CHAPTER 5
DETAILED INVESTIGATION INTO VAULT PROCESSES

ABSTRACT

It is hypothesised that the most advantageous approach to pathogen destruction in a urine-diversion (UD) toilet vault is to maximise the effects of various environmental factors, e.g. pH, temperature, low moisture, type of bulking agent and storage time. In order to quantify these effects a field experiment was set up consisting of 12 UD toilet vaults, each with a different combination of faeces and bulking agent (soil, ash, wood shavings, NaOH or straw), ventilation (ventpipe / no ventpipe) and vault lid material (concrete, metal or perspex). Temperature probes, which were connected to a data logger, were inserted in the heaps and the logger monitored over a period of nearly 10 months. This enabled a number of graphs to be drawn illustrating the effect of the above parameters on heap temperature over the experimental period. In addition, samples were taken at various intervals from each vault as well as from the main heap of faecal material that was left exposed to the elements. The samples were subjected to microbiological testing in order to quantify the pathogen die-off over time for each vault as well as for the main heap.

The conclusions drawn from the experimentation were the following:

- *Influence of ventpipe*
  Ventilation of the vault did not result in any meaningful difference in either the vault temperature or rate of pathogen die-off.

- *Influence of vault lid material*
  The lid material, and by inference also the material of the vault walls, has no significant effect on the temperature of the heap or the associated pathogen die-off.

- *Type of bulking agent*
  While the type of bulking agent used does not significantly influence the temperature of the faecal material, it does have an effect on the rate of pathogen die-off. The ordinary soil mix was seen to give the best results, and this was ascribed to the effect of competing microorganisms in the soil itself.

- *Influence of sunshine and rain*
  The main heap of material (faeces/soil mix) that was exposed to the elements performed among the best in terms of pathogen die-off. Apart from the influence of competing microorganisms in the soil on the pathogens as described above, this good performance was also ascribed to the effect of UV radiation as well as alternating wetting/drying and heating/cooling cycles, which suggests that open-air exposure is likely to provide the best treatment.

Comparing the results of this research with other local and international research, it appears that there is a great deal of convergence in the results. It is concluded that vaults of UD toilets should be sized for a storage period of 12 months from last use.

5.1 BACKGROUND AND HYPOTHESIS

In chapter 2 the following factors or environmental conditions were identified as playing the most important roles in the process of pathogen destruction within the faecal pile in urine-diversion (UD) toilets:

- Storage time
- pH
- temperature
- humidity
- moisture content
- organic content
- type of bulking agent

Moe et al (2001) suggested that no single factor can predict microbial indicator concentration and that microbial quality is a function of multiple factors. It is hypothesised, therefore, that the most advantageous approach to pathogen destruction in a UD toilet vault would be to maximise the effects of pH, temperature and low moisture content, while storing the material in the vault for an optimum time. There are various ways of raising the pH, while increased temperature and dehydration could possibly be facilitated by good aeration (ventilation) of the vault and suitable building materials, particularly in hot climates. If these factors could be combined in such a way that their individual effects are maximised, then it should be possible to reduce the vault storage time required to achieve a level of pathogen destruction commensurate with safety for handling. This in turn will decrease the size of toilet vault required and hence the construction cost.

5.2 OBJECTIVES OF STUDY

In an attempt to test the validity of the above hypothesis, it was decided to conduct field tests on toilet vaults operating under various conditions of ventilation, pH, bulking agent, etc. As it would not be possible to obtain controlled conditions in toilets that were actually in use, the approach was taken to rather build new toilet vaults and insert faecal material extracted from working toilets into them. eThekwini Water Services (EWS) was requested to assist by constructing vaults similar to those built in various villages in the municipal area (Figure 5.1). An agreement was concluded to build the required number of vaults in the grounds of the Northern Wastewater Treatment Works (NWWTW) where a measure of security was available for the equipment that would be installed. Only the toilet vaults would be constructed and not the toilet superstructures, as it was not the intention that these would be “live” (i.e. working) toilets.

Bearing in mind the various factors affecting pathogen destruction in UD toilet vaults, as already discussed, it was considered necessary to carry out tests allowing for the following variables:

- Aeration (i.e. ventpipe) or no aeration. A high ambient temperature could be transferred to the inside of the vault by movement of warm air. Dehydration of the material could also be facilitated.
- Type of bulking agent. Various agents, such as NaOH and ash for example, will normally increase the pH, while others may assist heat transfer and aeration through the faecal contents by increasing the porosity of the pile, e.g. straw, leaves

or wood shavings. Adding biomass would in this case, however, probably not promote composting due to the generally dry conditions in the vault.

- Type of vault lid (i.e. absorbing or encouraging heat transfer to the vault or not). Conventional wisdom in this case is to use a black-painted metal lid, while materials such as PVC and perspex are also known to allow the passage of heat.

The experimental protocol is described in the following section.

5.3 METHODS AND MATERIALS

5.3.1 General

The experimental setup, as originally proposed, is shown in Figure 5.2. Six double vault base structures, i.e. twelve vaults in all, were constructed by EWS. The standard vault size used by EWS is 735mm wide x 1310mm long x 800mm deep (internal dimensions). An exploded view of the toilet is shown in Figure 5.3, which illustrates the shape of the vaults. Figure 5.4 shows the completed experimental layout.

Figure 5.1: Typical double vault UD toilets built in the eThekwini municipal area. Vaults similar to these, without the superstructures, were constructed for the experimental work at NWWTW
(Photographs: F. Stevens, eThekwini Water Services).

Block A: Test ventpipe	
Vault A1	**Vault A2**
Vault lid Concrete **Bulking agent** Soil **Ventpipe** Yes	**Vault lid** Concrete **Bulking agent** Soil **Ventpipe** No

Block B: Test metal lid	
Vault B1	**Vault B2**
Vault lid Metal **Bulking agent** Ash **Ventpipe** No	**Vault lid** Metal **Bulking agent** Wood shavings **Ventpipe** No

Block C: Test PVC lid	
Vault C1	**Vault C2**
Vault lid PVC **Bulking agent** Ash **Ventpipe** No	**Vault lid** PVC **Bulking agent** Wood shavings **Ventpipe** No

Block D: Test concrete lid	
Vault D1	**Vault D2**
Vault lid Concrete **Bulking agent** Ash **Ventpipe** No	**Vault lid** Concrete **Bulking agent** Wood shavings **Ventpipe** No

Block E: Test NaOH	
Vault E1	**Vault E2**
Vault lid Concrete **Bulking agent** NaOH **Ventpipe** Yes	**Vault lid** Concrete **Bulking agent** NaOH **Ventpipe** No

Block F: Test porous agent	
Vault F1	**Vault F2**
Vault lid Concrete **Bulking agent** Grass, leaves, etc **Ventpipe** Yes	**Vault lid** Concrete **Bulking agent** Grass, leaves, etc **Ventpipe** No

Figure 5.2: The vault layout as originally proposed. Some parameters were revised for the final layout (see Figure 5.8).

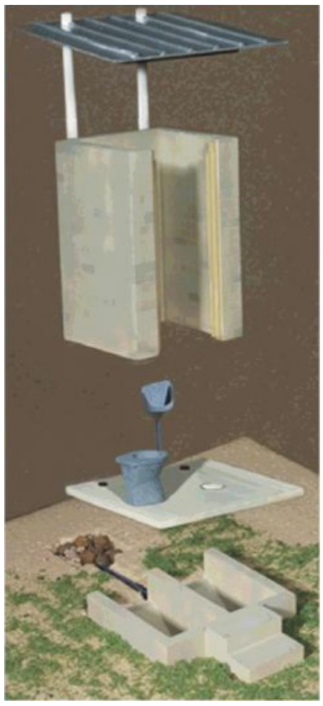


Figure 5.3: Exploded view of the eThekwini urine-diversion toilet
(Photograph: eThekwini Water Services)

Figure 5.4: Completed vault layout

Vent pipes, where installed, were fitted with umbrella-type caps in an attempt to prevent rainwater from entering the vaults. In order to ensure proper ventilation, a small brick structure with a lid was added over the pedestal hole in the slab to simulate a toilet lid with air gap. See Figure 5.5.

Figure 5.5: Ventilation of vault

Once the vault construction process was complete, the faecal material was inserted. The material was obtained by EWS, who extracted it from working UD toilets in various villages in the municipal area. This was then brought to the site in bags. Due to the difficulty of working with fresh faeces these were discarded, leaving material generally between one and three months old. As there was a limit on the amount of material available, it was not possible to insert more than a certain amount into the vaults. However, this was not considered to be a problem, as the amount of material inserted was roughly equivalent to what would be found in many types of UD toilets in the country (eThekwini's toilet vaults are actually very large when compared with others).

The bags were emptied onto a concrete slab and the material thoroughly mixed (Figure 5.6). The various additives (bulking agents) were obtained as follows:

- NaOH was purchased at a local pharmaceutical supply store;
- coal ash was obtained from a nearby industrial laundry that used coal for the boilers;
- wood shavings were obtained at a nearby lumber yard; and
- grass cuttings were fetched from a work team engaged in roadside maintenance.

All faecal material was already mixed with some soil instead of ash. The latter was not generally available because householders had access to electrical energy so did not often use fires.

The various bulking agents were mixed with the faecal material in the proportions indicated in Figure 5.8 before being inserted into the vaults. The mix proportions were such that the eventual heap sizes were more or less the same in each vault. The remainder of the original heap was left exposed to the weather on the concrete slab as a control (Figure 5.7).

It could be argued that this setup did not represent toilets in actual use, as in a “live” toilet the bulking agent is added after each defecation. However, as fresh faeces can contaminate the older pile beneath, recommendations on storage times are usually based on time from the last addition to the pile. As it was the intention to derive recommendations for bulking agents and minimum storage times, and because of the necessity for bringing each vault to a common “starting point” for experimental reasons, it was felt that this method would result in acceptable indications of the relative efficacy of each type of bulking agent.

Figure 5.6: Mixing and weighing the faecal material prior to addition of bulking agents

Figure 5.7: Remainder of original heap of faecal material used as a control

Block A: Test ventpipe	
Vault A1	**Vault A2**
Vault lid Concrete **Bulking agent** Soil **Ventpipe** Yes **80kg loaded**	**Vault lid** Concrete **Bulking agent** Soil **Ventpipe** No **80kg loaded**

Block B: Test metal lid	
Vault B1	**Vault B2**
Vault lid Metal **Bulking agent** Soil + ash **Ventpipe** No **80kg loaded** **40 faeces / 40 ash**	**Vault lid** Metal **Bulking agent** Soil + wood shavings **Ventpipe** No **64kg loaded** **40 faeces / 24 wood**

Block C: Test perspex lid	
Vault C1	**Vault C2**
Vault lid Perspex **Bulking agent** Soil + ash **Ventpipe** No **80kg loaded** **40 faeces / 40 ash**	**Vault lid** Perspex **Bulking agent** Soil + wood shavings **Ventpipe** No **64kg loaded** **40 faeces / 24 wood**

Block D: Test concrete lid	
Vault D1	**Vault D2**
Vault lid Concrete **Bulking agent** Soil + ash **Ventpipe** No **80kg loaded** **40 faeces / 40 ash**	**Vault lid** Concrete **Bulking agent** Soil + wood shavings **Ventpipe** No **64kg loaded** **40 faeces / 24 wood**

Block E: Test NaOH	
Vault E1	**Vault E2**
Vault lid Concrete **Bulking agent** Soil + NaOH **Ventpipe** Yes **55kg loaded** **40 faeces / 15 NaOH**	**Vault lid** Concrete **Bulking agent** Soil + NaOH **Ventpipe** No **55kg loaded** **40 faeces / 15 NaOH**

Block F: Test porous agent	
Vault F1	**Vault F2**
Vault lid Concrete **Bulking agent** Soil + dry grass (straw) **Ventpipe** Yes **60 kg loaded** **55 faeces / 5 grass**	**Vault lid** Concrete **Bulking agent** Soil + dry grass (straw) **Ventpipe** No **60kg loaded** **55 faeces / 5 grass**

Figure 5.8: Details of actual vault setup on 3 June 2004

The temperature probes were subsequently installed. These consisted of 450mm long stainless steel tubes containing sensors with 25mm long copper points connected by cables to a data logger. The voltage output was linearly proportional to the Centigrade temperature, thus enabling direct temperature measurements to take place. They were calibrated before connection. The logger took a temperature reading every three hours on a continuous basis. A car battery was used as a power source and the equipment designed in such a way that a notebook computer could be connected to the logger and the data downloaded to an Excel spreadsheet at intervals of up to six weeks.

The process of installing the probes is illustrated in Figure 5.9 below. The photograph on the left depicts the cables being pulled through the protective conduits. The top right photograph shows the probes being calibrated against a standard probe in a bucket of water, while the bottom right photograph illustrates the lockable box with battery and logger.

With the exception of vaults A1 and A2, one probe was inserted in each heap, to a depth of approximately 200mm. In order to obtain a temperature profile in the heaps, three probes were installed in each of the heaps of vaults A1 and A2 at depths of 100mm, 200mm and 300mm respectively. A final probe measured outside ambient temperature.

Figure 5.9: Calibrating and installing the temperature probes and data logger

Temperature and microbiological monitoring was carried out over a period of almost 10 months, after which time trends had become clear and there was no point in continuing the process. There were intermittent problems with the logging equipment that resulted in

short periods with no temperature data, but this did not detract from the overall value of the data as there was sufficient information available for analysis purposes.

A problem was also experienced in keeping the vaults dry. It was found that, due to some heavy rainstorms that were accompanied by strong winds, rainwater was often driven under the ventpipe umbrella and down the pipe, causing wetting of the material underneath. This caused the moisture content of the material to fluctuate and also prevented some of the heaps from drying out beyond their initial moisture content. A further problem was experienced in block E where both vaults were flooded at one stage, with the heaps (faeces + NaOH) being completely waterlogged for a long period. This negatively influenced the effect of the high pH of the NaOH, as will be seen from the microbiological results. It had the advantage, however, of illustrating the necessity for keeping the vaults dry in practice.

Sampling for microbiological testing was carried out at the following intervals, where t represents the time in days from when the vaults were loaded: t=0; t=44; t=97; t=174; and t=278.

5.3.2 Sampling

Sampling was done using a specially fabricated cylindrical coring device (Figure 5.10). The device was inserted into the heap while being simultaneously rotated, thus cutting a core of material 35mm wide and approximately 200mm long. The core was then expressed into a sterilised sample bottle (Figure 5.11). The equipment was cleaned with 70% ethanol before the following sample was cored.

Figure 5.10: Coring device and sample bottles

Figure 5.11: Expressing the cored material into the sample bottle

5.3.3 Microbiological parameters

Indicator organisms
It is impossible to test for all the possible organisms that could present a health risk, therefore indicator organisms are used to give a general indication of water quality. The "coliform group" of organisms has been found to be the most useful. This group comprises organisms such as *Escherichia coli*, *Klebsiella pneumoniae* and *Enterobacter aerogenes*. *Escherichia coli* is commonly found in the human intestine and most strains are normally not pathogenic. The "coliform group" is defined as all aerobic and facultative anaerobic gram-negative, non-sporeforming, rod-shaped bacteria that ferment lactose with the formation of gas within 48h at 35°C. The presence of these bacteria indicates that pollution has occurred that can be associated with faecal contamination from man or other warm-blooded animals.

Total coliform bacteria
As applied to the membrane filter technique, this term refers to a group of gram-negative, non-sporeforming bacteria that develop a dark red colony with a green metallic sheen within 24h at 35 ± 1°C on an Endo-type medium containing lactose.

Faecal coliform bacteria
This refers to the thermo-tolerant forms of the total coliform group that ferment lactose at 44,5 ± 0,5°C in 18 to 24h. Within the group, *E. coli* and *Klebsiella* species are the organisms of interest since, when present, they indicate that recent faecal contamination has occurred with the possibility of accompanying enteric pathogens. For the purpose of this test, faecal coliforms are defined as bacteria that produce various shades of blue colonies on m-FC medium within 24h when incubated at 44,5°C. Non-faecal coliform colonies are grey to cream-coloured.

Escherichia coli
E. coli are a member of the faecal coliform group of bacteria that yield a positive indole reaction at 44,5°C. Bacteria that conform to this definition generally consist exclusively of *E. coli* of almost definite faecal origin. They are more specific than faecal coliforms. This method is applicable to the confirmation of faecal coliform bacteria isolated on m-Fc media.

Faecal streptococci bacteria
These indicate faecal pollution and refer to those streptococci commonly found in human and animal faeces. They are used as a supplementary bacterial indicator. For the purpose of this test, faecal streptococci are defined as those bacteria that produce deep red or maroon colonies on m-Enterococcus agar after incubation at 35°C.

Coliphage
A coliphage is a virus hosting on the coliform bacteria. They have similar survival patterns as enteric viruses. Although they do not provide an absolute indication of the presence of enteric viruses in all conditions, they may provide an acceptable indication of the presence of viruses in general. They are present whenever total and faecal coliforms are found in high numbers. The presence of coliphages is demonstrated by the ability of the virus to infect its host and cause lysis of the bacterial cells. The lysis is evident by appearance of plaques (clear zones) on the agar plates with host cells (*E. coli*) background or lawn.

Faecal clostridia
Clostridium species are Gram-positive, rod-shaped spore-formers and are part of our normal flora. The spores are found in human and animal faecal matter and the presence of *Clostridium perfringens* is taken as conclusive proof of faecal contamination. For the purpose of this test, faecal *clostridia* are defined as sulphite reducing anaerobic bacteria that produce typical black colonies when incubated on tryptose-sulphite-cycloserine agar under anaerobic conditions for 24h at 45°C.

Heterotrophic plate count
This test quantifies viable aerobic bacteria. These bacteria do not represent the total number of microorganisms in the sample but only those that are able to form visible colonies in nutrient media under specific culture conditions. The test for the heterotrophic plate count is used together with total and faecal coliforms as an indication of sanitary quality.

Salmonella
These are rod-shaped, motile (except *S. gallinarum* and *S. Pullorum*) non-sporeforming, Gram-negative bacteria. The test method, described in section 5.3.5 below, is applicable to the examination of all kinds of water, soil, sewage and sludge samples for the presence or absence of *Salmonella* species.

Parasites
Giardia, *Cryptosporidium* and *Entamoeba* are protozoan parasites. *Taenia* (known as tapeworms) are cestodes (ribbon-like intestinal worms), while *Ascaris* are intestinal nematodes (roundworms).

5.3.4 Sample preparation

For the bacterial determinations, 20g of sample material were weighed off in duplicate. One was used for analysis and the other to determine moisture content. The bacteria

were extracted from the samples by adding sterile saline, the samples were sonicated for 10 minutes and then left overnight. Extracts (supernatant) were analysed the following day using the standard procedures described below.

For the *Ascaris, Entamoeba* and *Taenia* enumerations, as well as for Cryptosporidium oocysts and Giardia cysts, the sample was prepared according to the method of Franck (1988). This involved diluting the samples with physiological salt solution until they were just liquid enough to be ground in a homogeniser, after the addition of a few drops of anionic washing agent. Thereafter 100g of the sample was used to determine the moisture content, while the remaining material was weighed off in 10g portions and 100ml of physiological salt solution added to prevent them from drying out.

5.3.5 Test methods

All sample preparation and testing were carried out in the microbiological laboratory of the CSIR in Pretoria, which is a SANAS accredited laboratory. Due to cost considerations only one sample from each heap was taken and analysed each time, thus making a statistical analysis inappropriate.

Heterotrophic plate count
The pour plate method was performed in a biological safety cabinet. The extracts were mixed with a non-selective nutrient-enriched agar medium. The agar plates were then incubated at 35°C for 48h after which all visible colonies were counted.

Total coliform bacteria
The extracts were filtered through a membrane filter upon which the bacteria were trapped. The filter was then placed on m-Endo growth medium and incubated at 35°C for 24h. The bacteria produced colonies with a golden-green metallic sheen.

Faecal coliform bacteria
The extracts were filtered through a membrane filter upon which the bacteria were trapped. The filter was then placed on m-FC growth medium and incubated at 44,5°C for 18 to 24h. The bacteria produced various shades of blue colonies.

Faecal streptococci bacteria
The extracts were filtered through a membrane filter upon which the bacteria were trapped. The filter was then placed on m-Enterococcus agar medium and incubated at 35°C for 48h. The bacteria produced deep red or maroon colonies.

Salmonella
The detection of *Salmonella* involved four successive stages:

- Concentration of the sample by membrane filtration;
- pre-enrichment of the sample into a non-selective medium to ensure that injured organisms were resuscitated;
- enrichment of the sample in a selective medium to eliminate the growth of interfering organisms; and
- selection by plating the sample on selective media followed by incubation at 35°C for 48h.

Faecal Clostridia
The extracts were filtered through a membrane filter upon which the bacteria were trapped. The filter was then placed on tryptose-sulphite-cycloserine agar and incubated at 45°C for 24h. The bacteria produced typical black colonies.

Coliphage
- Coliphage agar plates were inoculated with the *E. coli* WG4 bacterial host and extract, for somatic coliphage detection;
- the plates were incubated at 35 ± 1°C for 18h;
- the presence of coliphages was demonstrated by the ability of the virus to infect its host and cause lysis of the bacterial cells. The lysis was evident by appearance of plaques (clear zones) on the agar plates with host cells (*E. coli*) background or lawn; and
- the plaques were counted and expressed as plaque forming units per g.

For the coliform, streptococci and clostridia assays, 100ml, 10ml and 1ml solutions, as well as dilutions of 1ml, were filtered and a plate with between 20 and 60 colonies chosen for the count. The *salmonella*, coliphage and heterotrophic plate count samples were not filtered, however.

pH
10g of the extraction was mixed with 500ml sterile water, shaken and left overnight. A pH probe with meter was used for the measurement.

Moisture content (MC)
10g of the sample was dried in an oven at 50°C for one week and weighed again.

$$MC = \frac{(\text{weight of moist sample} - \text{weight of dry sample}) \times 100}{\text{Weight of moist sample}}$$

Ascaris Lumbricoides, Entamoeba and Taenia
Enumeration of eggs, and the viability thereof, was carried out according to the method of Franck (1988) using a modified Visser filter. The sample was poured into the Visser filter and washed through with a strong jet of water. The remaining material was collected in a tube and centrifuged for 2 minutes at 1 680G, whereafter the supernatant was extracted. The tube was then filled with 40% zinc sulphate solution while being thoroughly mixed and centrifuged for 1,5 minutes at 420G, whereupon the supernatant was poured through a membrane filter. The sides of the filter container were washed with a strong jet of water and the process repeated until the zinc sulphate was removed and the eggs evenly distributed. The membrane filter was then put into an incubator for 30 minutes, after which the eggs were enumerated under a microscope.

Giardia and Cryptosporidium

Determination of the cysts and oocysts, and the viability thereof, was carried out in the same manner as for the helminths, except that there was a further step in the process. Because the organisms are much smaller, they were washed through all three of the filters in the Visser apparatus but were trapped on an additional filter of 1,2 micron, whereafter they were enumerated under a microscope.

5.4 EXPERIMENTAL RESULTS

The experimental results are grouped under three headings, namely, initial material characteristics, temperature results and microbiological results. The results are given according to the various vaults where they occurred. Temperature and microbiological results are also shown graphically in order to illustrate trends or occurrences.

The temperature and microbiological results are discussed separately at first and then seen together.

5.4.1 Initial material characteristics

The initial analysis of the vault contents is shown in Table 5.1. It should be noted that vaults A1 and A2 are the same material (faeces mixed with soil) as the main heap and the latter is thus not shown separately.

Heterotrophic plate counts varied between 3,9 x 10^7 and 3,0 x 10^8 cfu/g of material. Total coliform bacteria ranged from 1,5 x 10^4 to 3,3 x 10^6 cfu/g, and faecal coliform bacteria from 1,5 x 10^4 to 9,1 x 10^5 cfu/g. Faecal streptococci varied between 2,5 x 10^4 and 3,0 x 10^5 cfu/g. *Salmonellae* were detected in every vault. Coliphage counts ranged from 1,7 x 10^3 to 1,3 x 10^4 pfu/g and clostridium from 3,0 x 10^2 to 8,8 x 10^3 cfu/g. *Cryptosporidium* was present in five vaults, numbering between 0,9 and 2,4 per 10g, while *Giardia* was found in only two of the vaults, varying from 12 to 32 per 10g respectively. *Ascaris* was found in every vault, ranging from 201 to 305 per 10g respectively.

pH measurements of the heap samples varied between 6,37 and 10,09 while moisture content was between 8,6 and 59,6. The latter measurement, in vaults F1 and F2 (faeces + grass), was due to the grass being very wet from rain.

The pH of the coal ash was found to be only 6,20, which also affected the faeces/ash mixture (pH 6,90). This was contrary to expectations, as it was (wrongly) assumed that the value would be in the region of 10, as for wood ash. After consideration it was decided to leave the material in the vaults, as there was insufficient left in the original heap to mix with another source of ash, and using other faecal material would mean that the initial characteristics would be different. As the pH of the mixture was almost neutral and the ash was extremely coarse, it was considered useful to be used as a further example of a porous (aerated) mixture.

Table 5.1: Initial analysis of vault contents at start of experiment (t=0)

Organisms	Vault A1 (faeces + soil)	Vault A2 (faeces + soil)	Ash only	NaOH only	Wood shavings only	Grass only	Vaults B1, C1, D1 (faeces + ash)	Vaults B2, C2, D2 (faeces + wood shavings)	Vaults E1, E2 (faeces + NaOH)	Vaults F1, F2 (faeces + grass)
Heterotrophic plate count cfu/g	$2,9 \times 10^8$	$3,0 \times 10^8$	-	-	-	-	$2,1 \times 10^8$	$6,1 \times 10^7$	$3,9 \times 10^7$	$2,1 \times 10^8$
Total coliform bacteria cfu/g	$1,7 \times 10^6$	$3,3 \times 10^6$	-	-	-	-	$8,0 \times 10^4$	$6,6 \times 10^4$	$1,5 \times 10^4$	$2,8 \times 10^5$
Faecal coliform bacteria cfu/g	$9,1 \times 10^5$	$2,0 \times 10^5$	-	-	-	-	$2,5 \times 10^4$	$3,1 \times 10^4$	$1,5 \times 10^4$	$5,4 \times 10^4$
Faecal strepto-cocci bacteria cfu/g	$3,0 \times 10^5$	$2,9 \times 10^5$	-	-	-	-	$3,7 \times 10^4$	$6,0 \times 10^4$	$2,5 \times 10^4$	$1,8 \times 10^5$
Salmonella spp /g	Present	Present	-	-	-	-	Present	Present	Present	Present
Coliphage count pfu/g	$1,3 \times 10^4$	$1,7 \times 10^3$	-	-	-	-	$6,6 \times 10^3$	$4,9 \times 10^3$	$5,2 \times 10^3$	$2,0 \times 10^3$
Clostridium count cfu/g	$8,0 \times 10^3$	$6,0 \times 10^2$	-	-	-	-	$2,6 \times 10^3$	$1,1 \times 10^3$	$3,0 \times 10^2$	$8,8 \times 10^3$
pH	7,06	7,18	6,20	9,92	6,14	6,37	6,90	6,37	10,09	6,80
Moisture %	12,5	16,4	0,6	-	24,6	76,4	12,8	12,9	8,6	59,6
Cryptosporidium oocysts /10g	0,9	2,4					2,2	ND	ND	ND
Giardia cysts /10g	12	32					ND	ND	ND	ND
Ascaris eggs /10g *	201	237					218	305	272	237

Notes:
ND = not detected.
* Represents total no of eggs, i.e. viable plus non-viable.
cfu = colony forming units.
pfu = plaque forming units.

5.4.2 Temperature results

An example of some results from the data logger for a typical period is illustrated in Appendix A. The format of the information as an Excel spreadsheet made it possible to analyse any of the variables, or a combination thereof, for any selected period of time.

A number of graphs illustrating typical temperature trends in the vaults are now shown. The graphs represent the following:

- Heap, vault and ambient temperatures for the coldest week in July 2004 (winter) for all vaults (Figures 5.12 to 5.17);
- top, middle and bottom heap temperatures for the warmest week in January 2005 (summer) for vaults A1 and A2 (Figure 5.18);
- influence of ventpipe on heap temperatures in July 2004 (winter) and January 2005 (summer) for vaults A1 and A2 (Figure 5.19);
- influence of vault lid material on heap temperatures in July 2004 (winter) and January 2005 (summer) for vaults B2, C2 and D2 (Figure 5.20); and
- influence of various bulking agents on heap temperatures in July 2004 (winter) and January 2005 (summer) for vaults A2, D1, D2 and F2 (Figure 5.21).

Summary tables of the mean, minimum and maximum heap temperatures for the coldest week in July 2004 (winter) and the warmest week in January 2005 (summer) follow hereunder:

Table 5.2: Mean, minimum and maximum heap temperatures for the coldest week in July 2004 (winter)

Vault	Conditions	Mean temp °C	Min temp °C	Max temp °C
A1	Soil, concrete lid, ventpipe	17,2	16,1	18,6
A2	Soil, concrete lid, no ventpipe	17,5	16,4	19,0
B1	Ash, metal lid, no ventpipe	16,2	13,9	18,3
B2	Wood shavings, metal lid, no ventpipe	17,3	15,3	19,4
C1	Ash, perspex lid, no ventpipe	16,6	13,9	18,8
C2	Wood shavings, perspex lid, no ventpipe	17,5	15,4	19,6
D1	Ash, concrete lid, no ventpipe	15,9	13,3	18,2
D2	Wood shavings, concrete lid, no ventpipe	16,9	15,2	18,9
E1	NaOH, concrete lid, ventpipe	15,8	13,3	17,7
E2	NaOH, concrete lid no ventpipe	14,9	12,1	17,6
F1	Straw, concrete lid, ventpipe	17,2	15,0	19,0
F2	Straw, concrete lid, no ventpipe	18,4	17,4	19,9

Table 5.3: Mean, minimum and maximum heap temperatures for the warmest week in January 2005 (summer)

Vault	Conditions	Mean temp °C	Min temp °C	Max temp °C
A1	Soil, concrete lid, ventpipe	27,6	26,2	30,6
A2	Soil, concrete lid, no ventpipe	27,0	24,7	28,1
B1	Ash, metal lid, no ventpipe	27,6	25,6	29,2
B2	Wood shavings, metal lid, no ventpipe	28,7	26,7	30,1
C1	Ash, perspex lid, no ventpipe	27,5	25,4	29,0
C2	Wood shavings, perspex lid, no ventpipe	27,8	26,0	29,0
D1	Ash, concrete lid, no ventpipe	27,3	24,6	29,7
D2	Wood shavings, concrete lid, no ventpipe	28,2	26,3	29,6
E1	NaOH, concrete lid, ventpipe	27,7	25,5	29,4
E2	NaOH, concrete lid no ventpipe	ND	ND	ND
F1	Straw, concrete lid, ventpipe	ND	ND	ND
F2	Straw, concrete lid, no ventpipe	26,7	24,7	28,1

ND = no data

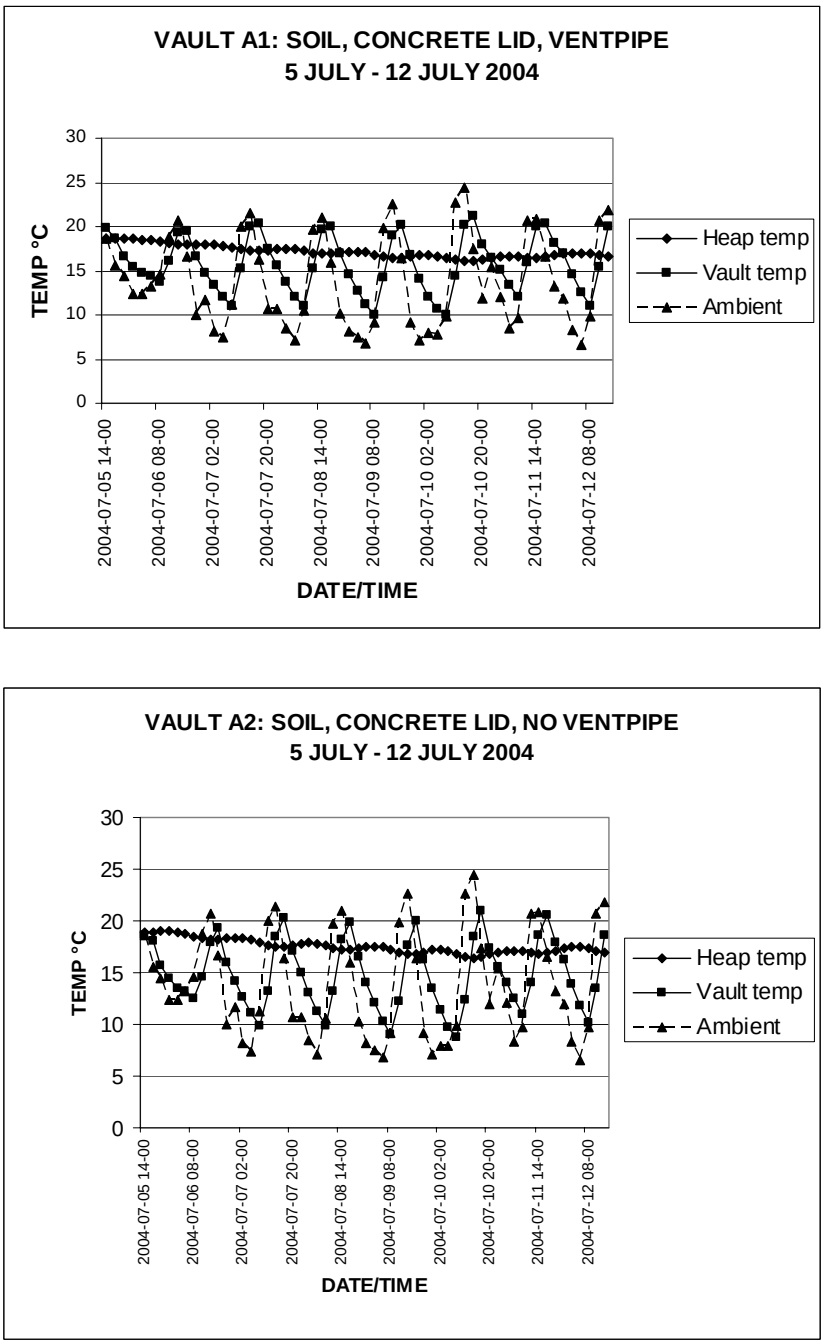
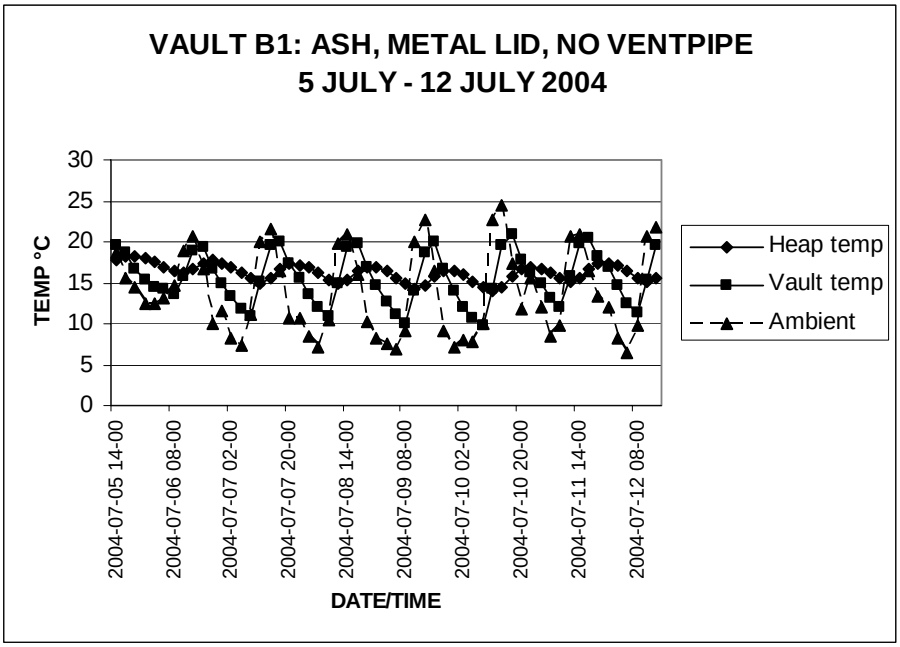


Figure 5.12: Heap, vault and ambient temperatures for the coldest week in July 2004 (winter) for vaults A1 and A2.

In vault A1 (soil, concrete lid, ventpipe) and vault A2 (soil, concrete lid, no ventpipe) the heap temperatures remain almost constant, fluctuating in a narrow band (about 1°C diurnally and 2°C over the full week) even while the outside temperature shows diurnal differences of up to 18°C. The overall heat gains in the heaps are therefore sustained. The vault temperatures, however, fluctuate more widely and follow the pattern of the outside temperature, differing generally less than 5°C from the latter.

It appears as if the presence or absence of a ventpipe has no discernable effect on the heap or vault temperatures.



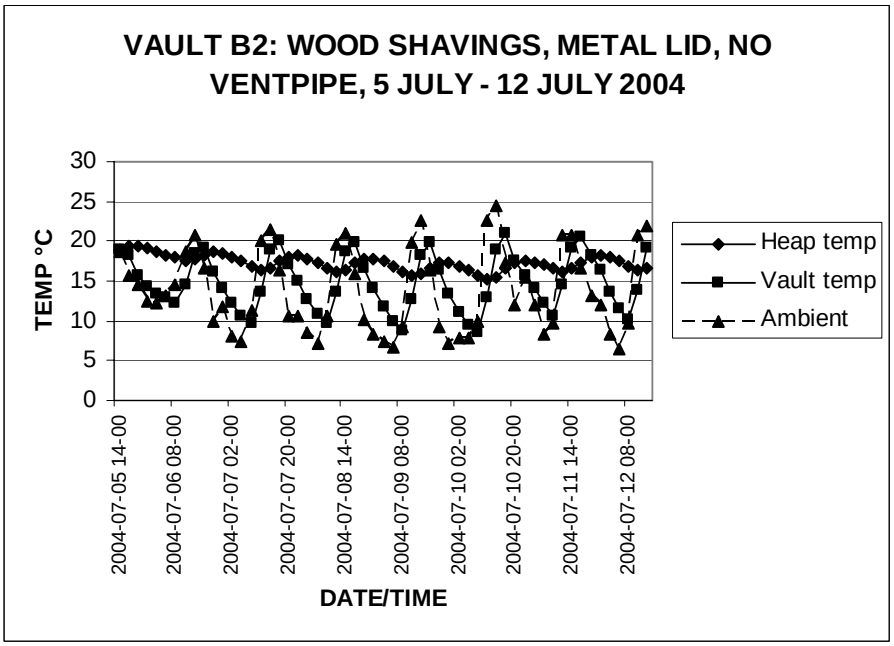
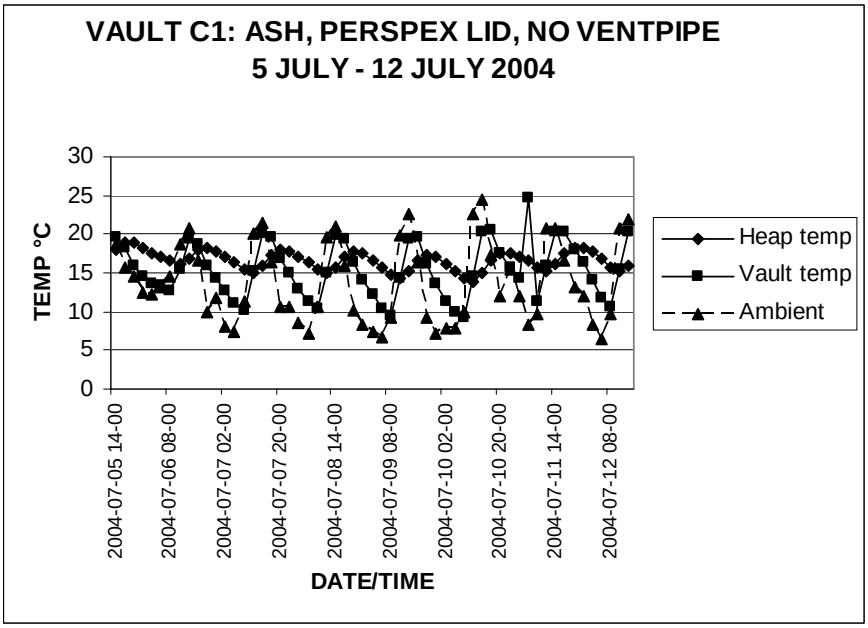


Figure 5.13: Heap, vault and ambient temperatures for the coldest week in July 2004 (winter) for vaults B1 and B2.

In vault B1 (ash, metal lid, no ventpipe) and vault B2 (wood shavings, metal lid, no ventpipe) the heap temperatures fluctuate in a narrow band (about 3°C diurnally and 4°C over the full week) while the outside temperature shows diurnal differences of up to 18°C. The overall heat gains in the heaps, while not constant, are therefore sustained. The vault temperatures, however, fluctuate more widely and follow the pattern of the outside temperature, differing generally less than 5°C from the latter. The diurnal fluctuations in heap temperatures are greater than in vaults A1 and A2 (soil mix) even though the vault temperatures are about the same. It is thought that the ash and wood shavings in vaults B1 and B2 respectively gain and lose heat quicker than the soil in vaults A1 and A2.



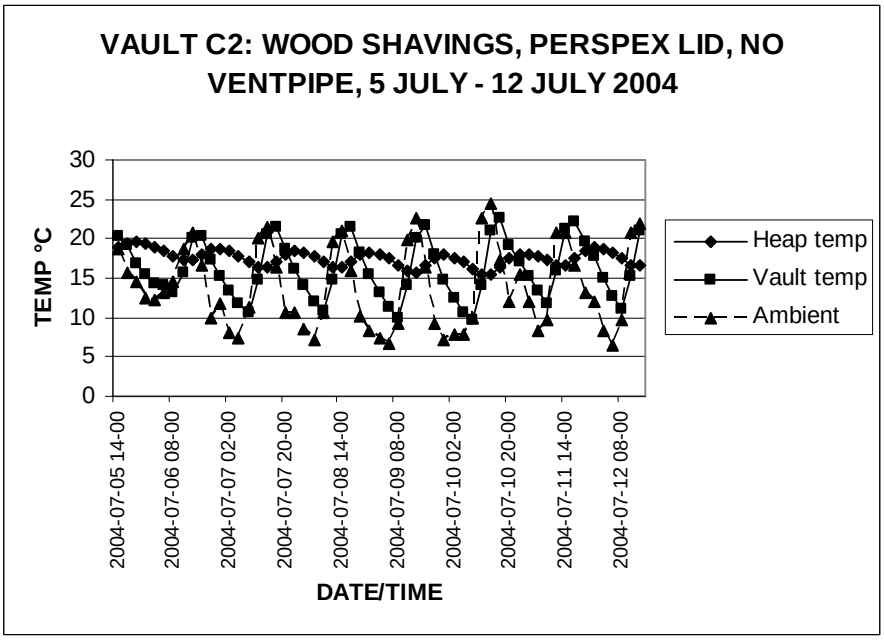
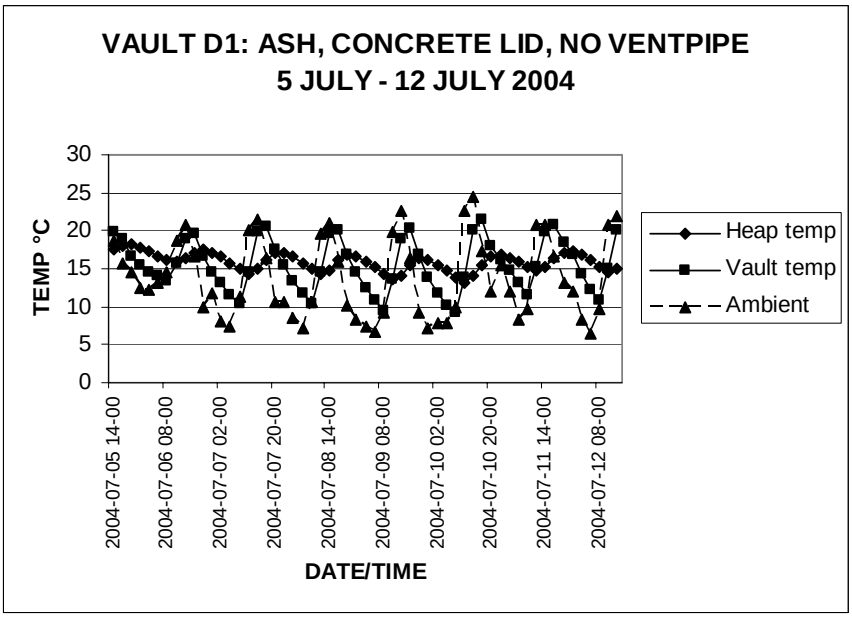


Figure 5.14: Heap, vault and ambient temperatures for the coldest week in July 2004 (winter) for vaults C1 and C2.

In vault C1 (ash, perspex lid, no ventpipe) and vault C2 (wood shavings, perspex lid, no ventpipe) the heap temperatures fluctuate in a narrow band (about 3°C diurnally and 4°C over the full week) while the outside temperature shows diurnal differences of up to 18°C. The overall heat gains in the heaps, while not constant, are therefore sustained. The vault temperatures, however, fluctuate more widely and follow the pattern of the outside temperature, differing generally less than 5°C from the latter. The diurnal fluctuations in heap temperatures are greater than in vaults A1 and A2 (soil mix) even though the vault temperatures are about the same. It is thought that the ash and wood shavings in vaults C1 and C2 respectively gain and lose heat quicker than the soil in vaults A1 and A2.



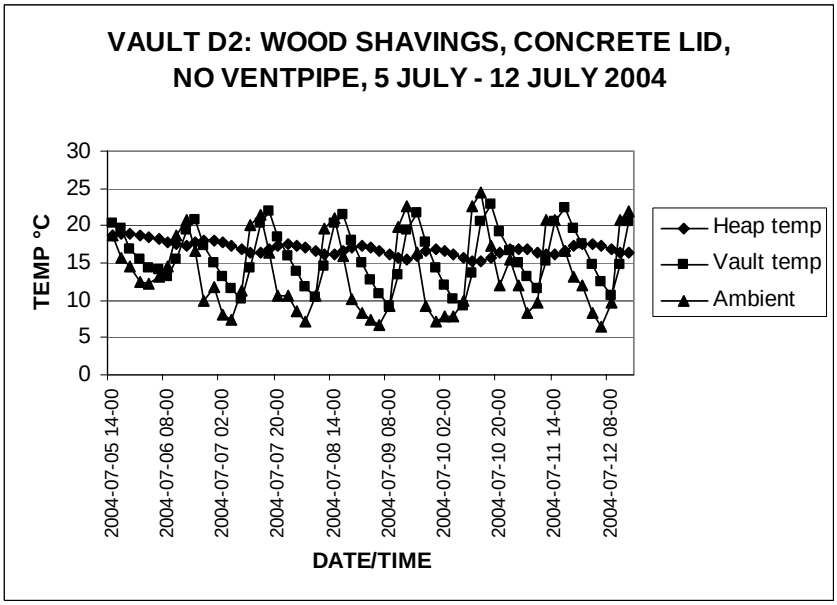


Figure 5.15: Heap, vault and ambient temperatures for the coldest week in July 2004 (winter) for vaults D1 and D2.

In vault D1 (ash, concrete lid, no ventpipe) and vault D2 (wood shavings, concrete lid, no ventpipe) the heap temperatures fluctuate in a narrow band (about 3°C diurnally and 4°C over the full week) while the outside temperature shows diurnal differences of up to 18°C. The overall heat gains in the heaps, while not constant, are therefore sustained. The vault temperatures, however, fluctuate more widely and follow the pattern of the outside temperature, differing generally less than 5°C from the latter. The diurnal fluctuations in heap temperatures are greater than in vaults A1 and A2 (soil mix) even though the vault temperatures are about the same. It is thought that the ash and wood shavings in vaults D1 and D2 respectively gain and lose heat quicker than the soil in vaults A1 and A2.

The heap in vault D1 shows bigger temperature fluctuations than the heap in vault D2. It is thought that the ash, being very coarse, made the heap more porous and thus subject to greater air exchange within the vault.

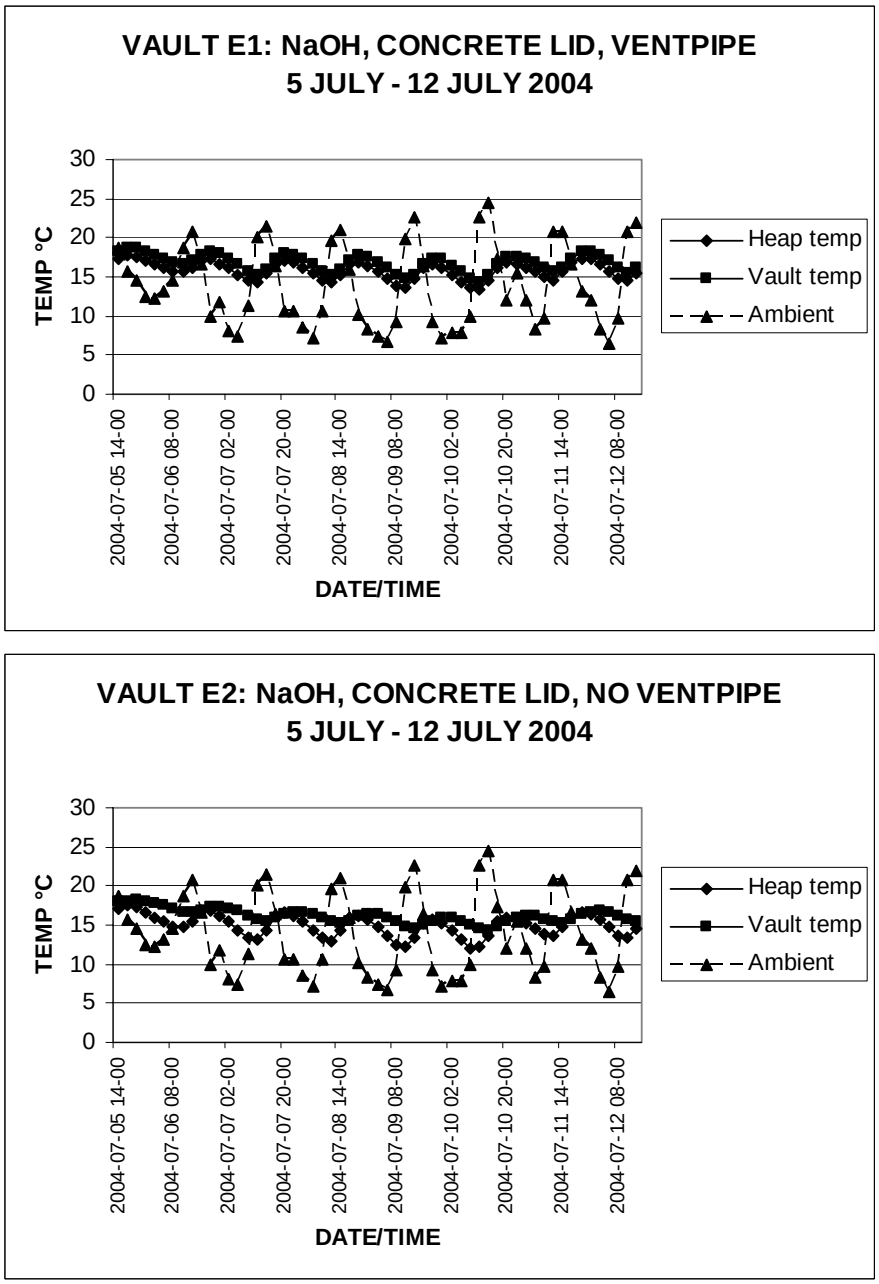
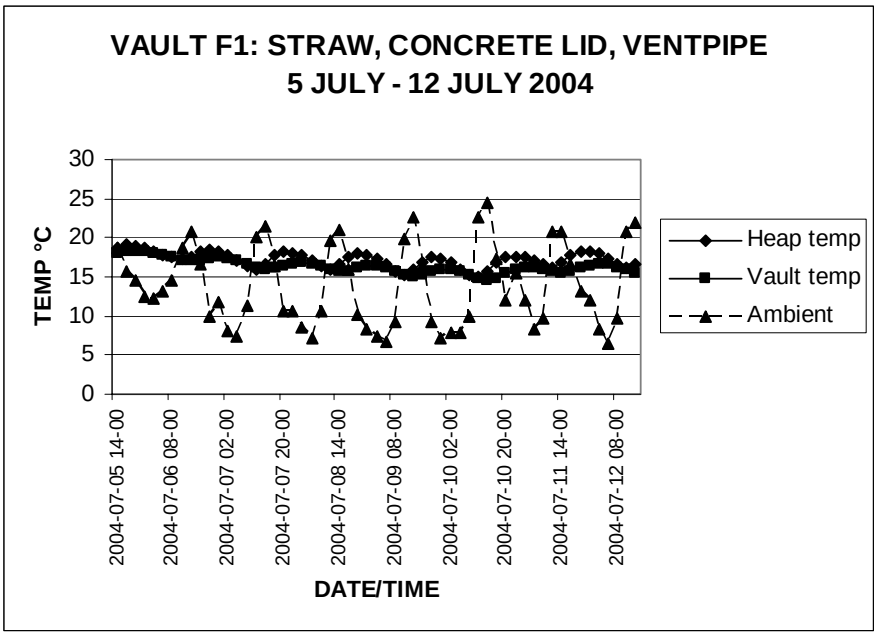


Figure 5.16: Heap, vault and ambient temperatures for the coldest week in July 2004 (winter) for vaults E1 and E2.

In vault E1 (NaOH, concrete lid, ventpipe) and vault E2 (NaOH, concrete lid, no ventpipe) the heap temperatures fluctuate in a narrow band (about 3°C diurnally and 4°C over the full week) while the outside temperature shows diurnal differences of up to 18°C. The overall heat gains in the heaps, while not constant, are therefore sustained. The diurnal fluctuations in heap temperatures in vaults E1 and E2 are greater than in vaults A1 and A2 (soil mix). It is possible that the NaOH gains and loses heat quicker than the soil in vaults A1 and A2. The vault temperatures, in this case, remain slightly higher than, and closely follow, the heap temperatures.

It does not appear as if the presence or absence of a ventpipe has any noteworthy effect on the heap or vault temperatures.



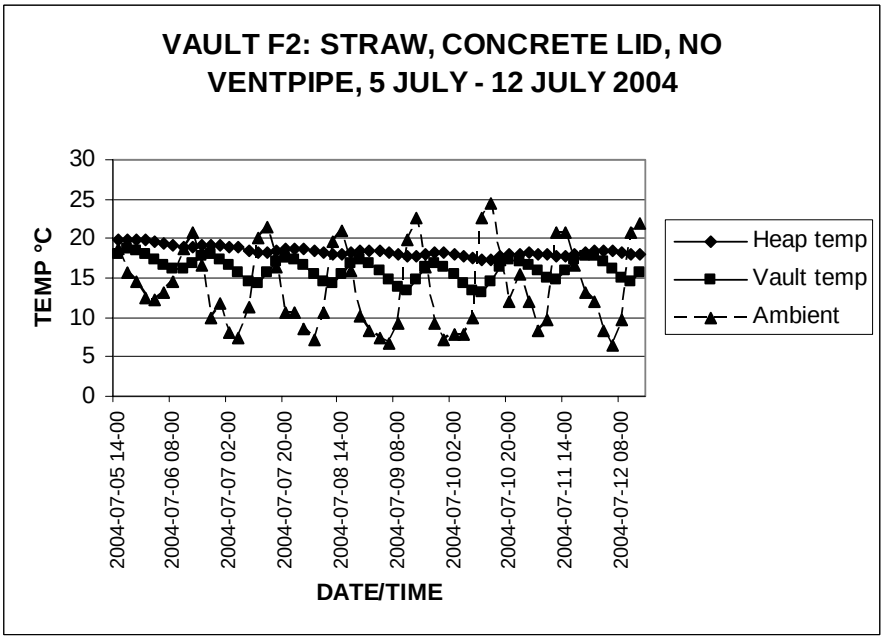


Figure 5.17: Heap, vault and ambient temperatures for the coldest week in July 2004 (winter) for vaults F1 and F2.

In vault F1 (dry grass, concrete lid, ventpipe) and vault F2 (dry grass, concrete lid, no ventpipe) the heap temperatures fluctuate in a narrow band (about 1-3°C diurnally and 4°C over the full week) while the outside temperature shows diurnal differences of up to 18°C. The overall heat gains in the heaps, while not constant, are therefore sustained. The diurnal fluctuations in heap temperatures in vault F1 are greater than in both vaults A1 and A2 (soil mix), while the fluctuations in vault F2 are about the same. The vault temperatures are, in this case, slightly lower than the heap temperatures.

It does not appear as if the presence or absence of a ventpipe has any noteworthy effect on the heap or vault temperatures.

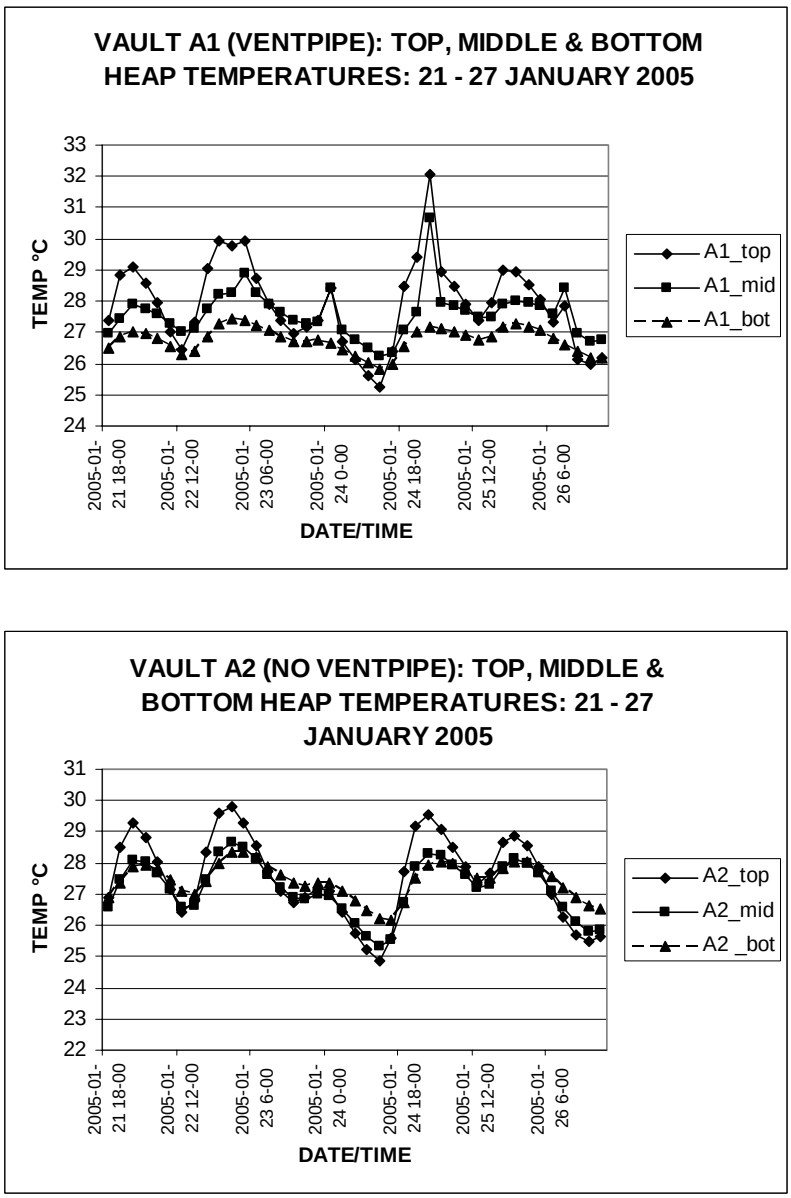


Figure 5.18: Top, middle and bottom heap temperatures for the warmest week in January 2005 (summer) for vaults A1 (top graph) and A2 (bottom graph).

The surface of the heap is the warmest for most of the time, followed by the middle of the heap, while the inside layer is usually the coldest. The surface temperature also shows the greatest fluctuations, occasionally becoming the coldest during pronounced drops in temperature.

The temperature difference between the top and bottom layers of the heap varies generally between 1-5°C, with the greatest difference coinciding with the highest temperature peak.

Vault A1 has a ventpipe which appears to play a small role only when the greatest temperature peak occurs, when the heap surface temperature in vault A1 rises to about 3°C higher than that in vault A2.

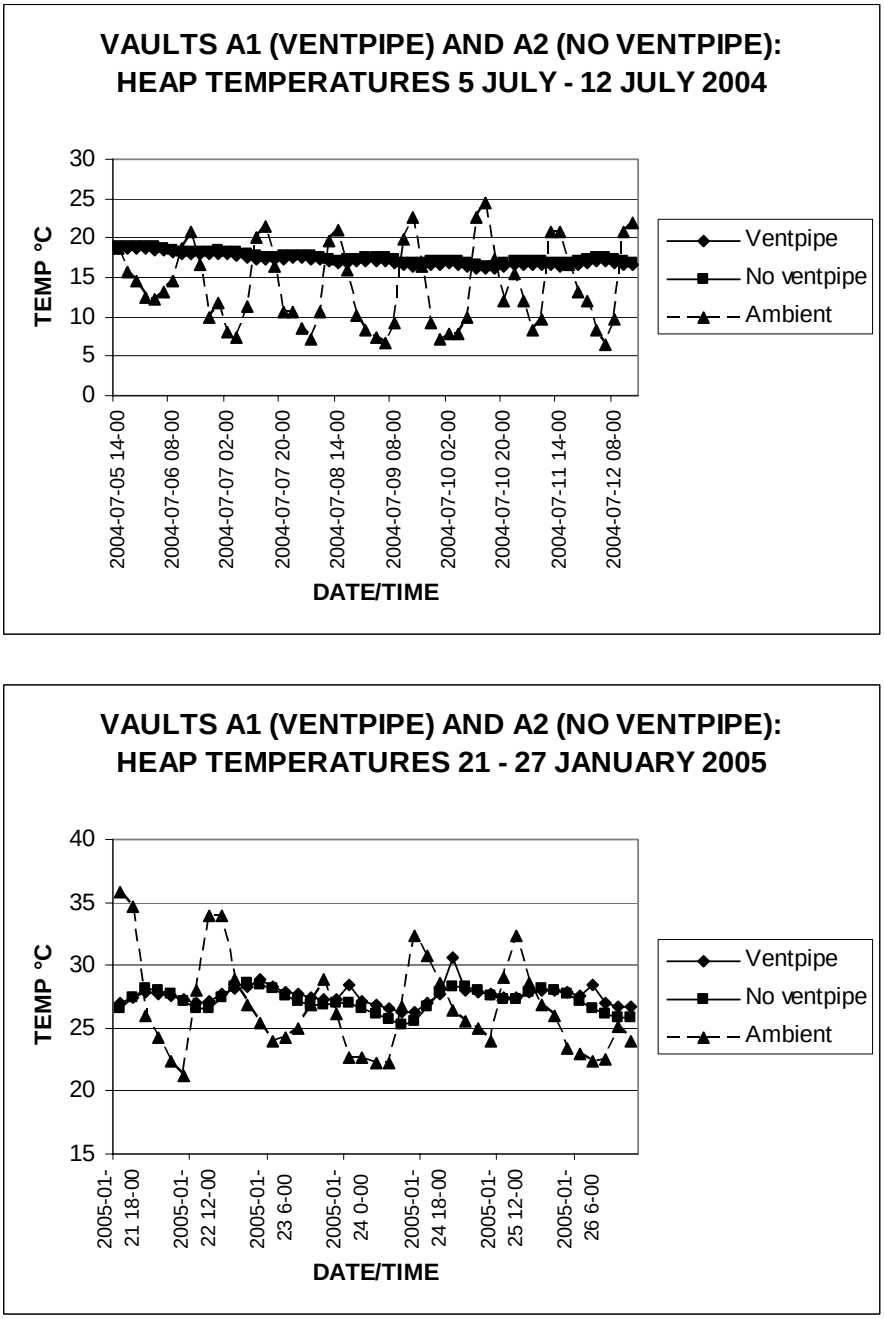
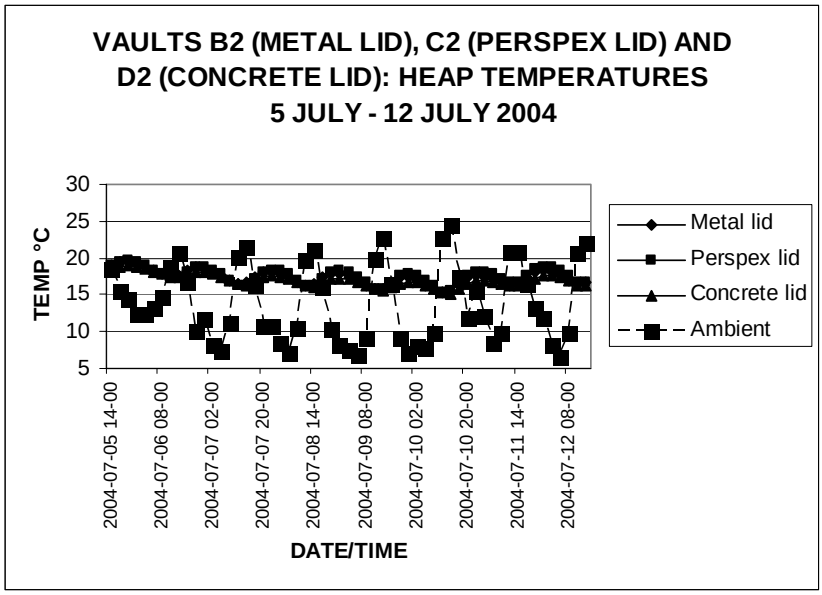


Figure 5.19: Influence of ventpipe on heap temperatures in July 2004 (winter) (top graph) and January 2005 (summer) (bottom graph) for vaults A1 and A2.

The heap temperatures in vaults A1 (ventpipe) and A2 (no ventpipe), for both the winter and summer periods, remain almost identical, although greater diurnal fluctuations are evident in summer. The heaps in both vaults consist of faeces plus soil only. Because there is no discernable difference between the two vaults in each case, it can be concluded that a ventpipe does not facilitate heat transfer to the faecal pile to any extent.

The reason for the greater diurnal temperature fluctuations in summer is not known, as the ambient temperature fluctuations are actually of smaller magnitude.



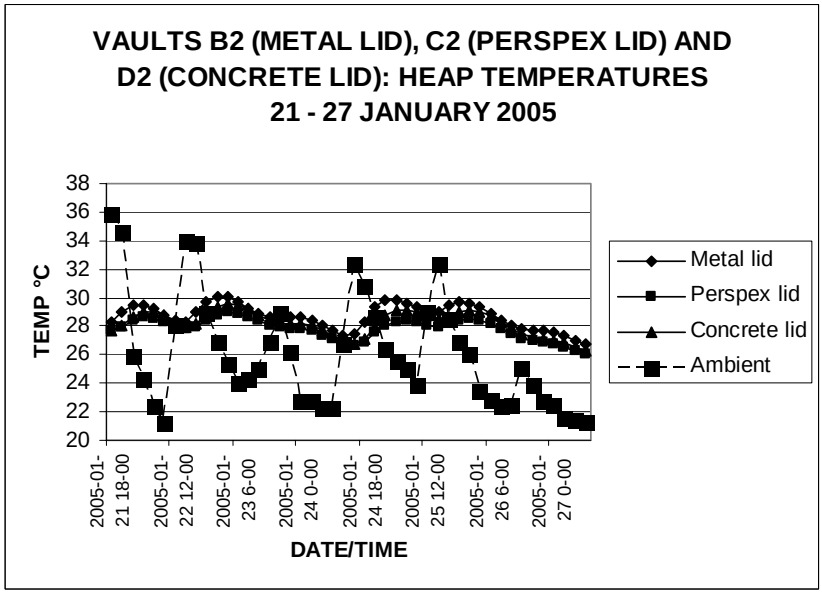


Figure 5.20: Influence of vault lid material on heap temperatures in July 2004 (winter) (top graph) and January 2005 (summer) (bottom graph) for vaults B2, C2 and D2.

The heap temperatures in vaults B2 (metal lid), C2 (perspex lid) and D2 (concrete lid), for both the winter and summer periods, remain almost identical, with a maximum difference of only about 2°C. The bulking agent in all three vaults is soil and wood shavings and none have ventpipes. In winter the perspex lid produces the highest temperature, followed by the metal lid, with the concrete lid producing the lowest. In summer the metal lid produces the highest temperature, followed by the concrete lid, while the perspex lid produces the lowest.

If the vertical scale effect is eliminated, there is virtually no difference between the magnitude of the diurnal temperature fluctuations between summer and winter.

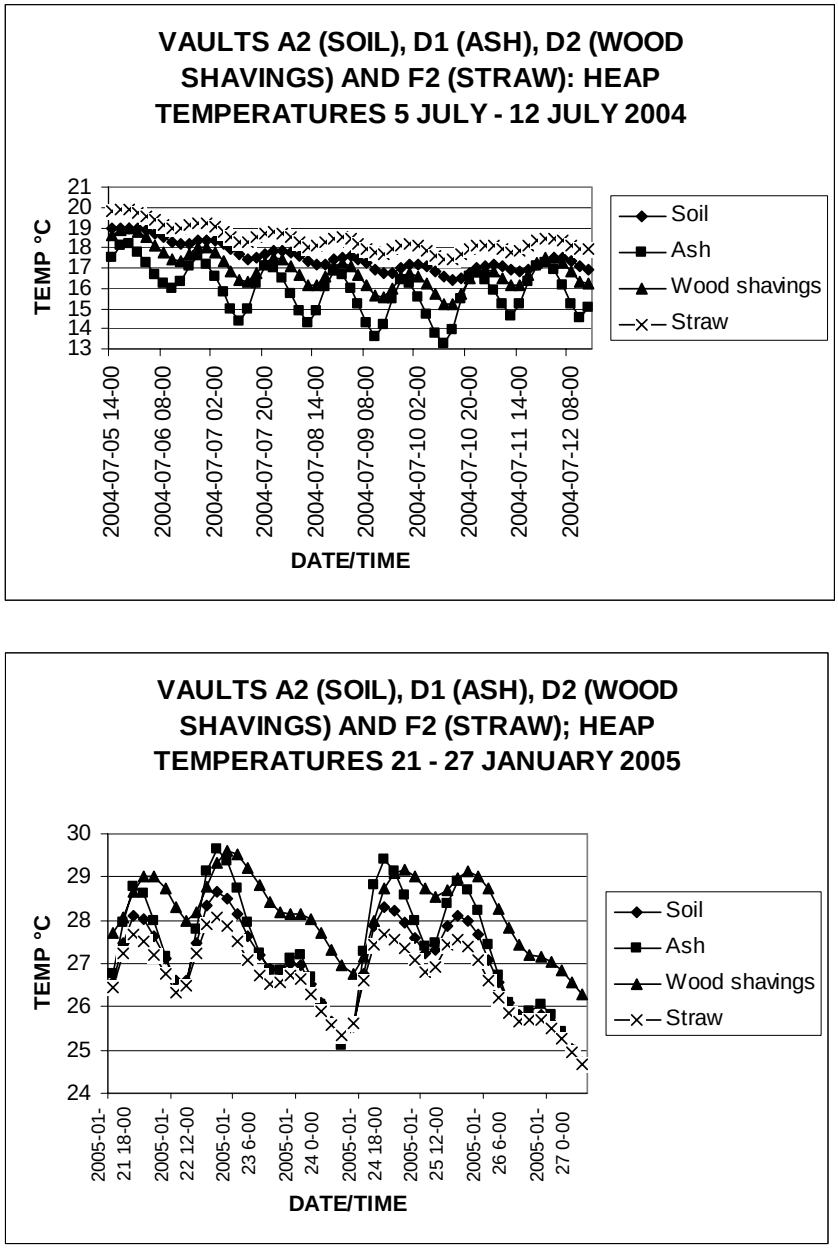


Figure 5.21: Influence of various bulking agents on heap temperatures in July 2004 (winter) (top graph) and January 2005 (summer) (bottom graph) for vaults A2, D1, D2 and F2.

The heap temperatures in vaults A2 (soil), D1 (ash), D2 (wood shavings) and F2 (straw) show clear differences during both the winter and summer periods. None of the vaults have ventpipes. The heap with straw shows the highest temperature in winter but the lowest in summer. The heap with ash shows the lowest temperature in winter but the second highest in summer. The heap with wood shavings has the second lowest temperature in winter but the highest in summer. The heap with soil varies between second highest and third highest in winter and summer respectively.

In winter the temperature differences vary between 2°C and 4°C and in summer between 1°C and 2°C. The reason for the reversal in trends between winter and summer is not known.

5.4.3 Discussion of temperature results

The following discussion should be seen in the light of the local climate in eThekwini – sub-tropical, mild to cool winters and warm summers with high humidity.

Influence of ventpipe:

There is very little difference in either the heap or the vault temperatures between vaults with ventpipes and those without. Ventilation should therefore not be considered to affect heat transfer to or from the faecal pile to any notable extent.

Residual warmth of heap:

Once the heap has developed a certain amount of warmth, the temperature fluctuates in a narrow band (1-3 degrees C) around that level even while the ambient temperature shows diurnal peak/trough differences of up to 18 degrees. This is an important observation as it implies that, should it be possible to raise the heap temperature to a satisfactory level for pathogen destruction, the temperature should remain high and not be subject to large daily fluctuations. This will obviously expedite pathogen die-off.

The fluctuations in heap temperature lag behind those of the ambient temperature, with highs and lows occurring at different times.

Temperature gradient in heap:

The surface of the heap is the warmest for most of the time, followed by the middle of the heap, while the inside layer is usually the coldest. The surface also shows the greatest fluctuations, occasionally becoming the coldest during pronounced drops in temperature. This is to be expected.

The temperature gradient in the heap is the opposite of what is found during a composting process, where the inside of the heap is generally the warmest.

Influence of vault lid material:

During summer the metal lid produces the highest heap temperature, followed by the concrete lid, with the perspex lid producing the lowest temperature. In winter the situation is different, with the perspex lid producing the highest heap temperature, followed by the metal lid with the concrete lid producing the lowest. These temperature differences should not be seen as significant, however, as the differences between them vary by less than 0,5°C to about 2°C.

Type of bulking agent:

In summer, wood shavings appear to allow the most heat transfer to the heap, with temperatures being almost consistently higher than heaps with other materials. In contrast to expectations, however, straw had the opposite effect and showed the lowest heat gain. It appears that wood shavings retain heat better than straw in this case. Even so, the difference was less than 2°C. Temperatures in the heap with only soil mixed with the faeces were roughly between the heaps with wood shavings and straw respectively. The coarse ash was second best.

In winter the situation was completely different, with straw showing the highest heat gain and ash the least, with soil and wood shavings in between. Once again, however, the total difference was small, being for the most part less than 3°C. The reason for the reversal in trends is not known.

Due to the relatively small temperature variation between bulking agents, the different treatments are not considered to have any significant effect compared with the basic mixture of faeces and soil. They should therefore not be considered to facilitate heat transfer in the heap to any notable extent.

In general, these additives tend to reduce the concentration of faecal matter in the mix, and less heat build-up can therefore be expected – it is not a composting process (which produces heat) that takes place. In an ignition test conducted on the faeces/soil mix, the content of organic material was found to be only 7,98%. If high-energy amendments, e.g. fruit peelings, food waste, etc. are added instead, then a higher heap temperature can be expected to occur.

The relatively low moisture content in the heaps also played a role in preventing a higher heat build-up than would be expected under e.g. composting conditions.

5.4.4 Microbiological results

Results are presented in tabular format in Appendix B. Graphical representations of selected parameters follow hereunder. The graphs shown are the following:

- All vaults: total coliform, faecal coliform and faecal streptococci (Figures 5.22 to 5.33).
- Main heap: total coliform, faecal coliform and faecal streptococci (Figure 5.34).
- Main heap rehydrated: total coliform, faecal coliform and clostridium (Figure 5.35).
- Main heap spiked: E.coli (Figure 5.36).
- Main heap spiked: Coliphage (Figure 5.37).
- Main heap: *Ascaris* eggs (Figure 5.38).
- Influence of type of bulking agent on *Ascaris* eggs (Figure 5.39).
- Influence of ventpipe on *Ascaris* eggs (Figure 5.40).

As mentioned previously, only one sample from each heap was taken and analysed each time, due to cost considerations. Further, not all parameters were analysed each time. It can be seen from the tables of results in Appendix C that the analyses of the different heaps, although each was taken from the same original heap, show varying results at the start of the experimentation, i.e. at t=0. This can be attributed to the fact that the results are reported for a certain weight of combined material (1g or 10g) and each vault had a different mix. Moreover, an inherent variability in sampling and testing is always present, particularly when only one sample is analysed each time, and there is considerable evidence of this in the results.

Comments on wood shavings and straw bulking agents:

The results show variability especially for the vaults where wood shavings and straw were used as bulking agents. These materials are well-known substrates for the growth or persistence of coliforms. Potentially also faecal streptococci will grow, and may also be a part of the decomposition flora of straw. This should be taken into account.

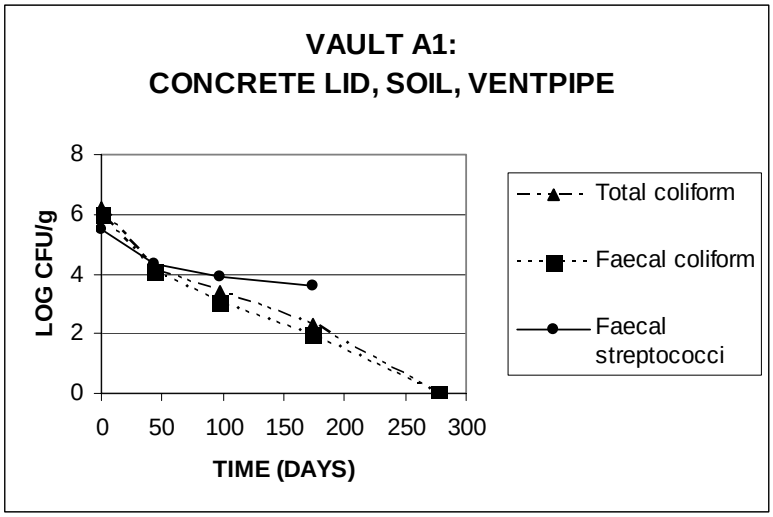


Figure 5.22: Vault A1 – total coliform, faecal coliform and faecal streptococci

In vault A1, total and faecal coliform numbers were reduced by approximately 6 $\log_{10}$ cfu/g over the 278 day experimental period, while faecal streptococci were reduced by 2 $\log_{10}$ cfu/g over 174 days. The $t_{99,9}$ value, i.e. time for 3 $\log_{10}$ die-off, for total coliforms was 135 days and for faecal coliforms 100 days, while faecal streptococci were not tested over a long enough period to determine this.

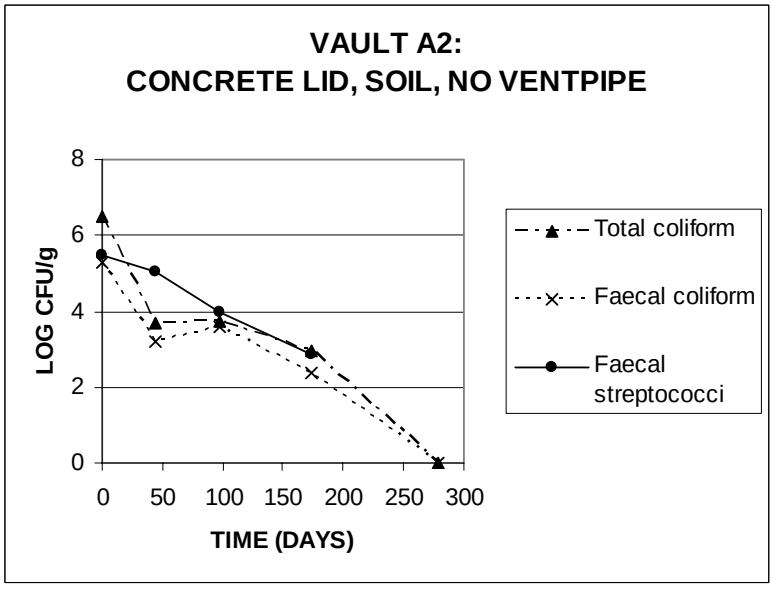


Figure 5.23: Vault A2 – total coliform, faecal coliform and faecal streptococci

In vault A2, total and faecal coliform numbers were reduced by approximately 6 $\log_{10}$ cfu/g over the 278 day experimental period, while faecal streptococci were reduced by approximately 2 $\log_{10}$ cfu/g over 174 days. The $t_{99,9}$ value for total coliforms was 140 days, for faecal coliforms 195 days and for faecal streptococci 140 days.

There appears to be no discernable difference that could be ascribed to the presence of a ventpipe in vault A1.

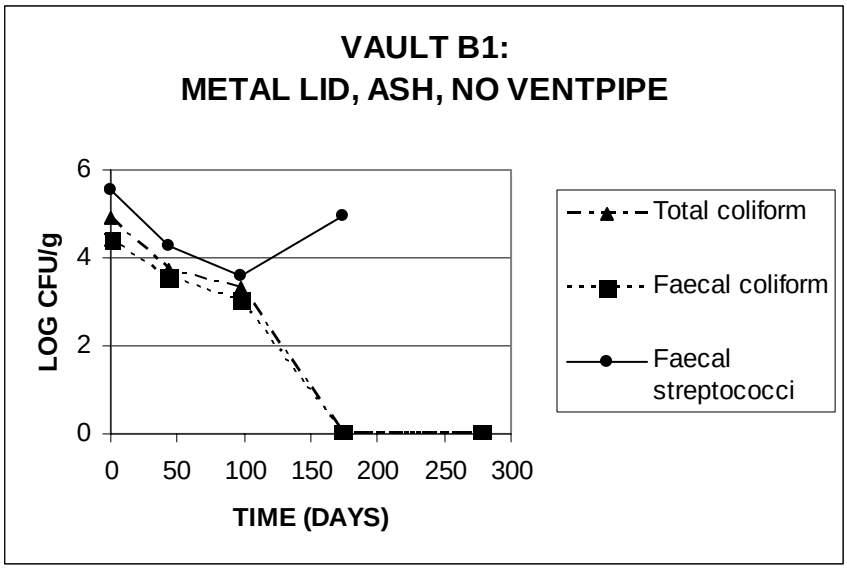


Figure 5.24: Vault B1 – total coliform, faecal coliform and faecal streptococci

In vault B1, total and faecal coliform numbers were reduced by approximately 5 $\log_{10}$ cfu/g over 174 days, while faecal streptococci were reduced by approximately 2 $\log_{10}$ cfu/g over 97 days before showing an upward trend again. This phenomenon is most likely due to sample variability and should not be seen as significant. The $t_{99,9}$ value for total coliforms was about 130 days, for faecal coliform about 140 days, while faecal streptococci were not tested over a long enough period to determine this.

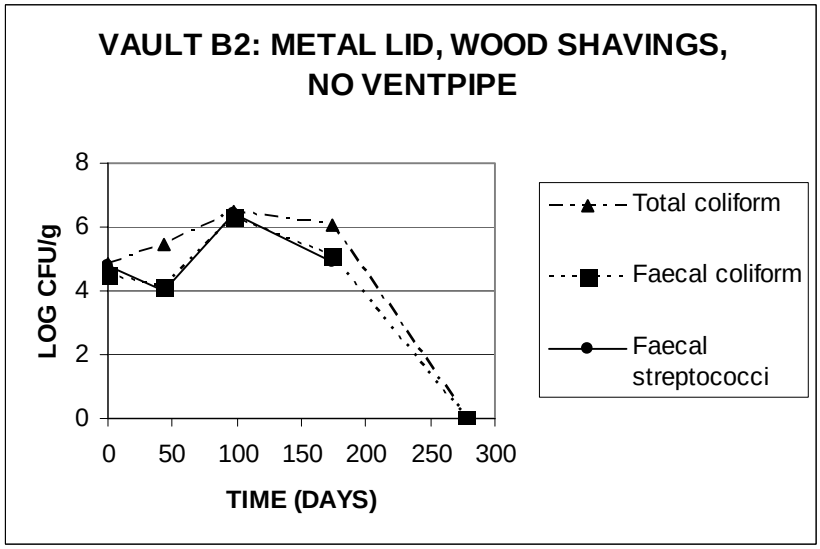


Figure 5.25: Vault B2 – total coliform, faecal coliform and faecal streptococci

In vault B2, total and faecal coliform numbers were reduced by approximately 5 $\log_{10}$ cfu/g over 278 days, while first showing an upward trend over the first 97 days due to reasons discussed earlier. Faecal streptococci exhibited large fluctuations over a period of 174 days. These fluctuations should not be seen as significant. Due to the variability, the $t_{99,9}$ value for total and faecal coliforms increased to about 250 days, while faecal streptococci were not tested over a long enough period to determine this.

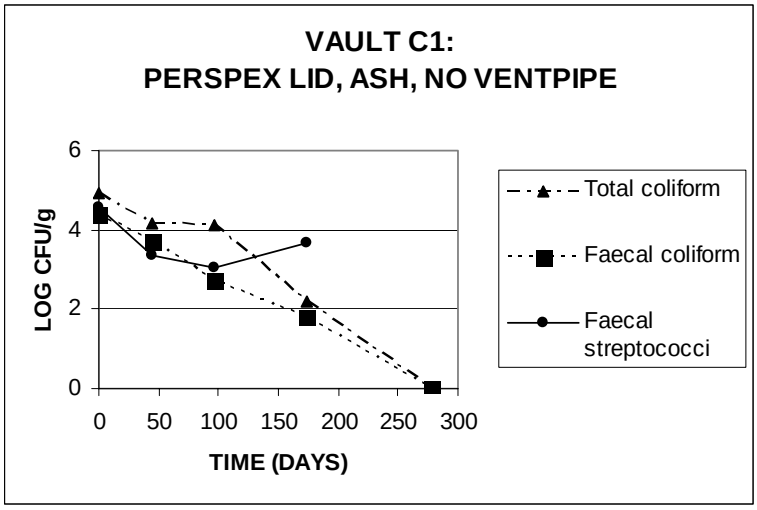


Figure 5.26: Vault C1 – total coliform, faecal coliform and faecal streptococci

In vault C1, total and faecal coliform numbers were reduced by approximately 5 $\log_{10}$ cfu/g over 278 days, while faecal streptococci were reduced by approximately 2 $\log_{10}$ cfu/g over 97 days before showing an upward trend again. This is most likely due to sample variability, as the sample at 174 days exhibited a much higher moisture content than the previous sample at 97 days – 21,8% as opposed to 7,1%. The $t_{99,9}$ value for total coliforms was about 135 days, for faecal coliform about 200 days, while faecal streptococci were not tested over a long enough period to determine this.

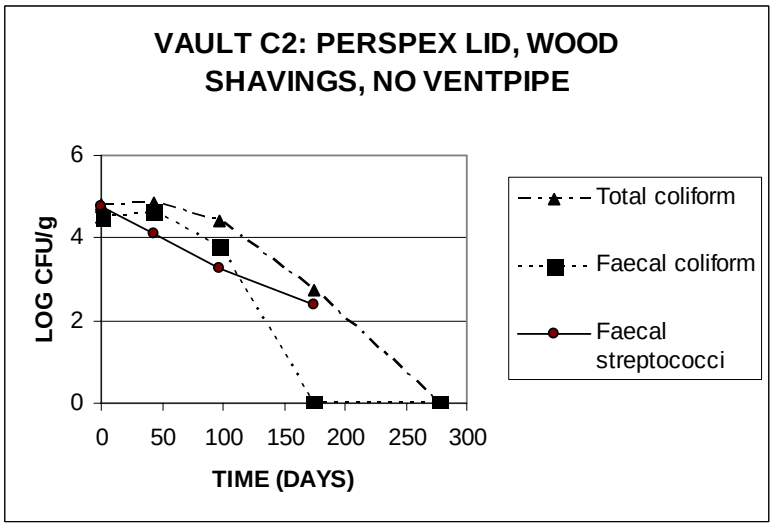


Figure 5.27: Vault C2 – total coliform, faecal coliform and faecal streptococci

In vault C2, total coliform numbers decreased by approximately 5 $\log_{10}$ cfu/g over 174 days, while faecal coliform reduced by 5 $\log_{10}$ cfu/g over 278 days. Faecal streptococci reduced by approximately 2 $\log_{10}$ over 174 days. The $t_{99,9}$ value for total coliform was about 210 days, for faecal coliform about 145 days, while faecal streptococci were not tested over a long enough period to determine this.

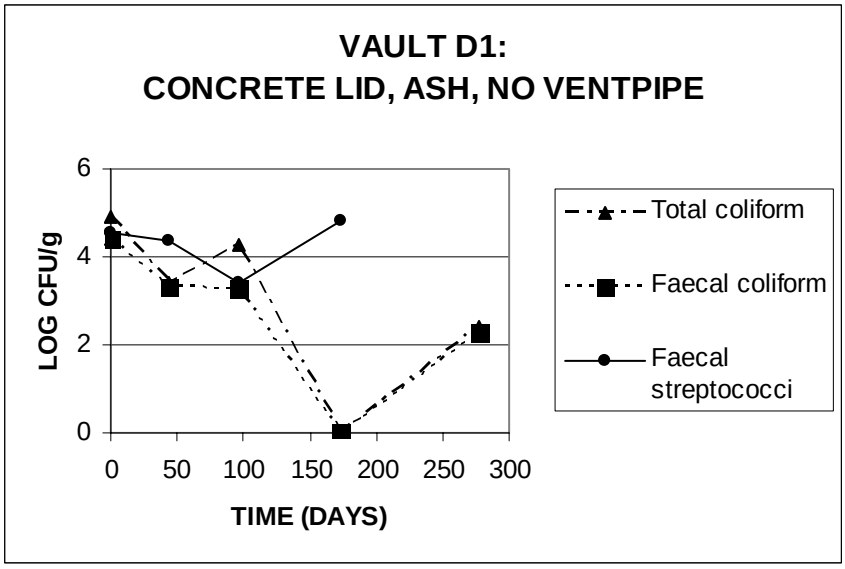


Figure 5.28: Vault D1 – total coliform, faecal coliform and faecal streptococci

In vault D1, all parameters exhibited large fluctuations. Total and faecal coliforms reduced by approximately 5 $\log_{10}$ cfu/g over 174 days, with total coliform showing a temporary increase of about 1 $\log_{10}$ cfu/g at 97 days. Total and faecal coliforms both show an increase again of 2 $\log_{10}$ cfu/g at 278 days, while faecal streptococci display an increase of approximately 2 $\log_{10}$ cfu/g at 174 days. Although sample variability played a noteworthy role in the fluctuating values of all the parameters, it can be seen that $t_{99,9}$ for total and faecal coliform was about 135 days, while faecal streptococci did not achieve this reduction.

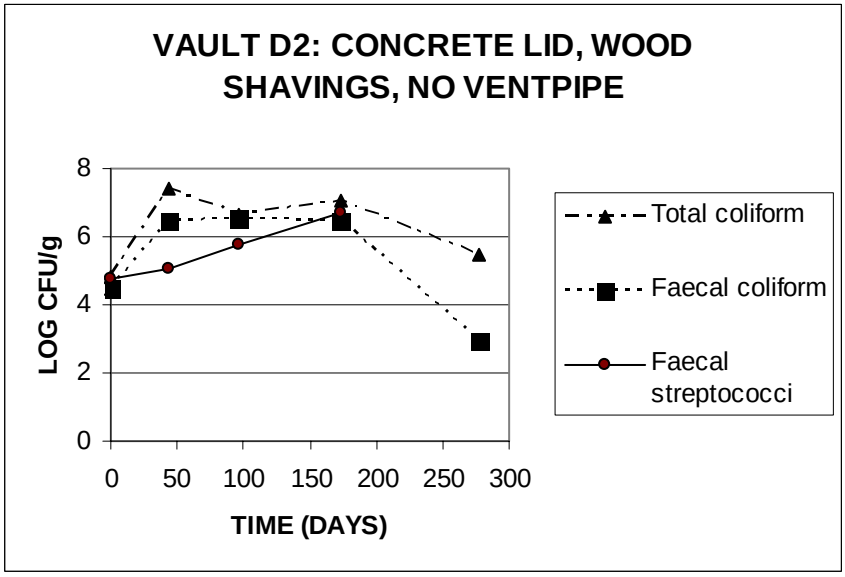


Figure 5.29: Vault D2 – total coliform, faecal coliform and faecal streptococci

In vault D2 only faecal coliform show an overall decrease in numbers – amounting to approximately 2 $\log_{10}$ cfu/g over 278 days. Total coliforms display an overall increase of approximately 1 $\log_{10}$ cfu/g over 278 days, while faecal streptococci exhibit a continuous increase amounting to approximately 2 $\log_{10}$ over 174 days. None of the parameters reached a 3 $\log_{10}$ reduction.

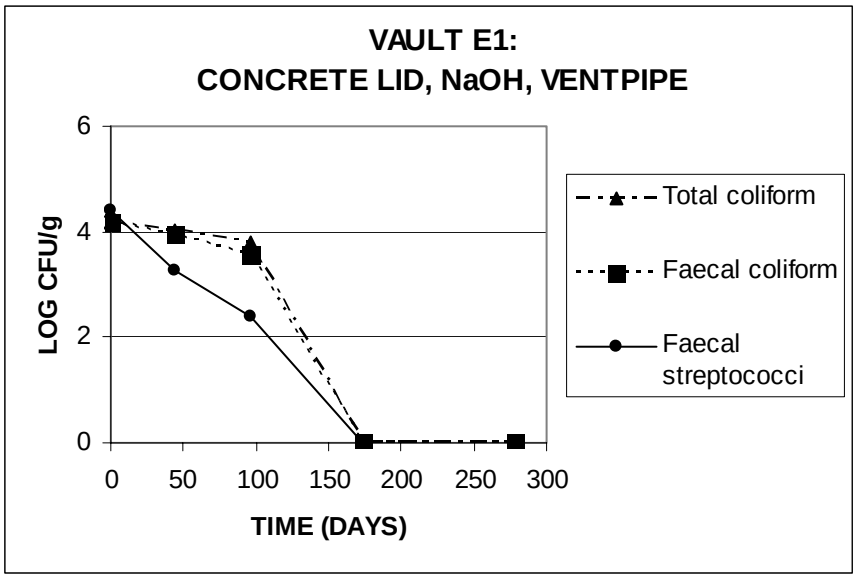


Figure 5.30: Vault E1 – total coliform, faecal coliform and faecal streptococci

In vault E1, all parameters exhibit strong decreasing tendencies, reducing by approximately 4 $\log_{10}$ cfu/g over 174 days. Faecal streptococci show the fastest rate of die-off, with a $t_{99,9}$ value of about 125 days, while total and faecal coliforms display a $t_{99,9}$ value of about 150 days.

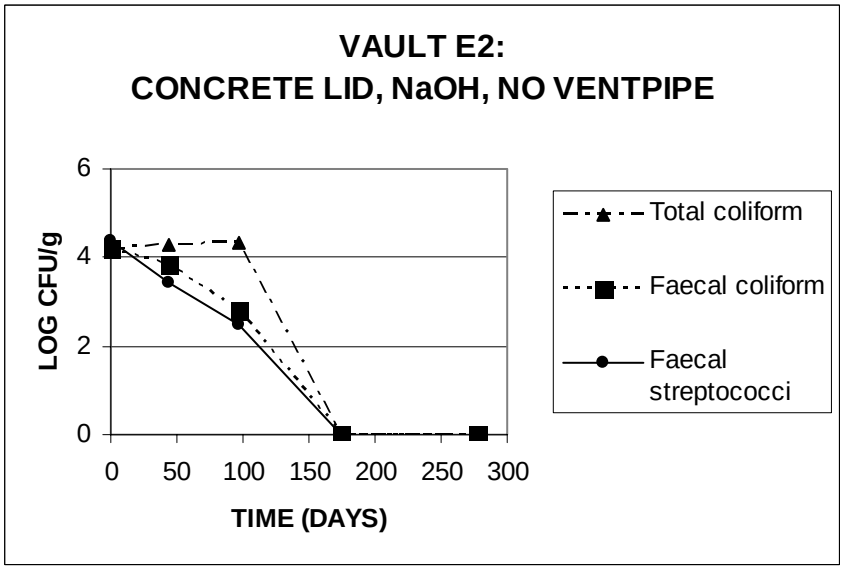


Figure 5.31: Vault E2 – total coliform, faecal coliform and faecal streptococci

In vault E2, all parameters show a decrease of approximately 4 $\log_{10}$ cfu/g over 174 days. Faecal streptococci numbers once again show the fastest rate of die-off, with a $t_{99,9}$ value of about 125 days, followed by faecal coliform at about 150 days. Total coliform numbers exhibit an increase until 97 days (possibly due to an increase in moisture content from 8,6% to 21,4%) and the $t_{99,9}$ value is about 155 days.

There appears to be no discernable difference that could be ascribed to the presence or absence of a ventpipe in vaults E1 and E2 respectively.

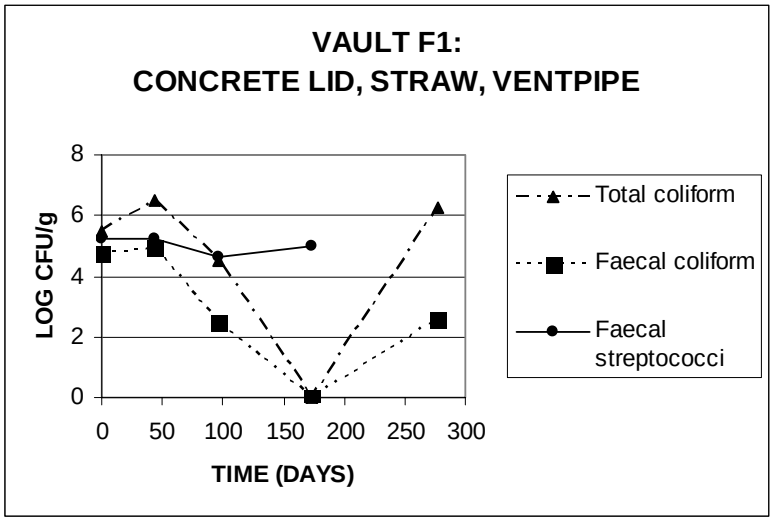


Figure 5.32: Vault F1 – total coliform, faecal coliform and faecal streptococci

In vault F1, faecal streptococci numbers remain virtually constant while both total and faecal coliform numbers show an increase initially before dropping approximately 5 $\log_{10}$ cfu/g by 174 days. Thereafter large increases are evident at 278 days. These fluctuations are most likely due to the reasons discussed earlier and should not be regarded as significant. The $t_{99,9}$ values for total and faecal coliforms are about 130 days and 125 days respectively, while faecal streptococci were not tested over a long enough period to determine this.

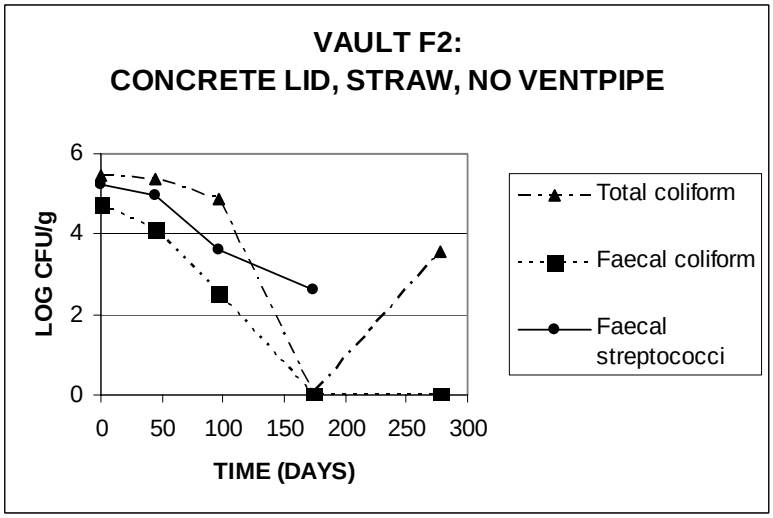


Figure 5.33: Vault F2 – total coliform, faecal coliform and faecal streptococci

In vault F2, all parameters show a decline in numbers: both total and faecal coliforms are reduced by approximately 5 $\log_{10}$ cfu/g after 174 days and faecal streptococci by approximately 3 $\log_{10}$ cfu/g in the same period. Once again there is a large increase in total coliform numbers at 278 days for reasons described earlier. The $t_{99,9}$ value of total coliform is about 130 days, faecal coliform about 120 days and faecal streptococci about 174 days.

There appears to be no discernable difference that could be ascribed to the presence or absence of a ventpipe in vaults F1 and F2 respectively.

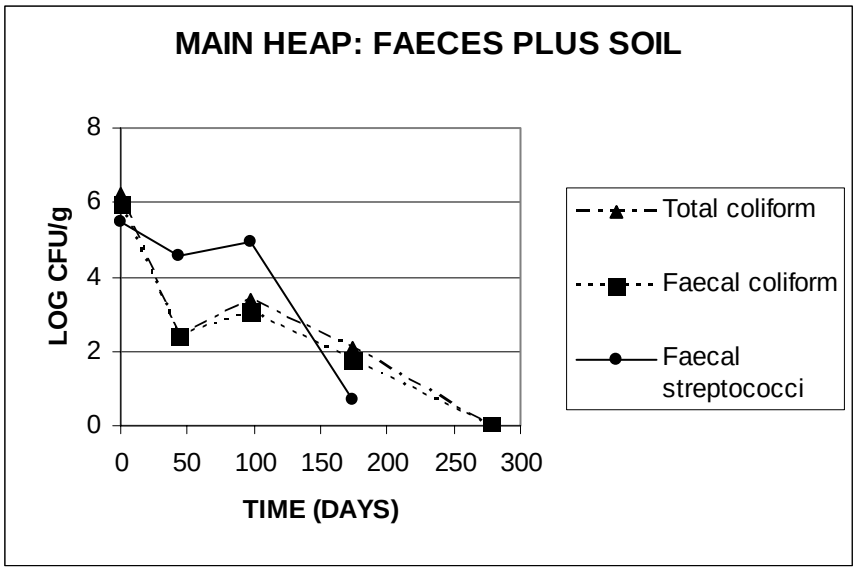


Figure 5.34: Main heap: total coliform, faecal coliform and faecal streptococci

In the main heap of material (faeces plus soil), total and faecal coliform numbers reduce in an almost identical fashion by 6 $\log_{10}$ cfu/g after 278 days, while faecal streptococci reduce by approximately 5 $\log_{10}$ cfu/g after 174 days. There are small increases for all parameters at 97 days, most probably due to sample variability. The $t_{99,9}$ value of both total and faecal coliforms is about 115 days and of faecal streptococci about 140 days.

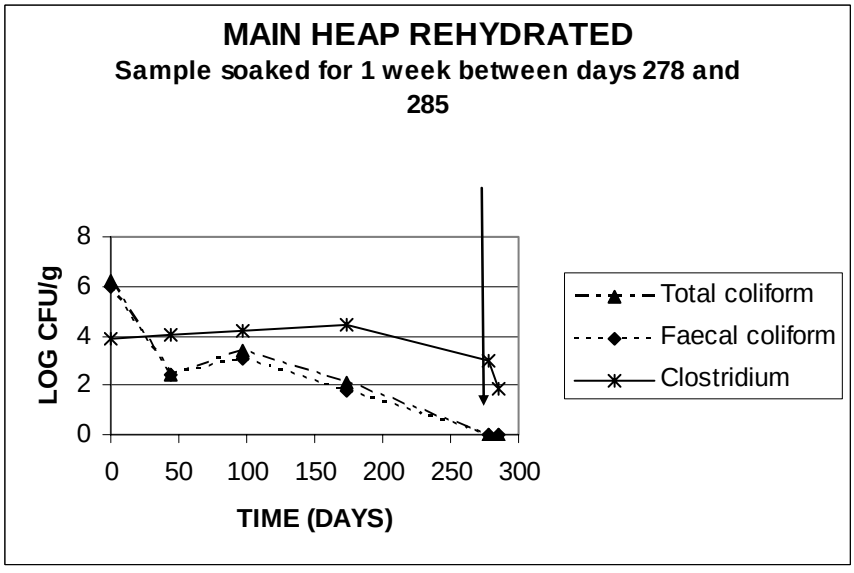


Figure 5.35: Main heap rehydrated: total coliform, faecal coliform and clostridium

The sample taken at 278 days was rehydrated with distilled water for one week, after which the organisms were enumerated again. For the coliforms the count was less than 3 on both occasions, showing that there had been no growth in these organisms, while clostridium decreased further by 1 $\log_{10}$ cfu/g. This indicates that the sample was probably microbiologically stable by this time.

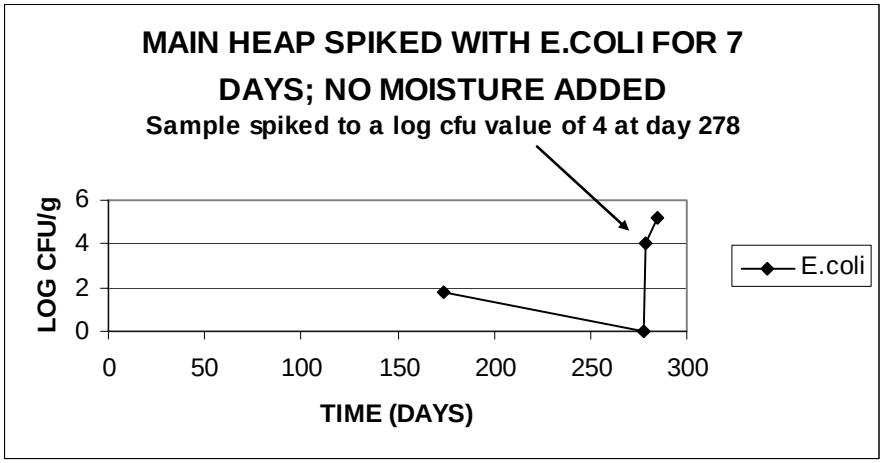


Figure 5.36: Main heap spiked: *E.coli*

The sample taken at 278 days was spiked with *E.coli* to a $\log_{10}$ cfu value of 4,0 (i.e. $1{,}0 \times 10^4$ cfu/g) following which the organism was enumerated again after one week. After this time the count had risen by 1 $\log_{10}$ to $1{,}6 \times 10^5$ cfu/g. Comparing this graph with the previous one (Figure 5.35), this phenomenon probably implies that there were not enough bacteria left in the sample to be able to compete with the *E.coli* for nutrients, thus allowing the latter organism to grow further.

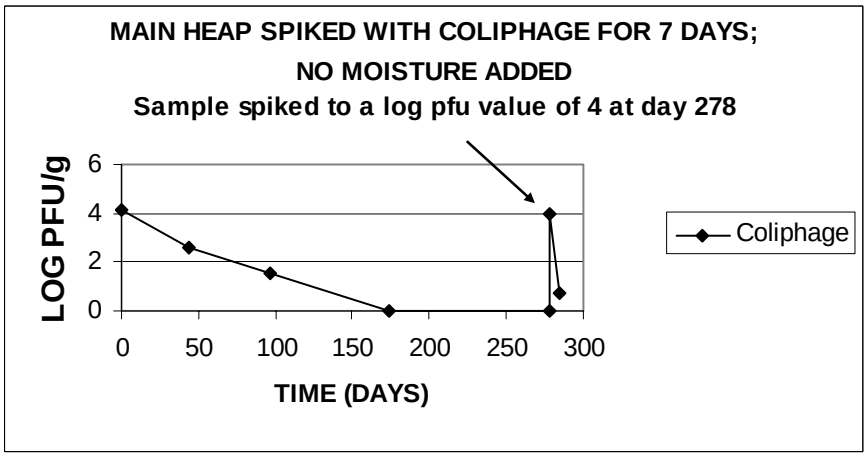


Figure 5.37: Main heap spiked: Coliphage

The sample taken at 278 days was spiked with coliphage virus to a $\log_{10}$ pfu value of 4,0 (i.e. $1{,}0 \times 10^4$ pfu/g) following which the organism was enumerated again after one week. After this time the count had reduced to 5. Comparing this graph with Figure 5.35, this phenomenon probably implies that there were not enough *E. coli* and other bacteria left in the sample for the virus to host on.

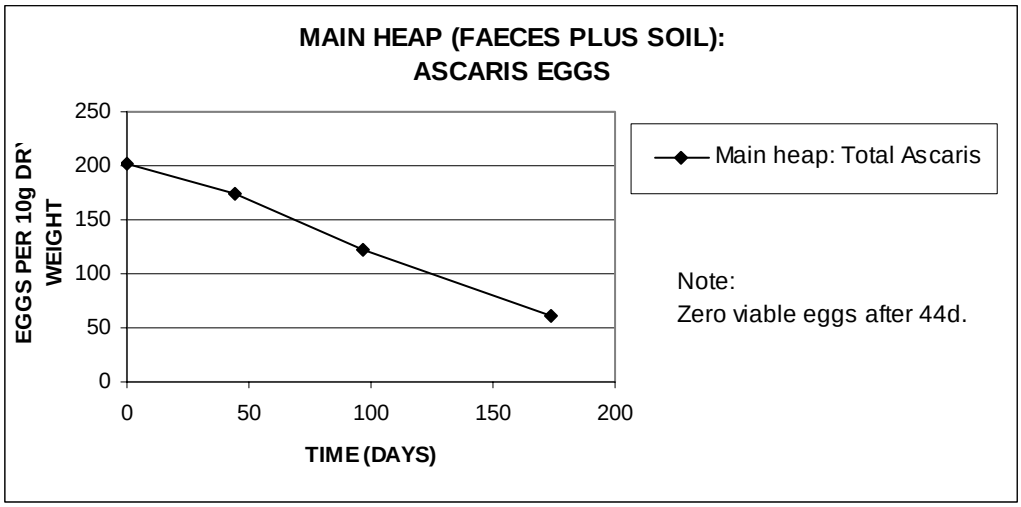


Figure 5.38: Main heap: *Ascaris* eggs

In the main heap (faeces plus soil), the number of total *Ascaris* eggs reduced consistently from an initial 201 to 62 over a period of 174 days. However, the actual viable eggs were reduced to zero by 44 days.

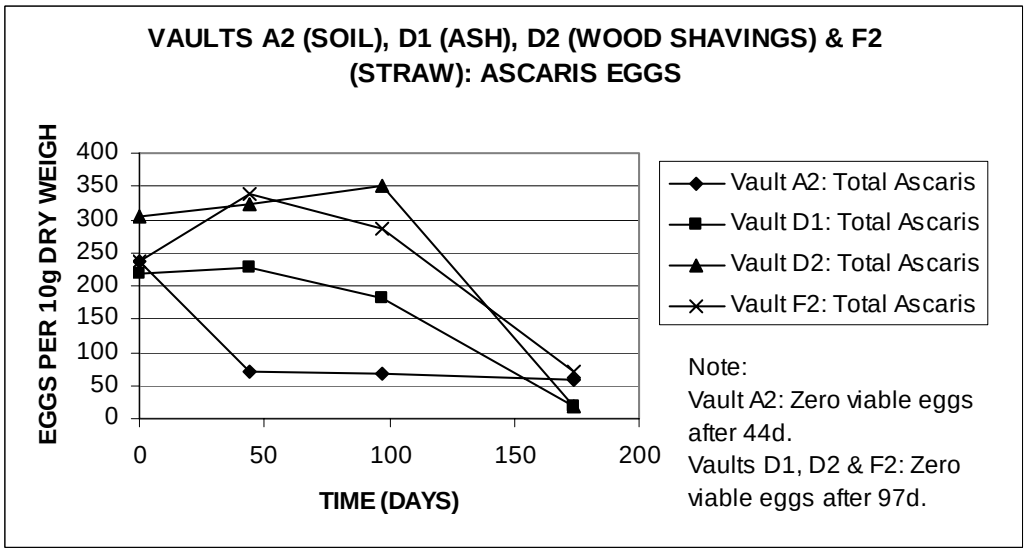


Figure 5.39: Influence of type of bulking agent on *Ascaris* eggs

In vault A2 (soil) the number of total *Ascaris* eggs reduced from an initial 237 to 60 in 174 days, with the actual viable eggs being zero by 44 days. In vault D1 (ash), the numbers of total eggs reduced from 218 to 20 by 174 days; in vault D2 (wood shavings) from 305 to 17 by 174 days; and in vault F2 (straw) from 237 to 72 by 174 days. In the latter three vaults the actual viable eggs were reduced to zero by 97 days. None of the vaults were fitted with ventpipes. The counts in the latter three vaults showed increases initially, but these were probably the result of sample variability.

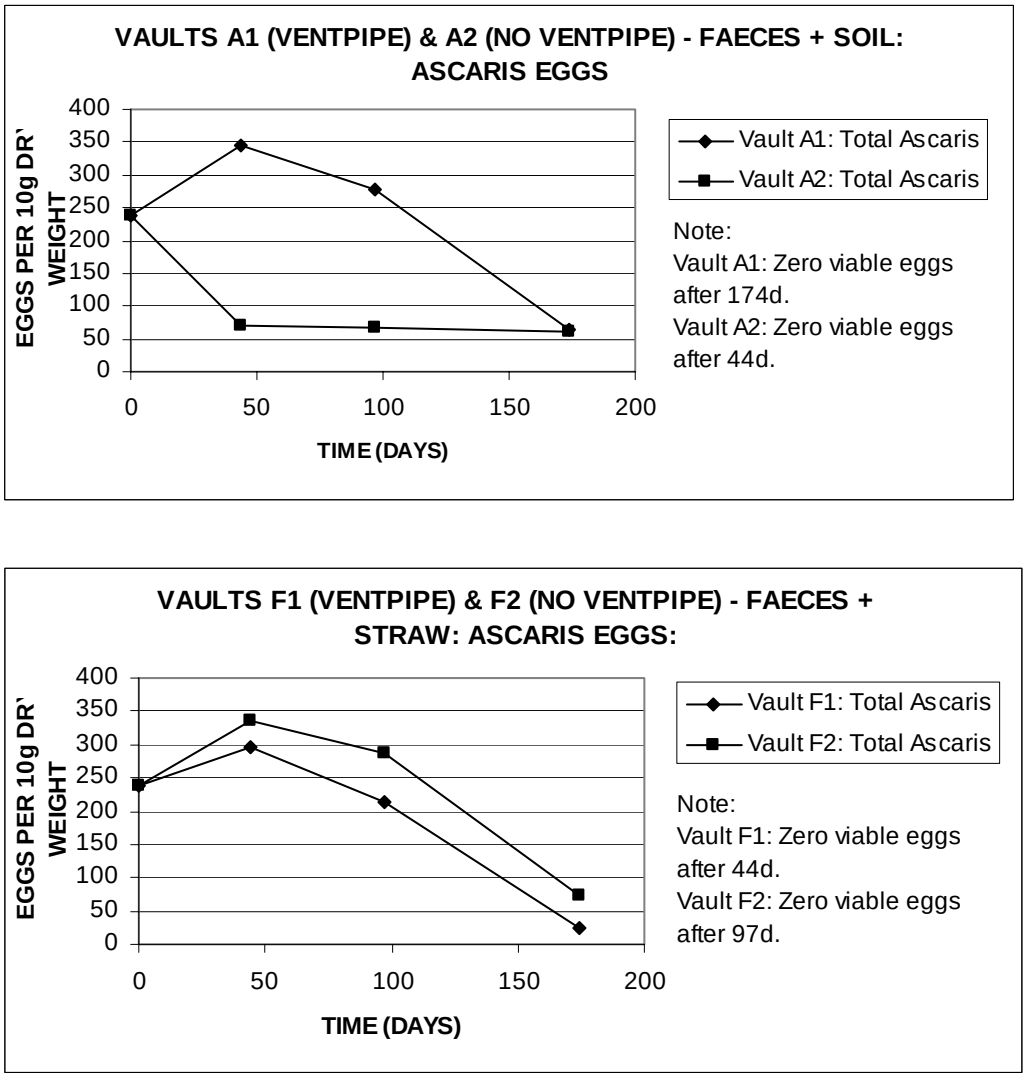


Figure 5.40: Influence of ventpipe on *Ascaris* eggs

In vaults A1 and A2 (faeces plus soil), the numbers of total *Ascaris* eggs reduced from an initial 237 to 64 and 60 after 174 days respectively, with the actual viable eggs being reduced to zero by 174 days and 44 days respectively. It appears, however, that the results of vault A1, because of the increase in numbers at day 44, were subject to sample variability. It cannot therefore be construed that the presence or absence of a ventpipe has any discernable effect. It is nevertheless clear that the eggs do not survive longer than six months in this type of environment.

In vaults F1 and F2 (faeces plus straw), the numbers of total *Ascaris* eggs reduced from an initial 237 to 23 and 72 after 174 days respectively, with the actual viable eggs being reduced to zero by 44 days and 97 days respectively. Once again it appears that the results of both vaults, because of the increase in numbers at 44 days, were subject to sample variability. It cannot therefore be construed that the presence or absence of a ventpipe has any discernable effect. It is nevertheless clear that the eggs do not survive longer than about three months in this type of environment.

5.4.5 Discussion of microbiological results

The various combinations of bulking agent, vault lid and ventpipe are summarised in Table 5.4 below.

Table 5.4: Treatments applied to each heap or vault

Heap/vault	Treatment		
	Bulking agent	**Lid type**	**Ventpipe**
Main Heap	Soil	None	–
Vault A1	Soil	Concrete	Yes
Vault A2	Soil	Concrete	No
Vault B1	Ash	Metal	No
Vault B2	Wood	Metal	No
Vault C1	Ash	Perspex	No
Vault C2	Wood	Perspex	No
Vault D1	Ash	Concrete	No
Vault D2	Wood	Concrete	No
Vault E1	NaOH	Concrete	Yes
Vault E2	NaOH	Concrete	No
Vault F1	Straw	Concrete	Yes
Vault F2	Straw	Concrete	No

For cost reasons, only one sample from each heap was taken at the various time intervals (t=0, t=44, t=97, t=174 and t=278, where t represents the number of days from the time the vaults were loaded). A summary of the tests undertaken is shown in Table 5.5. Due to the single samples, a statistical analysis was considered inappropriate.

In Table 5.6 the times for 3 $\log_{10}$ (i.e. 99,9% reduction) are indicated for total coliform, faecal coliform and faecal streptococci in the various vaults as well as in the main heap. These are seen to vary as follows:

Vaults:
130 to 250 days for total coliform, 100 to 250 days for faecal coliform, and 125 days and longer for faecal streptococci.

Main heap:
115 days for total and faecal coliform, and 140 days for faecal streptococci.

In addition, viable *Ascaris* ova were reduced to zero between 44 and 174 days in the vaults and by 44 days in the main heap.

Table 5.5: Parameters tested in each sample

Parameter
Heterotrophic plate count per g
Total coliform bacteria count per g
Faecal coliform bacteria count per g
Faecal streptococci bacteria count per g
Coliphage count per g
Clostridium count per g
Ascaris eggs per 10g dry weight
Moisture content %
E coli bacteria count per g
Salmonella spp per g (present/absent)
pH
Cryptosporidium oocysts count per 10g dry weight
Giardia cysts count per 10g dry weight
Entamoeba spp eggs per 10g dry weight
Taenia eggs per 10g dry weight

Table 5.6: Time for 3 $\log_{10}$ (99,9%) reduction for some parameters

Vault	Time for 3 $\log_{10}$ reduction - days		
	Total coliform	Faecal coliform	Faecal streptococci
A1	135	100	-
A2	140	195	140
B1	130	140	-
B2	250	250	-
C1	135	200	-
C2	210	145	-
D1	135	135	-
D2	-	-	-
E1	150	150	125
E2	155	150	125
F1	130	125	-
F2	130	120	-
Main	115	115	140

Figure 5.41 shows the trends in heterotrophic plate count, total coliform bacteria and coliphage for the various vaults in combined graphs.

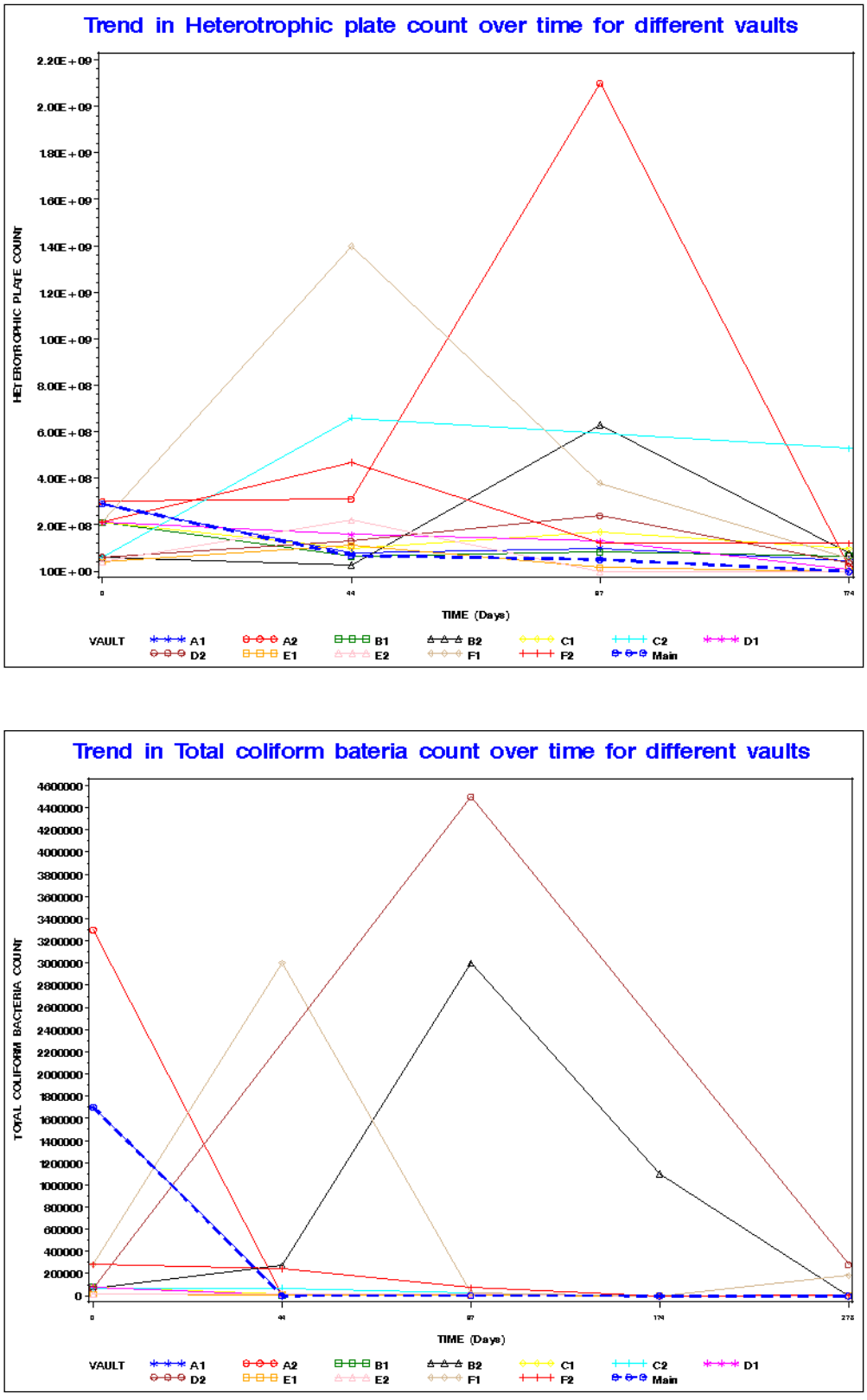


Figure 5.41: Trend in indicator counts over time for different vaults

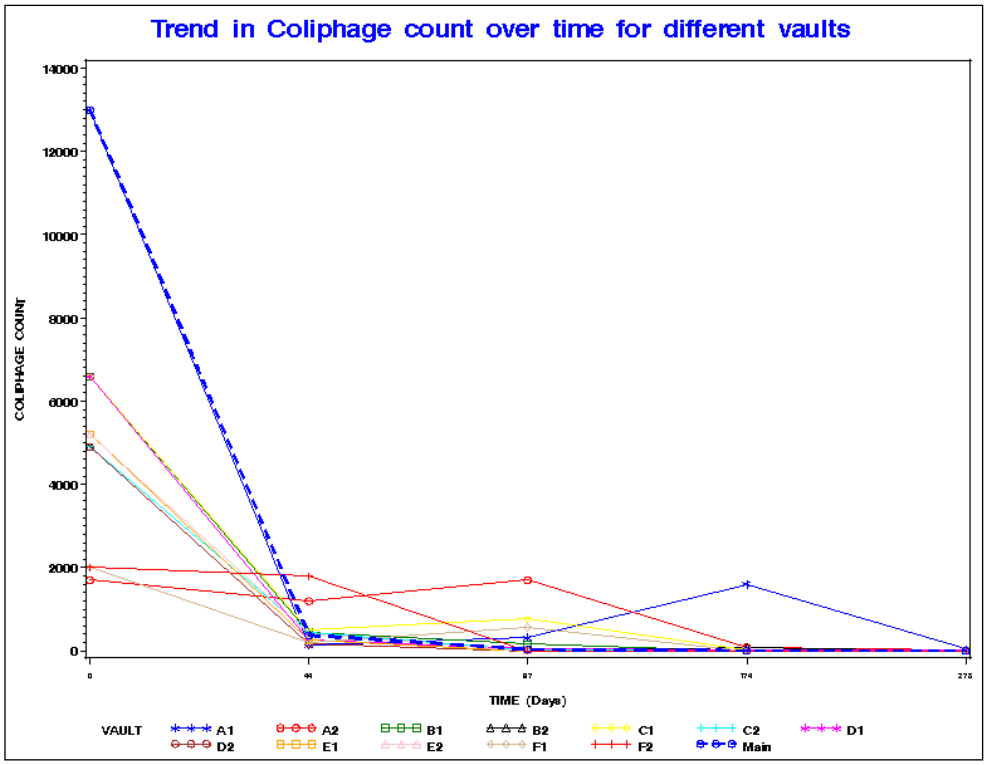


Figure 5.41 (cont): Trend in indicator counts over time for different vaults

Conclusions:

Overall, no effect of lid type and the absence or presence of a ventpipe can be seen in the results, but there is evidence that the type of bulking agent plays a role. Generally the soil mix shows a much better performance than the other mixes with regard to the objective (i.e. rate of pathogen die-off) irrespective of whether the soil mix is closed in a vault (vault A1) or on the open heap exposed to the elements. The ash and soil mixes appear to have the second best rate of pathogen die-off, while the NaOH and wood mixes appear to perform the worst of all the mixes in terms of pathogen die-off rate.

The importance of keeping the vaults dry is evidenced by the relatively poor performance of the NaOH mix with regard to the rate of pathogen destruction compared with most of the other vaults. From a study of the literature, the addition of a pH elevating agent should be one of the most effective treatments for the destruction of pathogens in faecal material. The beneficial effect of the additive was in this case, however, countered by the ingress of a large quantity of water into the particular vaults, as mentioned earlier in the chapter. The moist conditions favoured continued pathogen survival. Care should therefore be taken during design and construction of urine-diversion toilets to divert storm- or groundwater away from the vaults, and toilet users need to be made aware that no wastewater or other liquids should be poured into the vaults.

The selection of the type of ash for use as a bulking agent is important. In this particular case the pH of the faeces/coal ash mixture was virtually neutral and the result in terms of pathogen destruction was not as good as the best performing faeces/soil mixture,

although better than the wood shavings mixture with the lower pH. It is possible that a wood ash with a higher pH (±10) would have performed the best in this case. Ashes from different sources are seen to have different pH values, and this needs to be recognised during the project planning process. Local sources of ash (e.g. cooking fires) should be analysed for pH value and suitable recommendations made to the toilet users.

The material is likely to be microbiologically stable at the end of the recommended storage period, as evidenced by Figures 5.35 to 5.37. Should the material be used for agricultural purposes after this period, it is therefore unlikely that watering of crops grown in the faecally amended soil will pose any danger to crop handlers or consumers, or that any pollution of water resources will take place.

5.5 OVERALL DISCUSSION OF TEMPERATURE AND MICROBIOLOGICAL RESULTS AND CORRELATION WITH OTHER RESEARCH

As before, the following discussion should be seen in the light of the local climate in eThekwini – sub-tropical, mild to cool winters and warm summers with high humidity. It is likely that different results would be obtained in another climatic zone, for example a dry and hot area.

Influence of ventpipe:

Although there appears to be some correlation between moisture content and the presence of a ventpipe in vaults A1 and F1, ventilation of the vault did not result in any meaningful difference in either the vault temperature or the rate of pathogen die-off. Conventional ventilation (i.e. a ventpipe) should therefore not be considered to contribute anything other than a reduction of odours and flies in the toilet superstructure.

Influence of vault lid material;

The lid material, and by inference also the material of the vault walls, has no significant effect on the temperature of the heap or the associated rate of pathogen die-off. This implies that any suitable locally available building material may be used, which has favourable cost implications.

Type of bulking agent:

While the type of bulking agent used does not significantly influence the temperature of the faecal material, it does have an effect on the rate of pathogen die-off. Although the data obtained from the field experimentation implies that the ordinary soil mix gives the best results, it cannot (in this case) be ascribed to pH effects and is more likely to be the result of competing microorganisms in the soil itself. Furthermore, the (relatively) poor performance of the ash and NaOH mixes can be ascribed to external influences in this case – the pH of the ash was not as high as expected while the effects of the high pH of NaOH were negated by the presence of water in the particular vaults. Normally these are considered good additives and should be used wherever possible. While the use of NaOH is probably not economically justifiable, and will in any case not be readily available in rural areas, the use of ash from domestic cooking fires has proven to be effective in many

countries (Austin 2000; Austin 2001; Esrey and Andersson 2001; Gough 1997; Guzha 2004; Moe et al 2001; Proudfoot et al 2002; Winblad 1996).

Perhaps the most important observation regarding bulking agents is that where other suitable materials are not available (e.g. where households have access to electricity and may thus not have any ash) the addition of soil will promote satisfactory pathogen die-off.

Influence of sunshine and rain:

The main heap performed among the best in terms of pathogen die-off. While the heap was subject to frequent soaking by rain, it always appeared to dry out fairly rapidly and the moisture content at times of sampling was generally low compared with the vaults. It is surmised that the relatively good pathogen reduction evidenced here is as a result of the alternate wetting/drying and heating/cooling cycles, as well as UV light on the surface of the heap. This suggests that the best treatment, especially in hot, dry areas, could be obtained simply by open-air exposure. This has important implications for entrepreneurs involved in collection and further treatment (e.g. compost manufacturing) of faecal material from urine-diversion toilets, as expensive sheds or covered areas may not be required. Eco-villages using urine-diversion toilets could also beneficially use an open-air space for storage and further treatment (e.g. co-composting) of faecal material.

Rate of pathogen destruction:

The faecal material was, as previously noted, between one and three months old when collected from the UD toilets, after which the various samples were mixed together to produce a homogenous product. While it is not known what the relative “age” of the final, mixed, product was at the start of experimentation, initial pathogen counts were high enough to suggest a comparatively “fresh” product. However, some time (say three months) should, for safety, be added to the time for achieving the pathogen die-off indicated by the results of the experimentation. In the majority of cases, faecal coliform bacteria were reduced to below 10^3 per g (the South African limit for use of sewage sludge in agriculture (WRC 2006) which is also the USEPA limit) within 6 months from the start of experimentation, while viable *Ascaris* eggs were seen to be reduced to zero within 3 months, thus also fulfilling the South African requirement of <0,25/g. Cryptosporidium oocysts, Giardia cysts, as well as *Entamoeba* and *Taenia* eggs were also seen to be reduced significantly within six months. A total storage period of 9 to 12 months is thus considered sufficient.

Arnbjerg-Nielsen et al (2004) conducted a study in Denmark where scenarios associated with faeces use, such as emptying of the faecal container and distribution of the material in the garden, gardening itself as well as recreational activities in the garden were considered. They concluded that 12 months of storage of faeces without additional treatment (such as addition of pH elevating compounds) were not sufficient for inactivation of pathogens to acceptable levels (yearly risk of infection $<10^4$). Ascaris were seen to constitute the highest risk. In the eThekwini experimentation, however, even the addition of soil only and storage for a shorter time proved to be acceptable.

Moe and Izurieta (2003), in a study conducted on double-vault urine-diversion toilets in El Salvador, found that 81% of biosolids sampled met the USEPA faecal coliform standard of 10^3 per g within 12 months of storage, thus supporting the eThekwini research results.

However, only 59% of their samples met the USEPA *Ascaris* standard of 1 ovum per 4g in this time.

Stenström (2001) reported that Vietnamese and Chinese experiments on urine-diversion toilets showed a 100% reduction of viability in *Ascaris* ova after a storage period of six months. Further research showed reductions of 4 to 6 $\log_{10}$ in faecal enterococci within six months and 5 to >6 $\log_{10}$ in bacteriophage virus. These results therefore support the eThekwini observations.

Redlinger et al (2001b) report on research carried out in Chihuahua, Northern Mexico, where the climate is dry and sunny all year round, with hot summers and cool winters. According to these authors, solar exposure of the toilets was important for raising the temperature of the faecal material, with 95% of the samples complying with a USEPA class A rating being from toilets with good solar exposure. They maintained that class A biosolids were 10,2 times likelier to occur in these toilets than in toilets without good solar exposure. The low moisture content that resulted from the solar heat was found to promote pathogen destruction. This was not found to be the case in eThekwini. The authors noted that the year-round dry climate was an important factor in desiccation of the faecal material. Finally, the authors recommended that the faecal material not be used before six months of storage and that no six-month material should be disposed of on edible plants or in areas where persons could be exposed via dust or direct contact. This also supports the eThekwini observations.

Proudfoot et al (2002), in research conducted in informal settlements around Harare, Zimbabwe, found a complete reduction of *E. coli* in urine-diversion toilets within 8 weeks. They also found that Streptococci and Clostridium organisms were in most cases eliminated in 16 weeks and suggested that the faecal material would be safe to use within 4 to 6 months of storage. This is about half the period suggested above.

From the temperature data, particularly Figure 5.18, as well as the microbiological results, it is evident that certain areas of the heaps are colder than others, which may delay pathogen inactivation in these localised “pockets” of material. In order to obviate this problem the heaps would have to be turned regularly so that a homogenous temperature, as far as possible, is obtained throughout the heap.

Taking all the above into consideration it would appear that there is a great deal of convergence in the research results, both locally and abroad. Vaults of UD toilets should therefore be sized for a storage period of 12 months from last use. Further design guidelines are presented in chapter 6.