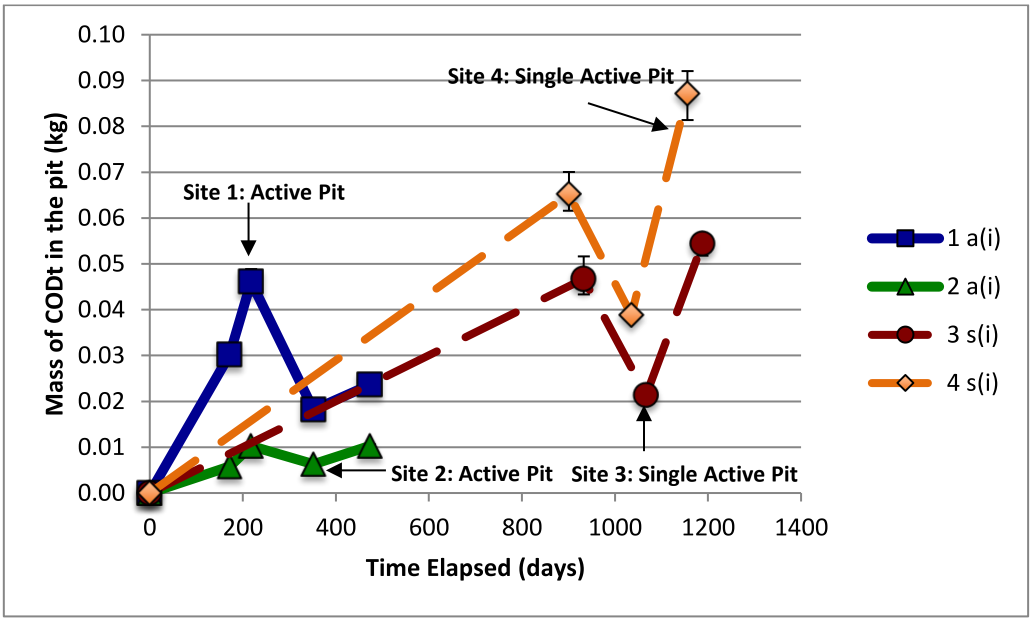


FIGURE 20. MASS OF TOTAL COD IN THE ACTIVE PITS SINCE START OF OPERATION

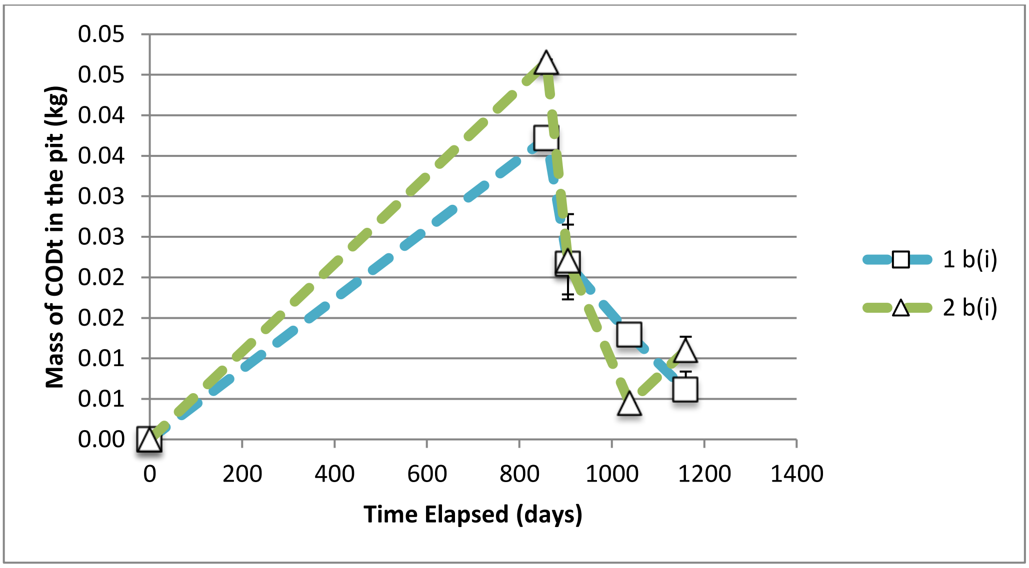


FIGURE 21. MASS OF TOTAL COD IN THE STANDING PITS SINCE START OF OPERATION

3.2.3.2 SOLUBLE COD

The mass of soluble COD decreases in both the active (Figure 22) and standing pits (Figure 23). The soluble COD was not measured for the samples collected on the first campaign. The mass of soluble COD for the active pits is less than half of the total COD for each campaign. The soluble COD decreases in both the active and standing pits because it is dissolved in the water present in the pit and can be possibly transported out as the water leaches into the surrounding soil.

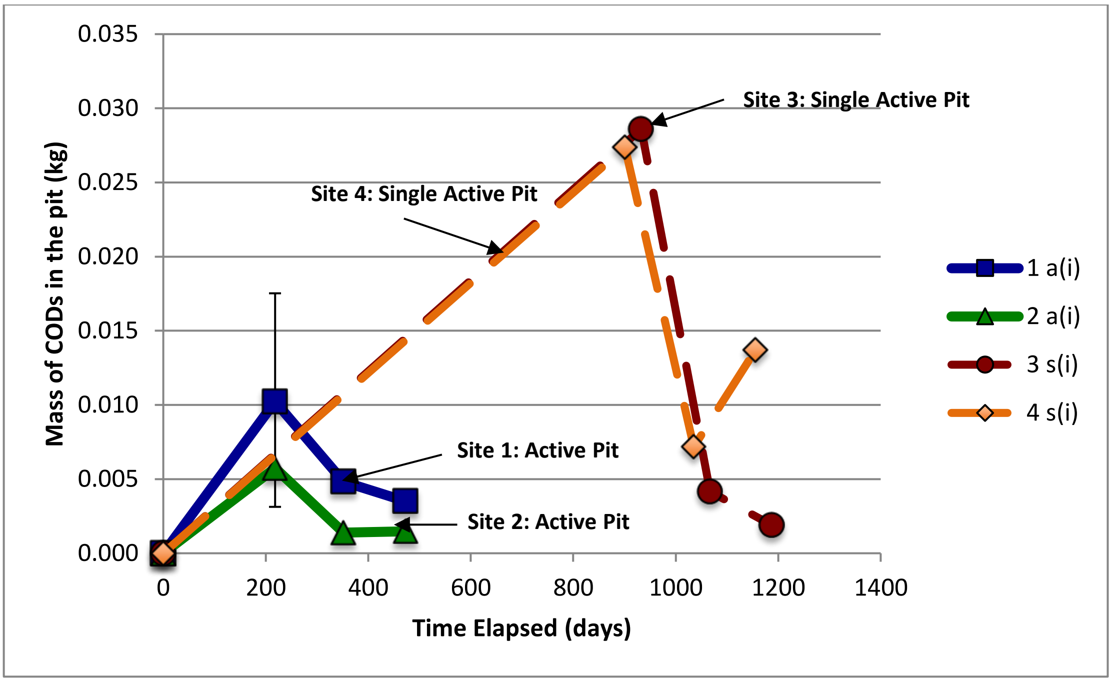


FIGURE 22. MASS OF SOLUBLE COD IN THE ACTIVE PITS SINCE START OF OPERATION

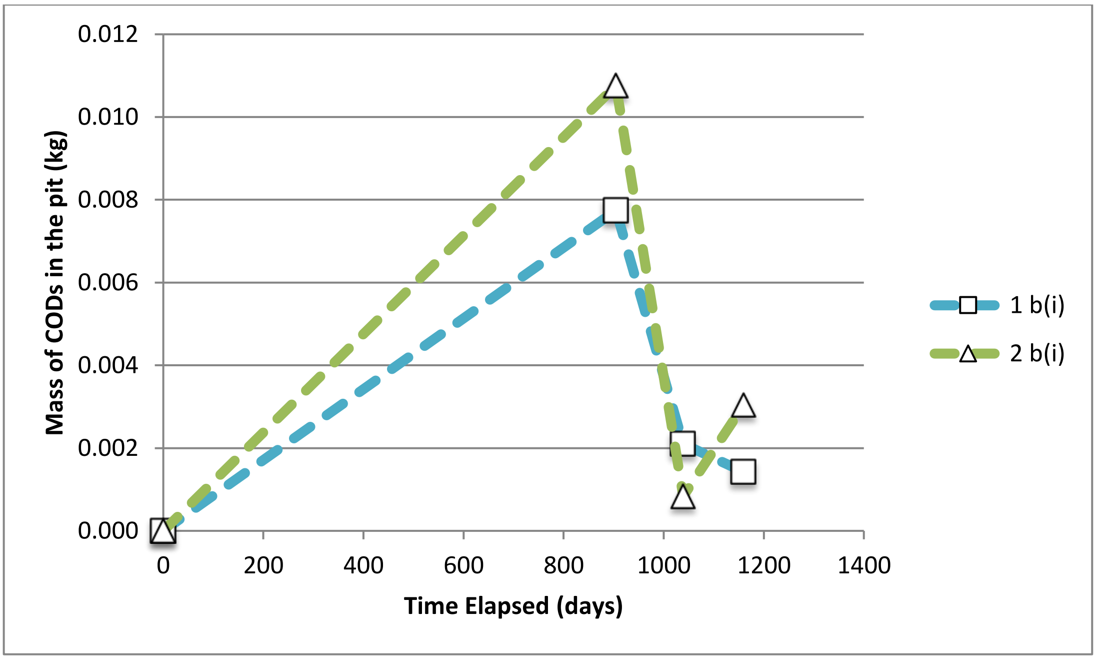


FIGURE 23. MASS OF SOLUBLE COD IN THE STANDING PITS SINCE START OF OPERATION

3.2.3.3 PARTICULATE COD

The particulate COD tends to increase with time in the active pits (Figure 24). No clear trend can be observed for the standing pits (Figure 25).

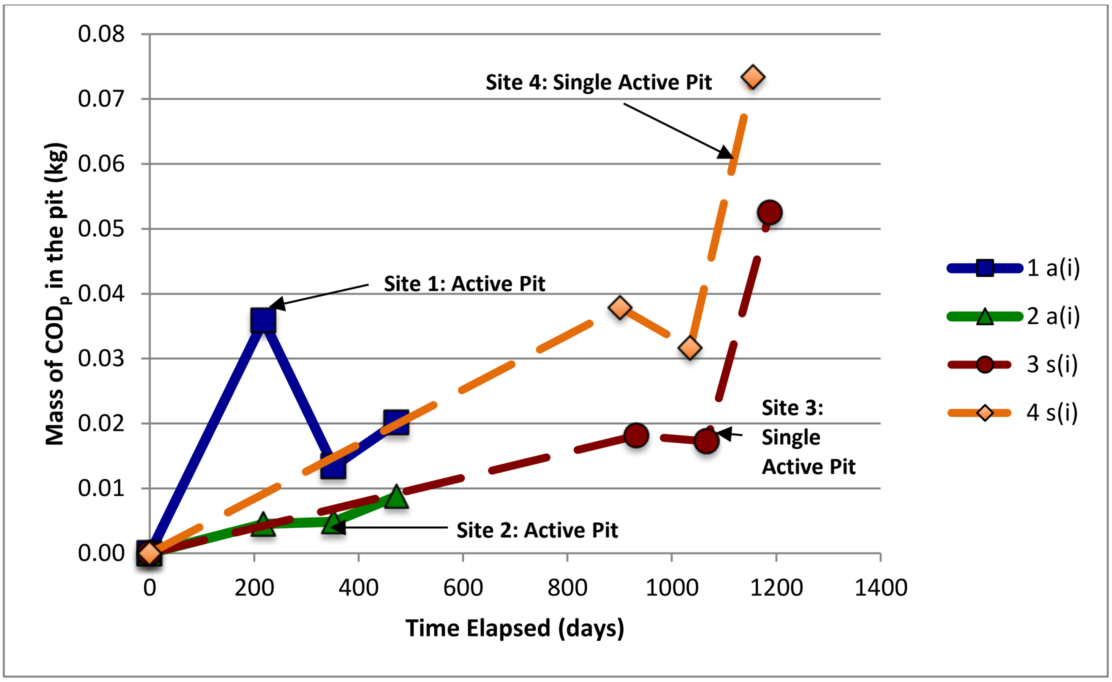


FIGURE 24. MASS OF PARTICULATE COD IN THE ACTIVE PITS SINCE START OF OPERATION

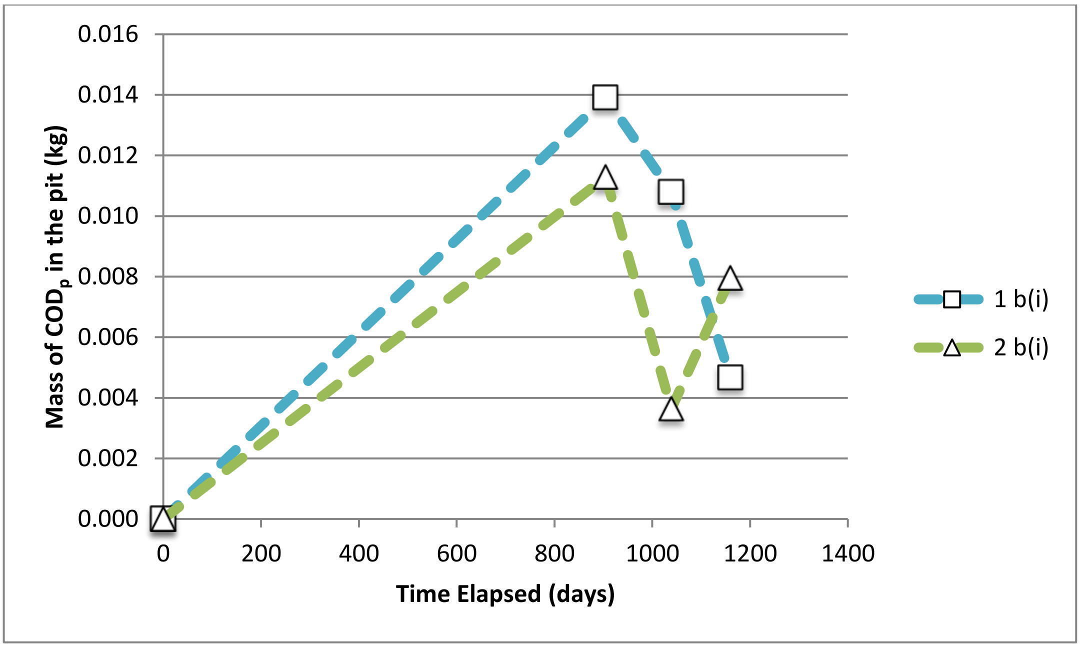


FIGURE 25. MASS OF PARTICULATE COD FOR STANDING PITS SINCE START OF OPERATION

3.2.4 NITROGEN SPECIES

This section has three sub-sections; the TKN results are presented in **section 3.2.4.1**, the Ammonia results presented in **section 3.2.4.2** and the nitrate results presented in **section 3.2.4.3**.

3.2.4.1 TKN

TKN could not be measured for samples collected on the final campaign because the equipment needed for the test was undergoing repair. The mass of TKN increases in the active pits, seen in Figure 26. All masses are below 0.0017 kg, except for the third point at Site 4, measuring 0.0032 kg.

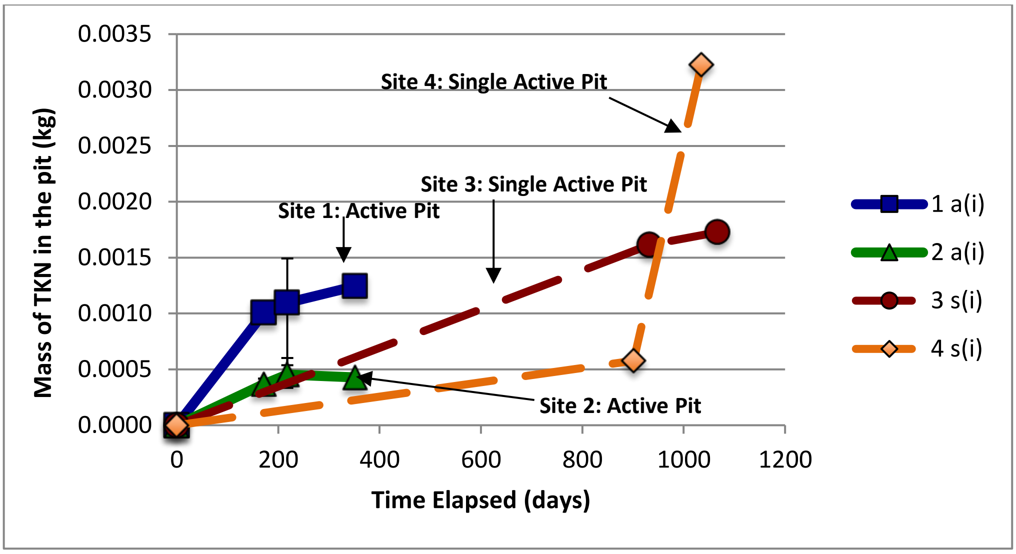


FIGURE 26. MASS OF TKN IN THE ACTIVE PITS SINCE START OF OPERATION

The mass of TKN in the standing pits (Figure 27) decreases after the initial measurement. A large decrease is noted from the second to the third campaign. The mass of TKN in the standing pit at Site 2 starts off higher than the mass of TKN in the active pit at the same site. The mass of TKN in the standing pit at Site 1 starts with approximately the same value that is present in the active pit at the same site. The mass of TKN decreases in the standing pit because the nitrogen species are probably being converted to gases and released from the pit.

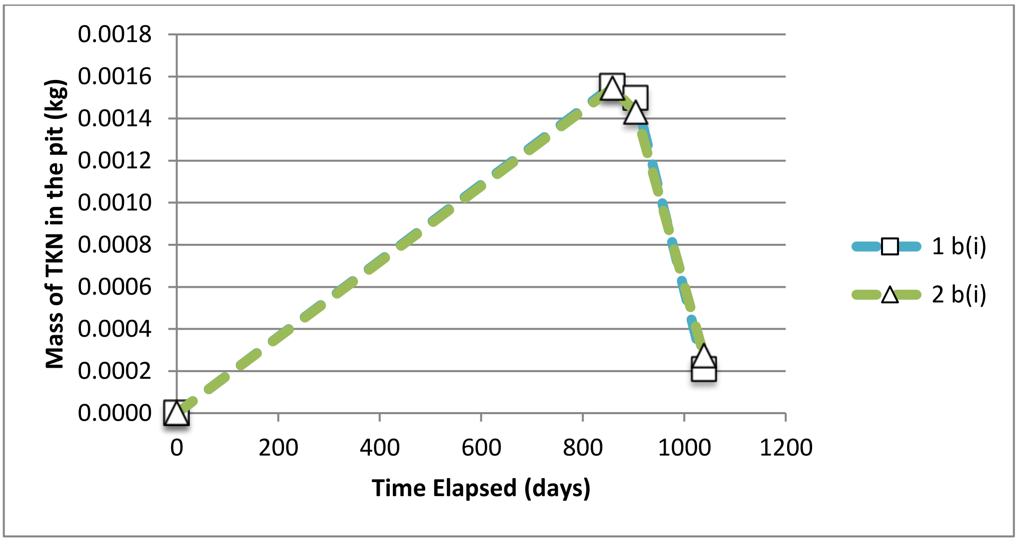


FIGURE 27. MASS OF TKN IN THE STANDING PITS SINCE START OF OPERATION

3.2.4.2 AMMONIA

Ammonia could not be measured for samples collected on the final campaign because the equipment needed for the test was undergoing repair. The mass of ammonia is very low in both the active (Figure 28) and standing pits (Figure 29). There was no ammonia detected in both active and standing pits at Site 1 and in the pit at Site 4 for the second campaign. It is difficult to state a trend in the mass of ammonia in either pit type due to the values alternating between zero and above.

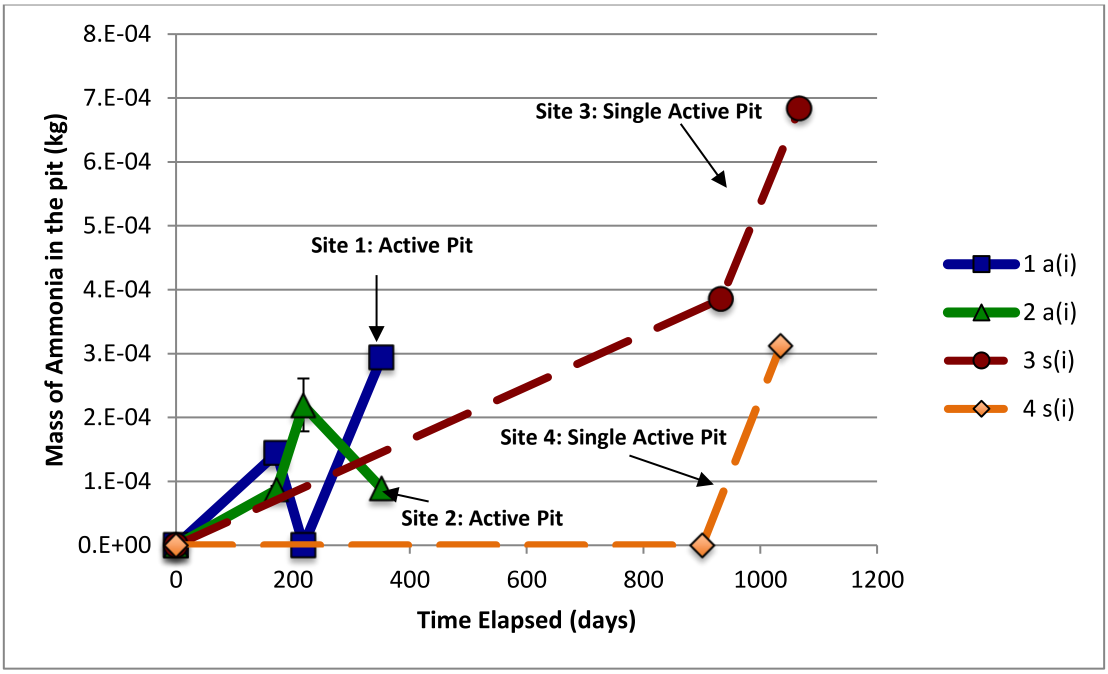


FIGURE 28. MASS OF AMMONIA IN THE ACTIVE PITS SINCE START OF OPERATION

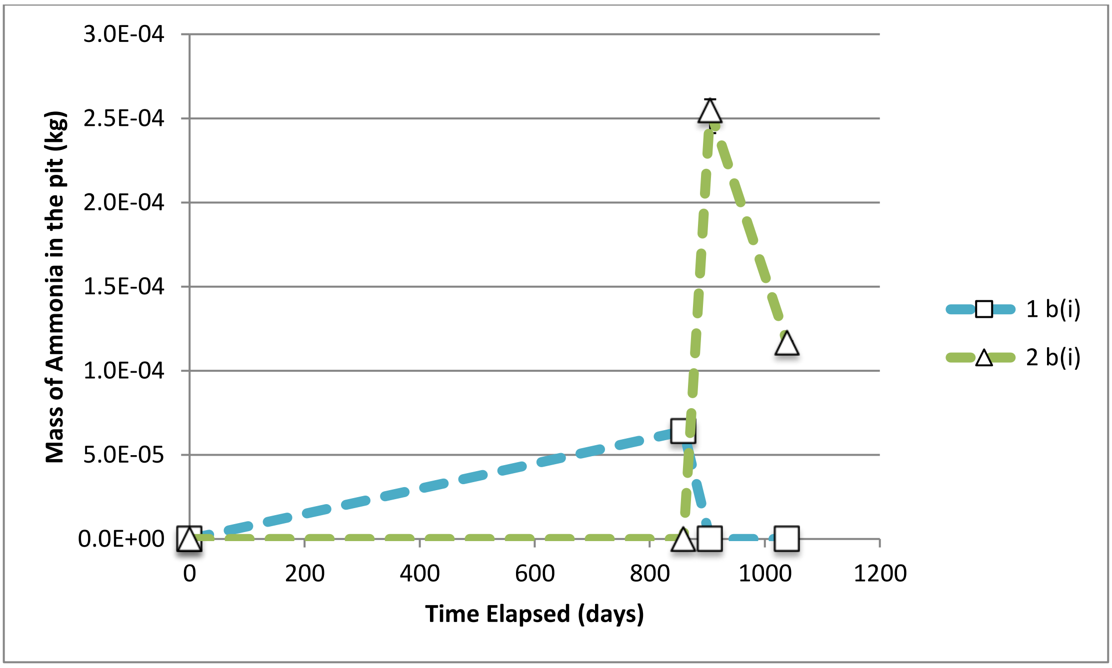


FIGURE 29. MASS OF AMMONIA IN THE STANDING PITS SINCE START OF OPERATION

3.2.4.3 NITRATE

The mass of nitrate in both active and standing pits (Figure 30 and Figure 31) is small. The values fluctuate making it difficult to determine a pattern.

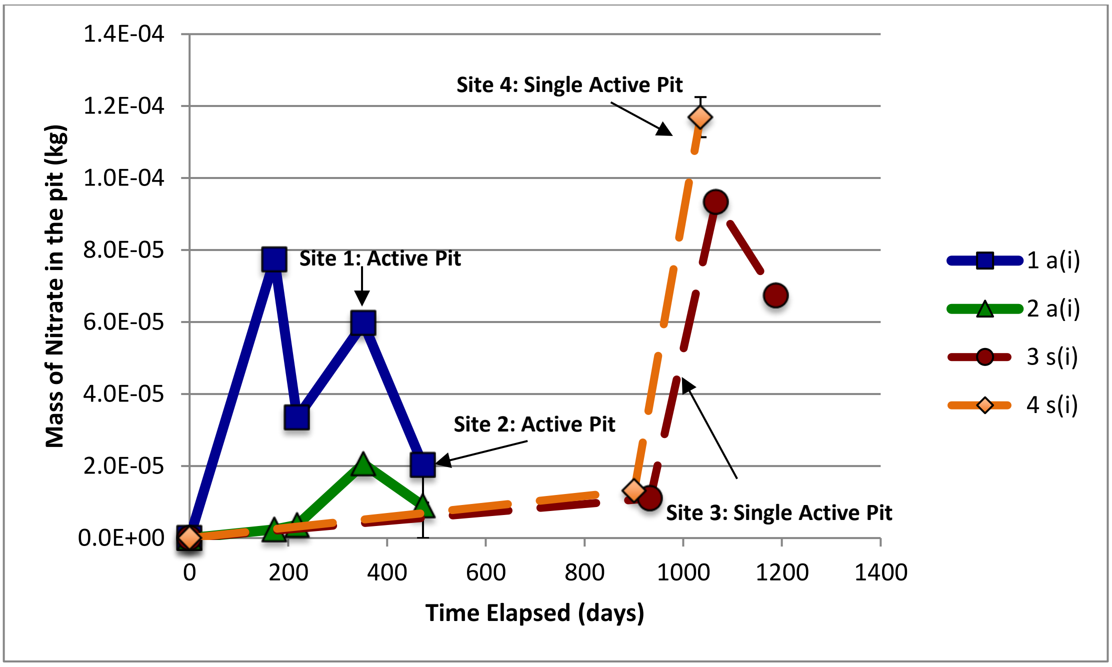


FIGURE 30. MASS OF NITRATE IN THE ACTIVE PITS SINCE START OF OPERATION

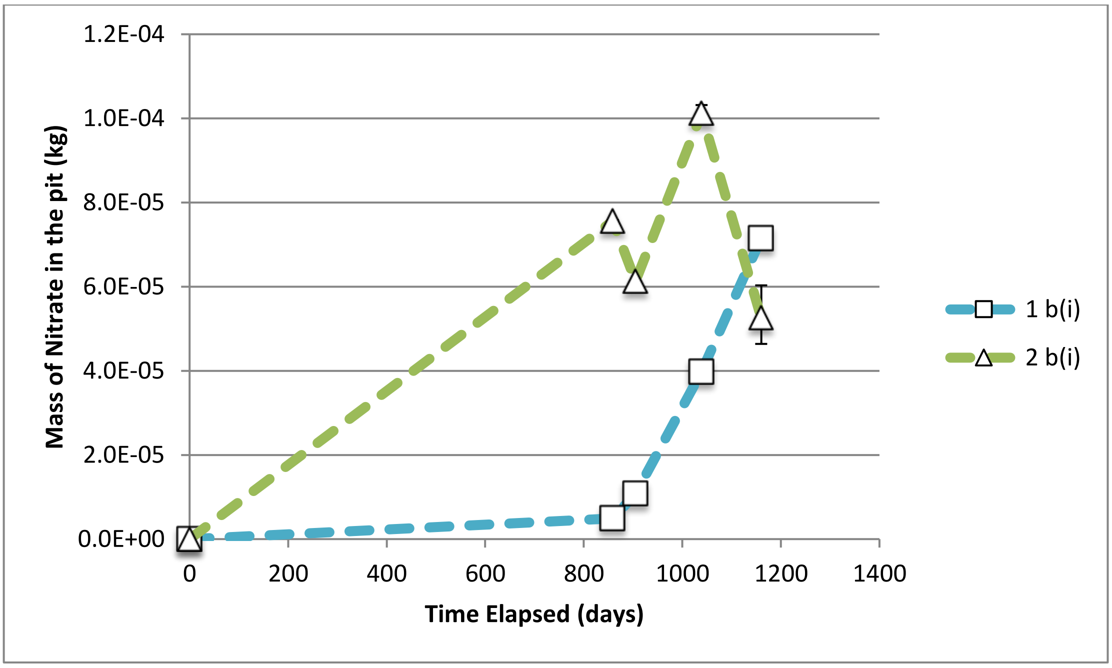


FIGURE 31. MASS OF NITRATE IN THE STANDING PITS SINCE START OF OPERATION

3.2.5 PHOSPHATES

This section has two sub-sections; the Total Phosphate results are presented in **section 3.2.5.1** and the Ortho-phosphate results presented in **section 3.2.5.2**.

3.2.5.1 TOTAL PHOSPHATE

The mass of total phosphate is below 0.001 kg for all samples, except the second campaign samples for Site 4. There does not appear to be a pattern of increasing or decreasing total phosphate mass in the active (Figure 32) or standing pits (Figure 33).

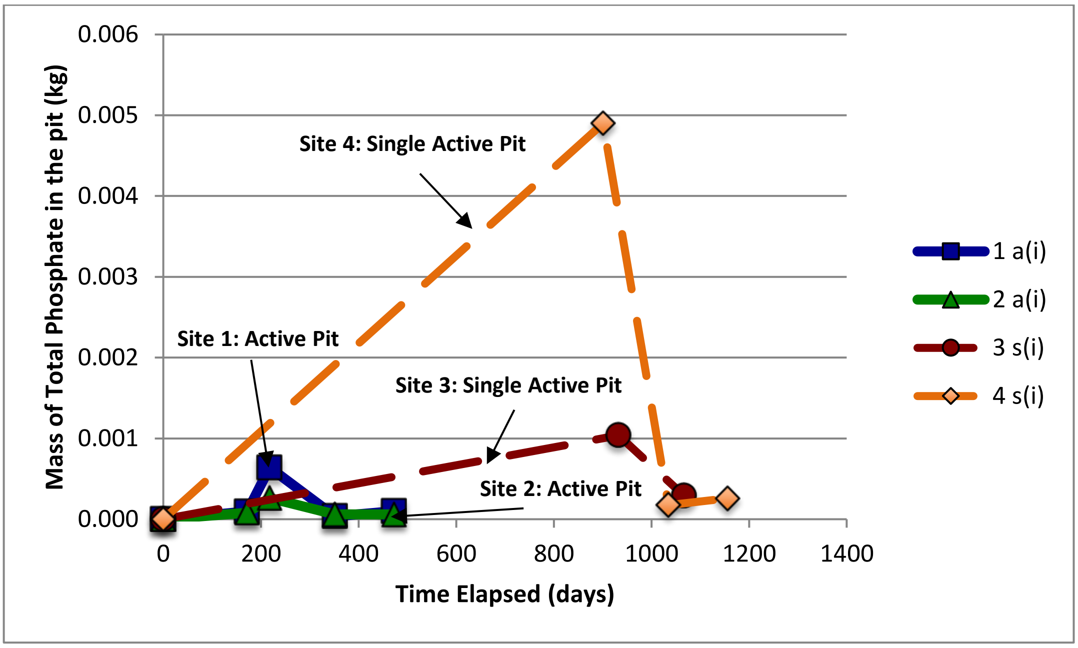


FIGURE 32. MASS OF TOTAL PHOSPHATE IN THE ACTIVE PITS SINCE START OF OPERATION

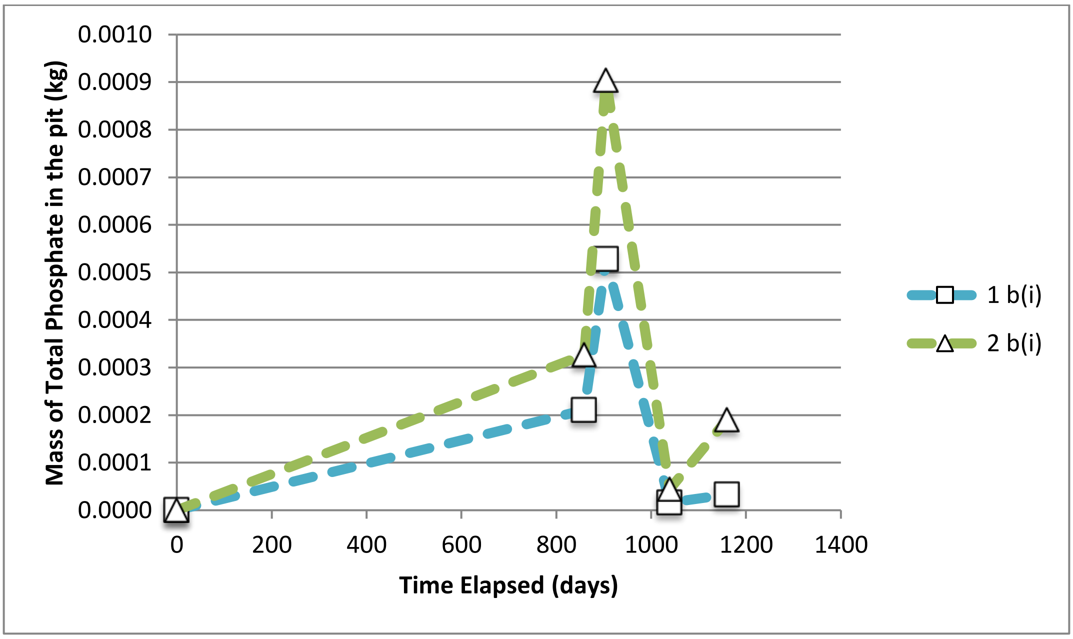


FIGURE 33. MASS OF TOTAL PHOSPHATE IN THE STANDING PITS SINCE START OF OPERATION

3.2.5.2 ORTHO-PHOSPHATE

The mass of ortho-phosphate fluctuates from one campaign to the next for both active and standing pits, making it difficult to interpret what reactions are occurring in the pit with regards to phosphorous.

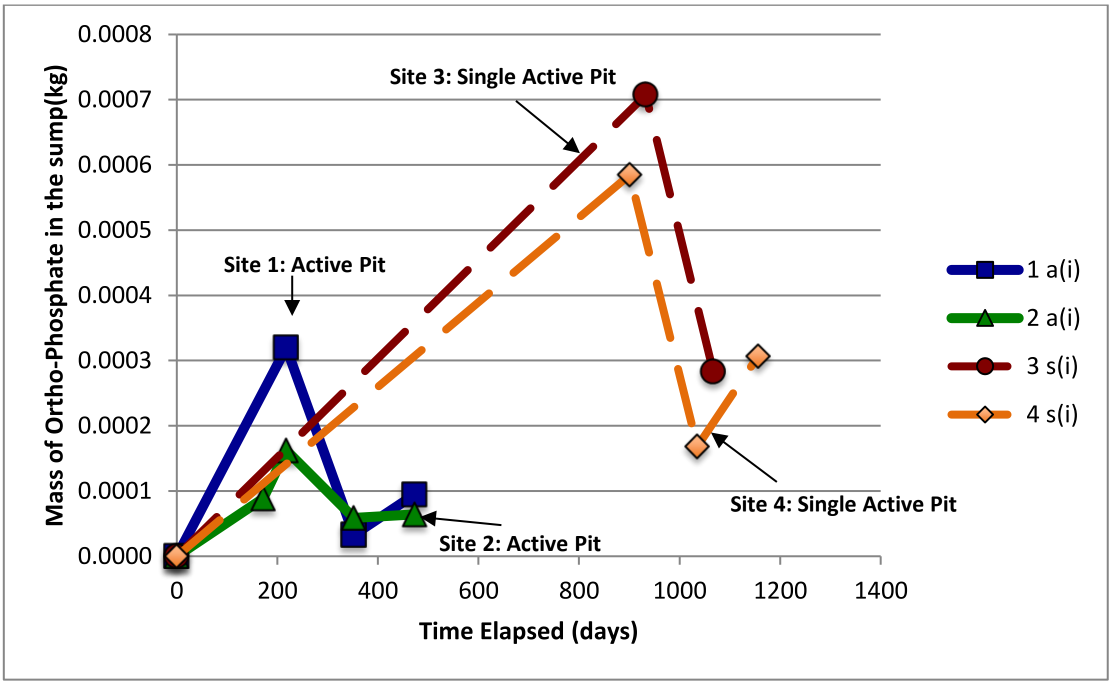


FIGURE 34. MASS OF ORTHO-PHOSPHATE IN THE ACTIVE PITS SINCE START OF OPERATION

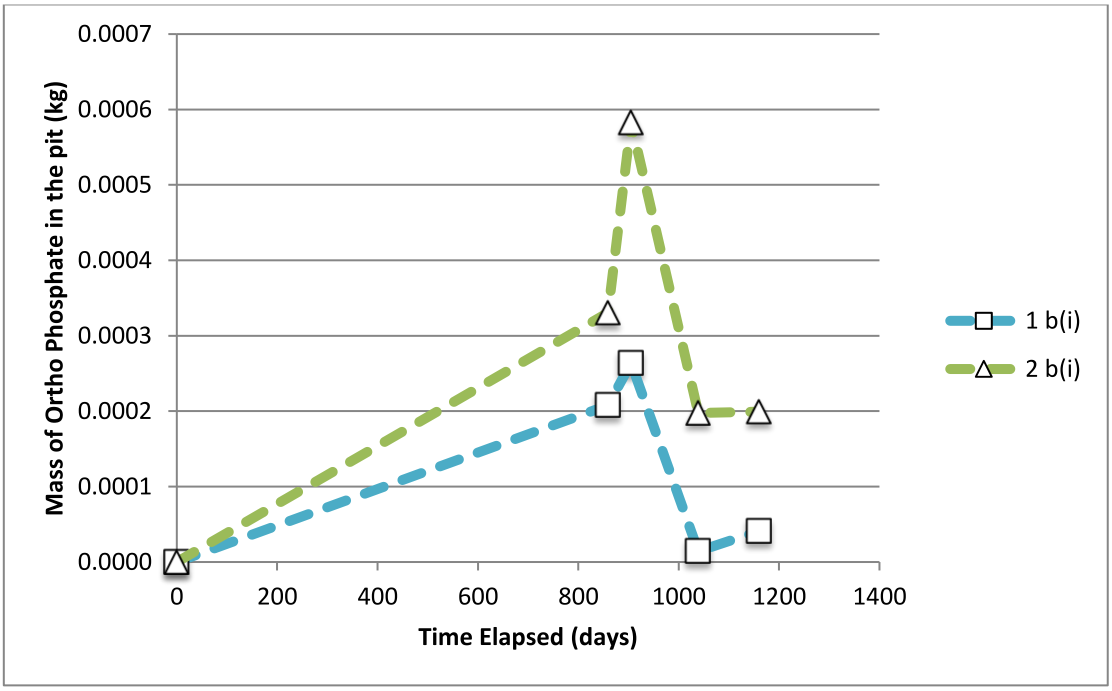


FIGURE 35. MASS OF ORTHO-PHOSPHATE IN THE STANDING PITS SINCE START OF OPERATION

3.2.5 POTASSIUM

The mass of potassium in the active pits increases initially and then drops significantly, as seen in Figure 36. The precipitation in the area is greater in the months just before the third and fourth campaigns. This might explain why the mass of potassium has dropped; the potassium might have been washed into the soil because of greater water movement in and out of the pits.

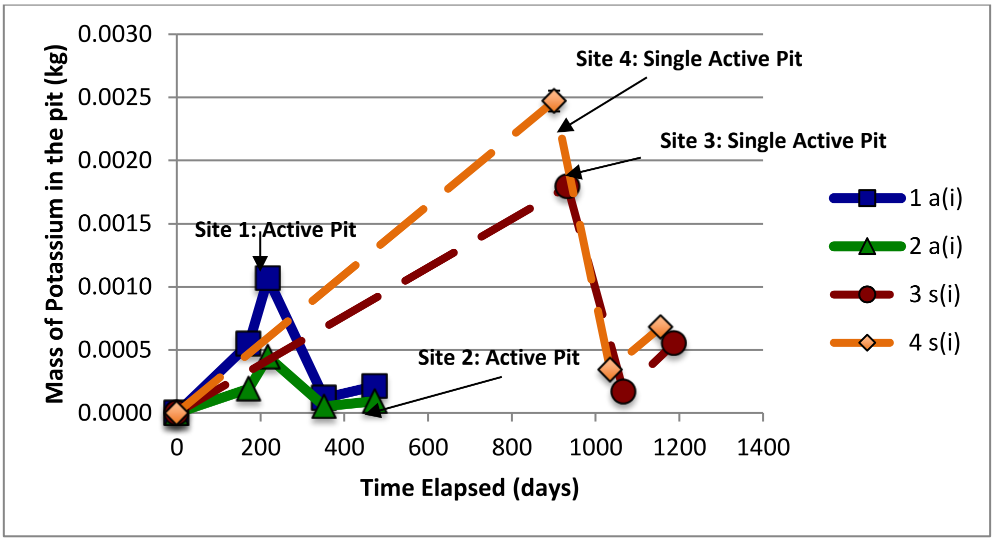


FIGURE 36. MASS OF POTASSIUM IN THE ACTIVE PITS SINCE START OF OPERATION

The mass of potassium in the standing pits (Figure 37) range from 0.0005 to 0.0001 kg, excluding the samples taken on the second campaign. Although, if including the data from campaign two, this could be explained by the driest month preceding the date of sampling, causing the potassium to be retained in the pits. The greatest rainfalls are seen from November to March, which could explain the drop in the potassium levels for campaign three and four.

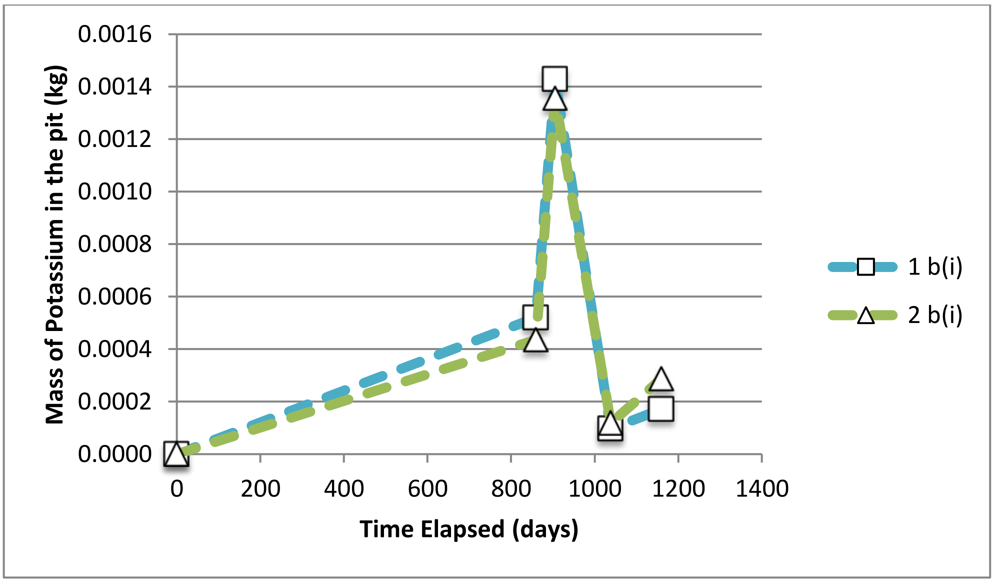


FIGURE 37. MASS OF POTASSIUM IN THE STANDING PITS SINCE START OF OPERATION

3.2.6 SODIUM

Sodium was not measured for samples collected on the third campaign. The mass of sodium is increasing in the active pits (Figure 38). It was expected that sodium and potassium would have similar patterns, however, they do not.

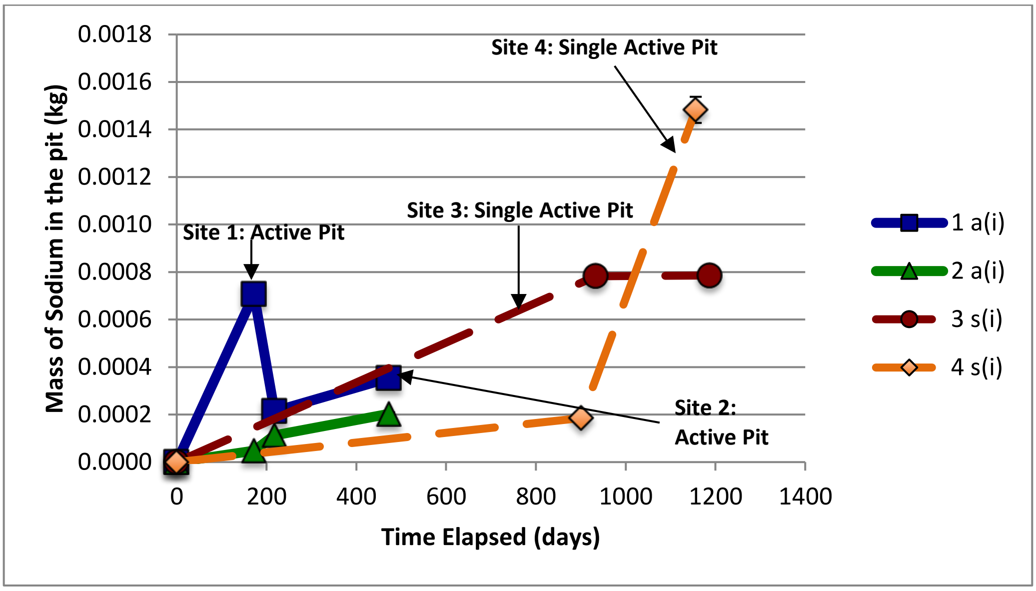


FIGURE 38. MASS OF SODIUM IN THE ACTIVE PITS SINCE START OF OPERATION

The mass of sodium is increasing in the standing pits (Figure 39), which is unusual. It would be expected the sodium would decrease as it would dissolve in the water in the pit and leave with it. User diet could possibly affect the mass of sodium present. Potentially sodium is leaching from the active pit into the standing pit, increasing its mass.

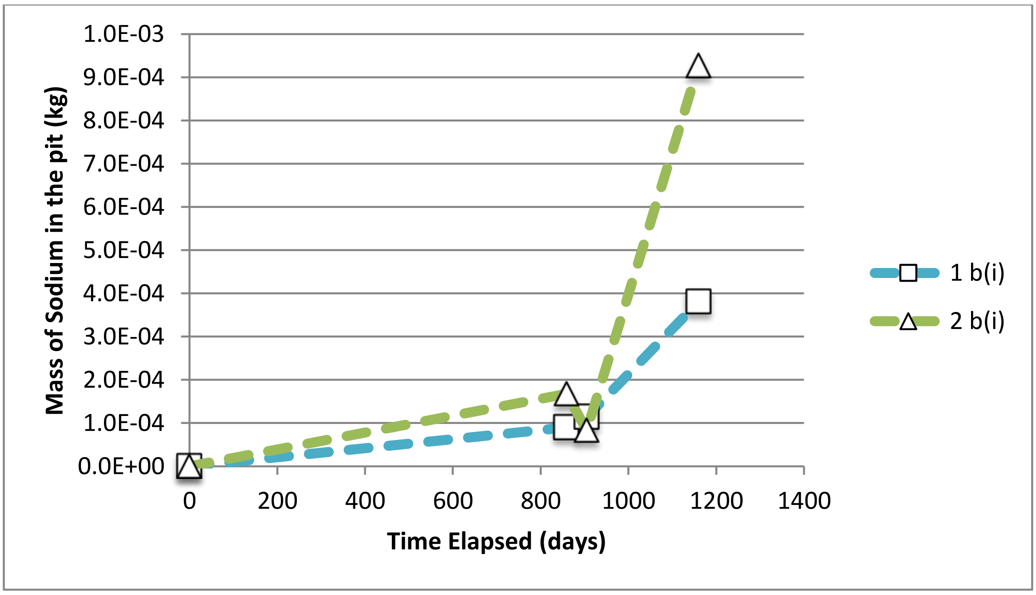


FIGURE 39. MASS OF SODIUM IN THE STANDING PITS SINCE START OF OPERATION

3.3 RHEOLOGICAL ANALYSIS

This section has four subsections. In **section 3.3.**1, the plastic and liquid limit results are presented. In **section 3.3.2**, the shear strength data is presented. Rheometer results are presented in **section 3.3.3**. Flow Table test results are presented in **section 3.3.4**.

3.3.1 PLASTIC AND LIQUID LIMIT

The liquid limit was initially conducted on the samples from the first campaign. The plastic limit was performed on the samples collected from the second campaign. Most of the sludge samples collected from these campaigns were too wet to perform the tests. It was decided, in particular, for the liquid limit that if the sample was too wet to perform the test that the Rheometer should be used instead, stating that the sludge was out of the range of the cone penetrometer to calculate the shear strength. If the sludge was too wet to perform the plastic limit it was attempted to dry out the sludge, as a smaller quantity was required compared to the liquid limit test. Sludge was dried in the oven at 105°C, checking hourly until it was determined that the sludge was dry enough to perform the plastic limit test. Approximately 30 g of sludge was placed in a crucible for drying. More appropriate drying techniques need to be developed; it was found that the surface dried and became crusty, while the material in the centre was still moist. Either frequent mixing of the sample while it is drying or spreading a thin layer of sludge on a baking tray might produce better drying results. Air-drying was attempted but was unsuccessful; the sludge did not dry significantly enough over 24hrs to be tested. Sludge was not dried for the liquid limit test as there was not appropriate equipment in the laboratory to dry a larger quantity of sludge that would be needed for the liquid limit test.

To calculate the liquid limit of a material, the cone penetration must be plotted against the moisture content. The liquid limit is the moisture content of the material corresponding to a cone penetration of 20 mm. In Figure 40, the sample from the front of the pit (1bi) produced a more linear relationship between moisture content and cone penetration than the sample from the back (1bii).

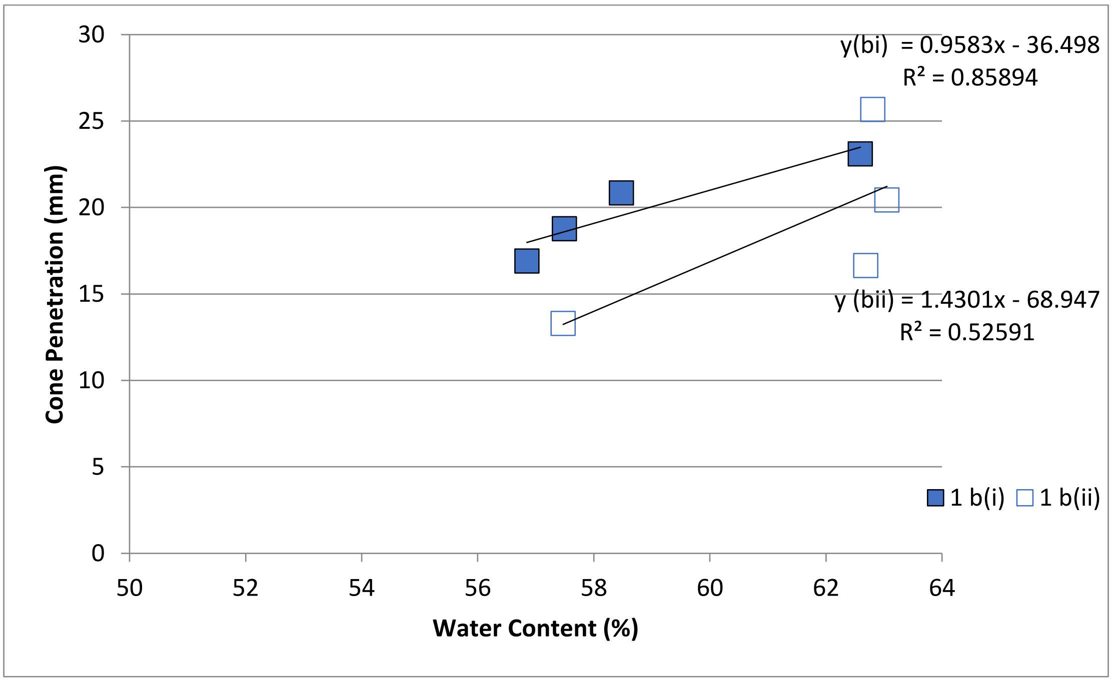


FIGURE 40. LIQUID LIMIT PLOT FOR SITE 1 B

The samples from both the front and back of the standing pit at Site 2 produce linear relationships between the moisture content and cone penetration values. The liquid limit for each plot was calculated using the equation for the best fit line and is displayed in Figure 41.

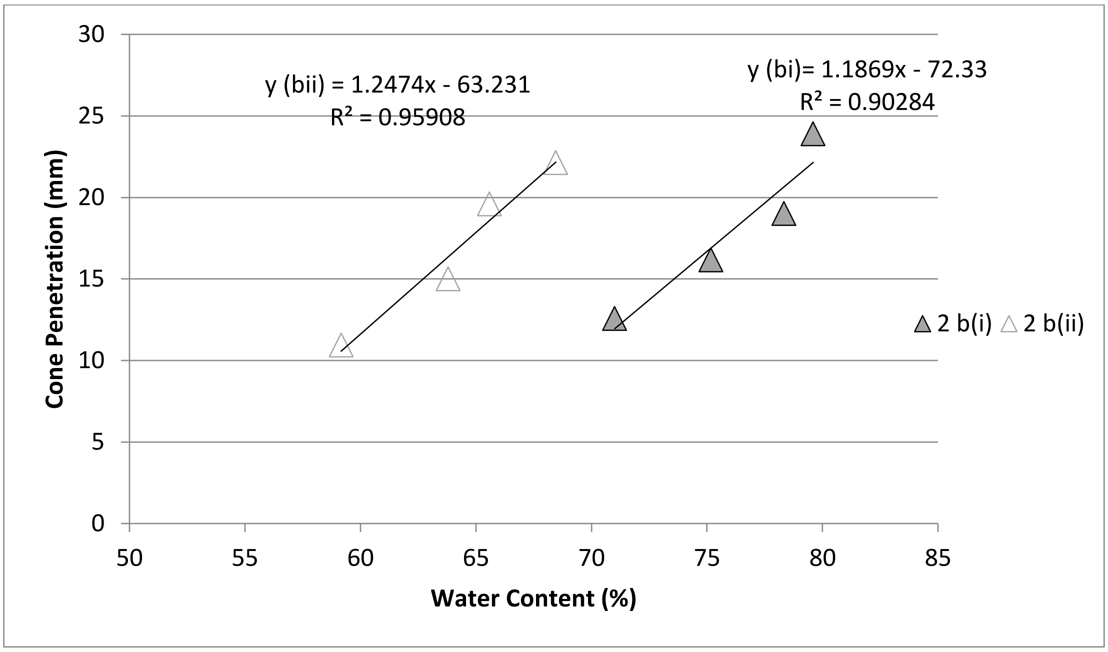


FIGURE 41. LIQUID LIMIT PLOT FOR SITE 2 B

The plastic limit is the moisture content at which a material stops behaving plastically. The plastic limit was determined for each sample collected from Campaign 4. The results are displayed in Table 2 below. The plasticity index was calculated, but is limited to the samples that were eligible for the liquid limit test as both the liquid limit and plastic limit are needed to calculate the plasticity index.

TABLE 2. PLASTIC LIMIT, LIQUID LIMIT AND PLASTICITY INDEX RESULTS

Sample ID	Plastic Limit	Liquid Limit	Plasticity Index
	[%]		
1 a(i)	40		
1 a(ii)	38		
1 b(i)	36	59	23
1 b(ii)	51	62	12
2 a(i)	62		
2 a(ii)	59		
2 b(i)	39	78	39
2 b(ii)	24	67	43
3 s(i)	55		
3 s(ii)	49		
4 s(i)	57		
4 s(ii)	61		

3.3.2 SHEAR STRENGTH

The cone penetrometer was used to determine the shear strength of the sludge, as well as the liquid limit, which was reported in the section above. The cone penetrometer was only able to produce results for the driest sludge. Wetter sludge was out of the range of the apparatus. Below in Table 3 are the results obtained for 4 samples from campaign 4. All other samples from this campaign were too wet to be tested using this method.

TABLE 3. SHEAR STRENGTH RESULTS FOR CAMPAIGN 4

Sample ID	Shear Strength	
	[kN/m^2]	[Pa]
1 b(i)	3.66E-06	3.66E-09
1 b(ii)	5.90E-06	5.90E-09
2 b(i)	6.61E-06	6.61E-09
2 b(ii)	8.73E-06	8.73E-09

3.3.3 RHEOMETER MEASUREMENTS

Each sludge sample was tested in triplicate with the rheometer. The samples were not in the operational limit of the rheometer and were thus excluded from this report. Alternative methods of determining the viscosity and shear stress of the sludge should be investigated.

3.3.4 FLOW TABLE TEST

The flow table test results from the first campaign are shown in Figure 42 below. There is a clear difference between the flow of active and standing pit sludge, with the active sludge having a flow almost twice that of the standing sludge. Ideally the flow would be related to the viscosity but due to the determined unreliability of the rheometer results this was not attempted. A series of sludge pumping tests should be conducted, with varying sludge consistencies and sludge emptying equipment to provide a relation between sludge flow and sludge ability to be pumped. This would be useful data when it comes to identifying appropriate pit emptying machinery.

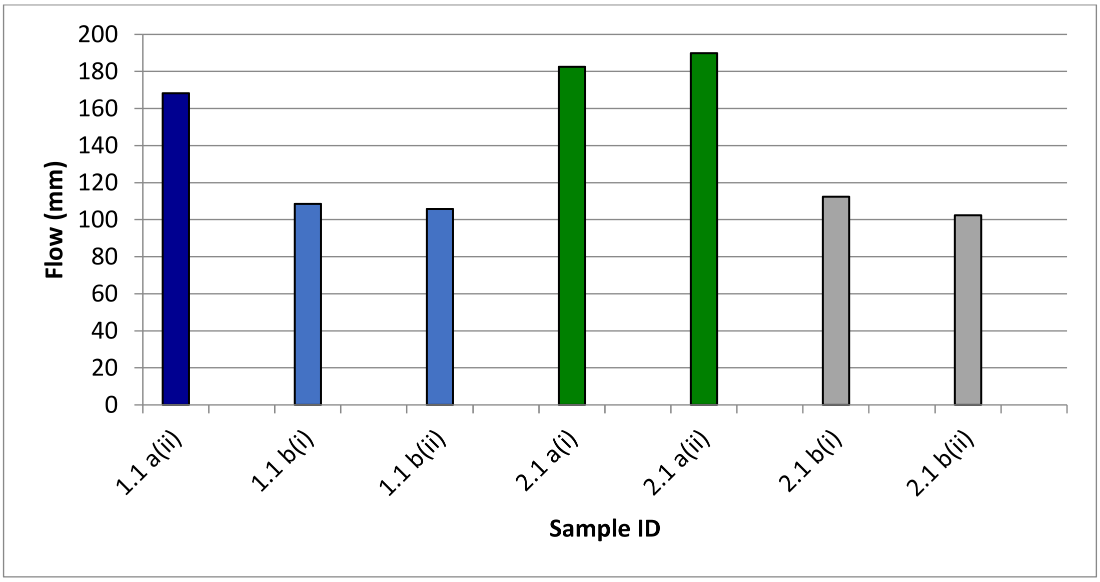


FIGURE 42. FLOW TABLE RESULTS FOR SAMPLES COLLECTED IN CAMPAIGN 1

3.4 BIODEGRADATION

This section has two sub-sections. In **section 3.4.1**, the results from CSTR are presented and in **section 3.4.2**, results from the repeated COD tests are presented.

3.4.1 CSTR

The CSTR was set up on the 1st of April 2014 and ran for just under 90 days. Initially, the total gas production was rapid. Three distinct phases can be seen in the graph below of the total gas production Figure 43. The initial phase occurs within the first few hours and gas production is rapid. This is probably caused by the oxygen present in the headspace of the tank, leading to rapid aerobic degradation. Following on from this the gas production slows a little but is still steadily increasing up until approximately day 25. After this, the curve changes and the slope is more gradual representing a slower rate of gas production. Towards the end of the test period, the slope begins to level-off.

A total of 27.8 ℓ of gas was produced from the system during the test period reported. By day 16 half of this gas was produced.

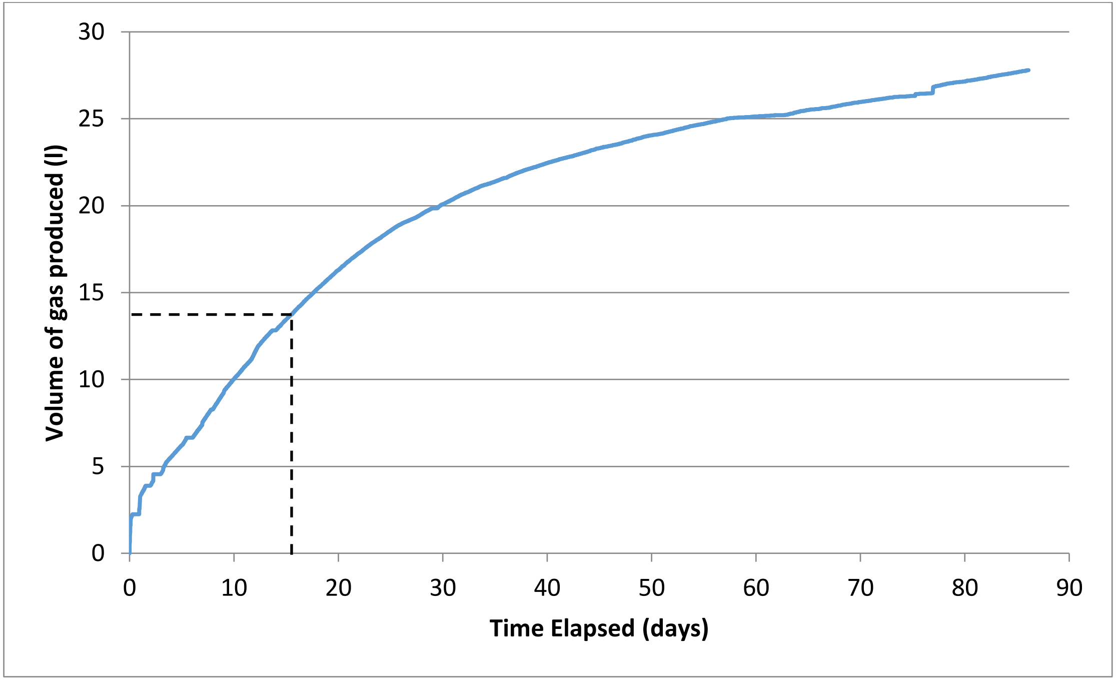


FIGURE 43. TOTAL GAS PRODUCTION PLOTTED AGAINST TIME FOR THE CSTR SYSTEM

3.4.2 REPEATED COD

Sludge from Site 3 was used for the repeated COD test to coincide with the sludge placed in the CSTR. Three different dilutions were made and stored at room temperature. The COD was determined every few days, each dilution was tested in triplicate. The dilution factor and total solids concentration are given in Table 4 below.

The COD value should decrease with time as the biodegradable material is used up depleting the oxygen present. This trend can be seen in Figure 44 below. An average of 85% decrease in COD concentration is seen between the first and last measurement. Hence, in 27 days approximately 84% of the COD is degraded in the sludge.

TABLE 4. DILUTION FACTOR AND TOTAL SOLIDS CONCENTRATION FOR THE SLUDGE TESTED IN THE SECOND RUN

Sample ID	**Volume**	**Mass**	**Dilution factor**	**Total solids**
	[ℓ]	**[g]**	**[l/g]**	**[g/g wet]**
A	0.5	0.42	1.20	0.19
B	0.5	1.04	0.48	0.19
C	0.5	1.43	0.35	0.19

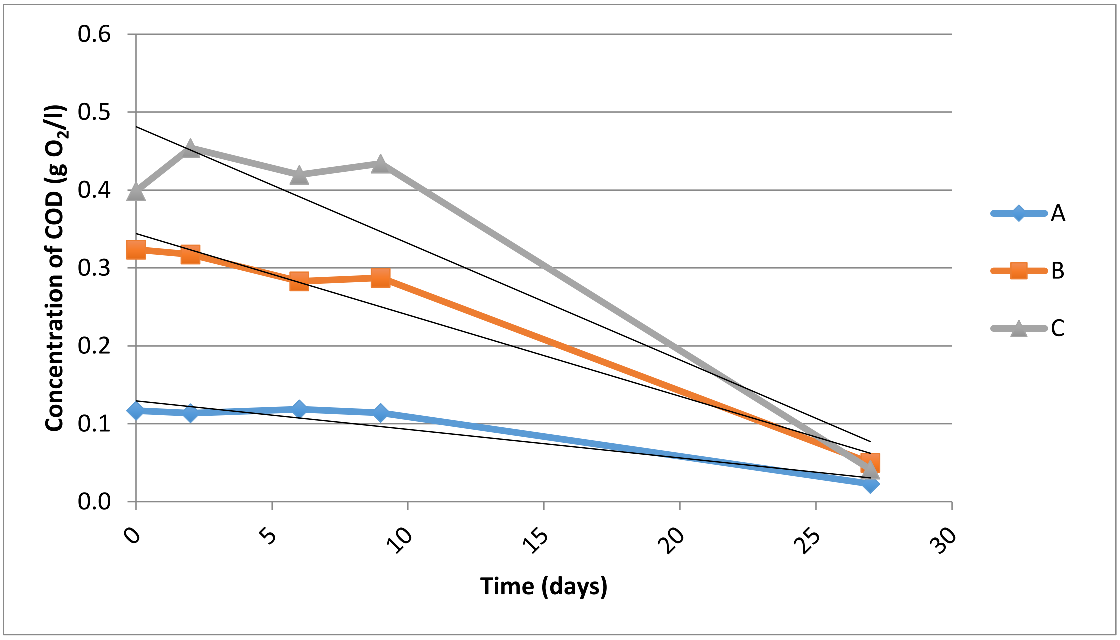


FIGURE 44. CONCENTRATION OF COD VS. TIME FOR THREE DIFFERENT DILUTION FACTORS OF THE SAME POUR-FLUSH SLUDGE SAMPLE

3.5 PIT FILL RATES OF POUR-FLUSH TOILETS

Data was taken from the literature to compare the filling rate of the pits in terms of the sludge height and volume of a theoretical closed system to the results gathered in this study. 50 ℓ/p/yr of faeces excreta and 500 ℓ/p/yr of urine excreted were taken from the Compendium of Sanitation [5] to calculate the theoretical filling rate of a closed system. An average household size was taken as 6.4 persons and an assumption of 4 flushes a day of 1.5 ℓ per flush was made. The filling rate of a standard Pour-Flush system was taken as 23 ℓ/p/yr as determined by PID. The theoretical height of sludge, PID average height increase and the data obtained from this study were plotted together in Figure 45. The sludge heights measured in this study fall in line with the PID average filling rate. Both the values obtained from this study and the PID average filling rate is lower than the theoretical projected filling rate based on a closed system. This proves there is movement of material out of the pit into the surrounding soil and the sludge in the pit is degrading by itself.

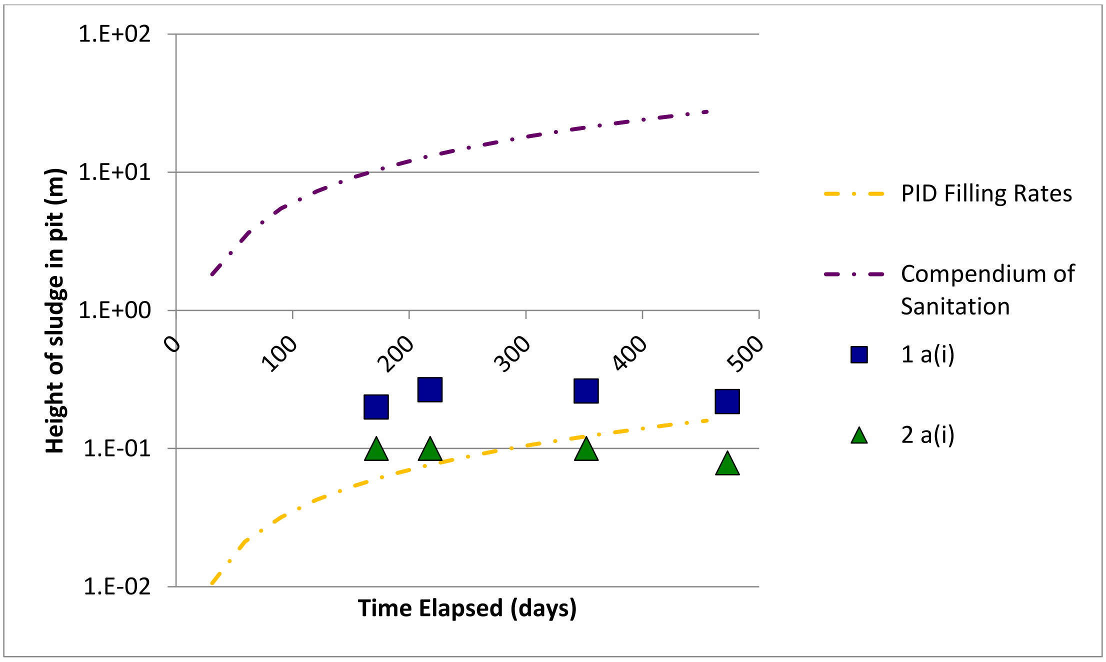


FIGURE 45. HEIGHT OF SLUDGE IN PITS COMMISSIONED IN 2012 PLOTTED WITH PROJECTED PID AVERAGE FILLING RATE AND ESTIMATED FILLING RATE OBTAINED FROM COMPENDIUM OF SANITATION [4]

Figure 46 and Figure 47 show the volume calculated of each the pits on each sampling campaign. A projected filling rate for a VIP latrine based on 60 ℓ/p/yr taken from Wood [6] is added to the theoretical plots. The filling rate for the Pour-Flush toilets is consistently lower than the VIP when compared to the PID average filling rate and the measurements taken from the active and standing pits in this project.

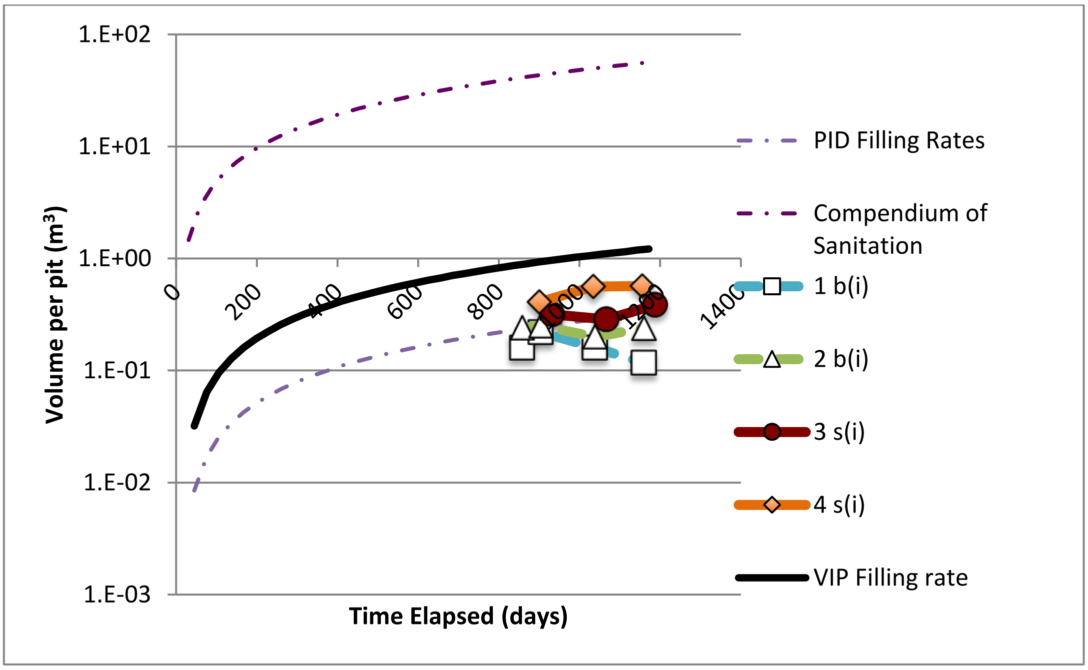


FIGURE 46. FILLING RATE OF PITS COMMISSIONED IN 2011 PLOTTED WITH PROJECTED VIP FILLING RATE, PID AVERAGE FILLING RATE AND COMPENDIUM OF SANITATION THEORETICAL FILLING RATE OF A CLOSED SYSTEM

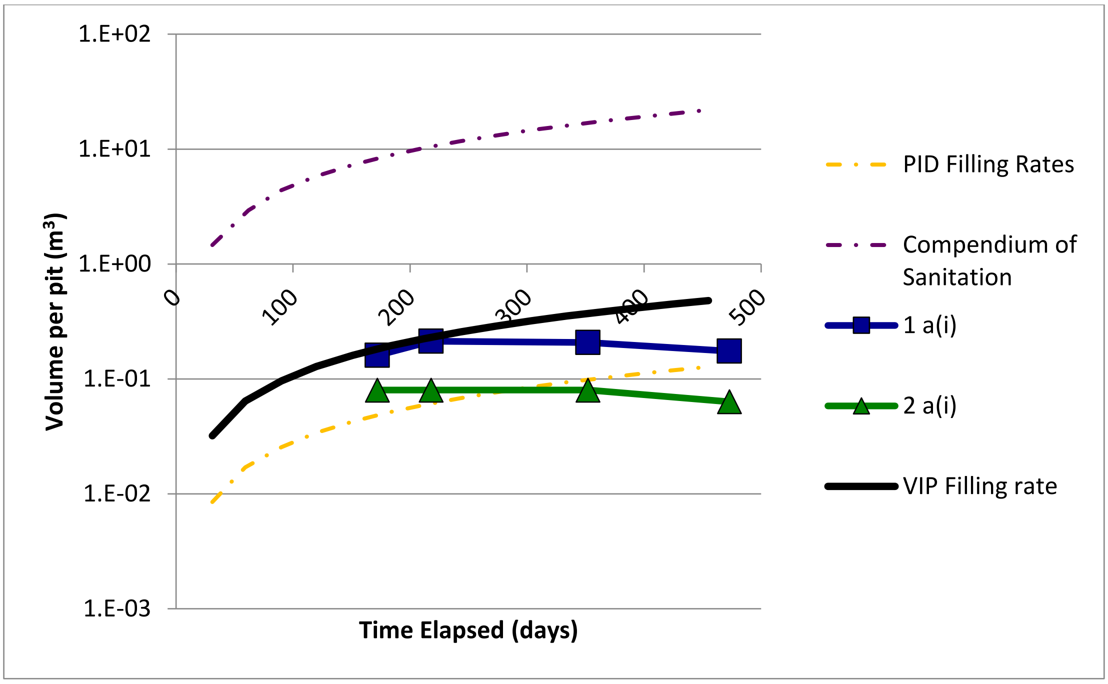


FIGURE 47.FILLING RATE OF PITS COMMISSIONED IN 2012 PLOTTED WITH PROJECTED VIP FILLING RATE, PID AVERAGE FILLING RATE AND COMPENDIUM OF SANITATION THEORETICAL FILLING RATE OF A CLOSED SYSTEM

Following on from comparing the sludge height and volumetric filling rates of the Pour-Flush latrines to literature data, the mass of chemical components of the sludge were calculated from the available data and compared to the results of this study. Jönsson, Stinzing et al. [7] provided values for the mass of total solids, COD, nitrogen, phosphorous and potassium found in excreta and urine. These values were used to calculate a projected accumulation of each component assuming a closed system. These projections were then plotted against the results obtained through the chemical analysis of Pour-Flush sludge for this study to observe the comparison. The values measured in the Pour-Flush sludge were all at least two orders of magnitude smaller than the predicted values calculated from Jönsson, Stinzing et al. [7]. This is shown in the series of graphs from Figure 48 to Figure 52. Only the data for pits commissioned in 2011 are shown, the pits commissioned in 2012 show the same patterns. From this, it can be assumed that soluble substances such as potassium, phosphorous and soluble COD are being transported out of the leach pit with the water that can freely leach into the surrounding soil. Also, it allows the assumption that material is being degraded within the pit, reducing the mass of total solids and COD present compared to the theoretical closed system.

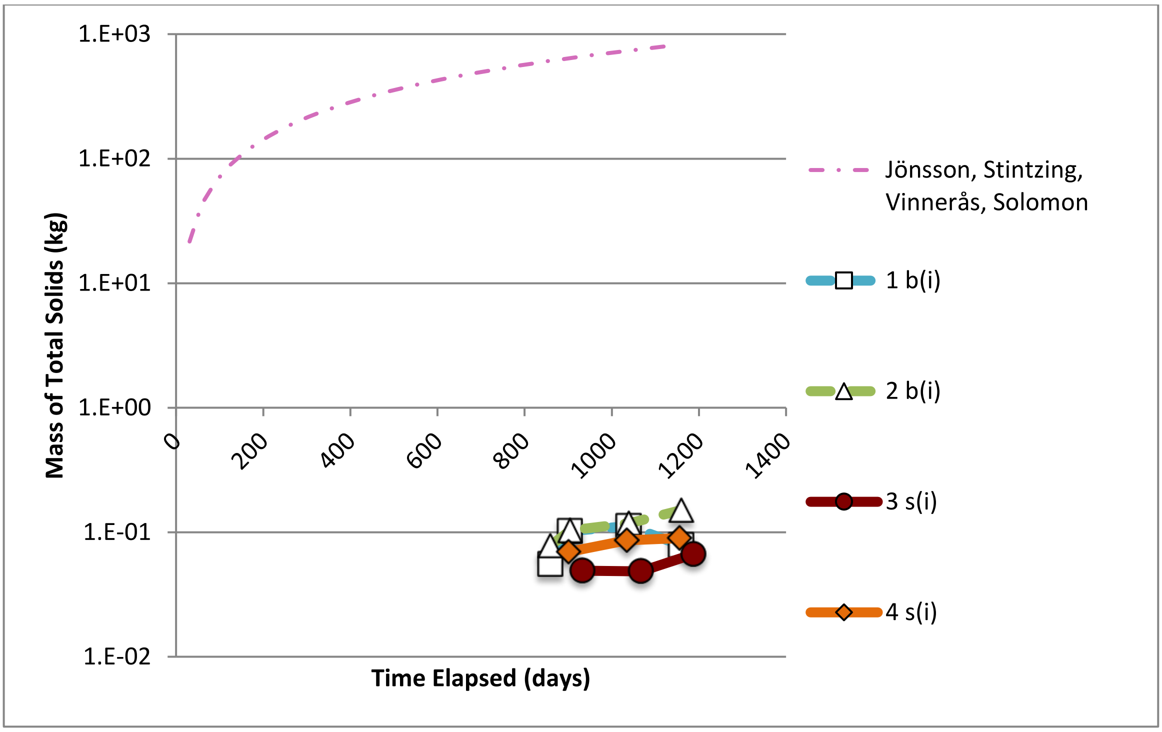


FIGURE 48. ACCUMULATION OF SOLID MASS IN PITS COMMISSIONED IN JANUARY 2011

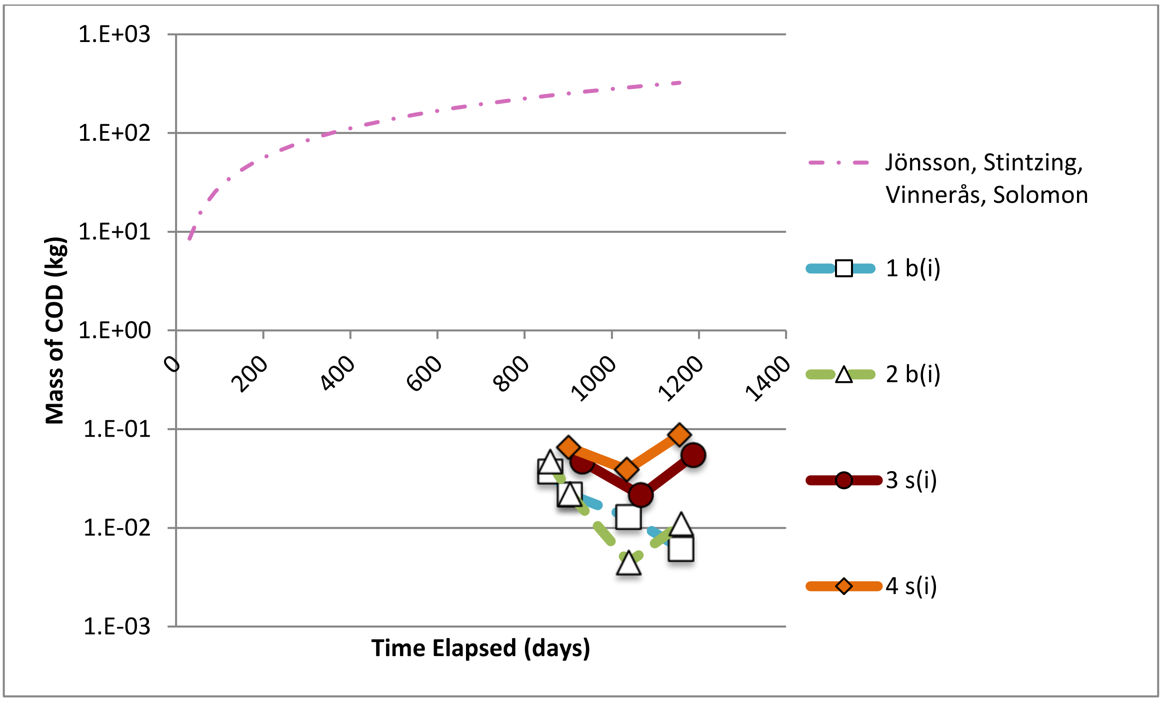


FIGURE 49. ACCUMULATION OF COD MASS IN PITS COMMISSIONED IN JANUARY 2011

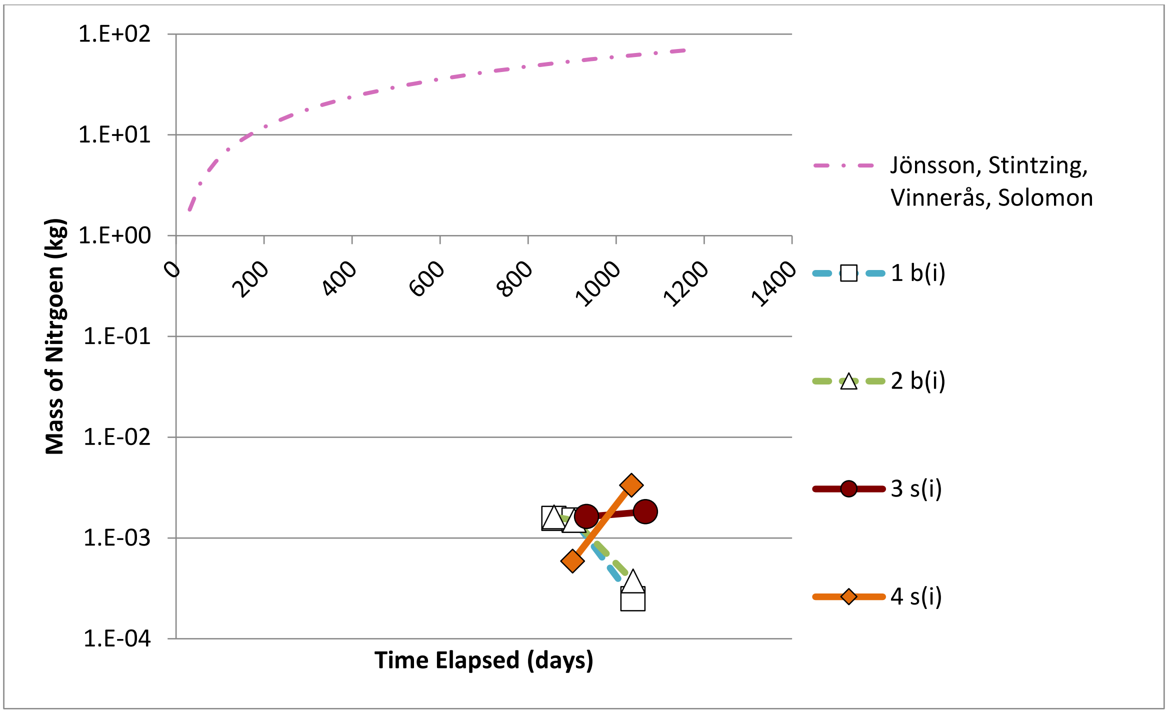


FIGURE 50. ACCUMULATION OF NITROGEN MASS IN PITS COMMISSIONED IN JANUARY 2011

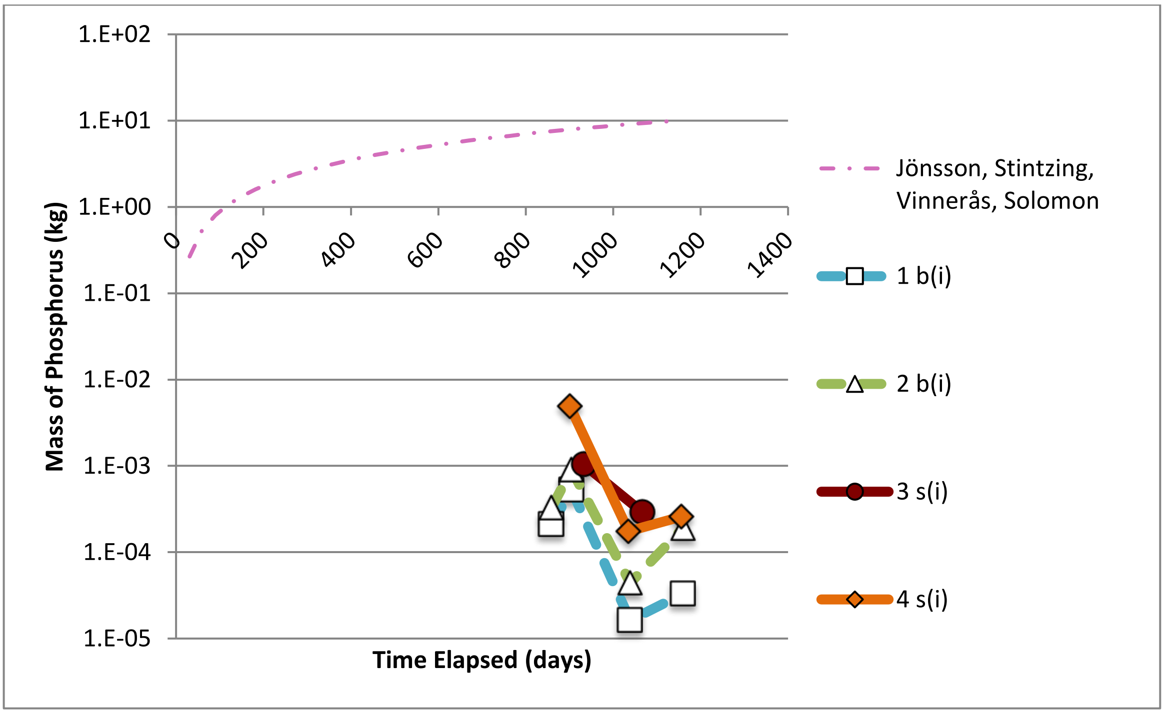


FIGURE 51. ACCUMULATION OF PHOSPHOROUS MASS IN PITS COMMISSIONED IN JANUARY 2011

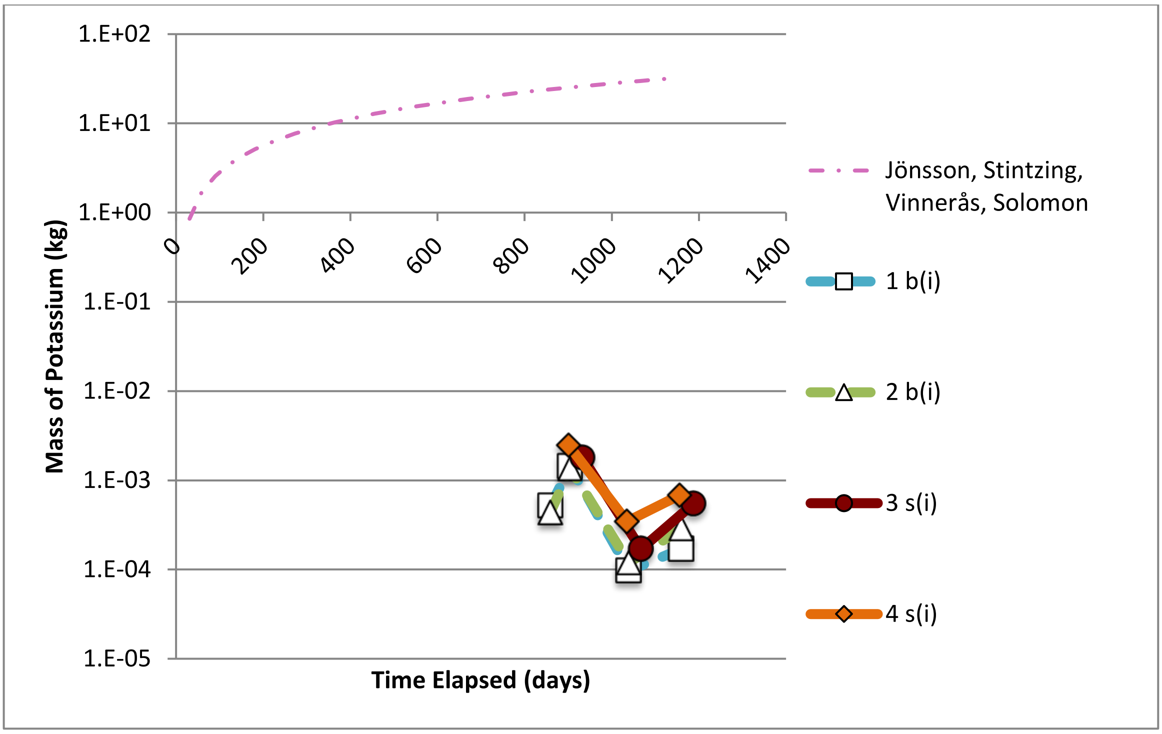


FIGURE 52. ACCUMULATION OF POTASSIUM MASS IN PITS COMMISSIONED IN JANUARY 2011

3.6 COMPARISON OF POUR-FLUSH SLUDGE TO VIP SLUDGE

This section has two sub-sections: **section 3.6.1** presents results from the visual inspection of the Pour-Flush leach pits while **section 3.6.2** presents a comparison of Pour-Flush sludge characteristics with that of VIP latrines.

3.6.1 VISUALLY

Visual inspection of Pour-Flush and VIP sludge indicates there is less non-faecal material present in the Pour-Flush leach pits. The sludge in the Pour-Flush pits is ‘cleaner’ than the VIP sludge. The narrow size of the pipe in the Pour-Flush pedestal design limits the amount of non-faecal material that can be disposed of into the pit. This will impact the filling rate of the Pour-Flush leach pit such that it will fill at a slower rate compared to the VIP latrine, which can be seen in **section 3.1.5**. The cleaner nature of the Pour-Flush sludge will lend itself to pit emptying via vacuum tanker or pumping more easily than VIP sludge. One of the issues with VIP emptying, aside from access to the pit itself, is the excess of non-faecal matter clogging or causing damage to the pit emptying equipment. This risk is reduced with the ‘clean’ Pour-Flush sludge.

3.6.2 CHEMICALLY

Table 5 below provides a comparison of chemical compositional data available in the literature for VIP sludge and fresh faeces, compared to the results obtained from this project for the chemical composition of Pour-Flush sludge. The data for VIP sludge [8,9] and for fresh faeces [10] was obtained from a Master thesis.

The Pour-Flush sludge has a greater range for total solids and water content, compared to VIP sludge. The Pour-Flush values display both wetter and drier sludge existing in the leach pits. A higher water content and hence wetter pit can be attributed to the use of flush water in the Pour-Flush system. The drier values seen in the Pour-Flush sludge can be explained by the practice of taking a leach pit out of use when it has filled up, allowing it to dry out and degrade.

Both the Pour-Flush and VIP sludge have the same minimum value for the concentration of ash present. The Pour-Flush however has a maximum value more than twice the VIP maximum value. This could be attributed to the standing pit; the sludge has been left to degrade and so the biodegradable material is being broken down and transported out of the pit dissolved in water, leaving behind insoluble ash which is gradually building up in the leach pit.

The Pour-Flush sludge has a lower minimum value and higher maximum value for total COD compared to the VIP sludge. This greater range is probably a result of combining the active and standing pit results in the maximum and minimum calculations. Both the VIP and Pour-Flush sludge have lower COD concentration compared to fresh faeces. This is explained by Wood [6] as a result of rapid aerobic degradation of the fresh faeces from when it is excreted to where it lands and is buried by the next use of the toilet.

The TKN concentration is lower in the Pour-Flush sludge compared to the VIP sludge. The Pour-Flush TKN concentration range of max and min falls within the VIP max-min range. It follows that the concentration of ammonia is lower in the Pour-Flush sludge compared to the VIP sludge.

The ortho-phosphate concentration is higher in the Pour-Flush sludge. The max and min pH of the Pour-Flush sludge is within the max-min range of the VIP sludge, without reaching the highest and lowest pH values of the VIP sludge.

TABLE 5. VIP SLUDGE CHEMICAL COMPOSITION COMPARED TO POUR-FLUSH SLUDGE CHEMICAL COMPOSITION

Species	**Unit**	**Pour-flush Active wet basis**			**Pour-flush Standing wet basis**			**VIP faecal sludge**		**Fresh Faeces**
		Mean	**Max**	**Min**	**Mean**	**Max**	**Min**	**Max**	**Min**	**Mean**
Total solids	[g/g wet sample]	0.19	0.38	0.08	0.44	0.72	0.16	0.44	0.19	
Ash	[g/g wet sample]	0.10	0.29	0.02	0.35	0.66	0.07	0.30	0.02	0.04
Moisture content	[g/g wet sample]	0.81	0.92	0.62	0.56	0.84	0.28	0.81	0.66	0.77
COD_t	[mg/g wet sample]	126.3	216.6	44.2	129.4	262.6	22.3	190	30	320
Total Nitrogen	[mg/g wet sample]	5.22	9.29	1.44	5.46	9.75	1.56			13.93
TKN	[mg/g wet sample]	5.06	9.24	1.41	5.23	9.72	1.31	14	4	
Ammonia	[mg/g wet sample]	1.02	2.73	0.00	0.33	1.59	0.00	5	0.31	
Total Phosphate	[mg/g wet sample]	2.29	12.0	0.17	1.22	3.62	0.10			140
Ortho Phosphate	[mg P/g wet sample]	1.16	3.52	0.16	1.05	2.72	0.09	0.17	0.02	
pH		7.06	8.22	5.98	7.56	8.36	6.33	8.6	4.7	

4. CONCLUSIONS

In conclusion, the VIP and Pour-Flush sludge have similar chemical characteristics, however the Pour-Flush sludge has a slower filling rate as a result of less non-faecal material present in the leach pit and the ability of the liquid component to seep into the surrounding soil, taking with it soluble material, reducing the mass of solids in the pit.

The masses of chemical components were plotted against a time period of 11-months, to determine processes occurring in the pit over time. It was observed that a general increase in the mass of total solids and ash in both the active and standing pits. The mass of moisture, volatile solids, suspended solids and COD all increase in active pits while they decrease in standing pits. It is difficult to determine a pattern over time in the mass of the nitrogen species, phosphates and potassium. An increase in sodium was observed in both active and standing pits.

More extensive testing of the physical properties is needed to determine the most appropriate method of characterising physical attributes of faecal sludge. Physical tests should be developed together with pit emptying methods, so as to provide value to the results obtained from physical tests. Relating the results of physical tests of sludge to the ease with which it was removed from the pit by specific pit emptying equipment would provide valuable information to improve efficiency in the pit emptying process.

5. REFERENCES

[1] Still, D., Louton, B. Piloting and testing the pour flush latrine technology for its applicability in South Africa (Report No. 1887/1/18). Water Research Commission, South Africa: 2012.

[2] APHA, AWWA, WEF. Standard Methods for the Examination of Water and Wastewater. 19th editi. Washington, DC: Association, American Public Health; 1995.

[3] Jiang, Y. Anaerobic digestion of food and vegetable waste. PhD thesis, University of Southampton, 2012.

[4] Lorentz, S., Wickham, B., Still, D. Investigation into pollution from on-site dry sanitation systems (Report No. 2115). Water Research Commission, South Africa: 2015.

[5] Tilley, E., Lüthi, C., Morel, A., Zurbrügg, C., Schertenleib, R. Compendium of Sanitation Systems and Technologies. Dübendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology (Eawag); 2008.

[6] Wood, K. Modelling the filling rate of pit latrines. Water SA 2013; 39:555-62.

[7] H. J, Stinzing RA, B. V, E. S. Guidelines on use of urine and faeces in crop production. Stockholm Environment Institute, Stockholm: 2004.

[8] Zuma, L., Rajan, M.A., Velkushanova, K., Buckley, C.A. Physico-Chemical Properties of Faecal Sludge from Dry and Wet Pit Latrines. Poster 3rd IWA Dev. Congr. Exhib. “Catalysing Urban Water Transitions“, Nairobi, Kenya: 2013.

[9] Zuma, L., Velkushanova, K., Buckley, C.A. Chemical and thermal properties of dry VIP latrine sludge. University of KwaZulu-Natal, South Africa: n.d.

[10] Nwaneri, C.F. Physico-chemical characteristics and bio-degradability of contents of Ventilated Improved Pit latrines in eThekwini Municipality. M.Eng thesis, University of KwaZulu-Natal, 2009.

APPENDIX A:LEACH PIT CONTENTS

FIGURE A.1. SITE 1, ACTIVE PIT

FIGURE A.2. SITE 1, STANDING PIT

FIGURE A.3. SITE 2, ACTIVE PIT

FIGURE A.4. SITE 2, STANDING PIT

FIGURE A.5. SITE 3, TWO VIEWS OF THE SINGLE PIT

FIGURE A.6. SITE 4, SINGLE PIT

APPENDIX B: FLOW TABLE

FIGURE B.1. FLOW TABLE APPARATUS, INCLUDING FLOW TABLE, WOODEN TAMPER AND METAL MOULD

FIGURE B.2. FLOW TABLE MOULD FILLED WITH SLUDGE

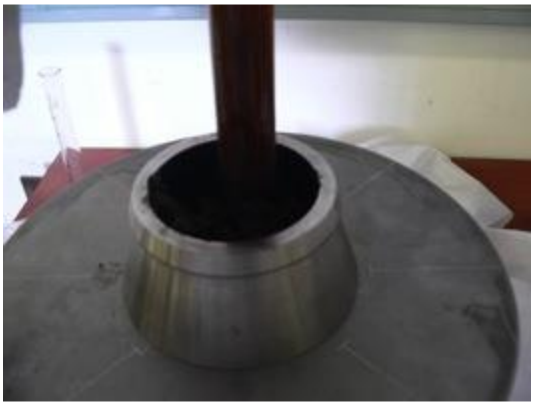


FIGURE B.3. TAMPER BEING USED TO COMPACT SLUDGE INTO THE MOULD

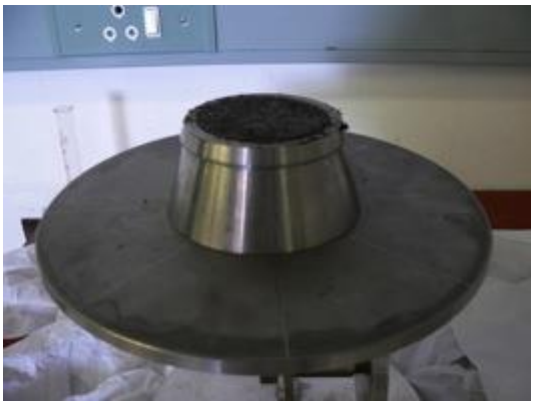


FIGURE B.4. SLUDGE LEVELLED OFF AND READY FOR THE MOULD TO BE REMOVED AND THE DROP CYCLES TO BE APPLIED

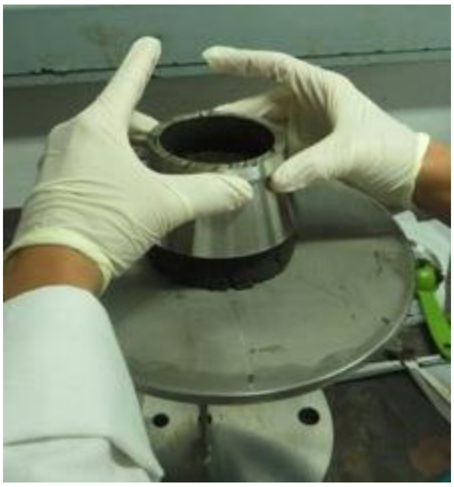


FIGURE B.5. MOULD BEING REMOVED CAREFULLY LEAVING THE SLUDGE BEHIND

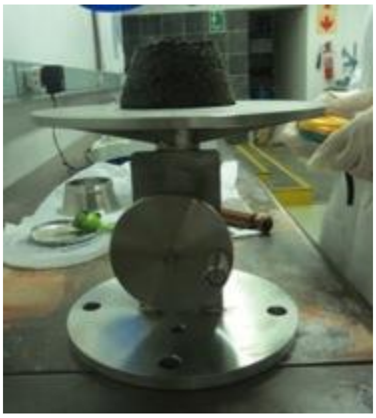


FIGURE B.6. SLUDGE REMAINING ON TABLE AFTER MOULD IS REMOVED

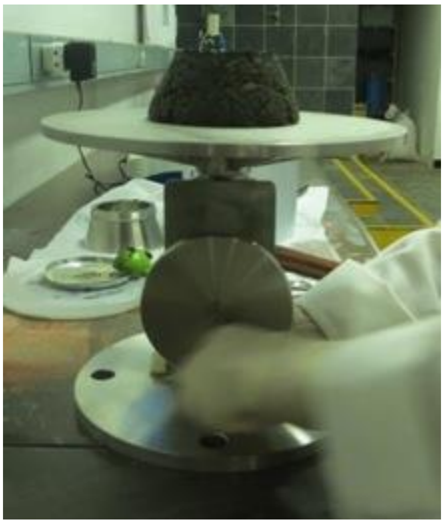


FIGURE B.7. DROPS BEING APPLIED TO THE SLUDGE ON THE TABLE BY TURNING THE HANDLE AND SLUDGE MOVING OUTWARDS

FIGURE B.8. SLUDGE AFTER DROPS HAVE BEEN APPLIED, THIS IS A DRY SAMPLE AND HAS NOT CHANGED MUCH FROM ITS' ORIGINAL POSITION

APPENDIX C:CONE PENETROMETER

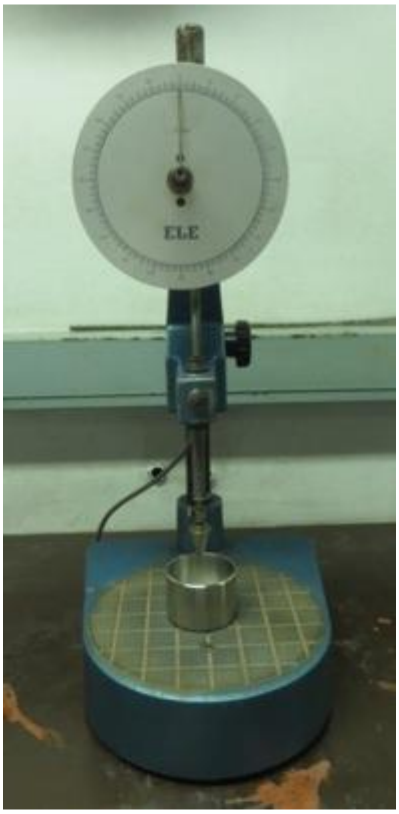


Figure C.1. Cone penetrometer apparatus consisting of a reading dial, drop cone and cup that gets filled with the sample being tested

Figure C.2. Sample cup being filled up, pressing sludge to the sides to ensure not air pockets are created

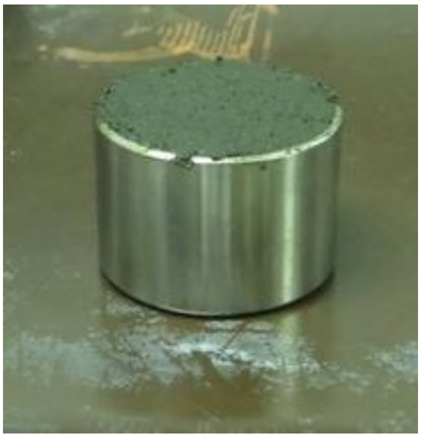


FIGURE C.3. SAMPLE CUP FILLED WITH SLUDGE AND LEVELLED OFF

FIGURE C.4. PREPARING APPARATUS TO PERFORM THE TEST. THE CONE MUST JUST SCRATCH THE SURFACE OF THE SLUDGE IN THE CUP

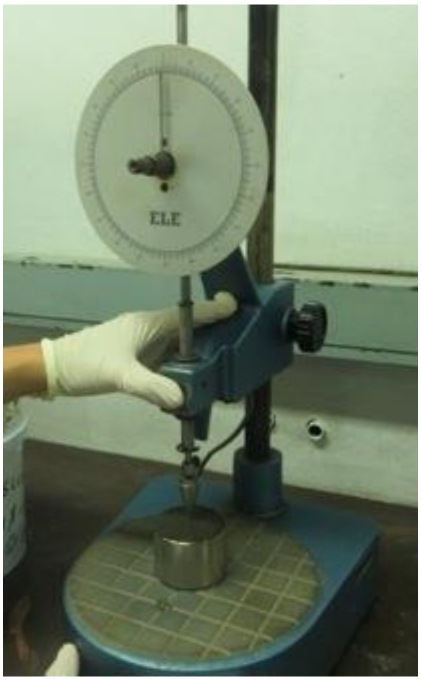


FIGURE C.5. THE BUTTON IS PRESSED FOR 5 SECONDS TO RELEASE THE CONE INTO THE SLUDGE

FIGURE C.6. THE DIAL IS TURNED UNTIL THE ROD MEETS THE BAR CONNECTED TO THE CONE AND THE READING TAKEN IS THE PENETRATION

FIGURE C.7. THE SECTION OF SLUDGE THAT THE CONE PENETRATED IS REMOVED FROM THE CUP TO BE TESTED FOR MOISTURE CONTENT.

APPENDIX D: RHEOMETER

FIGURE D.1. SLUDGE SAMPLE PLACED WITHIN THE CYLINDER WHICH ATTACHES TO THE RHEOMETER MACHINE

FIGURE D.2. THE CYLINDER CONTAINING THE SAMPLE IS SCREWED INTO PLACE ON THE RHEOMETER

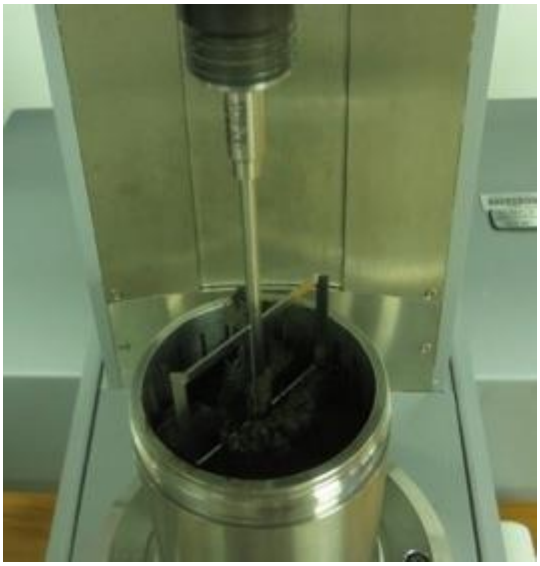


FIGURE D.3. THE VANE IS ATTACHED AND THE TEST IS STARTED VIA THE COMPUTER

FIGURE D.4. THE VANE IS MECHANICALLY LOWERED INTO THE SLUDGE AND THE TEST BEGINS, THE DATA BEING RECORDED AND STORED BY THE COMPUTER

APPENDIX E: CSTR

FIGURE E.1. CSTR SETUP, CONSISTING OF TWO TANKS HELD IN THE INSULTED GREY BOX, THE ORANGE WATER BATH AT 35°C ON THE LEFT AND THE INVERTED CYLINDERS ON THE RIGHT TO MEASURE THE GAS PRODUCTION

FIGURE E.2. THE INTERIOR OF THE TANK AND THE STIRRER

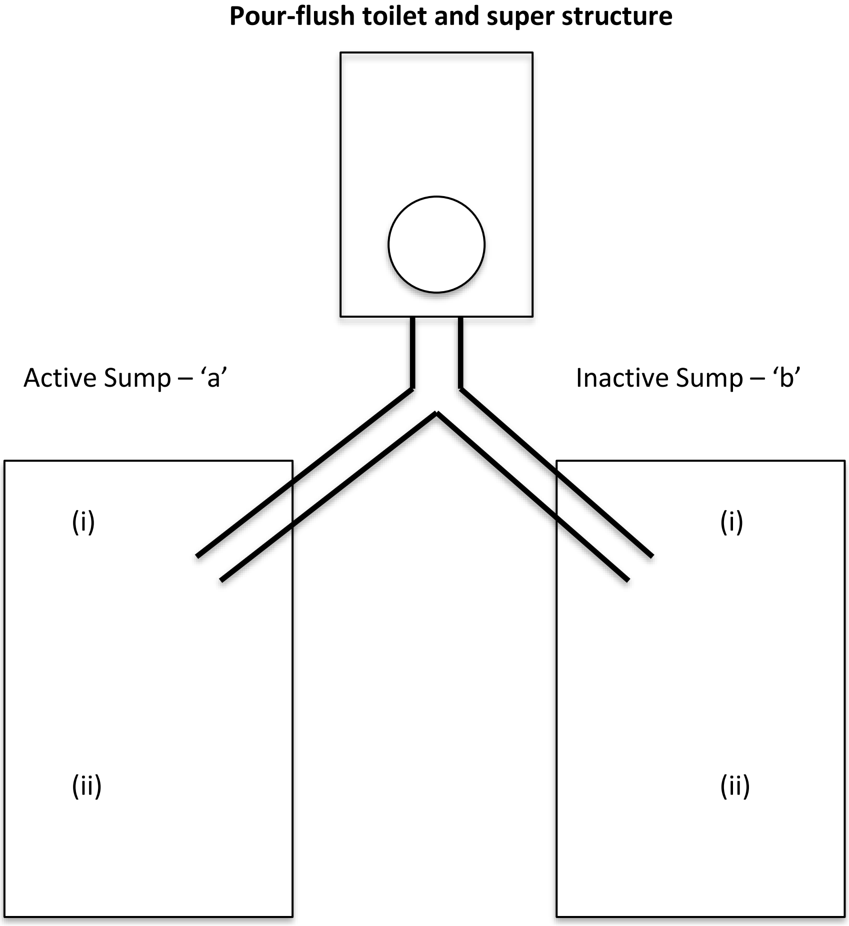
Figure E.3. The stirrer and lid, which is screwed onto the tank, on top of which is the motor to power the stirrer and the outlet pipe that directs the gas into the cylinders

Figure E.4. View of the lid of the tanks and the motors that power the stirrers

APPENDIX F: SAMPLE ID

The schematic below will assist in understanding the sample ID.

Sample ID example:
If a sample is taken from the front of an active pit at site 1 on the first sampling campaign, the sample ID is 1.1 a(i).
If the sample was taken from the back of the standing pit from the same site on the 2nd sampling campaign, the sample ID is 1.2 b(ii).
If the site has only one pit present the 'a'/'b' will be replaced with 's'.
There are four sites labelled 1, 2, 3 and 4.



APPENDIX G: HOUSEHOLD SURVEY RESULTS

Date: 19/E3/14		Households			
Question		Site 1	Site 2	Site 3	Site 4
How many household members use the Pour-Flush toilet on a regular basis?	Adults	5	3	1	6
	Children	2	3	1	2
	Total	7	6	2	8
How many times a day is the toilet used?	Defecation	1 each = 7	4	2	
	Urination	3x7 =21	4xchild; 2xadult = 18	7	
	Both	28	22	9	4
Are people flushing after urination or just defecation?		both	both	both	only flush after defecation
What type of anal cleansing material is used?	Toilet Paper	yes	yes	yes	yes
	Newspaper	sometimes	yes	no	no
	Other				
How much water is used for a successful flush?		2 litre	2 litre	litre	2.5 litre
What is used for flushwater?	Freshwater	yes	yes	yes	yes
	Recycled greywater	no	yes	no	no
	Rainwater	no	yes	no	no
	Other				
Is any additional material flushed down the toilet?	Additional greywater	no	no	no	no
	Household waste	no	no	no	no
	General rubbish	no	no	no	no
	Sanitary items or nappies	no	no	no	

Date: 19/03/14		**Households**			
Question		**Site 1**	**Site 2**	**Site 3**	**Site 4**
How often is the toilet cleaned?		3 times a week	Once a week	3 times a week	once a week
What is usually done with the waste materials and wastewater from cleaning the toilet – is it disposed of in the pit?		down the toilet	down the toilet	just flush after brushing	no
What products are used to clean the toilet?		Domestos, soap, water	Water & soap; sometimes Jeyes fluid	Handy Andy	water
Is the toilet used for personal washing or showering?		no	no	yes	no
Are any difficulties encountered with using the system?	Blockages	no	no	no	no
	Leaks	no	no	no	no
	Overflowing	no	no	no	no
If difficulties are encountered, how frequently?			none		no problems
Is the user satisfied with the Pour-Flush toilet in comparison with ventilated improved pit latrines that have been used previously?		yes!	yes!!	yes, happy with it.	yes

APPENDIX H: SAMPLING EQUIPMENT

	Preliminary Assessment	Campaign 1	Campaign 2	Campaign 3	Campaign 4
Date of Sampling	06/03/2013	22/05/2013	02/07/2013	18/11/2013	19/03/2014
Time Elapsed from first campaign (months)	0	0	1.4	4.6	4.0
Season	Autumn	Winter	Winter	Summer	Autumn
Rainfall (mm)	127	30	18	111	127
Sampling Equipment	Regular shovel & long PVC tube, a person's hand was needed to create a vacuum to hold the sludge in the tube once lifted out of the pit	Long PVC tube with a rubber bung to draw up the sludge – intended for wet sludge. A 2.5L sample bucket on a rope was made on site when to get the wetter sludge because the tube sampler didn't work	Short PVC tube on a long pole with a rubber bung intended for wet sludge. Metal bucket attached with wire to a long pole handle. Detachable handles made it easier to tip the sludge from the bucket into the sampling container.	PVC tube same as before. Metal bucket was altered- the base was made moveable. A handle was added to the back of the metal bucket.	PVC tube same as before. Detachable handles for the metal bucket were twisted to make it easier to flip the bucket over. Hook added at the bottom of the pole.
Sample Storage	Large plastic bucket with lid and black bin liner	2.5 ℓ white bucket with lid, lined with large clear plastic lunch bag	2.5 ℓwhite bucket with lid, lined with large clear plastic lunch bag	2.5 ℓwhite bucket with lid, lined with large clear plastic lunch bag	2.5 ℓwhite bucket with lid, lined with large clear plastic lunch bag
Depth measurement	Tape measure	Tape measure	Laser measure	Tape measure	Laser measure
Pits sampled	Site 1	Site 1; Site 2; Site 5; Site 6	Site 1; Site 2; Site 3; Site 4	Site 1; Site 2; Site 3; Site 4	Site 1; Site 2; Site 3; Site 4
Problems encountered	Shovel was too short to reach sludge. It was difficult to place a	Site 5 and 6 were flooded. The long tube didn't work on the wet	Sampling tube didn't draw up wet sludge as expected. However, it	The movable base of the bucket pushed the sludge out	Campaign delayed 2 weeks due to weather.

	hand on the top of the tube and lift it to retrieve a sample. It was difficult to clean the inside of the sampling tube.	sludge – it slide out of the tube as soon as it was lifted. However, it was useful to take samples of drier sludge	was useful to take a core sample of dry sludge and bung pushed out the sludge from the tube. It was difficult to empty the sludge from the metal bucket into the sampling bucket	under its self-weight when tipped to empty the sample into the sampling bucket.	The hook at the bottom of the pole used with the handle on the back of the bucket allowed it's positioning within the pit to be better controlled.

FIGURE H.1. ORIGINAL SAMPLING TUBE WHICH WAS UNSUCCESSFUL

FIGURE H.2. ALTERNATE VIEW OF ORIGINAL SAMPLING TUBE

FIGURE H.3. SAMPLING TUBE DEVELOPED TO TAKE CORE SAMPLE OF DRIER SLUDGE

FIGURE H.4. SAME SAMPLING TUBE AS BEFORE, WITH LONG HANDLE IN VIEW. THE HANDLE CONSISTS OF SEVERAL SMALLER PIECES FITTED TOGETHER TO ALLOW THE LENGTH TO BE ADJUSTED AS NEEDED

FIGURE H.5. SAMPLING TUBE IN USE

FIGURE H.6. SLUDGE RETRIEVED WITH THE SAMPLING TUBE SHOW ABOVE

FIGURE H.7. SLUDGE BEING PUSHED OUT OF SAMPLER INTO THE STORAGE CONTAINER USING THE INTERNAL BUNG

FIGURE H.8. BUCKET SAMPLER IN PIT TO RETRIEVE A SAMPLE. AGAIN, THE LONG HANDLE COMPRISES OF SEVERAL SHORTER PIECES THAT ARE FIT TOGETHER TO THE DESIRED LENGTH

FIGURE H.9. ATTACHABLE HANDLES USED TO EASILY TIP BUCKET TO EMPTY CONTENTS INTO THE STORAGE CONTAINER. A SLIT IS PLACED AT THE END OF ATTACHABLE HANDLE SO IT CAN BE USED TO GRIP THE RIM OF THE BUCKET AS WELL

FIGURE H.10. THE BASE OF THE BUCKET CAN MOVE, A WEIGHT WAS ADDED TO EXTERIOR OF BASE TO HELP PUSH THE SLUDGE OUT OF THE BUCKET INTO THE SAMPLING CONTAINER

FIGURE H.11. CLEANING THE EQUIPMENT USING PRESSURISED WATER

APPENDIX I: CAPACITY BUILDING

The table below presents a list of under-graduate and post-graduate students involved in this research (Volume 1: K5/2137).

Type	Name	Gender	Nationality	Race	Actual degree
M.Eng student	A. Bryne	Female	Irish	White	B.Eng
Post-doctorate	K. Velushanova	Female	Bulgarian	White	PhD
Post-doctorate	S. Septien	Male	Mexican	Latin	PhD
Lecturer	A. Singh	Female	South African	Indian	M.Eng