

Dry Sanitation Systems

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Dry sanitation systems (waterless or composting toilets) have been used since the 1970s. Their use has received acceptance in rural regions of Europe and the United States. Some of the advantages of dry sanitation systems include their waterless nature, their low energy requirement and the creation of fertilizer as an added value product. Moreover, the use of such a system is a sustainable sanitation approach that may reduce the burden on infrastructure and provide sanitation to the 2.5 billion people worldwide who do not currently have access to it. The critical factors when choosing a dry sanitation system and their optimum parameters include aeration, moisture content (50%–60%), temperature (40–65 °C), carbon to nitrogen ratio (25–35), pH (5.5–8.0) and porosity (35%–50%). The temperature–time criterion approach is the most common method used to evaluate the stability and safety of the compost as a fertilizer. The risks of handling the waste after 12 months of composting have been calculated as low.

Keywords: dry sanitation systems ; waterless toilets ; composting toilets ; fertilizer ; sustainability

1. Introduction

The energy invested to produce drinking water for use in a flush toilet for wet sanitation is not a sustainable activity; there is a requirement for alternative sanitation options to be trialled and eventually put in place^[1]. Although the use of greywater (water waste from all household activities except sewage)^[2] and rainwater is one option currently being used to save precious drinkable water, this option is still linked to a central wet sanitation system. Therefore, an option independent from the central wet infrastructure, such as the waterless or composting toilet, which represents dry sanitation systems, remains a key option.

Dry sanitation systems have been used in the developed world since Rikard Lidstrom invented the first composting toilet in 1939 in Tyreso, Sweden. A patent was created in 1962, and the company Clivus Multrum started selling models in the 1970s.

Currently, there are manufacturers of dry sanitation systems in several countries around the world including Japan, the United States, Germany, Sweden and France^{[3][4][5][6]}. Moreover, organizations promote both the manufacture and use of waterless and composting toilets in developing countries (e.g., Semarnat & Tierramor in Mexico), and there are also manuals for their construction^[7]. The main microorganisms reported to be involved in the composting process are bacteria, actinobacteria and fungi^[8].

Dry sanitation systems have been mainly used in rural areas and those areas with water shortages^{[9][10][11]}, but their use in urban areas has also been studied^[9]. A commercially available dry sanitation system (bio-toilet) has also been used in Japan in public parks, sightseeing locations and households^[12].

The main advantages of the dry sanitation systems are the decentralization of a water system and the production of fertilizer for plants. This activity falls within the sustainability approaches required nowadays since the increasing world population (7.7 billion in 2020) is constantly adding more pressure to the already limited drinking water resources. More importantly, it could lower the number of gastrointestinal infections recorded in rural areas. Increased sanitation can be cost-beneficial; it has been observed that the return of \$1 invested in sanitation was in the range of \$11.6–22.9^[13]. However, information on dry sanitation systems is still scarce and there is a lack of peer-reviewed literature. Therefore, this review is based on the available peer-reviewed and grey literature^{[14][15]} and aims to compile information on the different types of commercially available dry sanitation systems with an emphasis on the large-capacity waterless toilets that require the least maintenance. Such models could provide an alternative for the growing ecotourism industry, ski and hiking areas, refugee shelters or rural/impovertised areas in developing countries suffering water shortages.

2.Types of Dry Sanitation Systems

2.1. Self-Contained or Central

Self-contained refers to those where the composting chamber and the toilet are one unit. Central composting toilets have a much larger tank and can be connected to multiple toilets. Vertical piping is needed to direct the faecal matter to the composting tank.

2.2. Single or Multi-Chambered Tank

Single tank refers to toilets with only one chamber and where old and fresh waste is composted. Clivus Multrum, Phoenix and Sun-Mar are examples of commercial brands with single-chamber tank toilets.

Multi-chambered composting tanks usually have two or three chambers and are designed for the different stages of composting (composting, evaporating and finishing). Carousel composting is another version with four chambers; every time a chamber tank is full, the carousel is moved to the next chamber to collect fresh waste. Thus, when the fourth chamber is filled, the waste in the first chamber has been composted and is ready to be removed^[16]. The Eco-Tech Carousel and BioLet companies have these models. Another model is a bio-drum that rotates the waste into different chambers, each for a different composting stage.

2.3. Electric and Non-Electric Toilets

Electricity is used for fans, heating systems or to create a vacuum. The fan draws the air into the toilet, eliminating odours in the bathroom. In some dry sanitation systems, the air inside the toilet is heated and evaporates the excess liquid (BioLet). When a vacuum is created to convey the waste, a water flush is also usually used. Examples of electric toilets are the Phoenix and Nature-loo.

2.4. Urine Separating and Combined Collection Toilets

It has been estimated that 500 L of urine and 50 L of faeces are produced per person annually^[17]. Separating the urine has the advantage of reducing the odours and excess liquid in the composting pile and has been recommended previously^[18]. Moreover, the urine can be used as a fertilizer due to its low pathogen concentration and high nitrogen, potassium and phosphorus content^[19]. Another study also found that vermicomposting toilets that separate the urine (or no-mix toilets) performed better in mass reduction, pathogen destruction, compost quality and operational cost than the ones not separating the waste^[20].

3. Factors Affecting Aerobic Composting Toilets

In general, a dry sanitation system works by converting the waste into compost that can later be used as fertilizer for crops. Compost is a mixture of decomposing manure or vegetable waste, where the decomposition is carried out aerobically by specific microorganisms that include bacteria, fungi and actinomycetes^{[21][22]}. Four stages of the compost can be defined: (1) the mesophilic phase, (2) the thermophilic phase, (3) the cooling phase and 4) the curing phase^[23]. In the initial decomposing stage, mesophilic bacteria such as *Escherichia coli* and other Enterobacteria produce CO₂ and energy that is partially used for reproduction and growth and the rest is released as heat, raising the compost temperature to 44 °C. This is followed by the thermophilic microorganisms that further raise the temperature to 65 °C, and in this process the pathogens are killed. At the cooling phase, the mesophilic microorganisms take over again and continue digesting the more resistant organic materials. Humus is produced by fungi and other microorganisms such as earthworms and sowbugs. The last step in the composting process called curing, aging or maturing is long and should last around 12 months after the thermophilic phase to make sure pathogens have been destroyed^[23]. This was confirmed by a study that found the risks of handling the compost after 12 months are low. This study is described in more detail below ^[24].

4. Commercial Dry Sanitation Systems Currently on the Market

Some of the most common commercially available dry sanitation systems for houses and public facilities include self-contained or central, urine-diverting, electrical, and single or multi-chambered. Although these toilets are more expensive than flush toilets, the cost in the long term will be lower than the flushing ones^[13] since water bills will be significantly lowered. However, to date, there is no standard guideline for composting toilets, which creates a lack of consistency in the presentation of toilet capacity. Some factors to take into consideration when choosing the right dry sanitation system are the capacity, which is the number of uses/day, the availability of electricity, the population density, position of the

composter (ground level or above) and climatic conditions, among others. It is also important to note that most of the models require frequent maintenance for their proper functioning. Adding bulking agents, spraying liquids and mixing the compost pile are critical to maintaining a good rate of decomposition.

5. Future of Dry Sanitation Systems

Alternative options (not commercially available) include toilets using nanotechnology and solar power. In addition, the separation of urine to be used later as fertilizer has been advocated as a sustainable solution. Urine is nitrogen rich (75%–90% contributed by urea), and its phosphate and potassium compounds are readily water soluble and available for plants^[25]; urine also has a low concentration of heavy metals compared to synthetic fertilizers^[26]. Thus, its collection in diverting toilets represents a good alternative to conventional sanitation systems and it has been implemented in several developed and developing countries^[27].

Some projects funded by the Bill and Melinda Gates foundation^[28] include designs/prototypes such as a solar-powered toilet that generates hydrogen and electricity by CalTech, a toilet that produces biological charcoal, minerals and clean water, designed by Loughborough University, and a toilet that sanitizes faeces and urine while recovering resources and clean water, designed by the University of Toronto^[29]. A toilet user interface designed by the Eawag has also been recognized.

A nanomembrane toilet was designed by researchers from Cranfield University and was also funded by the Bill and Melinda Gates Foundation in September 2012^[29]. This toilet is intended for urban poor areas because it requires maintenance only every six months. It uses thin nanofibres arranged in bundles inside the chamber that help move the water vapour through beads that condense the vapour into water. The solid waste is left to dry in a holding chamber until a technician removes it^[29].

Thus, the future of dry sanitation systems appears promising. This review categorizes these systems and provides the latest commercially available models, with an emphasis on those with large capacities which require the least maintenance. We also aimed to describe the principal factors required to maintain an efficient composting process and, in general, to increase awareness of dry sanitation systems as a sustainable alternative for waste management, especially for remote and rural areas, as well as refugee shelters where water may be limited.

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