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SUSTAINABLE DEVELOPMENT OF WATER RESOURCES, WATER SUPPLY AND ENVIRONMENTAL SANITATION

Operational safety of urine diversion toilets in Durban, South Africa

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There are approximately 50 000 urine diversion (UD) toilets in South Africa. Emptying the vaults implies that the faecal material must be handled, usually with spades or rakes. Should the material be used for agricultural purposes then further handling must of necessity take place. There are currently no guidelines in the country on the safety aspects of handling faecal material from UD toilet vaults, particularly regarding the storage period required for achieving satisfactory pathogen die-off. This paper describes a research project carried out in Durban with the aim of establishing a recommended vault storage period for the material. The research concluded that the toilet vaults should be sized for a minimum storage period of 12 months after last use.

Introduction

Urine diversion (UD) sanitation technology was first implemented in South Africa in 1997. Since then approximately 50 000 such toilets have been built in the country (the majority in the Durban area) and the number continues to increase as local authorities and communities become aware of their advantages compared with VIP toilets, e.g. shallow vaults that are easily emptied, ease of disposing of faecal material, no odours and the possibility of incorporating the toilet into the dwelling. However, despite much research having been carried out internationally as well as locally, various questions still remain, particularly on the health aspects of operation, maintenance and excreta use or disposal. Not enough is known about the dehydrating processes taking place inside the faeces vault, and there is still disagreement on safe retention periods and microbiological stability of the final product. The roles of dryness, pH, temperature and time in pathogen die-off also need to be further clarified.

It is important to treat and contain human excreta as close to the source as possible before it gets introduced into the environment (WHO 2001). Human health is always the primary objective of any sanitation system; it must minimise the risk of disease and be capable of destroying or isolating pathogens. A need exists for documentary evidence to support various claims about different storage periods for ensuring pathogen die-off and safe handling of biosolids (Peasy 2000).

Handling of faecal material is an aspect inherent in the operation of UD sanitation systems, because emptying of the vaults is usually done using hand tools. If the faecal material is also used for agricultural purposes then further handling must of necessity take place. As such, there is a health concern, both for persons handling the material and for the wider public who may be consumers of the fertilised crops. It is therefore necessary that these health concerns be quantified, in order that proper regulation may take place. Information should be collected concerning the safety of handling faecal material collected from the toilet vaults, so that sound recommendations can be made concerning the optimum storage period required. This paper describes experimental work carried out in Durban with the aim of establishing this criterion.

Materials and methods

UD toilets built by the municipality's Water Services department are of the double vault type (see Photograph 1). These consist of a brick and mortar base and superstructure with a plastered finish and a precast concrete floor slab. The vault covers are also precast concrete with vertical opening sections at the rear. For the purposes of this research a new base set (i.e. two vaults) was constructed in a secure area. Vault A was provided with a ventpipe while vault B had none. No superstructure was provided as it was not the intention that these would be "live" toilets. Because controlled conditions would be required for the experiment it was intended to extract faecal material from a number of working UD toilets in the field and insert it into the vaults. The faeces were already mixed with soil, as this is sprinkled on the faeces by toilet users as a covering agent. In most other parts of the country ash is used, but because most of the residents in the Durban area enjoy electricity for cooking, no fires were made and thus no ash was available.

Faecal material was collected from various UD toilets in early June 2004. Due to the difficulty of working with fresh faeces, these were discarded and the final material selected was generally between one and three months old. The material was thoroughly mixed on a concrete slab (Photograph 2) and each vault loaded with 160kg in a heap. Some material was left behind on the slab exposed to the weather as a control (Photograph 3).



Photograph 1. Typical double vault urine diversion toilet in the Durban area



Photograph 2. Mixing the faecal material prior to vault insertion



Photograph 3. The control heap of faecal material

Temperature probes were inserted into the heaps inside the vaults. These were first calibrated and connected to a data logger that 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 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.

Samples of the material in the vaults and the main heap were taken 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 $t=278$. Sampling was done using a specially fabricated cylindrical coring device (Photograph 4). The device was inserted into the heap while being simultaneously rotated, thus cutting a core of material. The core was then expressed into a sterilized sample bottle (Photograph 5). Equipment was cleaned with 70% ethanol before the following sample was cored.



Photograph 4. Coring device and sample bottles



Photograph 5. Expressing cored material into the bottle

Sample preparation

Samples were prepared for testing total coliform bacteria, faecal coliform bacteria, faecal streptococci bacteria and *Ascaris Lumbricoides* eggs.

For the bacterial determination, 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* enumeration, the sample was first diluted with physiological salt solution until it was just liquid enough to be finely milled in a homogeniser. A few drops of anionic washing medium were added before the homogenising process. 100g of the sample was used to determine the moisture content and the remainder was divided into 10g portions after mixing with physiological salt solution to prevent them drying out.

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.

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.

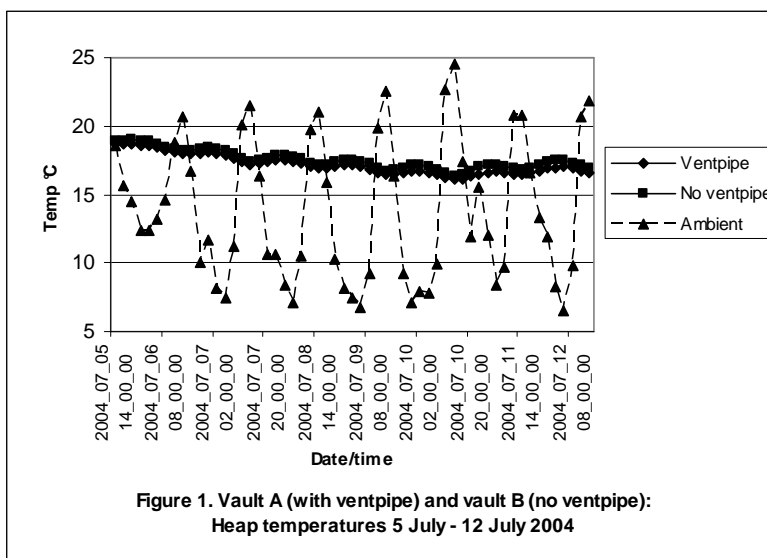
Ascaris Lumbricoides

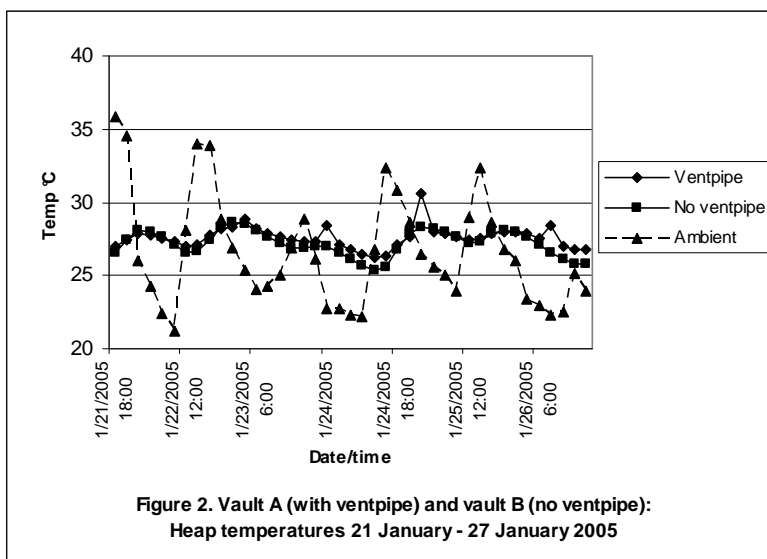
Enumeration of eggs was carried out according to the method of Franck (1988) using a modified Visser filter.

Experimental results

Temperatures

Examples of temperature recordings for the coldest week in July (winter) and the warmest week in January (summer) are illustrated in Figures 1 and 2.





In both summer and winter the heap temperatures fluctuated in a narrow band of about 3°C while the diurnal ambient temperature varied by up to 18°C. There was a negligible difference between the heap temperatures of vaults A and B in both cases.

Pathogen die-off

The analyses of samples taken from the two vaults and main heap over the experimental period are reflected in Tables 1-3. The parameters are also illustrated graphically in Figures 3-7.

Table 1. Microbiological analyses for vault A (with ventpipe)

Parameter	t=0	t=44	t=97	t=174	t=278
Total coliform bacteria count per g	1.7E+06	1.4E+04	2.8E+03	214	<3
Faecal coliform bacteria count per g	9.1E+05	1.2E+04	1.1E+03	88	<3
Faecal streptococci bacteria count per g	3.0E+05	2.2E+04	8.6E+03	4.0E+03	
pH	7.06				
Moisture content %	12.5	10.1	9.6	6.4	12
<i>Ascaris</i> eggs per 10g dry weight	237*	344* / 13**	277* / 1**	64* / 0**	

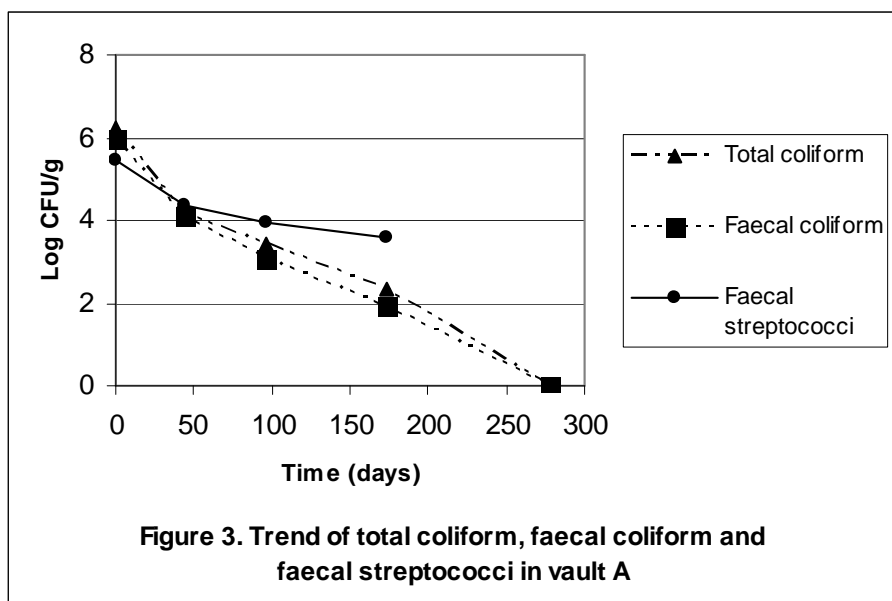
Note:

* indicates total number, i.e. viable plus non-viable

** indicates viable only

blank cells indicate no analysis done

The bacterial indicator numbers for vault A in Table 1 and Figure 3 showed a constant downward trend. Total coliform bacteria decreased by 6 log₁₀, while faecal coliform bacteria and faecal streptococci bacteria decreased by 5 log₁₀ each. The moisture content of the heap also showed a constant downward trend except for the final period when rainwater got into the vault, thus causing an increase. *Ascaris* counts decreased to zero over the experimental period. The pH of the mix was approximately neutral.

**Table 2. Microbiological analyses for vault B (no ventpipe)**

Parameter	t=0	t=44	t=97	t=174	t=278
Total coliform bacteria count per g	3.3E+06	5.0E+03	5.6E+03	882	<3
Faecal coliform bacteria count per g	2.0E+05	1.5E+03	3.9E+03	235	<3
Faecal streptococci bacteria count per g	2.9E+05	1.1E+05	9.8E+03	7.5E+02	
pH	7.18				
Moisture content %	16.4	14.5	15.5	15.2	15.0
<i>Ascaris</i> eggs per 10g dry weight	237*	71* / 0**	68* / 0**	60* / 0**	

Note:

* indicates total number, i.e. viable plus non-viable

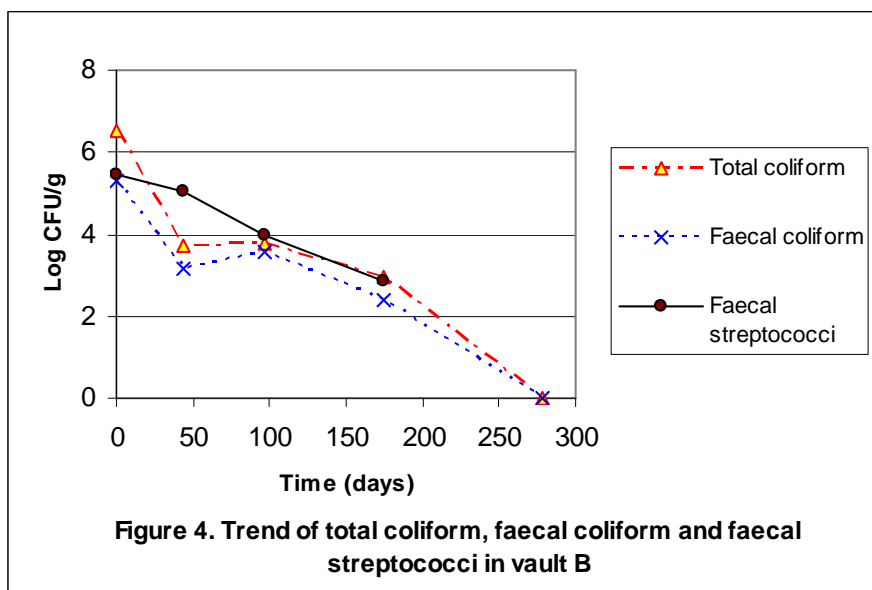
** indicates viable only

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The bacterial indicator numbers for vault B in Table 2 and Figure 4 showed a downward trend. Total coliform bacteria decreased by 6 log₁₀, while faecal coliform bacteria and faecal streptococci bacteria decreased by 5 log₁₀ each. The moisture content differed very little over all samples. *Ascaris* counts decreased to zero over the experimental period. The pH of the mix was approximately neutral.

The bacterial indicator numbers for the main heap in Table 3 and Figure 5, although showing a tendency to fluctuate up and down, showed a general downward trend over the experimental period. Total coliform bacteria decreased by 6 log₁₀, while faecal coliform bacteria and faecal streptococci bacteria decreased by 5 log₁₀ each. The moisture content fluctuated as a result of the heap being exposed to the weather. *Ascaris* counts decreased to zero over the experimental period. The pH of the mix was approximately neutral.

After the end of the experimental period (278 days) a sample of the main heap was rehydrated with sterile water for a period of one week (Figure 6). The figure shows that neither total coliform nor faecal coliform showed any growth, which suggests that the faecal material was microbiologically stable and that no pathogens had survived.

**Table 3. Microbiological analyses for the main heap**

Parameter	t=0	t=44	t=97	t=174	t=278
Total coliform bacteria count per g	1.70E+06	270	2.3E+03	126	<3
Faecal coliform bacteria count per g	9.1E+05	270	1.2E+03	60	<3
Faecal streptococci bacteria count per g	3.0E+05	3.8E+04	9.1E+04	5	
pH	7.06				
Moisture content %	12.5	6.8	17.3	16.9	5.3
<i>Ascaris</i> eggs per 10g dry weight	201*	174* / 0**	123* / 0**	62* / 0**	

Note:

* indicates total number, i.e. viable plus non-viable

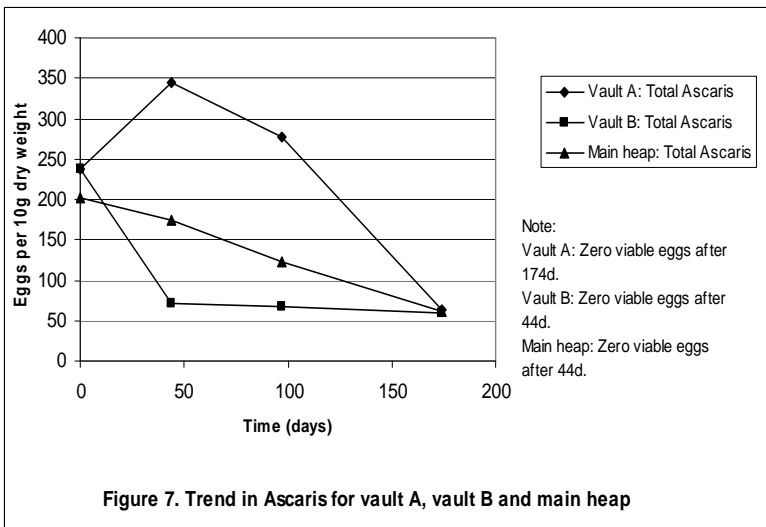
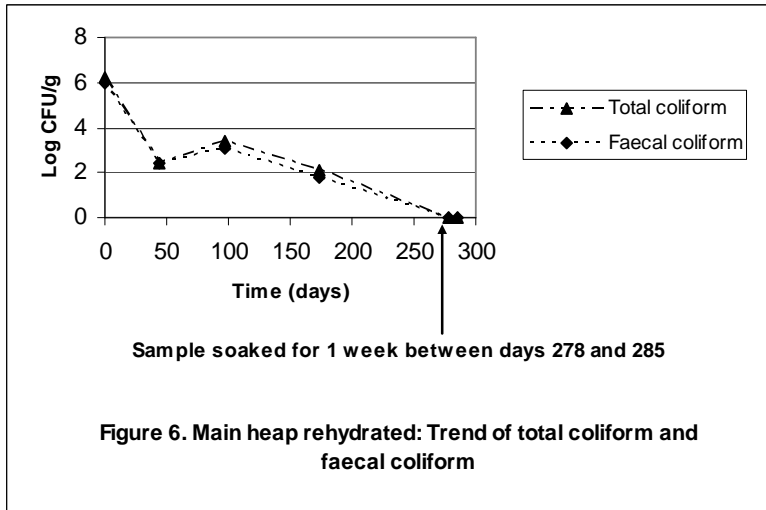
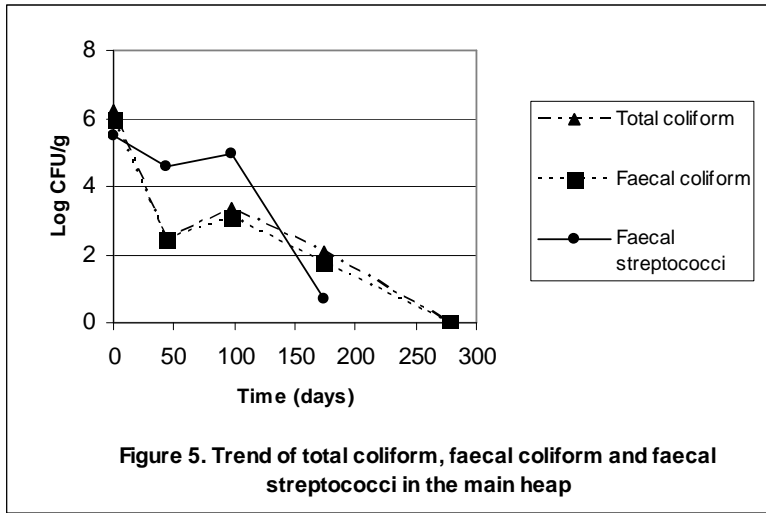
** indicates viable only

blank cells indicate no analysis done

The *Ascaris* numbers in Tables 1-3 and Figure 7 illustrate a continual downward trend, except for vault A where a localised upward fluctuation appeared at day 44, after which the downward trend continued. This upward fluctuation, as well as those in Figures 4 and 5, can probably be ascribed to the fact that each sampling was carried out at a different point in the heap where local conditions such as moisture or quantity of faecal material in the faeces/soil mix could have been different from the other sampling points. These fluctuations should therefore not be seen as significant. The overall trend in *Ascaris* egg numbers is clear, with no viable eggs remaining from 44 days for vault B and the main heap, and at 174 days for vault A.

Discussion and conclusions

The following discussion should be seen in the light of the local climate in Durban – 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 hot and dry area.



1. Influence of ventpipe:

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. It is, however, possible that forced aeration, especially in a hot climate, would play a role.

2. 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 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 rapid pathogen destruction (above about 55°C) by artificial means, the temperature should remain high and not be subject to large daily fluctuations. A practical means of achieving this increased temperature should be investigated.

3. Influence of UV light:

The main heap performed somewhat better than the two vaults in terms of rate of pathogen die-off. The effect of UV radiation on pathogens is well known. 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 not significantly different from that in the two vaults. This suggests that satisfactory treatment, especially in hot, dry areas, could be obtained simply by open-air exposure in a secure place.

4. 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 it was mixed together to obtain a homogenous product. While it was 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. Faecal coliform bacteria were, within six to nine months from the start of experimentation, reduced to below the South African maximum limit for use of sewage sludge in agriculture of 10^3 per 10g. Viable *Ascaris* eggs were reduced to zero within three months, thus also fulfilling the South African requirement of 0 per 10g.

5. Recommended size of vaults:

In the Durban area of South Africa, in order to achieve sufficient pathogen die-off for safety of handling faecal material, UD toilet vaults should be sized for a storage period of 12 months from last use. In the hotter, drier areas of the country it is likely that this could be reduced to between six and nine months.

References

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