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A novel sanitation model based on EcoSan philosophy

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Zero Discharge Toilet System (ZDTS) which incorporates EcoSan philosophy and the advantages of water flushed system has been described in this paper. The system uses a solid-liquid separator and a thin flat filter which enables recycling for flushing the toilet pan and separate collection of urine and fecal slurry. Inorganic liquid or solid fertilizer is obtained by concentrating the liquid residue. The solid residues containing around 2 % solids are first processed using activated composting and finally polished to obtain quality organic manure using vermicomposting. The quality of product is much superior as indicated by higher water holding capacity and much lower total carbon, volatile solids, coliforms and C/N ratio. The zero discharge toilets are well accepted among users. The residues generated per person are about 1/5th as compared to conventional toilet system. ZDTS has lower capital cost and higher NPV as compared to conventional wastewater treatment system.

Introduction

An alternative to the present practice of water based sanitation could be based on the wisdom of isolating the water bodies from human and animal excreta. The alternative practices based on minimum or no use of water for conveyance of waste to avoid entry of fecal matter into the water bodies are referred as ecological sanitation (EcoSan). EcoSan symbolizes a vision of sustainable sanitation systems based on a systematic material-flow-oriented recycling process of nutrients and water as a hygienically safe, circular and holistic alternative to conventional solutions. It recognizes the rational utilization of human excreta as a useful resource, so as to achieve the purpose of health protection of human beings and ecological balance. In EcoSan approach sanitization of human excreta and nutrient recovery is achieved by three different methods: diversion, separation and combined processing. The most commonly used ecological toilet is urine-diverting. Separation of the fecal solids from the flush water can be achieved by using an Aquatron type separator (Aquatron, 2005). Combined processing is achieved by composting toilets.

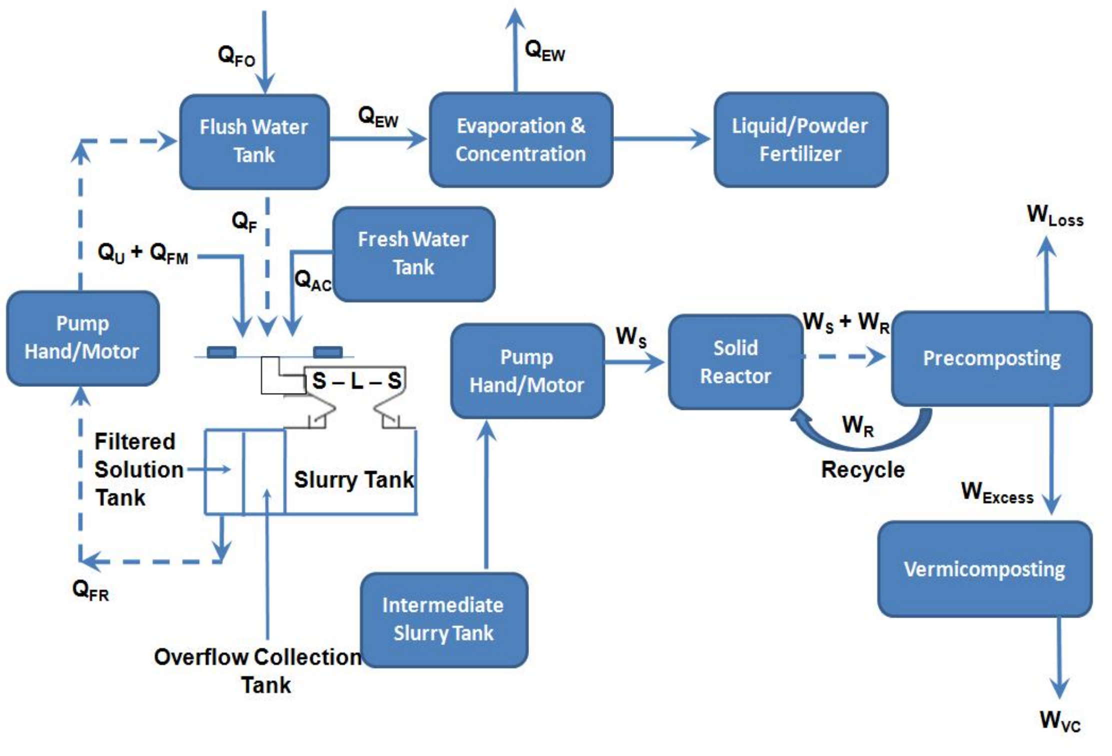
One of the key obstacles that an eco-san programme must overcome is the rational fear of human excrement, which might be referred to as 'faecophobia'. Faecophobia is a personal or cultural response to the fact that human feces are malodorous and potentially dangerous (Esrey, 1998). The foremost concern that should be considered while designing an EcoSan toilet is keeping the user end facility same as in water flush toilets, both physically and aesthetically. Urine diversion toilet seat-risers and squatting slabs are a unique innovation intended to keep vault contents dry and in some cases to allow the urine to be used as a fertilizer. These are so unfamiliar in most areas of the world that newcomers to the systems often find it uncomfortable to use (Esrey, 1998). Men are often reluctant to sit down for urinating. This would cause a loss of urine and a mixing of urine with feces (Johansson, 2001). In general people regard EcoSan as an inferior alternative: it will be smelly, fly producing and incompatible with modern living. EcoSan systems are more sensitive to bad design and management than other on-site options such as pit toilets (Johansson, 2001).

While basic principles of EcoSan are sound, a number of issues have to be addressed before the same could be adopted on a larger scale in both rural and urban setting. One of the challenges faced is to develop toilet models which are ecologically, economically and socially accepted across all traditions and religions. In an attempt to address the issues related to EcoSan practice, environmental engineering laboratory at IIT Kanpur has developed a toilet system which incorporates EcoSan philosophy and the advantages of water flushed system. The system is referred to as "Zero Waste Toilet System, ZDTS" (Tare, 2008). However, there are issues which need to be addressed before the toilet could be adopted on a large scale. Much less information is available to judge the ecological and economical viability of such models in practice. The present research, therefore, is an attempt to advance the state-of-the-art on eco-sanitation concept with the ultimate objective of proposing “water flushed zero discharge toilets” as an alternative option in management of human excreta.

The system

Concept: The system is based on the wisdom of isolating the water bodies from human and animal excreta and recognizes the fact that human faeces and urine are valuable resources for supporting agriculture. The toilets are identical to those in conventional water borne system as these are the most acceptable and known to be hygienically safe. The collection and processing of the waste, however, is entirely different from the conventional system. The solid and liquid matters are separated underneath the toilet seat itself. The liquid is passed through a micro filter and recycled for flushing the toilet; thus avoiding the excessive use of fresh (tap) water for flushing while no compromise is made on using the required quantity of liquid for completely flushing the toilet pan. This ensures that the hygiene in the toilet is of the highest standard. The excess flush solution and the solid matter are evacuated and transferred for processing to obtain valuable solid and liquid fertilizer. Eco-friendly coloring substances and specially developed microbial cultures are used to control odor in the recycled flush solution and fecal slurry. The system flow sheet is schematically represented in Figure 1 and a typical set of components involved is depicted in Photograph 1.

Pilot Project: A set of four zero discharge toilets are operational in a congested locality in Aligarh, UP, India since April 2008. Each toilet is designed for 25 users per day. Together this toilet block can be used effectively by approximately 100 people on a daily basis. The fecal slurry and excess flush solution are transferred using hand pump into covered containers which are then transported to the humanure plant. At the humanure plant the fecal slurry is mixed with the pre-compost in a cyclic manner, and after several cycles the pre-compost is vermicomposted to get quality organic manure.



Legend: Q=Liquid flow rate (l/day); W=Solid flow rate (kg/day); S-L-S=Solid-Liquid Separator.
Subscript Legend: FO=Fresh water; F=Water flushed; AC=Water used for anal cleaning; U=Urine; FM=Fecal matter; FR=Flush water recycled; EW=Excess water removed for treatment; EV=Water evaporated; S=Slurry; R=Compost used for mixing; LOSS=Loss due to evaporation and decomposition; EXCESS=Excess pre-compost produced; VC=Vermicompost produced

Figure 1. Flow diagram of zero discharge toilet system

Result and discussion

User feedback and review reports of UNICEF team suggest that the ZDTS is well received by users, sponsoring agency and the Aligarh Nagar Nigam, Aligarh, India (Mehrotra, 2008; Tare, 2008). The residues generated in two different streams, namely fecal slurry and excess flush solution, per person in ZDTS is about 1/5th as compared to conventional toilet system. The solids content in the slurry is about 1.84±0.12%. The dry weight of solids in slurry is about 28-30 g/capita/day which are in accordance with the average value of per capita feces generation reported in literature.

Nutrient Recovery from Flush Solution: The results of study on evaporation and concentration of excess flush solution reveal that the lowest evaporation rate is about 1.5 liters/sq.m/day during November through February and the highest about 7 liters/sq.m/day during the months of March through May. There was no change in the pH of the flush water. The variations in mass of TKN, phosphorous, and potassium as fraction of reduction in volume of flush solution are shown in Figure 2. About 70-75 % reduction in volume of flush solution occurs on evaporation in practice. There is essentially no loss of phosphorous and potassium throughout the cycle period. However, TKN is lost during the evaporation cycle. The loss is perhaps due to volatilization of ammonical nitrogen.

Photograph 1. Pictorial representation of the various operations involved in converting human excreta into quality manure

Processing of Slurry: The results of pre-composting (aerobic composting of mixture of fecal slurry and recycled precompost) and vermicomposting operations are presented in Table 1. Vermicomposting is done only after several cycles of mixing and pre-composting. It can be observed that pre-composting process causes significant reduction in total and fecal coliform. This is due to the loss of moisture during the precomposting process. Also, vermicompost formed by the action of earthworm is of superior quality as indicated by higher water holding capacity and much lower total carbon, coliforms, and C/N ratio. There is significant reduction in volatile solids content which is an indicator of compost maturity (Ramos *et al*, 2005). Thus, it is possible to obtain good quality organic manure by vermicomposting of human feces. In practice, loading cycles can be continued till organic content is 25% of dry weight of compost beyond which the quality of compost deteriorates in terms of moisture holding capacity and texture. The maximum number of cycles can be up to 30 (Yadav, 2008). This is beneficial as the area requirement for vermicomposting reduce with increasing cycles resulting in reduction in land requirement and cost.

Cost Benefit Analysis of ZDTS: The results of economic analysis (Table 2) indicate that the conventional system of wastewater treatment is economically unsustainable. Hence, at places where there is a scope to build zero discharge toilets these models may prove to be sustainable. This has an additional advantage of arresting the nutrient leakages into the environment by trapping into liquid/solid inorganic fertilizer and conversion of the human feces to organic manure through vermicomposting. Further developments in the technology will certainly bring down the initial costs in future. Lower capital cost and higher NPV is an advantage of zero discharge models. The entire investment could be paid back within the life time. In addition to the tangible benefits, several intangible benefits such as recovery of water through evaporation/condensation of excess flush solution, avoiding pollution from land filling of sludge produced in conventional treatment systems, etc. can be obtained.

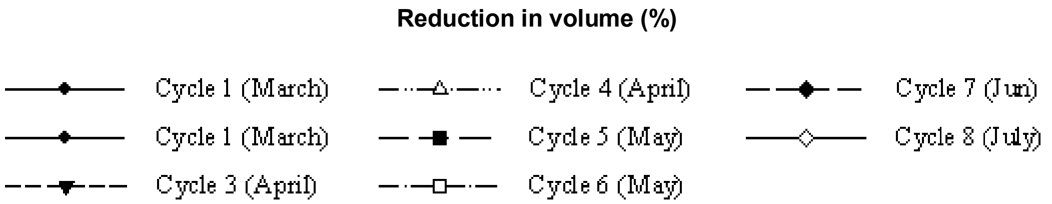


Figure 2. Variations in mass of various nutrients in excess flush solution on direct solar heating

Table 1. Characteristics of compost after 9 cycles of mixing and Vermicompost

Parameter	Slurry	Compost after 9 cycles of mixing	Vermicompost
pH	7.6-8.2	6.5-7.3	7.88-8.06
Water Holding Capacity (%)	-----	60.75±3.6	71.38±2.2
Total Coliform MPN*	10^6-10^8	10^3-10^4	<8
Fecal Coliform MPN*	10^6-10^8	10^3-10^4	<4
Total Carbon (% dry weight)	41±0.6	20.48±1.01	13.86±1.71
Total Nitrogen (% dry weight)	5.7±0.9	2.20±0.84	1.83±0.16
C/N ratio	7.19	9.30	7.57
Volatile Solids (mg/g dry weight)	850±30	410±20	250±20

* for slurry the unit is MPN/100ml. For compost and vermicompost the unit is MPN/gm.

Table 2. Cost-benefit results of different models based on economic analysis

Model	Benefit-cost ratio	Pay-back period (years)	Net present value (millions of rupees)
I (ZDTS for a Residential Colony of 500 Houses)	1.147	16	3.027
II (ZDTS for a Community Toilet Serving 500 Persons)	3.321	4	14.50
Community Toilet producing biogas	0.158	------	-2.528
Conventional STP*	0.12	------	negative

* Digar (2005); ZDTS: Zero Discharge Toilet System.

Conclusions

Based on the synthesis of the available information and the results obtained in the present studies, following inferences may be drawn.

- The ZDTS is very well accepted among users, project sponsors and local governing body. The system results in significant saving of fresh water.
- It is possible to obtain concentrated inorganic fertilizer from liquid residue using solar energy. It is also possible to recover fresh water from the liquid by using commercial evaporators.
- The quality of product formed by the action of earthworms is much superior as indicated by higher water holding capacity and much lower total carbon, volatile solids, pathogens, and C/N ratio.
- Economic analysis indicates that the conventional system of wastewater treatment is economically unsustainable. ZDTS has lower capital cost and higher NPV as compared to conventional wastewater treatment system. The entire investment could be paid back within the life time of the system.

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Keywords

Eco-Sanitation, Human Excreta Management, Solid-Liquid Separation, Zero Discharge Toilet, Inorganic Liquid/Solid Fertiliser, Vermicomposting, Cost-Benefit Analysis, Pay-Back Period.

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