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DESIGN AND OPERATION CRITERIA FOR URINE-DIVERSION ECOLOGICAL SANITATION SYSTEMS WITH PARTICULAR REFERENCE TO PUBLIC HEALTH

by

LORIMER MARK AUSTIN

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SUMMARY

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Supervisors:	**Prof E Horak** **Prof TE Cloete**
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SANITATION, PUBLIC HEALTH AND THE ENVIRONMENT

The approach to sanitation worldwide should be ecologically sustainable, i.e. concerned with protection of the environment. This means that sanitation systems should neither pollute ecosystems nor deplete scarce resources. It further implies that sanitation systems should not lead to degrading water or land and should, where possible, ameliorate existing problems caused by pollution. More research and better designs are needed. Human excreta can be rendered harmless, and toilet designs that do this in harmony with agricultural and social customs hold promise for the future.

Problems with conventional sanitation systems have been shown to include inadequate institutional capacity to deal with the sanitation process, a fixation with providing either a full waterborne system or a VIP toilet, the social acceptability of various systems, and the perception that dry, on-site sanitation systems are inherently inferior. The basic purpose of any sanitation system is to contain human excreta (chiefly faeces) and prevent the spread of infectious diseases, while avoiding damage to the environment. An alternative sanitation technology known as urine-diversion (UD) performs these functions with fewer operational and maintenance problems than those associated with conventional VIP toilets, (for example, it is a major and expensive operation to desludge full pits, which is not the case with UD toilets as the vaults can be quickly and easily emptied using hand tools) and also provides a free, easily accessible and valuable agricultural resource for those who wish to use it. This technology represents one aspect of an approach, or philosophy, termed "ecological sanitation" or "ecosan." Key features of ecosan are prevention of pollution and disease caused by human excreta, treatment of human excreta as a resource rather than as waste, and recovery and recycling of the nutrients. In nature, excreta from humans and animals play an essential role in building healthy soils and providing valuable nutrients for plants. Conventional approaches to sanitation misplace these nutrients, dispose of them and break this cycle.

UD systems have been successfully implemented in many countries, including South Africa where more than 60 000 of these toilets have been built since 1997. However, despite much research having been carried out internationally and 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 destruction also need to be further clarified. In addition, it is critically important that toilet users are able to operate and maintain their systems easily and safely, particularly while emptying the vaults and recycling or otherwise dealing with the contents. Engineers need to understand and take all these issues into consideration before they can properly design and implement sustainable UD sanitation systems.

It is therefore important to develop guidelines for sanitation practitioners that set out best practices for construction and operation of UD toilets. Construction recommendations are important because good construction facilitates easy operation, and also promotes rapid pathogen destruction. Easy operation in turn directly influences the health risks associated with removing faecal material from the vaults.

Handling of faecal material is an aspect inherent in the operation of UD ecological sanitation systems, because emptying of the vault 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 the person(s) 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.

CONCLUSIONS FROM THE LITERATURE REVIEW

The primary aim of sanitation is to prevent the transmission of excreta-related diseases. However, with all sanitation systems there is a risk of disease transmission related to the handling or use of the end product. Therefore, even a well functioning system could enhance pathogen survival and lead to an increased risk of disease transmission for those handling the end products or consuming crops fertilised with them. A greater understanding of pathogen die-off in dry sanitation systems is required where handling and/or use of excreta are expected.

Pathogen destruction in dry sanitation systems, particularly in the vaults of urine-diversion (UD) toilets, is mainly dependent on storage time, pH, temperature, humidity, moisture content, organic content of the faecal material, and type of bulking agent added. It is of utmost importance to ensure that the material is safe to handle. This implies that the primary treatment in the vault should, as far as possible, ensure the required level of safety.

While much research has been carried out internationally into pathogen destruction in the vaults of UD toilets, the same cannot be said of South Africa. There is also a wide range of results and conclusions, with recommended storage times varying from six months to two years. Construction and operational guidelines are required in order to assist practitioners in these and other respects.

Sound management practices could play an important role in reducing the health risks involved in emptying the vaults of UD toilets and the disposal or further use of faecal material. From the public health viewpoint, it is necessary to reduce, as far as possible, the risk of handling faecal material. To do this, a better understanding of the factors influencing pathogen die-off in the vaults is required.

FOCUS OF THIS THESIS

The primary aim of this thesis is to investigate the efficacy of various methods aimed at enhancing pathogen destruction in the vaults of UD toilets, with the aim of (a) establishing the best combination of factors/methods, in particular the vault storage period required, and (b) producing guidelines for the construction, operation and regulation of these systems. The overall purpose of the research is to establish safety criteria for handling of faecal material from UD toilets.

FIELD TRIALS: MICROBIOLOGICAL EFFECTS ON FOOD CROPS FERTILISED WITH FAECAL MATERIAL FROM URINE-DIVERSION TOILETS

Recycling excreta to soils reduces the need for chemical fertilisers; however, pathogens are recycled to humans if improper agricultural practices are followed. Concerns about using faecal material include higher pathogenic content in developing countries compared to that in developed countries. This material, as well as that from other sanitation alternatives in small-scale systems, demands more personal involvement from the users (including handling), which constitutes a higher human exposure level compared to that from conventional piped systems. Nevertheless, it is considered that where the material can improve agricultural productivity, it can contribute to improving the nutritional status of the population, thus improving public health.

Although ecosan technology is spreading all over the world, and with it the recycling of excreta to soils, only a few researchers have addressed the problems associated with the revalorization practice or documented the pathogen die-off. Moreover, little data about the microbial quality of ecosan faecal material from developing countries (where the health risks are the highest) are available. The objective of this research was thus to investigate the potential health risks of using faecal material in agriculture by determining the pathogen uptake on the surfaces of the edible portions of the crops.

Faecal material of between one and three months old was extracted from a number of UD toilets in the eThekwini (Durban) municipal area. This was used primarily for the experimental work described in the next section, but for the purposes of this particular experiment it was first left in a heap in the open air for a further four months. Thereafter it was used as a soil amendment in the cultivation of spinach and carrots. Detailed microbiological tests were conducted on this material as well as on the in situ soil before sowing and after harvesting, on the irrigation water, and on the harvested crops.

Applying different rates of material to spinach and carrots, two common edible crops, it was found that the bacteria and fungi content were only noticeable for the higher application rates (>35t/ha), while the helminth ova content varied, both in leaves and stems, depending on the quantity of material applied. Helminth ova content was, for both crops, more prevalent in leaves, suggesting that the ova adhere preferentially to plants rather than soil.

It was thus illustrated that there is a health implication involved in growing edible crops in soils amended with ecosan biosolids. Even if in this case the spinach and carrots were cooked before consumption, normal handling of the crops during harvesting and preparation could have caused infection if personal hygiene was unsatisfactory. It is therefore important that crop growers and consumers, as well as proponents of biosolids use, are aware of the storage and treatment requirements for ecosan biosolids before these are applied to soils where crops are grown.

DETAILED INVESTIGATION INTO VAULT PROCESSES

It is hypothesised that the most advantageous approach to pathogen destruction in a UD toilet vault is to maximise the effects of various environmental factors, e.g. high pH, high 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). Faecal material was obtained from UD toilets in the eThekwini area, as described above. 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. During the coldest week in winter the mean heap temperatures averaged 16,8°C, while the minimum and maximum averaged 14,8°C and 18,8°C respectively. During the warmest week in summer mean heap temperatures averaged 27,6°C, while the minimum and maximum averaged 25,6°C and 29,3°C respectively.

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. In the vaults, total coliform reduced by 3 $\log_{10}$ (99,9%) at between 130 and 250 days, faecal coliform between 100 and 250 days, and faecal streptococci from 125 days and longer. In the main heap, these times varied from 115 days for both total and faecal coliform to 140 days for faecal streptococci. Viable *Ascaris* ova were reduced to zero between 44 and 174 days in the vaults and by 44 days in the main heap.

The conclusions drawn from the experimentation were the following:

- *Influence of ventpipe*
  Ventilation of the vault by means of a ventpipe does 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 and alternate 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.

RECOMMENDATIONS FOR CONSTRUCTION, OPERATION AND REGULATION OF URINE-DIVERSION TOILETS

The standard of UD toilets in South Africa varies greatly. While there are many good examples of the technology, there are also many that have been ill-conceived and are badly built and poorly operated. Project implementers are responsible for the quality of sanitation schemes and should be equipped with the necessary information to oversee the process.

The guidelines are aimed at providing implementers with, firstly, the necessary technical information to build good quality UD toilets and, secondly, the basic operation and maintenance tasks that should be conveyed to the toilet owners. Basic regulatory guidelines for the responsible authorities are also given. The guidelines are intended to be a stand-alone document and some repetition of information from earlier chapters is thus unavoidable.

The technology of urine diversion is introduced, followed by basic design and construction guidelines, including drawings, for the superstructure and vault of a UD toilet. Both single- and double-vault toilets are discussed. A number of photographs are also provided, illustrating good and bad building practices. Further aspects discussed are requirements for urine pipes and ventilation.

Operation and maintenance of UD toilets are subsequently covered. Topics discussed are dehydration, odour, fly control, cleaning of the pedestal, disposal of anal cleansing material, urine collection and disposal, clearing of blockages in urine pipes, and faeces management.

The above guidelines are aimed at designers, builders and toilet users. However, organisations responsible for administering public and environmental health, such as Departments of Health, Environmental Affairs, etc, as well as the local and regional authorities that actually implement the sanitation schemes, should become actively involved in regulating the operation of UD toilets, particularly the removal and disposal of faecal material. Some regulatory guidelines are therefore also included to assist these organisations to set uniform (high) standards in their respective jurisdictions.

RECOMMENDATIONS FOR FURTHER RESEARCH RELATED TO THIS THESIS

It is deemed important that the field trials conducted in the various vaults as described earlier are repeated in other climatic areas, for example a hot and dry area, as it is likely that different results regarding recommended minimum storage periods will be obtained. This should be supplemented by trials involving co-composting of the faeces mix with other organic material, in order to compare the efficacy of this method with the dehydration process. Further, vault lids made of PVC should be tested for enhancing heat gain in the vaults. Finally, long-tem measurements of heap pH should be made in order to ascertain if high pH amendments (wood ash, lime, etc) do in fact maintain their initial pH level.

Additional field trials, similar to those described earlier for spinach and carrots, should be undertaken with a view to making recommendations regarding maximum application rates of faecal material. These should consist of food crops where the edible portions are either in or near to the soil, such as beetroot, onion, potatoes, tomatoes, etc. Trials involving urine should also be considered in order to determine the most advantageous application rate for the various crops.

Another important topic is recommended for further research on the subject of UD toilets. At present, virtually all the UD toilets built in the country have been for communities on the lower end of the income scale and who previously had no formal sanitation facility at all or, at best, an unimproved pit toilet. Research carried out by CSIR in a number of communities has revealed people's resistance to handling their faecal material, while in others it has not been a problem. There is often a general viewpoint in a village that "the municipality must take the faeces away."

However, willingness has also been expressed in some villages to pay for a faeces removal service. For instance, this has borne fruit in an area of Kimberley with UD toilets where householders pay a local resident to remove the faecal material on a regular basis. This is done by means of a wheelbarrow, and the material is stockpiled at a nearby approved facility from where it is destined for co-composting with other municipal waste.

However, this has not yet been attempted on a large scale in an area with hundreds, or even thousands, of UD toilets. While a theoretical desktop study has been carried out on the feasibility of setting up a large-scale faeces collection concern, such an enterprise does not yet exist in the country. It is suggested that one be set up utilising a horse- or donkey-drawn cart in a village, or group of villages, with sufficient UD toilets available to ensure that a viable business can be conducted. The cooperation of the particular local authority will be required.

If successful faeces collection/disposal services could be established in areas with UD toilets it would greatly enhance the social acceptability, and therefore the viability, of this sanitation technology.

KEY WORDS

Bulking agent
Dehydration
Ecological sanitation
Ecosan
Faecal material
Fertiliser
Guidelines
Health risk
Human excreta
Pathogens
Sanitation
Storage period
Toilets
UD
Urine diversion

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SOLI DEO GLORIA

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“Science and technology are neither hostile nor friendly towards human development. They provide tools, and it is the way in which these tools are used by decision-makers, politicians and others that determine whether they are destructive or constructive. The mistake made by scientists, technologists and engineers is that they have not educated people on how to use the tools they have created and the implications of the various uses.”

UNCHS, Habitat II: City Summit, Istanbul, June 1996