The Application of Ecological Sanitation for Excreta Disposal in Disaster Relief:

Experience, Selection and Design

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Abstract

When responding to an emergency situation, ensuring safe excreta disposal is an urgent priority in the disaster relief effort. Aid organizations typically dig trench or pit latrines, but in some challenging environments, different methods such as ecological sanitation (Ecosan) must be employed. Ecosan is sanitation methods and technologies which promote the safe reuse rather than the disposal of excreta. Currently, Ecosan is mostly implemented in disaster relief for flood-prone areas and locations where excavation is not possible. In addition to meeting the sanitation needs of the affected population, Ecosan can be implemented to allow added benefits such as nutrient recovery, reforestation, and to help begin post-disaster recovery and the transition to peaceful and sustainable development.

Several examples of disaster relief situations where Ecosan methods are employed are investigated. Statistics about these case studies are presented along with successful and challenging aspects of the implementation. Four forms of Ecosan, urine diverting dehydration toilets (UDDT), Arborloo, biodegradable bags and composting toilets are discussed in six countries (Bolivia, Haiti, Chad, Philippines, New Zealand and Bangladesh). UDDTs had the widest extent of implementation and their flexible design makes them a good option for areas where excavation is difficult or there is a high chance of groundwater pollution (such as in flood prone regions). The composting processes offer the best success with reuse of excreta material as compost. Unfortunately though, these processes were quite complicated and do not necessary provide groundwater protection. The Arborloo provided a simpler solution with resource reuse, but this design is unfortunately not appropriate in regions where either excavation is not possible or where high groundwater is present. The Peepoo solution has shown itself to be successful in the preliminary trials, but the design still has many challenges such as cost effectiveness and user-friendliness.

In addition to exploring current case studies for Ecosan solutions, a sanitation decision flow chart is developed to compare different sanitation systems in different scenarios. In order to make a successful evaluation of the different technologies, the various design variables affecting the design of an appropriate excreta removal system are discussed.

Unfortunately, the Ecosan solutions already employed have been rather expensive and time-consuming to construct and/or they do not provide adequate groundwater protection. Additionally, there is a need to increase the portability of the sanitation solutions to increase the ease of access for disabled and elderly people as well as ensure that more women and children have access to sanitation option at the household level to decrease the security risk of nighttime toilet use. To respond to these needs, a rapidly deployable and inexpensive Ecosan solution has been proposed, the Porta Preta. The proposed solution uses Terra Preta Sanitation in an inexpensive, simple and portable design, providing some hygienization of the waste, significantly reducing odors, and facilitating the reuse of the urine and the excreta. To achieve these objectives, the separate collection of urine and feces is incorporated into the design. The urine is diverted and both the feces and the urine under go a lactofermentation process. Biochar is added also to the feces to eliminate odor and facilitate the reuse of the excreta as a soil additive. The design, costs, logistics and expected challenges of the Porta Preta are discussed in this report. Fixed costs would be approximately \$70 for the first month of operation serving a household of five individuals. The monthly cost would be approximately \$0.80 per user per month.

Table of Contents

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1. Introduction

Background: Disaster Relief

Disasters inflict widespread suffering and physical loss or damage on communities. The communities, which are stretched beyond their normal coping mechanisms, face serious societal disruptions. The term disaster is used to describe challenges which communities can not overcome in their own capacity. Then, if the situation is so severe that the community can only return to a functioning society with outside help, an emergency situation is declared, and external assistance is requested. The capacity for a community to prevent and respond to disasters is seriously limited when appropriate infrastructure and services are not established in a community prior to the adverse event.

Earthquakes, floods, hurricanes and volcanic eruptions are examples of natural phenomena which represent a serious hazard for a community, inflicting what is often referred to as "natural disasters". In addition to natural causes, humanitarian emergencies can also arise from political or military situations. When a person is forced to flee from their own country, and they seek asylum in another country, they are referred to as a refugees. According to the 1967 'Protocol Relation to the Status of Refugees', refugees are "all persons crossing an international border in genuine fear of persecution". Internally displaced persons, or IDPs, are individuals which are displaced from their home within their own country as a result of armed conflict, human rights abuses or natural hazards. Since they do not have the ability to seek asylum across an international border, they are thus entitled to international protection within their own country.

The economic cost and the destruction of infrastructure which occurs during disasters make future development even more challenging. Yet, on the other hand, disasters also present an opportunity for positive change in some impoverished communities. For example, communities without improved access to sanitation prior to a disaster may be able to maintain sanitation solutions after the disaster relief period ends. Thus, humanitarian relief programs should strive to plan for both relief in the immediate term, and peaceful and sustainable development in the long term. Without a focus on the latter, societies remain more susceptible to future disasters. Thus, it is worth while to investigate ways to propagate a more sustainable society in disaster relief, where immediate response often seems to trump any other concerns.

During humanitarian emergencies, there are several main organizations that work with the local government to lead the disaster response efforts including the UN Refugee Agency, UNHCR, and the UN Children's Fund, UNICEF. Two predominant non-governmental organizations which coordinate and lead response efforts are Oxfam and the Red Cross. Additionally, the Emergency and Humanitarian Action (EMA) section of the World Health Organization (WHO) are involved with health related aspects of disaster response such as sanitation.

Excreta Removal in Disaster Relief

A key element in any emergency situation is the proper disposal of human excreta. The proper separation, handling and disposal of human excreta serves as the main barrier against the transmission of excreta-related disease (cholera, typhoid, dysentery, diarrhea).[1] Human feces are especially hazardous. The diagram below shows the different pathways by which human feces can transfer pathogens.

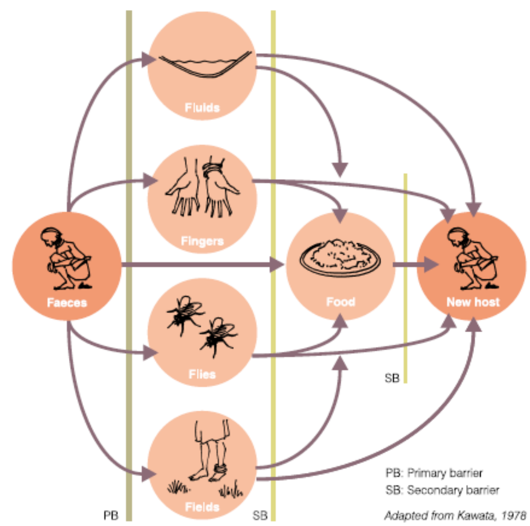


Figure 1: Transmission of Diseases from Feces[1]

Thus, one of the top priorities in any humanitarian disaster response is the safe removal of human excreta, especially human feces.

Humanitarian efforts for excreta disposal are often divided into three phases. The first phase, the immediate emergency, lasts for the emergency period and usually a few weeks beyond. Interventions in the immediate stage must be rapid and quickly reduce faecal-oral disease transmission. Solutions in this phase are often controlled open field defecation, shallow trench latrines, chemical toilets and container latrines. Which type of sanitation used is often dependent on the climate where the disaster occurs, and whether the relief is needed in an urban or rural context. After immediate measures are taken, then short-term measures can be implemented. The short-term solutions are more sustainable, and are implemented for longer use. Typical measures during the short-term response are deep trench latrines, simple pit latrines and shallow family latrines, with a technology sustainability of 6 months.[1] After the short-term measures are successfully implemented then long-term measures should be put in place. In practice, long-term measures are often just improvements (in number and proximity to households) to the short-term measures. This phase may last for several years and it should be designed to be sustainable for three years.[1] More information about the appropriate technologies for each disaster response phase can be found in section "Current Practices of Excreta Disposal".

The Opportunity for Ecological Sanitation

While a disaster can occur any where in the world, there are some factors which increase the likelihood of where an emergency will occur, such as pre-existing poverty and political instability. The following image is a map of the current emergencies to which OXFAM is responding.

Figure 2: Map of Oxfam Emergency Response[2]

These areas affected by disaster, often face great extents of deforestation and soil degradation as well. To illustrate this point, the map of the active OXFAM emergency response sites is super-imposed over maps of soil degradation and deforestation from UNEP in Figure 3 and 4. In Central America, Sub-Saharan Africa and many parts of Asia, there is a great extent of soil degradation and deforestation. Almost all of the Oxfam emergency sites are located in regions with very severe soil degradation. Many more of the emergency sites are located in regions where severe deforestation has occurred, leading to soil erosion and desertification.

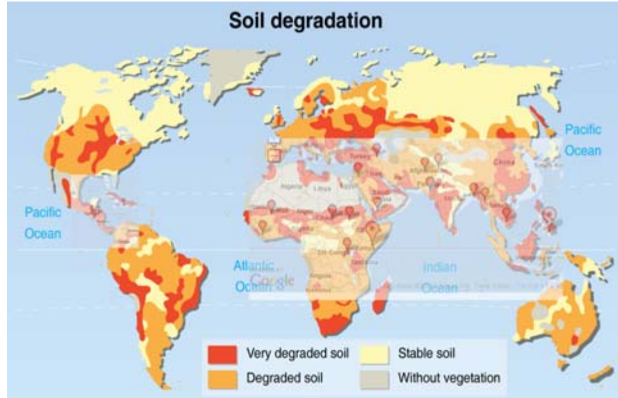


Figure 3: Map of Soil Degradation[3] and Oxfam Emergency Response[2]

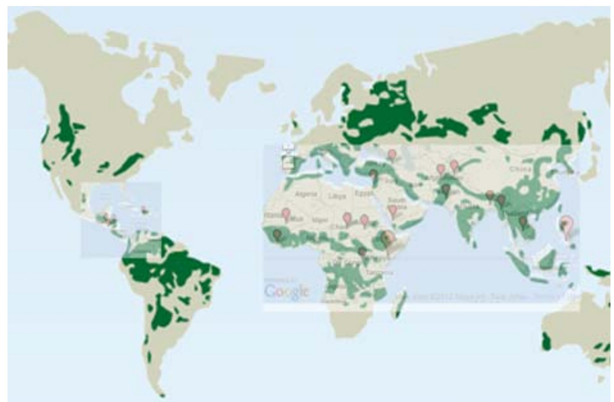


Figure 4: Map of Deforestation[4] and Oxfam Emergency Response[2]

The degraded environmental conditions of these countries are a problem by themselves, but they also inhibit a community's preparedness to response to stressors, making disasters more frequent and the impacts more severe. Countries are more vulnerable to disaster when their natural infrastructure is destroyed. Reducing the vulnerability to future disasters requires the rebuilding of infrastructure, both in the built environment and in the natural environment. Ecological sanitation (Ecosan) concepts, which treat the energy and materials contained within human excreta as a resource, rather than waste, offer the promise to help restore natural infrastructure. During disaster relief, sustainable technologies should be introduced which can increase future public health and welfare, and strengthen the community's ability to prevent and respond to disasters in the future. The introduction of Ecosan technologies and the building of local knowledge is one way to contribute to accomplishing these objectives.

Current Practices of Excreta Disposal in Disaster Response

The Sphere Project which created a Humanitarian Charter and Minimum Standards in Humanitarian Response recommends that context-oriented and phased approached are implemented to ensure quick and safe excreta disposal immediately following disasters. Several recommendations are made and will be discussed below.

First, it is recommended to clear all uncontained feces and to demarcate areas for controlled defecation. Then, later, it is recommended to construct community and family latrines in the middle to long term response phase. Family, rather than communal toilets are the preferred option when possible. With communal toilets, they must be segregated by sex, be no more than 50 meters from a dwelling and have no more than 20 users per toilet is the recommended maximum (although it is okay to start with one toilet per 50 users and decrease to one toilet per 20 as soon as possible). Toilets must be able to be used safely by all sections of the population, including children, the elderly, and persons with disabilities and be accessed safely, posing a minimum security threat to users (especially women and girls at night). Additionally, they must provide a degree of privacy and cleanliness which is acceptable to the users with separate, internally lockable toilets in public places for women and men. The systems must minimize fly and mosquito breeding. Also, the sanitation system in place must allow for the disposal and/or cleaning of menstrual hygiene products. Finally, it is noted that in high water table or flood situations, the excreta storage mechanisms (pits or containers) must be made watertight in order to minimize environmental and groundwater pollution. In all stages of disaster response the defecation systems, including soak pits, trench latrines and toilets, should be at least 1.5 meters above the groundwater table and at least 30 meters from any water source which is used. It is also recommended that particular attention must be paid to the safe disposal of children's feces as they are often more dangerous than adult feces. A summary of the appropriate methods for the safe removal of human excreta approved by the Sphere Handbook are listed in the table below.[5]

	Safe excreta disposal type	Application remarks
1	Demarcated defecation area (e.g. with sheeted-off segments)	First phase: the first two to three days when a huge number of people need immediate facilities
2	Trench latrines	First phase: up to two months
3	Simple pit latrines	Plan from the start through to long-term use
4	Ventilated improved pit (VIP) latrines	Context-based for middle- to long-term response
5	Ecological sanitation (Ecosan) with urine diversion	Context-based: in response to high water table and flood situations, right from the start or middle to long term
6	Septic tanks	Middle- to long-term phase

Table 1: Summary of Appropriate Methods for Safe Excreta Disposal[5]

The recommendations proposed by the Sphere report are similar to the recommendation of several predominant publications on excreta removal in disaster response from RedR, Medicins San Frontieres, Oxfam, the World Health Organization and UNICEF and UNHCR. Further details of the recommended excreta disposal methods during the three stages of disaster response are described in further detail below. These solutions are most appropriate for rural areas where there is no functioning sanitation infrastructure in place. Further information is given at the end of this section regarding the sanitation options most often applied in urban areas with pre-existing infrastructure.

Immediate Response Phase Solutions

In the immediate disaster response stage, it is of critical importance to control indiscriminate open defecation as quickly as possible. In order to do this, an area can be set up for controlled open defecation which is sloped away from the settlement and water resources. Strips can be partitioned off which are no more than 20-30 meters in width and people can be encouraged to cover there feces with soil when possible. Workers can quickly construct walls surrounding the area to provide privacy, security and to direct the flow of use. A diagram of such an operation is shown below.

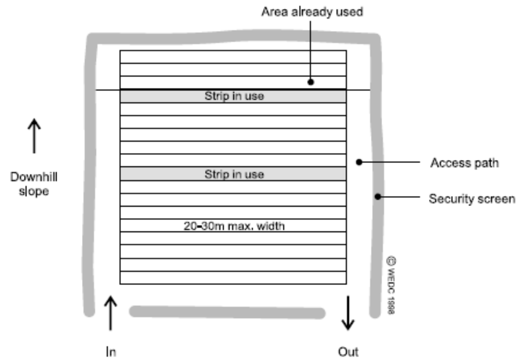


Figure 5: Controlled Open Defecation[1]

In the immediate and also in the short-term response phase, there are some situations, such as limited space, or in cases of disabilities or illnesses where collection of human excreta in buckets or containers with tight fitting lids is appropriate. These buckets must be emptied at least daily and the excreta contained undergo some other form of treatment. This option is only used in practice as a last resort option due to the lack of user acceptance and the large quantity of chemicals required. Another alternative to the bucket toilet are the collection of excreta in sealable plastic bags. More information on this technology can be found in the case studies section.

Short-term Response Phase:

After the first response phase and open defecation is controlled, then solutions with a greater level of comfort and a higher standard of health and environmental safety should be employed. The most common solution in this stage of the response is the shallow trench latrine. Trenches are dug 0.2-0.3 meters wide, 1.5 meters deep, and 4.0 meters long, and then surrounded by a screen. In this approach, the shallow trenches can be dug quickly and be brought quickly into operation. The users squat across the trench and defecate, and then use the dug soil to cover their feces. A diagram of how a shallow trench latrine operates is shown in Figure 6 below.

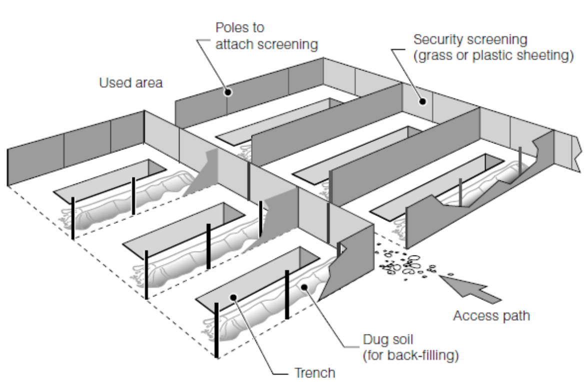


Figure 6: Shallow Trench Latrine Scheme [1]

Shallow family latrines or deep trench latrines may be also be appropriate in this phase. The shallow family latrine has a privacy screen surrounding a hole which is approximately 0.3 x 0.5 meters in area, and 1 meter deep. The hole is surrounded by two wooden food rests to increase the user comfort as he/she squats. The deep trench latrine is 0.8 to 0.9 meters wide, 6.0 meters long and at least 2.0 meters deep. The deep trench is then covered by a wooden or plastic floor and divided into sections or stalls with appropriate privacy and comfort provided. Each day 0.1 meters of soil is added to the deep trench latrines by the workers to decrease odors and fly breeding.[6]

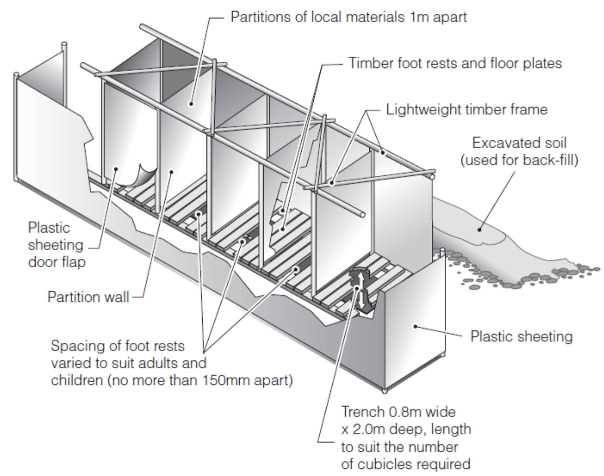


Figure 7: Deep Trench Latrine Diagram[6]

Long-term solutions

The most common long-term excreta disposal method currently in place in disaster relief is the simple pit latrine, either at the household or the community level. It is generally recommended to build household latrines whenever possible if there is more than 20 m^2 of land available per person.[1] In addition to the simple pit latrine, borehole latrines are appropriate in areas with deep soils. Borehole latrines have holes of 0.3-0.5 meters in diameter and are 2-5 meters in depth. The top of each hole is lined with a pipe and wood is provided for a foot rest to increase the comfort.[6]

Yet, in some situations it may be impossible to implement simple pit latrines without posing a significant health and environmental risk. These situations include; a high groundwater table, hard rock which makes excavation exceedingly difficult, soft ground which collapses, and in flood-affected areas. In these special situations, alternative sanitation options such as degradation (with UD) latrines, composting (with combined collection) toilets, raised pit latrines, twin pit latrines and sand enveloped latrines.

Disaster Response in Developed Urban and Suburban Areas

In disaster response in developed urban and suburban areas, existing infrastructure may still be usable to some degree. In these situations temporary latrines can be constructed over the sewer or drain.[6] Alternatively, if the wastewater system is still functioning, but the drinking water system is not-operating, then water could be provided in buckets so that water-flush toilets in community centers or schools could be used. This was one way that sanitation was provided in 2011 in response to the Tsunami in Japan as pictured below.

Figure 9: Use of existing infrastructure in Japan[7]

If there is not pre-existing infrastructure or the infrastructure is beyond repair in the urban area, then other methods must be employed. If the ground is easily dug, then latrines can be used (either with or without the addition of chemicals). In situations where this is not possible, or where a household solution is demanded, then chemical toilets can be used. One example used in 2011 in New Zealand is the Red Desert chemical toilet which was ordered from China shown in Figure 10. These were distributed to households when the sewer system in the town was declared unusable. The residents were instructed to bring the waste from their toilets to centrally located collection bins.

Chemical and portable toilets are often the sanitation solution of choice in many richer countries. Unfortunately these options are expensive, are not environmentally friendly, and problems have occurred with distribution. The Civil Defense in New Zealand spent $8.07 million to purchase and transport tens of thousands of toilets into suburbs impacted by the earthquakes in 2011. Included in this expenditure was $2.09 million for portaloos and $1.38 million for chemical toilets in addition to nearly $1 million which was also spent on the chemicals used in the portable toilets.[8] Many citizens had to wait a few weeks for these sanitation solutions to arrive, and in the waiting period, people simply dug holes in their gardens.[9] For residents who had to continue to use the chemical toilets after several weeks, composting bucket toilets were proposed as a better alternative to the chemical toilets used in Christchurch's which were "not nice to deal with". Thus, an Ecosan alternative to chemical toilets which provides the same or better safety and comfort would be of great use in many disaster relief situations. More details on the use of composting in New Zealand in the case studies section.

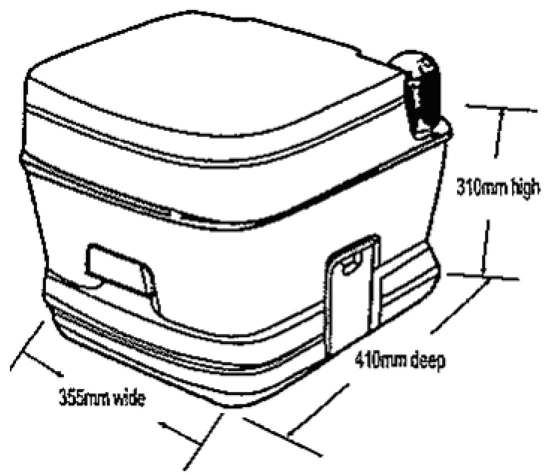


Figure 10: Chemical Toilet Used in the 2011 New Zealand Earthquakes

In the disaster relief efforts in Haiti following the earthquake in 2010, many chemical toilets were used at the beginning, but quickly discontinued due to their high maintenance costs. Oxfam had difficultly using the two donated vacuum suction trucks due to delays in customs and because there was simply no vehicular access to empty the toilets. Thus, they instead tried to use hand operated sludge pumps, but these were not successful because of the miscellaneous waste disposed of into the toilets which blocked the pump diaphragm. As a final alternative manual desludging had to be done with ropes and buckets at night using appropriate safety equipment for the workers.[10] Oxfam's experience in this situation illustrates the advantage of a dry Ecosan solution.

2. Ecological Sanitation

Introduction

Ecological sanitation or Ecosan is system of sanitation which promotes material flow cycles instead of waste generation to provide greater economic and environmental benefits while protecting human health from the entry of pathogens into the water cycle. This concept champions the safe hygienic recovery of nutrients, organic material, energy and water.[11]

In order to achieve these objectives, several factors must be considered such as nature, society, processes and devices. No single device or process is proposed as a single solution for all geographical and cultural needs, but rather, an assortment of technologies have been developed which are more or less appropriate depending on the context. The factors of nature considered are: climatic factors such as temperature and humidity, water availability, and soil properties such as stability and permeability. The societal factors considered include the settlement density, the attitude towards feces, hygiene habits, beliefs, and the economic status of the community. The combination of all of these factors must be considered to select an appropriate process (the biological, physical and chemical processes used to stabilize and hygienize human feces) and the device for the excreta collection.[12]

Hygienization of Excreta

Several processes can be employed to disinfect human excreta and kill the microorganisms contained. Physical conditions can be changed such as increasing the temperature, increasing the pH, decreasing the moisture content (dehydration), and changing the oxygen availability. When decreasing the moisture content, a specific storage time is necessary. Recommended storage times are listed in Table 2. Additionally; toxic conditions such as increased concentrations of ammonia and various other organic and inorganic chemical compounds, or solar radiation/UV-light are effective at killing off pathogens. Finally, competition between bacterial species for nutrients and predation by other microorganism species can eliminate pathogenic microorganisms.[13] A more extensive summary of the factors which affect microorganism survival in the natural environment is provided in Table 3.

Treatment	Criteria	Comment
Storage; ambient temperature 2–20 °C	1.5–2 years	Will eliminate bacterial pathogens; regrowth of *E. coli* and *Salmonella* may need to be considered if rewetted; will reduce viruses and parasitic protozoa below risk levels. Some soil-borne ova may persist in low numbers.
Storage; ambient temperature >20–35 °C	>1 year	Substantial to total inactivation of viruses, bacteria and protozoa; inactivation of schistosome eggs (<1 month); inactivation of nematode (roundworm) eggs, e.g. hookworm (*Ancylostoma/Necator*) and whipworm (*Trichuris*); survival of a certain percentage (10–30%) of *Ascaris* eggs (≥4 months), whereas a more or less complete inactivation of *Ascaris* eggs will occur within 1 year.
Alkaline treatment	pH >9 during >6 months	If temperature >35 °C and moisture <25%, lower pH and/or wetter material will prolong the time for absolute elimination.

[a] No addition of new material.

Table 2: Recommendations for Storage Times of Dry Excreta and Fecal Sludge before use at the Household or Municipal Level[14]

Temperature	Most microorganisms survive well at low temperatures (<5°C) and rapidly die off at high temperatures (>40-50°C). This is the case in water, soil, sewage and on crops. To ensure inactivation in e.g. composting processes, temperatures around 55-65°C are needed to kill all types of pathogens (except bacterial spores) within hours (Haug, 1993).
pH	Many microorganisms are adapted to a neutral pH (7). Highly acidic or alkaline conditions will have an inactivating effect. Addition of lime to excreta in dry latrines and to sewage sludge can increase pH and will inactivate microorganisms. The speed of inactivation depends on the pH value, e.g. it is much more rapid at pH 12 than at pH 9.
Ammonia	In natural environments, ammonia (NH_3) chemically hydrolysed or produced by bacteria can be deleterious to other organisms. Added ammonia-generating chemical will also facilitate the inactivation of pathogens in e.g. excreta or sewage sludge (Ghigletti *et al.*, 1997; Vinnerås *et al.*, 2003*a*).
Moisture	Moisture is related to the organism survival in soil and in faeces. A moist soil favours the survival of microorganisms and a drying process will decrease the number of pathogens, e.g. in latrines.
Solar radiation/ UV-light	UV-irradiation will reduce the number of pathogens. It is used as a process for the treatment of both drinking water and wastewater. In the field, the survival time will be shorter on the soil and crop surface where sunlight can affect the organisms.
Presence of other microorganisms	The survival of microorganisms is generally longer in material that has been sterilized than in an environmental sample containing other organisms. Organisms may affect each other by predation, release of antagonistic substances or competition (see Nutrients below).
Nutrients	If nutrients are available and other conditions are favourable, bacteria may grow in the environment. Enteric bacteria adapted to the gastrointestinal tract are not always capable of competing with indigenous organisms for the scarce nutrients, limiting their ability to reproduce and survive in the environment.
Other factors	Microbial activity is dependent on oxygen availability. In soil, the particle size and permeability will impact the microbial survival. In soil as well as in sewage and water environments, various organic and inorganic chemical compounds may affect the survival of microorganisms.

Table 3: Physicochemical and biological factors that affect the survival of microorganisms in the Environment[12]

Handling of Urine and Feces

As with any sanitation system, Ecosan promotes the stabilization and hygienization of waste. Within the scope of this work, the focus will remain on the treatment of human excreta. Ecosan, in addition to promoting stabilization, reduction of volume and weight, and hygienization of human excreta, promotes the safe reuse of these materials. In order to achieve these objectives several process and collection technologies have been developed. These technologies can be broadly divided into two categories: urine-diverting (UD), and combined collection.

One advantage of UD toilets is the treatment of the highly pathogenic blackwater solids is facilitated. When the urine is properly diverted from the feces, this significantly reduces the unpleasant odors associated with latrines and the fly breeding. Also, if the feces remain dry and are not mixed with the urine, the pathogens are not mobilized and are not able to migrate as easily and contaminate groundwater. The remaining yellowwater can be treated very easily by simply storing the urine for sufficient time and then it can be reused as fertilizer since it has low levels of pathogens. Urine can be directly applied to crops from homesteads, but should be stored for about a month before use if collected from large-scale systems according to Esrey et al.[12] According to Richard et al, the urine from one person during one year is sufficient to fertilize 300-400 m^2 of crop, but care should be taken not to apply urine within one month of harvest for vegetable, fruit and root crops which are to be consumed raw. The nutrients contained within urine make urine a valuable fertilizer. More information on the reuse of urine can be found in “Practical Guidance on the Use of Urine in Crop Production”.[15] An additional benefit is that the UD toilets can be made from locally available materials and benefit the local economy.

Unfortunately though, if the users are not sufficiently motivated and do not properly understand the function and the purpose of the UD toilets, they can misuse the toilets and destroy the intended function of the systems.

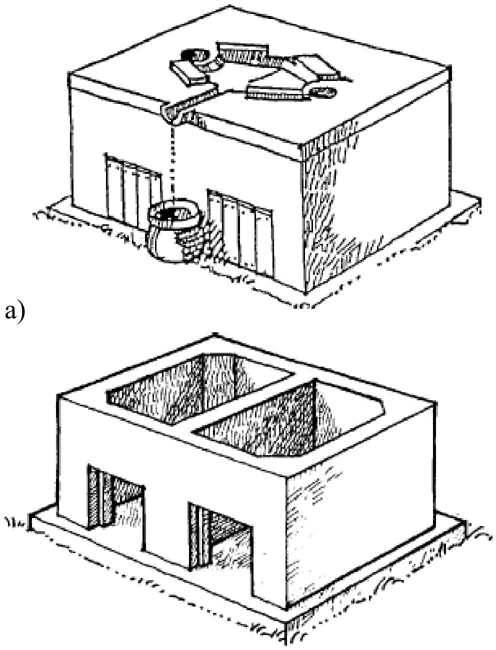
Another disadvantage of UD toilets is that men must sit to urinate, unless a waterless urinal is installed. Additionally, complications can arise in certain regions and with certain religions which require wet anal cleansing, since wet anal cleansing is not compatible with all UD toilets.
A summary of tested and operating Ecosan toilets categorized by either UD or combined ('combo') is listed in the table below.

	Dehydration	Anaerobic Digestion	Decomposition
UD	- Vietnamese double-vault Toilet - Solar-heated toilet - Desiccation toilet - Diverting Double-vault toilet - Kerala double Vault Toilet		-Composting Toilets with UD
Combo		- Vacuum blackwater collection with biogas production	- Arborloo - Fossa Alterna - Composting Toilets

Table 3: Categorization of Ecosan Toilets

In general, most UD toilets use the principle of dehydration to hygienize and reduce the volume and mass of the fecal matter, while the combined toilets employ decomposition more frequently. A discussion of the general principles of dehydrating, digestion and degradation toilets can be found in the next section. A more detailed discussion of the specific technologies listed above can be found in "Ecological Sanitation: revised and enlarged addition".

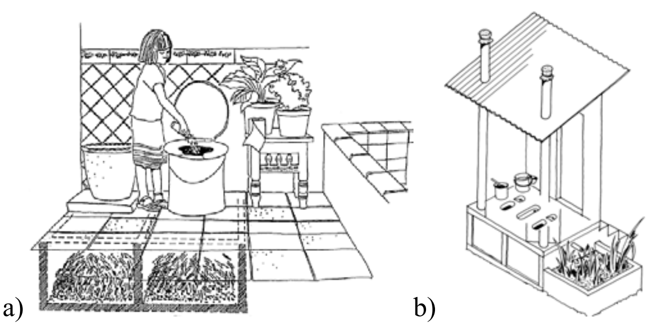
Dehydration
In properly dehydration, or dry toilets, there should be no bad smell, wetness or fly breeding. In general, a well-managed dry toilet should have significant reductions of pathogen levels. In dehydration toilet designs, there are often two chambers, one which is in use, and a second which stores the feces for adequate time to reduce the moisture and pathogens before the contents of the chamber are removed. A very successful model is the Vietnamese double vault toilet.[13] A schematic of this toilet without the superstructure can be seen in the images provided below.



a) b)

Figure 11: Vietnamese Double Vault with (a) and without (b) the Squatting Tablet[13]

Several adaptations to this design have been made so that it is more appropriate in different climates and with different cultural and behavioral practices. In the Mexican version shows an adaptation which is suited for people who prefer to defecate in the sitting rather than the squatting position. The Kerala double vault design is an example of a design which is appropriate for individuals who practice wet anal hygiene. These two models are shown below.[13]



a) b)

Figure 12: Mexican (a) and (b) Kerala Double Vault Toilet[13]

Decomposition

The separation of the urine from the fecal matter is an easy way to reduce the odors and discomfort of the toilets, but a similar level of comfort can be achieved with well functioning composting toilets with combined collection of feces and urine. Toilets which function by the principle of decomposition, also called composting, rely on aerobic processes to transform human feces into a valuable soil addition. These systems can function with or without urine diversion, but they typically function with mixed collection. The sterilization of the soil is possible through the high temperatures which are generated during a secondary composting process with other co-substrates such as food scraps. In order to allow an aerobic process, bulk material can be added to provide structure and desiccating material such as ash or saw dust can be added to reduce the moisture (especially in mixed collection systems). Composting is a very sensitive process. When composting is done properly, odors and fly-breeding are minimized, but if the process is not done correctly, the compost can become hygienically unsafe and unpleasant. An example of a composting system is the 'Clivus', a single-vault composting toilet which accepts both faeces and organic household residues.[13] This system is shown in the figure below.

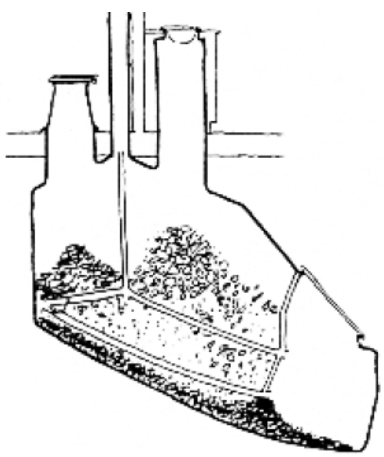


Figure 13: The 'Clivus' Single-vault Composting Toilet[13]

Several variations of the standard composting models have been created to decrease the cost and the difficulty of the composting process. One example is the 'Sirdo Seco' Mexican double vault toilet is built entirely from fiberglass to create a lightweight, portable and inexpensive composting toilet. The composting process is facilitated by simple solar heaters which increase the surface temperature of the compost.[13] This model is illustrated in Figure 14.

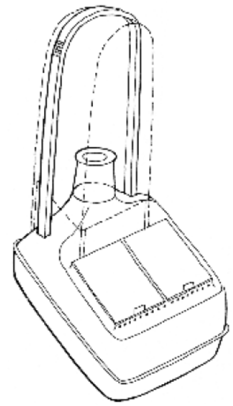


Figure 14: 'Sirdo Seco' Double-vault, solar-heated composted toilet[13]

Another, even simpler system is the Arborloo. In the Arborloo system the excreta are deposited into a pit and then covered with soil after each use. When the pit is nearly full (about 6-12 months), the superstructure is removed and the pit is filled with additional topsoil where a tree is then planted. The young tree is intended to grow only in the top soil in the beginning, so that there is sufficient time for the degradation of excreta/soil mixture beneath. The users simply move the superstructure to an adjacent hole where the process is repeated. A scheme of the Arborloo process is shown below.[13]

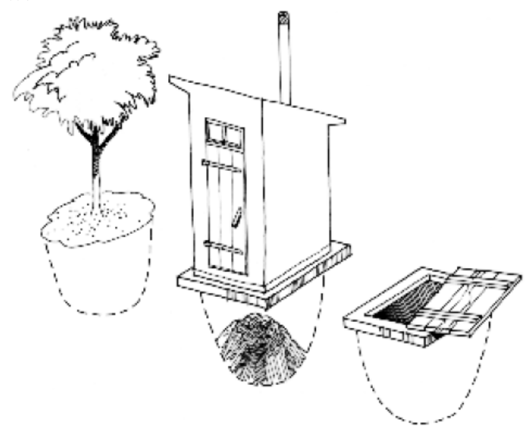


Figure 15: The Arborloo Toilet[13]

A similar approach to the Arborloo toilet is Fossa Alterna, where the excreta mixture is allowed to decompose for 6-12 months, but instead of the soil being used for a tree, it is dug up and mixed with poor quality topsoils to enhance the soil fertility. The quality of the soil in the Fossa Alterna system is enhanced by the addition of wood ash and leaves into the pit.

Digestion

Digestion is another process with can successfully gain energy and nutrients. The urine and the feces can be collected with a small amount of dilution water using a vacuum system and then be digested with the blackwater combined from several households to create biogas for heat and power generation and natural gas production. A functioning digestion system is the currently in place at the Lübeck–Flintenbreite establishment. An overview of this system can be viewed below.

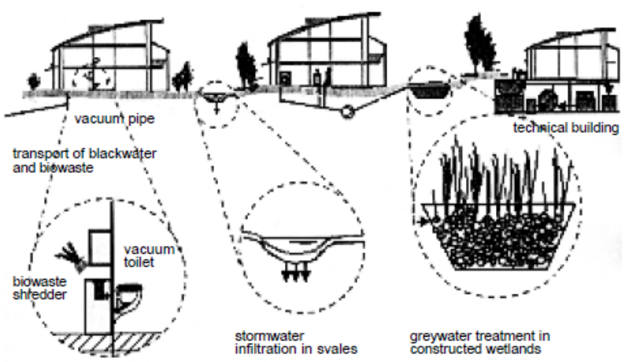


Figure 16: Schematic view of the vacuum–biogas system Lübeck–Flintenbreite[13]

Digestion systems are in general too complicated to implement in disaster relief at the present, but with future developments in the technology, this technology may become appropriate. For example, a new, portable toilet, called a Loowatt, is currently being developed in the United Kingdom, and it is currently undergoing a pilot trial in Madagascar. The unit functions by collecting the excreta in a biodegradable plastic using a sealing device. The plastic enclosed contents are later digested to provide energy. While the system, specifically the biodegradable plastic, is quite expensive now, the Loowatt company is optimistic that the prices can be reduced. Fausto Marcigo of the Loowatt company stated through personal correspondence that they "hope to have the cost of a sealing unit down to $20 and once we are producing large volumes and the plastic we are developing becomes more acceptable worldwide we envisage that it will cost less than 1 cent per flush."

Lactofermenting toilets

Terra preta is the name given to the nutrient rich soils discovered in the Brazilian Amazonia. These soils were produced by the pre-Columbian cultures by the incorporation of manure, charcoal and bones in the ground. The terra preta concept can be applied in the field of sanitation to treat human excreta and create rich, fertile compost (terra preta). The terra preta sanitation (TPS) is based on three steps: collection, lactic acid fermentation and vermi-composting. Lacto-acid fermentation process inhibits the formation of malodorous compounds associated with stored excreta, allowing an essentially odor free experience. The excreta is collected (with or without UD) and a mixture of charcoal or biochar, lime and lactic-acid bacteria. The charcoal masks the slightly acid smell of the lactic acid fermentation process, and allows for an odor free experience.

There are several design options for TPS. Some have been tested at the laboratory scale, and some are still in development. The most basic design is the simple bucket system with urine separation. This system is shown in Figure 17 below. The second option is the retrofitting of UD dry toilets. The third option is a luxury, mechanized, automated dry toilet which is currently under development. Finally, the TPS can be used with UD flush toilets when the solids are caught in a lacto-acid sieving unit, called the Rottesbehälter system still in development. More details on the design of TPS systems can be found in Appendix 3.

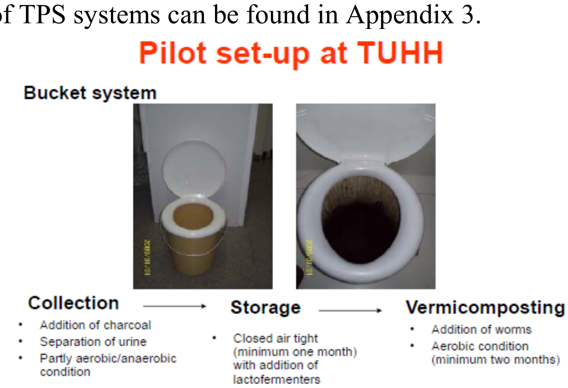


Figure 17: Example of TPS Bucket System[16]

3. Case Studies: Ecosan Applied in Disaster Relief

The following four sections will discuss the current experience in the application of Ecosan in disaster relief. The experience from urine diverting toilets, the Arborloo, biodegradable bags and a composting process are discussed in the next sections. Most of these solutions would qualify as long-term solutions with the exception of the UD system in Bolivia and the biodegradable bags which both qualify as short-term solutions. An overview of the sections is provided below:

1. Urine Diversion Toilets: Bolivia, Haiti, Chad, Philippines and Bangladesh
2. Composting Toilets: Haiti and New Zealand
3. Peepoo Bags: Haiti
4. Arborloo: Haiti

Ecosan solutions were chosen to be implemented in the following cases mainly for safety and practical reasons arising from the risk of flooding and/or difficulties with excavation. Up to this point, the reuse of the excreta as a resource has been a secondary objective in all mentioned systems with the exception of the thermophilic composting carried out in Haiti.

1. Urine Diversion Toilets in Disaster Relief

Experience has been gained with urine diversion (UD) toilets on four different continents in five different countries during disaster relief work. These systems were chosen due to difficulties with excavation, concerns about flooding, and in order to prolong latrine life. The experience gained and the lessons learned from implementation of UD toilets in Bolivia, Haiti, Chad, the Philippines and Bangladesh will be discussed in the following sections.

1a. Bolivia: Urine Diversion Toilets during High Flood Risk

Summary: Following flooding of the Rio Beni in Bolivia in March 2008, approximately 20,000 people moved to higher ground on flood protection embankments. Open defecation presented a health risk, and sanitation units were installed as quickly as possible. The latrines were urine-diversion toilets, and were supplied from the local authority contingency stock, following floods in 2007. Faeces were collected in 200 liter drums lined with bin liners, and urine was drained into separate containers for disposal. The faeces were collected each day, and transported by truck to a landfill site.[10]

Figure 18: Urine Diverting Toilets in Bolivia[10]

Challenges: Throwing toilet paper into the toilets was forbidden, yet, no toilet paper collection bin or disposal option was provided. Thus, problems were encountered, and the people, accustomed to a toilet paper receptacle bin placed next to the toilet, simply left the toilet paper on the floor of the latrine. This caused a hygiene risk as well as a litter problem. of toilet paper. In Bolivia, people throw their used toilet paper into a bin next to the toilet. The cleanliness of the system could have been improved if the people would have been encouraged to throw their used paper into the toilets. While this does not normally work with this type of system for reuse, in this situation where the waste is land-filled, the addition of toilet paper would have been completely appropriate. Another challenge with this system was the reuse. While this system is set-up to facilitate re-use, the authorities found it too much of a hassle in this emergency situation.[10]

1b. Haiti: Urine Diversion Toilets After an Earthquake

Summary: Sustainable Organic Integrated Livelihoods (SOIL) in collaboration with OXFAM, worked to promote ecological sanitation in Haiti after the earthquake in Port-Au-Prince. SOIL constructed urine diversion toilets and converted standard latrine units into dry composting. 194 UD toilets units were installed at 32 sites, and many of the units were still in operation 12-months after their initial construction.

Details: The initial sites for the UD toilets were selected by SOIL staff based on field visits to earthquake-affected areas in Delmas, Tabbare, and Cite Soleil. Soil presented their range of UD solutions to the camp representatives, and when their was clear interest from the camp side, the communities became involved in choosing the most appropriate design. Most often, the toilets were raised with UD seats above a 50-liter plastic drum with a screw lid. Another common solution was the retrofitting of standard Portaloos to create dry composting toilets (by substituting the toilet tank with a bucket and a urine diversion seat toilet). An image of one urine diversion toilet seat is seen in Figure 19 below.

Figure 19: UD toilet seat developed by SOIL and manufactured in Port-au-Prince.[17]

At each site, hygiene promotion sessions were held with the whole community. The purpose of these sessions was to highlight the importance of safe excreta disposal, and to demonstrate the how to properly use the UD toilet unit, including a demonstration of how to use desiccating material such as sawdust or sugar cane bagasse to improve the function. The use of a desiccating material was successful at not only preventing flies but also at preventing smells, making the toilets popular with users.[17]

Challenges: One of the challenges discussed was the design a urine outlet that doesn't block easily. Another challenge was the materials used for the superstructure were at risk for theft, and thus local artists were hired to paint sanitation themed paintings on the latrines to deter theft. It is assumed that this problem is not isolated to Ecosan solutions alone.[17]

1c. Bangladesh: UDDTs after a Cyclone

Summary: 100 UDDTs were constructed in southern Bangladesh in response to the damage inflicted by Cyclone Sidr on November 15th, 2007. The construction of the UDDT was carried out by Terre des homes and it began in May 2008 and was finished in June, 2009. The 100 UDDT served 1,200 families. Terre des homes decided to install UDDT because of the very high groundwater level, and the risk of future flooding of the area. Their design allowed for the infiltration of urine and anal wash water in the soil and consisted of two chambers for the collection of fecal matter. One chamber was used for a year while the other chamber is able to rest and allow desiccation of the feces. The design of the UDDT can be seen in Figure 20 below. As can be seen in the image on the far right, this system proved effective for containing the excreta during the subsequent flooding event of cyclone Aila in May of 2009.[18]

Figure 20: Design of UDDT for Flooding[18]

The design of the squat pan for achieving the urine diversion can be seen in Figure 21 below.

Figure 21: UDDT Double Vault Squat Pan[18]

Challenges: There were three main issues encountered with the implementation of UDDTs in Bangladesh. First, the location of the toilet in the compound and the orientation of the toilet itself. The orientation of the toilet was an important consideration for Islamic beliefs which mandates that people not defecate facing towards Mecca. Second, problems were encountered with the daily user habits and maintenance aspects of the UDDT. Users had to be quickly and effectively trained to ensure the proper function of these units. The users expressed uncertainty regarding the procedure of emptying the dried feces from the dehydrating chamber. Thus, additional training was necessary in this area. Finally, issues were encountered with achieving the reuse of the dried excreta. It was noted that the concept and infrastructure necessary for reuse of the dehydrated feces should be considered from the beginning of the operation of the UDDTs.[18]

Successes: It was noted that the odor control benefits helped facilitate the acceptance of the new technology. Since appropriate odor-control was achieved by these units, and it was found that the UDDTs could be placed closer to households than standard latrines.[18]

Recommendations: In terms of emergency response, it was noted that a solution which can be implemented more quickly with a lower cost would be more ideal to ensure faster and more extensive coverage.

1d) Philippines: Provision of Urine Diverting Toilets after a Typhoon and Flooding

The Typhoon Sendong hit the Philippines in January, 2012, wiping out the entire water and sanitation city in Cagayan de Oro and Iligan Cities in the Philippines. Thus a quick response was needed to avoid the spread of disease. To respond to the need, 54 portable Ecosan toilets we installed in evacuation centers and in scattered communities followed by an addition 53 more a few weeks later. These units were installed by small teams of expert carpenters, trainers and waste collectors. The fecal mater was collected an stored in a chamber and the urine was collected in jerry cans. Both the fecal matter and the urine are stored with the intention of further processing and later use.[19] An example of the urine diversion seats is shown in Figure 22 below.

Figure 22: Urine Diverting Fixtures Used in the Philippines[19]

The entire system can be viewed in Figure 23 below.

Figure 23: Ecosan Toilets in the Philippines[19]

Findings: The Ecosan solution was found to be functioning much better than the water-based portalets provided by the majority of the international aid agencies. These water-based portalet solution is said to be "ineffective and instead poses health hazard". One the other hand, the Ecosan toilets are "proven to be effective". Yet, this effectiveness is attributed to the education given to the communities and the provision of efficient waste management in place. Without these two measures, the organization states that the Ecosan toilets would have also proven ineffective.[19]

1e) Chad: Urine Diversion Toilets in a Refugee Camp to Extend Toilet Life

Summary: Family pit latrines with lined walls which can easily be emptied have been implemented in the Farchana refugee camp in Chad to address a number of problems. 500 inhabitants were served by the construction of 102 pit latrines. 80 of these latrines were single-pit latrines, and 22 were double pit latrines to increase the safety and ease of emptying the fecal matter from the pit. Urine diversion is achieved by an inclined slab which allows the liquids (urine and washing liquid) to flow in a different direction from the excreta. Urine diversion was included in the design of the user interface to extend the time between each emptying of the pit and to facilitate the reuse of the feces, yet the proper separation is only ensured if the user makes a conscious effort to use the system in place.[20]

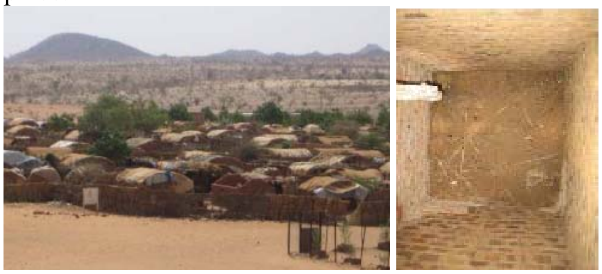


Figure 24: Farchana Refugee Camp with Lined-pit Latrines[20]

Challenges: It was reported the soils were highly degraded in the region where this project was implemented, so there was the intention to reuse the feces, but no plan was yet devised nor carried out. The first emptying of these latrines will need after two to three years of use, and has thus not yet occurred at the time this report was written. Thus it is not yet established if these latrines will be used as a single action latrine, or if the more sustainable multi-use function will be achieved.

2. Composting Toilets

2a) Haiti : Thermophilic Composting in Port-Au-Prince

Five urine separating toilets were built by the New Directions Foundation in Haiti for camp 1 at Sainte Marie, Canape vert, Port Au Prince after the earthquake in 2010. These five toilets served 200 users per day. The fecal matter was collected in 30 liter biodegradable liner bags. These fit snuggly into the five gallon buckets which were placed underneath the urine separating toilet squatting pans (provided by Oxfam). The users were then instructed to cover the feces after each use with one scoopful of a mixture of collected earth, dry grass, leaves and small amounts of ash.[21]

Figure 25: Thermophilic Composting in Haiti[21]

After the separate collection, the separated excreta streams underwent a semi-centralized thermophilic composting process. This process is referred to as semi-centralized because the composting operation takes is not done by each household or toilet, but instead the waste from a small number of toilets (in this case five toilets which served 200 people). The fecal matter in the biodegradable bags was combined with organic waste, and assembled on pallets. Heaps are built up over 7 days with alternating layers of fecal waste in bags, grass, and organic waste. One double pallet can hold 56 biodegradable bags of fecal matter, this represents the waste of 200 people over six days. These pallets were then covered with tarps with air holes to control the moisture level (in the case of heavy precipitation events) and allowed to rest for an initial 14 days. Urine is used in this time for the irrigation of the heap. Then the heap is turned onto another pallet for 14 days to allow aeration. During this second period, only freshwater is used for the irrigation. The remaining urine can be used for other irrigation processes. Finally the heap is removed from the pallet and allowed to rest for 60 days for a total processing time of 90 days.[21]

The thermophilic composting process also accepted Peepoo bags at a rate of 100 per day. Both the biodegradable bags for fecal collection and the Peepoo bags were found to disappear within 14 days. To operate the collection and composting process, two managers and three laborers were hired.[21]

The purpose of this system was to provide sanitation to the camp and produce an optimum fertilizer. In this specific situation in Haiti, it was recommended that the compost product could be used as a rough mulch on certain crops after 30 days, but not on agricultural crops for food consumption until after a year.[21]

Challenges: It was claimed that the pilot project at Sainte Marie was "proved a 100% success", yet this was only due to the fact that a composting expert was present to supervise the entire process which is rather technically complex. A warning was issued that "it is essential that any site is set up and run by a qualified consultant at the outset, i.e., as supplied or trained by New Directions Foundation."[21] This is a major hindrance towards the large scale application, as the cost of such an expert may be 50% of the sanitation budget.

2b) New Zealand: Home Composting Toilets in Christchurch

As mentioned earlier, advocates in Christchurch advocated home composting systems as an alternative to chemical toilets. The proponents state that "a compost toilet, if it's done properly, doesn't smell and it's not wet." [22] A structure is built with two seats, one for defecation and one for urination. Two buckets are placed beneath each hole as seen in Figure 26 below. It is also suggested to have a separate basket for the collection of anal hygiene material.[23]

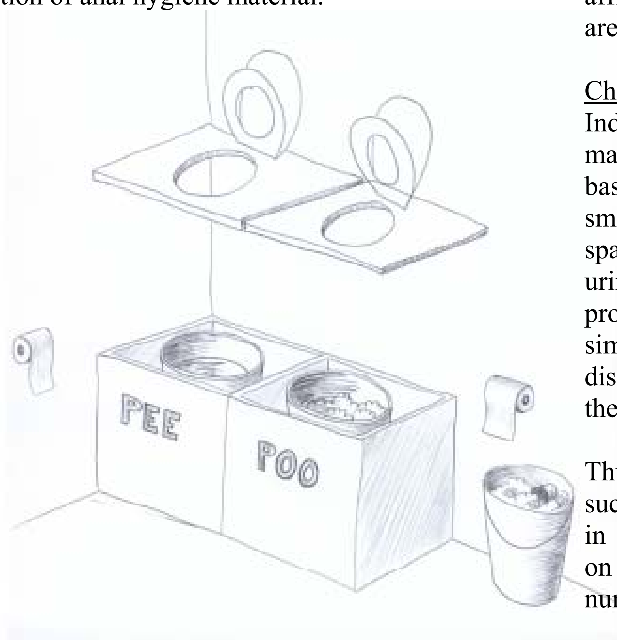


Figure 26: Emergency Composting Toilets in New Zealand[23]

In order to use the urine component, it is suggested to fill the bottom ¼ of the urine bucket with water at the beginning of the day, and then to empty the contents of the urine bucket at the end of the day in the garden. For the fecal receptacle, it is required to add carbon material such as dry leaves, dry lawn clippings, shredded news paper or untreated woodchips after each defecation. This is added to decrease the moisture level. The bucket collecting the fecal matter should be emptied when it is half full into another container where the compost can further mature. After each addition of the fecal matter into the bin, a layer of organic matter should be placed on top. The container should then be closed and placed in a warm, sunny location. The bucket should then be rinsed cleaned with water, and this rinse water can be used in the compost process or safely disposed of.

To build the compost container to collect the bucket additions of the fecal matter, one needs a large container which is preferably portable (such as a wheelie bin). Place structure material at the bottom such as sticks or a wooden fruit crate. Cover this layer with plastic, hessian sack or another material to separate the compost from the structure material at the bottom. One pipe with holes drilled throughout the length should be placed in the corner to allow aeration. When ¾ full, then place organic layer one top. It is mentioned that the addition of tiger worms when available can improve the composting process.

This may be a promising solution for disasters in affluent suburban areas where basic housing structures are still usable but the sanitation infrastructure is not.

Challenges:
Individuals must be responsible for finding their own materials to construct these toilets and be capable of basic carpentry. Each user must have a garden, or a small lawn to handle the urine and the compost. Public space could also be dedicated for composting bins and urine application. Another difficulty would be the provision of the carbon material. Woodchips and similar materials may not be available during a disaster, especially in the time immediately following the disaster event.

Thus far there is only anecdotal data regarding the success of these systems. A survey will be conducted in May 2012 which should provide more information on the acceptance of these systems and the total number of people served.

3. Biodegradable Personal Bag Systems

Haiti: Peepoo bags

Oxfam conducted a trial from April to May 2010 with the Peepoo excreta disposal system in two IDP camps. A diagram of how to use the Peepoo bag is provided in Figure 27 below. Oxfam provided 7 bags per person per week, and they set up centralized commodes with a modified bucket to hold the bag to provide comfort and privacy during use. After use, the users were expected to deposit the bags in specially designated waste receptacles. The collected bags were then take for composting.[24]

Figure 27: Use and Closure of the Peepoo Bag[24]

The Peepoo served its intended function of providing a quick and effective sanitation method in a difficult environment (refugees residing on land where it was not possible to excavate the ground). The Peepoo was found to be difficult to use due to the small circumference of the bag, the need for a receiving container to hold the bag, and difficulties encountered with making a self-knot after use.[24] Additionally, this method was quite expensive, but the cost is expected to significantly decline with mass production. Nonetheless, the overall feedback reported was positive, in an evaluation of the Peepoo bags in Haiti, it was written:

> "This approach has also received very good beneficiary feedback, even from people who had flush toilets before the earthquake. It is good for sites that de-sludging trucks cannot access, or where it is impossible to dig pits."[24]

Previous trials have shown that the Salmonella reduction levels were sufficiently met which are required for reuse of faeces as fertilizer when 1% urea is provided in the bag after 2 months at 14°C or within 1 week at 24°C and 34°C. Thus, it is assumed that this method provided a sufficient level of hygiene, so long as the user was able to use the Peepoo bag as intended.[24]

4. **Arborloo**

Grande Saline, Haiti.

Oxfam implemented the Arborloo sanitation method in Grande Saline, Haiti. The beneficiaries dug their own pits (0.9m in diameter and 2.0m deep) and made the superstructures. The pit dug for the Arborloo process is shown in Figure 28 below. A local contractor manufactured the reinforced slabs and installed the metallic roofing. This method proved to be a simple post-flood solution that people could easily replicate using local materials.[10]

Figure 28: Arborloo in Refugee Camps, Haiti[10]

Concluding Remarks on Case Studies

UDDTs have shown the widest implementation as an ecological sanitation option for disaster relief. They have a flexible design and are a good option for areas where excavation is difficult or there is a high chance of groundwater pollution (such as in flood prone regions). The composting processes offer the best success with reuse of excreta material as compost. Unfortunately though, these processes can be quite complicated. The Arborloo provides a simpler solution with resource reuse, but this design is unfortunately not appropriate in regions where excavation is not possible and it does not protect adequately against the risks of groundwater pollution in high water tables and flood-prone regions. The Peepoo solution has shown itself to be successful in the Oxfam trials in Haiti, but the design still has many challenges such as cost effectiveness and user-friendliness. While Ecosan solutions have shown promise in disaster relief, there is still great potential for further innovation to create a truly appropriate design which promotes health and efficient use of resources.

4. Selection of Sanitation Systems in Disaster Relief

Before discussing how to select a sanitation system to safely dispose of excreta in the context of disaster relief, it is important to address what makes an ideal sanitation system. The ideal sanitation solution would provide coverage for all members of the effected population, safe containment of the excreta, dignity for the users, and added-value (such as energy or a soil enhancer) to the community. These objectives are obviously very difficult to meet, especially in the situation of disaster response or in the creation of refugee camps where resources are very limited.

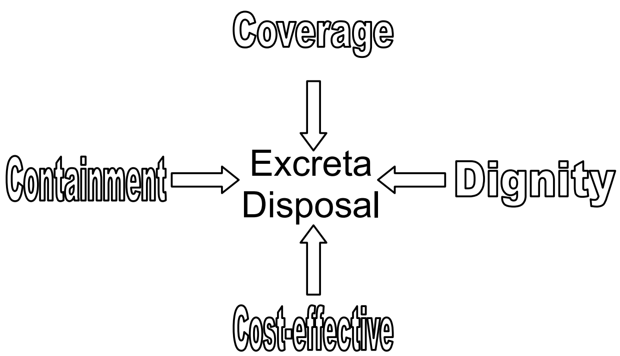


Figure 29: Considerations for Excreta Disposal

The application of Ecosan in disaster relief provides a means to meet several of these objectives listed above such:

- Increased dignity (less odor for the user)
- Greater coverage (designs which are also appropriate for the disabled and elderly)
- Increased safety (portable toilets for the night-time use for women and children)
- Increased public health (reduced threat of water-borne illness, especially in flood prone areas)

As discussed in the introduction, Ecosan also has several other benefits for the environment such as:

- Restoration of natural capital to decrease the likelihood and severity of future disasters
- Foster the adaptation of new technologies in communities which promote long-term sustainable development.

Ecosan is already established as an appropriate sanitation alternative for flood prone areas or when the soil cannot be excavated. In these situations, the advantages of source separation are applied to allow the safe treatment of excreta. Examples of how ecological sanitation has previously been implemented were seen in the case studies section. The purpose of this section is to use the design variables to identify different scenarios with different constraints for the application of sanitation in the context of disaster relief. Work has been done in the past by Fenner et al to develop a decision algorithm for the selection of adequate excreta-disposal solutions in different scenarios. This project builds on that work and adds Ecosan solutions which were neglected by the first evaluation.[25] A second objective is adding relevant criteria for identifying which scenarios would benefit most from inclusion of Ecosan.

First, the relevant design variables chosen for this evaluation will be discussed. Then a decision flow chart will be presented with the solutions determined to be the most appropriate in each situation. In the following section an evaluation of the various technologies will be conducted including an evaluation of current Ecosan solutions in the context of disaster relief. Finally, in the section "Additional Opportunities for Ecosan to be Applied in Disaster Relief" future Ecosan solutions which have not yet been applied in disaster response will be discussed.

<u>Relevant Design Variables</u>

Appropriate excreta disposal measures is highly-case dependent. Thus, the objective of this project is not to identify a single, feasible solution, but rather, to provide context-dependent solutions based on several parameters. The simplest solution in any disaster situation is using the existing sanitation infrastructure when possible. When this is not possible, new sanitation infrastructure must be built. This section deals with the design of new sanitation infrastructure in disaster response, and the assumption is made that there is no functioning sanitation infrastructure previously in place. Various parameters will be investigated to determine the suitability of ecological sanitation options in the disaster relief effort. The design of a solution in the immediate response stage is the least complicated. This is usually accomplished by very quick and crude approaches such as open defecation. Thus the variables listed below are most appropriate for the design of solutions at the short-term and long-term phase of disaster response.

Several factors for selecting an appropriate system for excreta removal have been discussed in "Low-Cost Sanitation" in the context of non-disaster situations. Thus the list of factors provided in this text is very thorough, but not appropriate for disaster relief. There are other suggestions of variables to consider in designing sanitation systems for excreta removal in disaster relief from the publication "Sanitation in Emergencies" published by WEDC, and "Engineering in Emergencies" published by RedR. Using these three sources, a compilation of relevant variables for selecting sanitation systems for emergencies was created and presented in the section below. These variables will be used for evaluating the appropriateness of several sanitation designs. There are six main factors: natural features, the planned built environment, camp residents, pre-existing sanitation practices, construction and involved parties. Each of these main factors is further elaborated into sub-topics, which are assigned numbered design variables when appropriate.

I. Natural Features

- **Surface gradients:** it is important to consider the flow direction of the water so that contaminated water flows away from the camp and water sources.
- **Nature of soil:** it is important to consider various properties of the soil in design. These properties include: the bearing capacity of the soil (to support superstructures for example), the soil stability (to prevent pit collapse during excavation or use), soil characteristics (the depth of excavation which is possible and the infiltration rate) and finally the risk of groundwater pollution. The soil can be either unstable and highly permeable, stable with normal infiltration rates, or rocky and difficult to dig.
- **Groundwater level:** this is important for ensuring that the given excreta disposal design does not contaminate the groundwater. The groundwater level must but sufficiently deep during all seasons.
- **Groundwater condition:** this is important for deciding to what extent groundwater resources should be protected. If the water is of very high quality it can be used for the water supply during the relief effort or in the near future. If the water is of medium quality, it may not used during the present relief effort for the water supply, but it could be feasible in the future. This last situation is if the groundwater is already highly polluted to such an extent that it is not feasible for use at present or in the foreseeable future.
- **Surface water drainage:** important for determining the current and seasonal flow of surface water through the camp proximity. This is of especial consideration for areas with high risk of flooding where it is probable that feces may come in contact with surface water if proper precautions are not in place.

II. The planned built environment

- **Plot size:** how much space is available per family unit either in a constructed camp or in the family's current residence (which is presumed to have no available sanitation methods). This is important for determining whether community or household sanitation solutions are appropriate.
- **Shelter structure:** what type of structure is provided for the family. This is important for determining if a sanitation solution at the household level can be placed indoors or outdoors.
- **Vehicular access to units:** is there enough space between units for central sewage sludge to be collected by vehicles for central processing.
- **Water supply:** how much water is available to each family unit.

III. The camp residents

- **Family size:** how many users would be using a household sanitation solution
- **Family composition:** the age and gender distribution in typical housing units. This is especially important for the appropriateness and the user-friendliness (especially for children and disabled persons) of the selected design. Also, when there are a high proportion of women and children, it may be appropriate to provide household level solutions for at least part of the population to reduce to personal risks of rape or theft during night-time toilet use.
- **Prevalent regional diseases:** these are important to identify so that an appropriate sanitation system is selected to meet the public health concerns.
- **Current awareness of faecal-oral disease connection:** is there a significant lack of awareness of faecal-oral disease connection, and a high prevalence of indiscrete, open defecation which must be addressed through a significant education campaign?

IV. Pre-existing sanitation practices

- **Present approach in region/people group to sanitation:** this regards which type of sanitation solution was in place in the community prior to the disaster. Was open defecation, pit latrines, Ecosan or wet sanitation the most common practice? This can help to decide which sanitation solution is most likely to be accepted in the community.
- **Satisfaction with current sanitation practices:** this deals with whether the residents were content with the previous sanitation solution.
- **Preferred defecation posture:** whether sitting or squatting the preferred. This is important for the design of the collection system.
- **Material used for anal cleaning:** do the local customs favor dry materials or water for anal cleaning? This is important for the design of the container for the anal hygiene materials.
- **Preferred sanitation options:** if defecation is culturally acceptable near the home, or if it is culturally preferred to defecate off the house property.

V. Construction

- **Local availability of construction laborers:** are there workers available who are trained in construction, particularly of latrines?
- **Local availability and cost of materials***:* are the materials required for the construction of a sanitation solution available locally?

VI. Involved Parties

- **How long the agency is willing to commit to running the camp:** whether the agency is willing to invest in and implement long-term sanitation solutions and provide the necessary follow-through on operation and maintenance until solution is well established or whether they will only agree to short-term disaster relief involvement.
- **Financial constraints of donors and relief agency:** does the agency emphasize the quality and sustainability of the solutions or does the agency emphasize maximum coverage at the minimum cost

- **Socio-political factors:** These include the attitude which the host country or responsible authorities have towards the situation of the displaced populations. Often, these organizations do not want to promote solutions which promote feelings of permanence.

In addition to all of the factors which affect the design selection listed above, there are some very important factors which affect the implementation of any project. These include the urgency of the needed solution, the extent of the disaster, and the extent of the migration of the affected peoples. In this work, these factors will not be dealt with in great detail, since these factors are very dependent on the specific situation and require the discretion of the individuals responding to each response. Instead, the parameters dealing with the technological aspect of discreta removal will be considered in the context of the short-term and long-term response stages.

Given the design variables above, five important decisions where identified which affect which process should be selected. These questions include whether or not the system should be above or below ground, wet or dry, whether the ground water should be protected or not, the size served (toilets for the community or for the household), and finally whether the excreta should be reused or not. The processes appropriate for the household level can be further separated into portable (a sanitation system that can fit inside the house) or a traditional system with a chamber requiring a large amount of space. The decision flow chart is shown in Figure 30. The recommended solutions have a number which corresponds to a specific sanitation technology as stated in the key in Table 4. This decision flow chart, along with the questionnaire, can help to decide which sanitation solution should be implemented for short- and long-term phases.

Based on these scenarios listed in the flow chart, recommendations for sanitation solutions are made and listed in the right-hand column. Each number represents a sanitation options which is defined in Table 4 on the next page. The bold numbers are appropriate for short- as well as long-term sanitation solutions.

The purpose of this evaluation is to identify additional opportunities for ecological sanitation to be implemented in disaster relief. For each scenario, there are two sets of solutions listed, one with reuse in mind and one without. The questions in the second part of the survey are useful for the responder to make a decision whether or not reuse is appropriate.

In order to facilitate the decisions in the flow chart, a survey was created to identify the different design variables which would affect each process decision. This survey can be found in Appendix 2: Design Variable Survey.

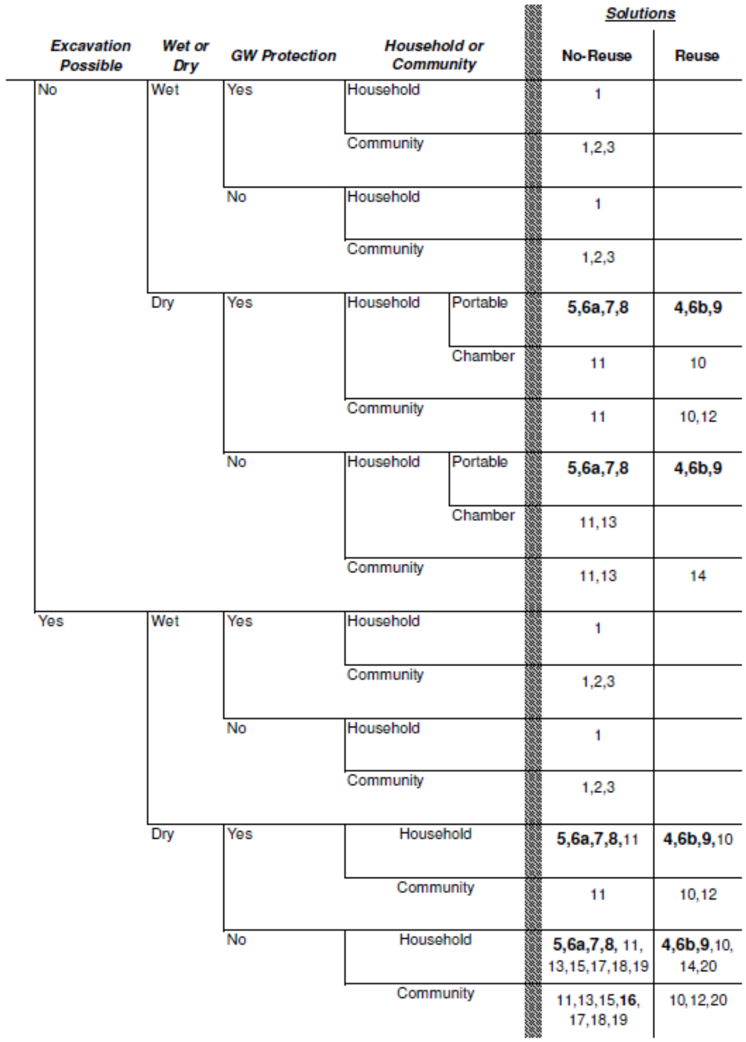


Figure 30: Decision Flow Chart for Excreta Disposal

System	Reuse	Wet/Dry	GW Protection	Excavation Necessary
1) Aquaprivy	No	Wet	Some	Maybe
2) Septic Tank System	No	Wet	Some	Maybe
3) Oxfam Septic Tank	No	Wet	Some	Maybe
4) Separate Collection Buckets for Composting	Yes	Dry	Yes	No
5) Bucket Toilet	No	Dry	Yes	No
6) Porta Preta (a=with composting, b=without)	Yes	Dry	Yes	No
7) Chemical Toilet	No	Dry	Yes	No
8) Disposable Bags	No	Dry	Yes	No
9) Biodegradable Bags	Yes	Dry	Yes	No
10) UDDT	Yes	Dry	Yes	No
11) Urine Diversion without reuse	No	Dry	Yes	No
12) Thermophillic Dry Composting	Yes	Dry	Yes	No
13) Raised Lined Latrine	No	Dry	No	Yes
14) Composting Toilet (mixed collection)	Yes	Dry	No	Maybe
15) Bore hole	No	Dry	No	Yes
16) Trench Latrine	No	Dry	No	Yes
17) Pit Latrines	No	Dry	No	Yes
18) Lined Pit Latrines	No	Dry	No	Yes
19) Ventillated Improved Pit (VIT) Latrine	No	Dry	No	Yes
20) Arborloo	Yes	Dry	No	Yes

Table 4: Key for the Sanitation System Number

5. Design of a New Ecosan Toilet

An ideal Ecosan toilet for disaster response would provide coverage for all members of the camp, the safe containment of the excreta, dignity for the users, and added-value (such as energy or a soil enhancer) to the community. One key issue which could be addressed by Ecosan is the design want to address at the present is a portable toilet for the elderly, disabled and for night-time use (so women and children do not have to exit their tent/dwelling. This toilet would need to be essentially odor free since it would be in such close proximity to the user. The new, promising Terra Preta Sanitation toilet offers such a solution. A portable Terra Preta toilet could act as an short- and/or long-term solution for providing sanitation during disaster relief efforts. This design could be deployed essentially anywhere, and implemented when the first shipment of relief supplies arrives (normally about 3 to 4 weeks after the situation is declared a disaster).

Design

The current portable Terra Preta Toilet design, the "Porta Preta", is based on a urine-separating bucket toilet, as pictured below in Figure 31.

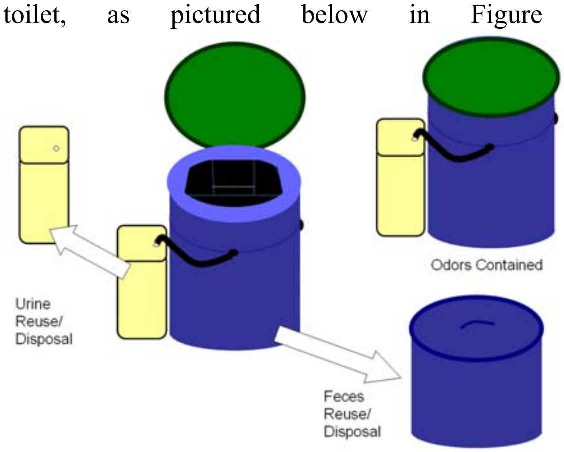


Figure 31: Separate Collection in a Portable Toilet

More detailed sketches of the unit can be referenced in Appendix 5. The toilet, and the necessary accessories and materials for one month of operation for five individuals will fit in 30x32x40 cm^3 space. Anal hygiene material (either water or paper) should be collected in a separate bucket. The dry material can be burned, and the wash water can be treated in a soak-pit.

The Porta Preta should be portable and odorless, so that the toilet could be used within very close range of a family dwelling. When the lactic acid fermentation process is functioning properly and with the addition of the biochar mixture, there should be no odor generated.

In order to achieve hygienization and minimalization of odor, the toilet is based off of the Terra Preta Sanitation (TPS) concept. There are several models for TPS underdevelopment, but all the models share three common steps: (1) Collection, (2) Lactofermentation, and (3) Composting. [26] More information on the TPS systems currently underdevelopment has been compiled and can be found in Appendix 3.

A mixture can be formed with water, milk lactic acid bacteria (LAB) with the appropriate amount of sugar (3-5% by weight). 500 mL of this mixture can be added to the bottom of the container at the beginning of the week with an additional sugar source (this can be molasses, kitchen waste or table sugar). The feces are then covered with charcoal before they are deposited in the bottom receptacle, and after each use to slightly cover the receiving surface of the toilet (to facilitate the transfer of the feces). This process is highlighted in Figure 32 below.

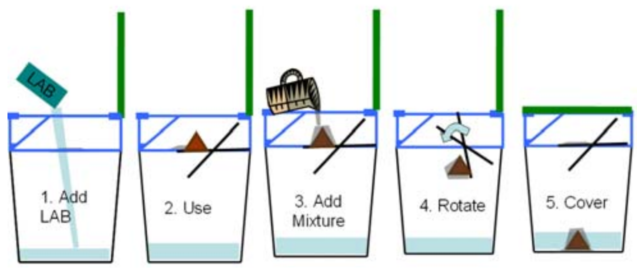


Figure 32: Operation of the Porta Preta

During the lactic acid fermentation stage, the pH of the mixture is significantly lowered, providing hygienization of the feces as well as odor control. The lactofermentation process must be carried out under anaerobic conditions, so it is important that the collection chamber is closed after each use. Additional odor control is provided by the addition of charcoal or biochar (about 1.00 kg/user/month) so that no ventilation is necessary.[31]

The volume of the receptacle can hold the feces produced by five individuals over one week's period. After the receiving bucket is full, the bucket can be covered and collected by a local laborer. The material can then be composted to produce rich terra preta for application in agriculture and/or reforestation. If the composting step is forgone, the lactofermented feces can be stored indefinitely until they can be further utilized without posing any environmental or health threats. If the terra preta is applied in agriculture, it is recommendable that it would not be used in a food crop for human consumption within the first two years of its production.

Biochar Production

The Porta Preta design requires the input of about 1kg biochar per user per month. In the initial response stage, the biochar could be shipped to the site with the toilet model, but after one to two months, the charcoal could be locally sourced or biochar could be produced on-site. One example of how the biochar could be produced would be semi-centralized using 200 gallon barrels. These barrels could accept the input of various feedstocks which could feasibly be produced in an Internally Displaced Persons camp such as wood-based disaster debris, biomass from a constructed wetland, dehydrated feces, organic waste, and agricultural waste. This scheme is featured in Figure 33 below.

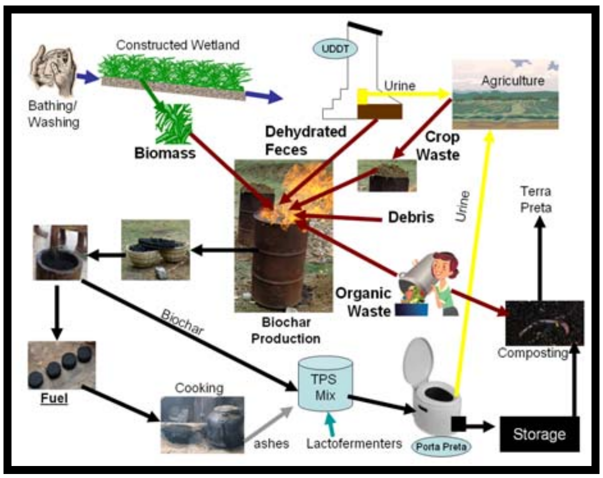


Figure 33: Integrated Biochar and TPS System

One to five of these feedstocks could be used to undergo the carbonization process to produce the biochar necessary to operate the Terra Preta toilets. Based on one or more of these situations, enough biochar could be produced to meet the Porta Preta needs. The expected quantities of biochar produced per month are listed in Table 5 below for a camp of 2000 individuals. The biochar needed for the Porta Preta to serve half of the population would be 1000 kg/month. When extra biochar is produced it can then be used as a fuel source for cooking.

Situation	Description	Total Biochar Produced (kg)	% of Biochar need for Porta Preta
A	Organic Waste	1172	117%
B	Dehydrated Feces	500	50%
C	Wetland biomass	500	50%
D	Agricultural Waste	400-4000	40-400%

Table 5: Production of Biochar from Different Feedstocks

These quantities are based on the assumption that 25% mass to biochar conversion would be achieved during the carbonization process which can be carried out in one location using the process developed by the D-labs of MIT.[27] For organic waste it is assumed that organic waste is produced at a rate of 0.08 kg (by dry weight) of organic waste per inhabitant per day.[29] For the production of dehydrated feces it is assumed that half of the camp is equipped with urine diverting dehydration toilets (UDDTs). Another assumption is that the UDDTs will be emptied after one year at a staggered interval in the camp (therefore not all of the dried fecal matter would need to be carbonized at the same time). This resource would thus not be immediately available at the start of the camp, but after more than one year's operation, and thus only appropriate for semi-permanent refugee camps.

For the production of wetland biomass, it is assume 1400 m2 of constructed wetlands will be constructed. The wastewater for the constructed wetland would come from the bathing and cloth washing facilities and/or the urine from the urine diverting dehydrating systems. The charcoal produced from biomass is calculated assuming the production of papyrus biomass at a rate of 1.4kg/m2 per month.[28] For the agricultural waste it is assumed that local crops are grown for the camp producing 4-40 metric tons of crop waste and residues

Logistics

The portable nature and rapid assembly of the design make the Porta Preta appropriate for both urban and rural disaster response as soon as the first humanitarian supplies have arrived. All the components of the design can be incorporated into a space with a height of 40 cm and a diameter of 30cm with any extensions being within 33cm as shown in Figure 34 below.

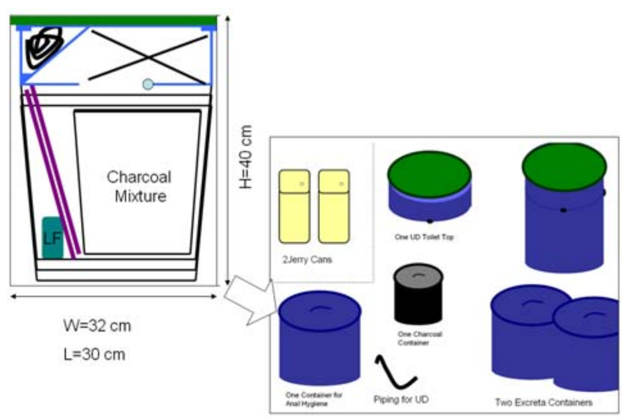


Figure 34: Easily Transportable Porta Preta Kit

In order to increase the efficiency of the delivery, logistical aspects are considered in the design. The dimensions were chosen to ensure that 36 units can be placed onto a standard pallet for placement in a forty foot high cube unit for marine transport. This allows for the cost of logistics for the delivery of the unit from production to the site of the disaster relief effort is approximately $10 or less per unit.

Costs

Another target of the design is to be more cost effective in terms of cost per user per month than a simple pit latrine. To achieve this, the target fixed cost for the Porta Preta is $10 per unit for delivery, $20 for the construction of a urine/anal hygiene soak-away pit, and $25 the toilet unit (a further break-down is seen below in Table 7). The target fixed costs include are listed in Table 6 below.

Fixed Costs	
Porta Preta Unit	$25
Logistics (delivery)	$10
Labor (distribution and user training)	$0.60
Processing Equipment Cost	$2.00
Urine Soakaway patch	$20

Table 6: Total Fixed Costs

The breakdown of the cost of the Porta Preta unit with the materials for one month of operation for five people is listed in Table 7 below.

Component	Target Cost
Plastic Urine Diverting Top	$8.00
Buckets (3)	$4.50
Lids (2)	$1.00
Charcoal Bucket with lid (1)	$2.00
Urine Jerry Cans (2)	$3.00
Tubing	$1.00
Charcoal (5.0kg)	$3.00
EMA + Sugar (1.25 kg)	$2.50
Total:	**$25.00**

Table 7: Target Cost of Porta Preta Parts

$10 per unit is the cost for delivery following the calculations listed in Appendix 1. The initial labor per unit is expected to cost $0.60 assuming local hygiene promoters can be trained (and paid at $4/day), and train approximately 6-8 families each day.

The monthly costs are targeted to be $3.50 for consumables 5.0 kg of charcoal and 1.25 kg of sugar for the LF bacteria) and $0.50 for collection and treatment. The cost of charcoal is estimated at $0.50 per kilogram from an average of the prices given on charcoalproject.org. The cost of sugar is estimated to be $1 per kilogram. The labor for collection and treatment is estimated at $0.50/Porta Preta unit per month. This is assuming the buckets are picked up once a week by a laborer who can collect 40 buckets a day and earns $4.00/day. More details on these calculations in Appendix 4.

Given these costs, the monthly cost per user for the Porta Preta used over one year would be between $1.20 (if urine is reused and biochar is locally produced) to $1.80 per month. This would be less expensive or comparable to a pit latrine when it is assumed that the simple pit latrine would cost about $100 to construct[30]. At the current design stage, the Porta Preta seems to offer promise as a feasible ecological sanitation alterative to the standard pit latrine for disaster response.

Expected Challenges

There are some challenges expected to be encountered in this design which must be addressed:

1. **Training: t**he users must be quickly and effectively trained how to use the system. This can be facilitated by diagrams present on the lid or the side of the system. The negative odor feedback with improper use is also expected to help encourage proper use.

2. **Ergonomics:** the bucket must be designed to support the weight distribution of the user during defecation and anal cleaning. This can be improved by local materials (rocks, concrete or bricks) as well as user precaution.

3. **Lactofermenting bacteria:** work must be carried out to deliver the bacteria in a reliable, transportable way. One approach may be freeze-drying and encapsulating the bacteria as done for many probiotic supplements for human and animal diets.

4. **Squatters:** this design is not particularly suitable for individuals which prefer to defecate in the squatting position. Further development is required to tailor the design to these needs.

5. **Stirring:** Intermittent stirring by the user may be required for proper functioning of the system. If this is the case, then a stirrer can be added to the design for about $1 per unit. A possible design to implement stirring can be seen in Appendix 5.

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Appendix 1: Calculation of the Logistic Costs for the Porta Preta Delivery

In order to estimate the approximate cost per Porta Preta unit for delivery in disaster response situation using sea freight, it was assumed that the parts were produced in and shipped from Chennai, India. The dimensions of the units are 30 cm by 32 cm by 40 cm so that 36 units can fit on a pallet, and 22 pallets can fit in a 40 foot high cube container. Three shipping destinations were chosen around the globe to model the potential costs, Bangladesh, Haiti and Kenya. These locations are shown on the map below in Figure A1.1.

Figure A1.1: Model of the Distribution of Porta Preta toilets across the world.

Using the origin of Chennai, and the three mentioned destinations, prices estimates were used from Maersk to calculate the estimated shipping/logistic cost per unit. The results and the assumed quantities are listed in Table A1.1 below. Using these assumptions, it was estimated that the cost of the logistics for the delivery of each Porta Preta unit would be $10.

Origin	Destination	Cost of 40'HC	Origin Charge	Destination Charge	Ground Transportation	$/unit
Chennai, India	Bangladesh	$1,100	$1,000	$1,200	$2,000	$7
Chennai, India	Haiti	$3,800	$1,000	$1,200	$2,000	$10
Chennai, India	Kenya	$2,700	$1,000	$1,200	$2,000	$9

Table A1.1: Estimation of Logistics Cost per Unit for Delivery

Appendix 2: Sanitation Survey

Sanitation Survey Part I

1. What is the nature of the soil?

a. Unstable, highly permeable
b. Stable, with normal infiltration rates
c. Rocky ground, difficult to dig

2. What is the level of the groundwater?

a. Reasonably deep groundwater
b. Permanent, or seasonally high groundwater table

2. What is the present groundwater condition?

a. High quality groundwater which can be used at present or in the future for water consumption
b. Medium quality groundwater: not used at present for water supply, but it could be feasible in the future
c. Highly polluted: polluted to such an extent that it is not feasible for use at present or in the foreseeable future

4. Is there a flood risk?

a. The are has a very low risk of flood and surface water contact with feces
b. Flood risk zones

5. Is there enough space for vehicular access to each housing units?

a. Enough space for vehicular access for sludge collection
b. Not enough space for vehicular access for sludge collection

6. How much water is available to each family unit?

a. Enough water for wet sanitation solutions
b. Not enough water for wet sanitation solutions

7. What was the previous approach in region/people group to sanitation?

a. Wet sanitation systems were employed
b. No previous sanitation infrastructure
c. Pit latrines were widely used
d. Ecological sanitation practices widely used

8. What is the size of the land available for every household?

a. Enough space on family unit site for family sanitation unit
b. Not sufficient space family unit site for family sanitation unit

9. Is the shelter structure large enough to house a toilet inside?

a. Yes, structures suitable for compact inside sanitation solutions

b. Structures unsuitable for compact inside sanitation solutions

10. What is the preferred defecation posture?

a. Sitting
b. Squatting

11. What is the preferred material used for anal cleaning?

a. Water used
b. Dry materials used

12. What is the preferred sanitation location?

a. Defecation preferred near home
b. Defecation preferred off of the house property

13. How long is agency willing to commit to the camp?

a. Agencies are not willing to implement long-term sanitation solutions
b. Agencies are willing to implement long-term sanitation solutions but will provide minimum follow-through on operation and maintenance
c. Agencies are willing to implement long-term sanitation solutions and will provide the necessary follow-through on operation and maintenance until solution is well established

14. What are the financial constraints of donors and relief agency?

a. Agency emphasizes quality and sustainability of the solutions
b. Agency emphasizes maximum coverage at the minimum cost

15. What is the attitude of the host country or responsible authorities?

a. Authorities are willing to allow long-term sanitation solutions
b. Authorities are not willing to allow long-term sanitation solutions

The results from this survey can be transferred to the answer key seen below in Figure A2.1 using the directions given.

	Collection						Treatment		Size				Cultural Preferences			
	Above	Above/ Below	Wet/ Dry	Dry	non-UD	UD possible	Reuse Considered	Not Considered	House-hold	Comm-unity	Portable	Container	Sit	Squat	Water	Dry
Q1	a/c	b														
Q2	b	a														
Q3	a/b	c														
Q4	b	a														
Q5			a	b												
Q6			a	b												
Q7					a	b/c	d									
Q8									a	b						
Q9											a	b				
Q10													a	b		
Q11															a	b
Q12									a	b						
Q13				a		a	b,c									
Q14							a			b						
Q15							a	b								
Total																

Figure A2.1: Answer Key to the Sanitation Design Questionnaire

Directions:

1. Mark the appropriate answer from each question of the sanitation design survey on the above grid.
2. Sum the number of circles in each column
3. The column with more points for each column is the recommended approach for the given aspect
   - If there is a tie, then both options are feasible, and individual factors must be evaluated
   - When two options are present such as “Wet/Dry” then individual factors should be evaluated

4. Use the results to make a decision using the sanitation decision flow chart.

Sanitation Survey Part II

Supplemental questions to ensure all needs are met in the community.

S1. Is there risk/fear for women and child to use community toilets at night?

If the answer is yes, then a portable sanitation solution should be provided for these individuals for at least nighttime use.

S2. Are there individuals which can not access the community toilets due to disability?

If the answer is yes, then a portable sanitation solution should be provided for these individuals which they are able to use without great difficulty.

Additional questions for determining whether or not reuse should be recommended:

R1. Do family garden plots exist?

a. Yes (reuse of urine)
b. No

R2. Is food produced locally for the camp?

a. Yes (reuse of urine)
b. No

R3. Is there significant soil degradation which makes growing crops difficult?

a. Yes (reuse of urine and feces)
b. No

R4. Is it desired to produce biomass for local fuel needs?

a. Yes (reuse of urine and feces)
b. No.

R5. Is there deforestation in place and are there incentives for reforestation?

a. Yes (reuse of urine and feces)
b. No

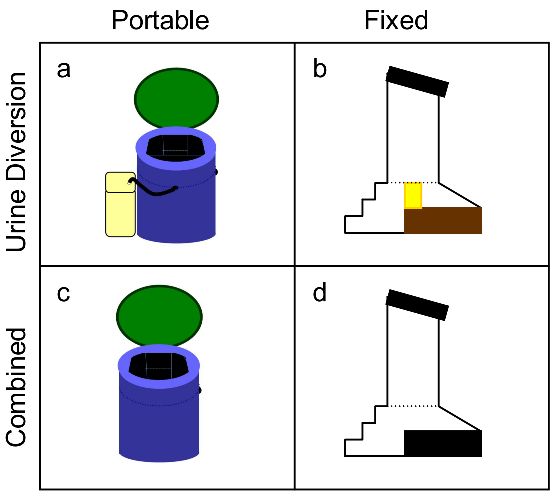
Appendix 3: Terra Preta Sanitation Design Factsheet

Terra Preta Sanitation Fact Sheet

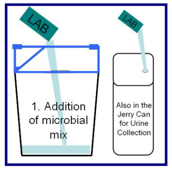
Created by: Katherine Kinstedt

Terra Preta Sanitation (TPS) is a novel sanitation method to provide a dry, comfortable odor-free system which produces a rich soil additive know as Terra Preta. TPS systems function with three basic steps: collection, lactic acid fermentation (processing), and composting. These steps and some basic design parameters are discussed in the sections below. The information presented below results from ongoing research at the Technical University of Hamburg.

1. Collection



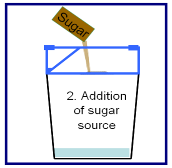
The receiving container should be sealable to allow an anaerobic or semi-anaerobic environment. The collection system can be either fixed (such as a retrofitted latrine) or portable (such as a bucket toilet). The toilet can have urine diversion or combined collection (feces and urine collected together).



1. MICROBIAL MIX

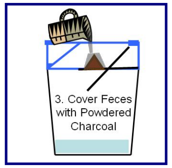
TYPE: A solution can be prepared from the dry or freeze-dried bacteria from the Reckin mix, from the commercially available Effective Microorganism mix, or from sauerkraut liquor.
ROLES: 1) Begin the lactic acid fermentation process (lower pH to hygienize the excreta) 2) Inhibit the production of malodors
HOW TO ADD: In solution with water, milk and an energy source (sugar content=3-5%).
AMOUNT: 10-50 mL/use with 1*107-1*109 CFU/mL of LF bacteria (0.2-1 L/person/month) and 0.5 liters per 10L jerry can when urine is diverted.

After Use



2. SUGAR SOURCE

TYPE: Can be molasses, food scraps or refined sugar
ROLE: Allows lactofermenting bacteria to grow
AMOUNT: 1-10% of mass of the feces when molasses is used (40-400 g/person/month) with urine diverting systems. A greater quantity (500-1000 g/person/month) is needed when collection is combined.



3. Powdered Charcoal

TYPE: Locally available charcoal can be used, or biochar can be produced.
ROLES: 1) Absorbs odor to make the process completely odorless 2) Visually covers the feces 3) Prepares the mixture for use as Terra Preta, a rich soil additive
HOW TO ADD: The powder charcoal should be added to cover the feces after each defecation
AMOUNT: A half cup per use (50-100 g/use) or about 1-3 kg/person/month.
CONCERNS: The charcoal has been shown to increase the pH of the mixture, particularly when combined collection of urine and feces is practiced. This increase in pH is beneficial for the composting process, but may negatively affect the hygenization of the excreta. Thus the addition of the charcoal after the lactic acid is completed may also be appropriate.

2. Further Processing

After the collection of the urine and feces, or the combined product, further treatment must occur. This treatment can take place at the household or the community level. If further processing occurs at the community level, an efficient and safe transport system must be implemented.
Urine: Can be used directly, composted or used for comfrey production
Feces: Must be further stored to allow full maturation of the lactic acid fermentation process. This time is between 1-3 months. Then the third step, composting can be performed.

3. Composting

A final composting process is necessary to allow the use of the TPS product as a soil additive. This TPS soil additive product is not recommend for use with food crops within the first 1-2 years. The composting process can be carried out at the household level, or with centralized collection at the community level, and the vermicomposting process is the most recommended composting process.

Information Sources:

1. Personal correspondence with Horacio Factura, Asrat Yemaneh, Stefan Deegener and Prof. Ralf Otterpohl
2. Gensch. Terra Preta Sanitation. Cagayan De Oro, 2010.

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Appendix 4: Cost of Processing for the Porta Preta

The terra preta processing equipment cost for one unit would be $2, assuming the following collection scheme was followed as presented in Figure A5.1.

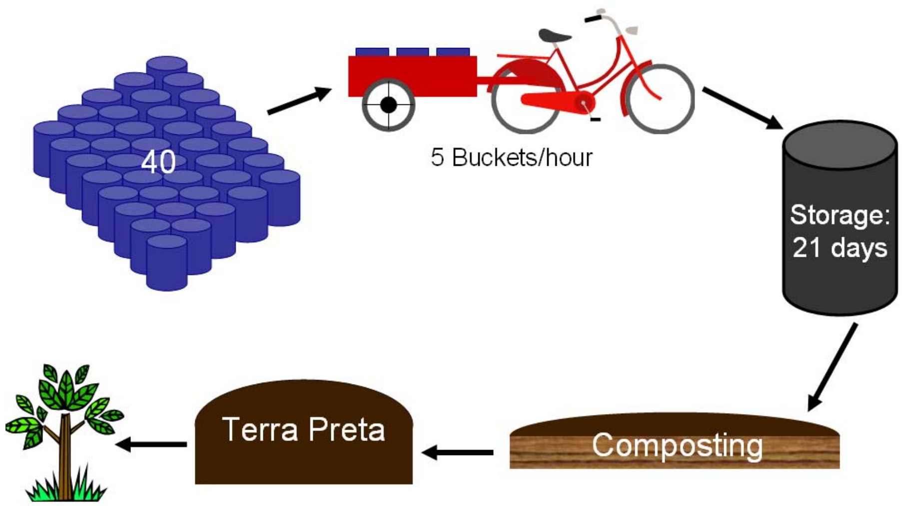

Figure A5.1: Porta Preta Collection Scheme

Assuming a person produces 1 liter of feces per week, and that the volume is not affected significantly by the small addition of the biochar and lactofermenters. Each unit, assuming five users, would have five liters contained after one week. If 40 buckets were collected in a day, then the treated feces from one day of collection could be treated in one 200 liter oil drum (estimated to cost $15). Thus, one laborer could handle the input from 200 units, or 1000 people. At a centralized collection area, the feces should be stored for three weeks to allow further sterilization before being composted. Thus, assuming a residence time in the drum of three weeks to allow further hygienization, 21 units would be required. Thus the initial equipment costs for 200 units, would be $395, or about $2 per unit. Details of the cost breakdown are shown below.

21 Holding Drums	$315
1 bike	$40
1 wagon	$40
Total	$395
Cost/unit	$1.98

Table A5.1: Porta Preta Collection and Treatment Costs

The cost of the composting materials is not included because it is proposed that the pallets from the TEU be used for this purpose. The terra preta which is produced can be used for crop production (for non-food production for the first two years) or reforestation. The added value of these benefits is not included in the cost analysis.

Appendix 5: Additional Renderings of the Porta Preta Unit

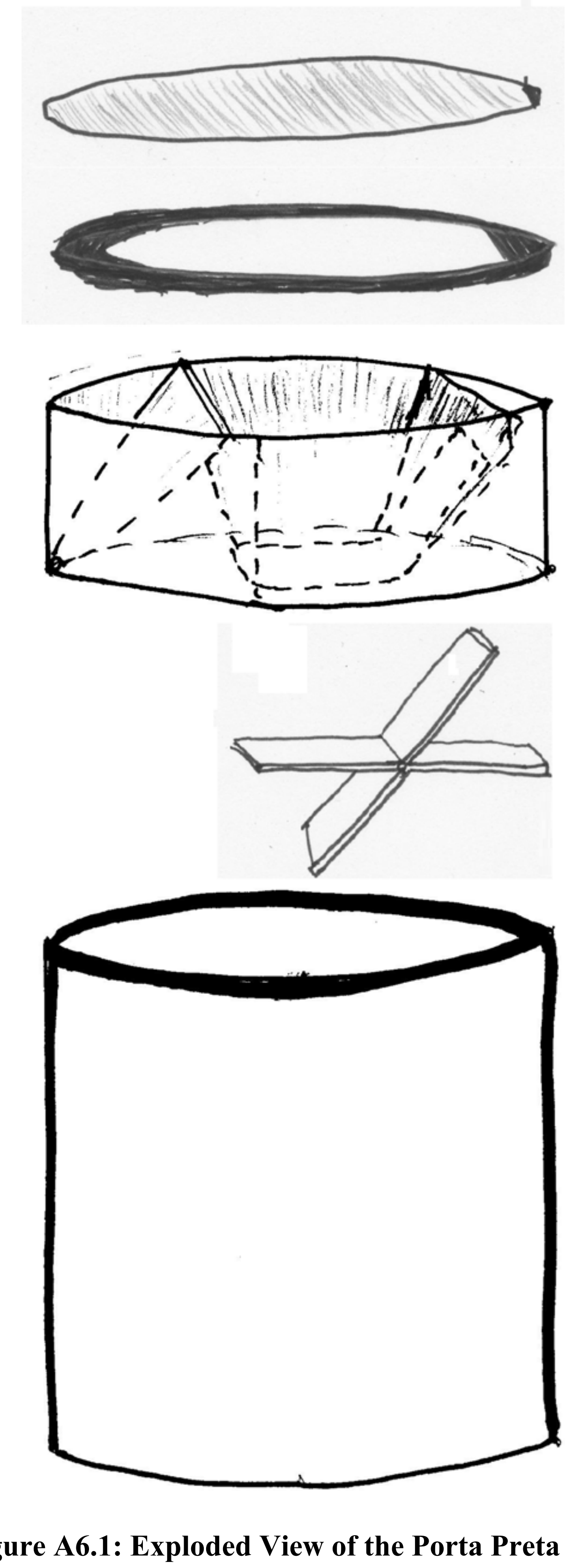

Figure A6.1: Exploded View of the Porta Preta Unit

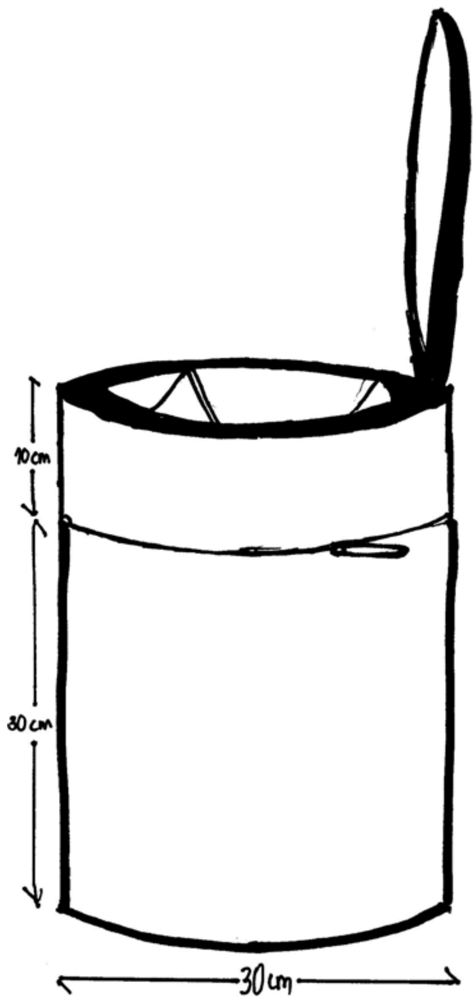

Figure A6.1: Porta Preta Unit with Dimensions

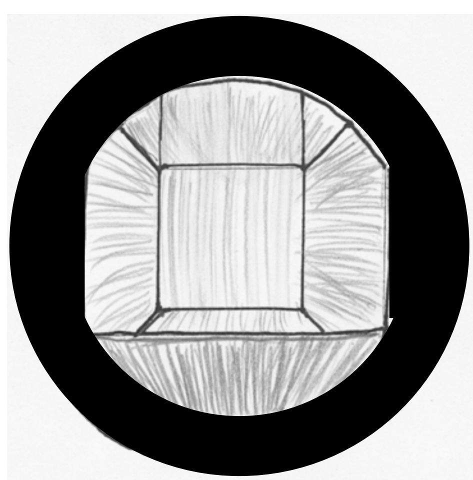

Figure A6.3: Top View of the Porta Preta Unit

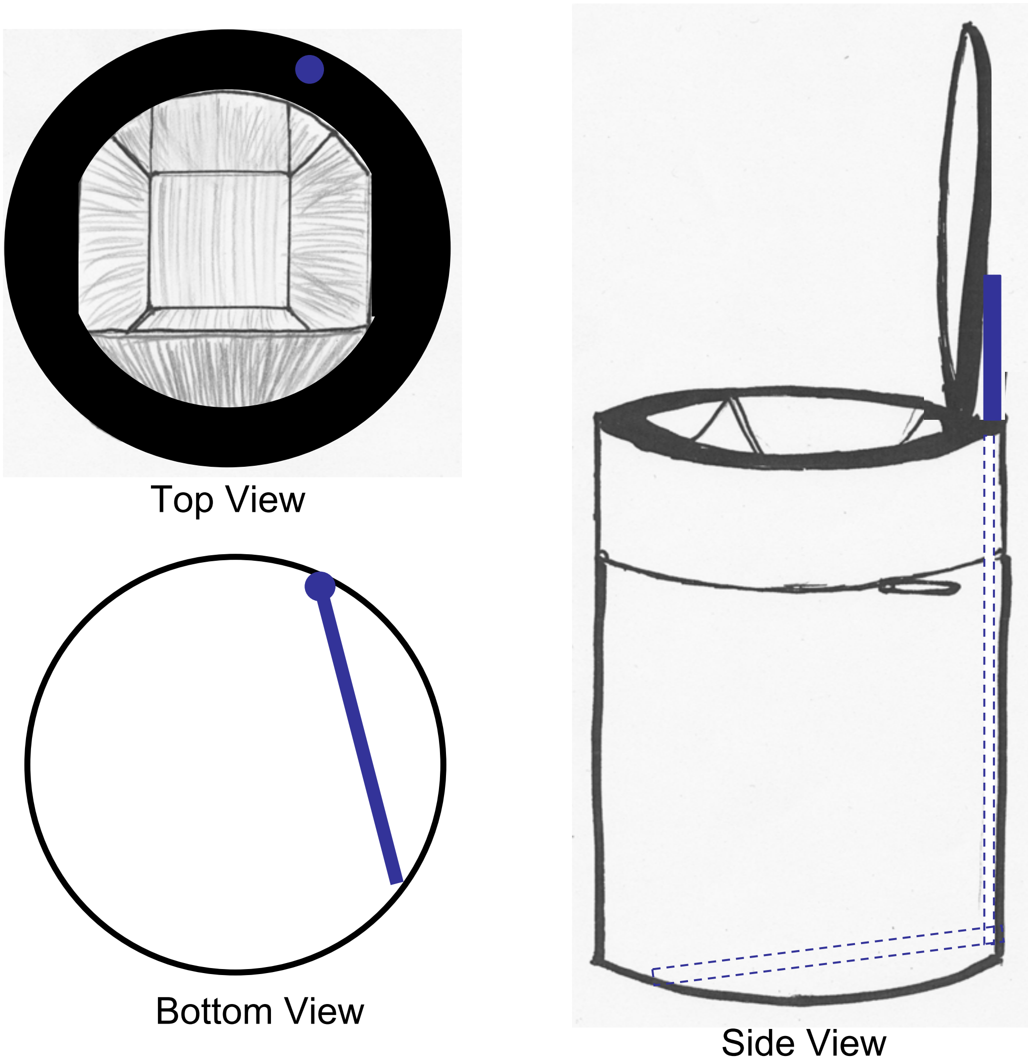

Figure A6.4: View of Model with a Stirrer