

Practical Paper

Sustainability-inspired composting latrine design

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ABSTRACT

In support of the Millennium Development Goals to provide improved sanitation to the world, a sustainability-inspired composting latrine design based on work in rural Panama, but also applicable to similar situations, is offered here. The design is based on the three aspects of sustainability namely economic, social, and technical. The new design will allow for improved health for current and future generations. The design is less costly (economic), is based on concepts to improve the likelihood of use based on interviews with potential users (social), and provides better quality compost through ammonia-based treatment (technical). The design consists of two ferrocement compost vaults to save money over conventional vaults, urine storage tanks to improve ammonia conditions in the compost, urine control valves for urine control, a water-washing bidet for personal washing (as preferred by the users), and a handwashing station within the latrine superstructure for convenience.

Key words | developing country, ferrocement, public health, sanitation, social habits

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INTRODUCTION

According to the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), 842,000 deaths could be prevented annually by improving water, sanitation, and hygiene (WASH). This is despite the final progress report on the Millennium Development Goals (MDGs) by the WHO/UNICEF Joint Monitoring Programme (JMP) stating that 91% of the world's population has access to an improved water source. This disparity stems from the sanitation situation that 2.4 billion people who have no access to improved sanitation facilities (ISFs).

An ISF is defined by the WHO as (a) not being shared among households and (b) able to 'hygienically separate human excreta from human contact' (WHO 2014; Exley *et al.* 2015). This is in contrast to unimproved sanitation facilities, which include the absence of any facility at all, as is the case for 946 million people who practice open defecation worldwide (JMP 2015). Current ISFs include pit latrines, pour-flush latrines, and the focus of this work, composting latrines (CLs) (Exley *et al.* 2015). The JMP has developed the 'sanitation

ladder' hierarchy for sanitation technologies that include open defecation on the bottom 'rung' and ISFs like flush toilets connected to sewerage on the top rung (Kvarnström *et al.* 2011).

LITERATURE REVIEW ON PROBLEMS ADDRESSED

Latrine cost

Cost of the compost vaults slab can be reduced by using ferrocement. Ferrocement is common in developing countries and uses light-gage wire as reinforcement instead of steel rebar and is, therefore, less expensive than reinforced concrete. The cement portion refers to the 1:2 or 1:3 cement-to-sand mortar that is plastered over the reinforcing steel. These ratios must be prescribed by weight rather than volume for optimal performance and differ depending on cement origin and fabricator. Ferrocement calls for a workable mortar consistency for application, yet the

water-to-cement ratio must be as low as possible for the best strength conditions. Although not the focus of the current study, thicker walls for insulation or applying a dark material to the outside of the ferrocement could improve the mechanisms described for pathogen inactivation in CLs and in ammonia-based sanitation (ABS). Ferrocement construction can be less expensive than masonry block walls due to the ease of construction not requiring skilled labor.

Latrine user acceptability

Despite the proposed benefits gained through improved sanitation interventions – including those involving CLs – there still exist sizeable issues aside from the aforementioned technical ones. Latrine use has much more to do with other barriers like convenience, comfort, privacy and safety (Jenkins & Scott 2007). The governments of developing countries may have some moral obligation to aid in the elimination of open defecation through pit latrines and other methods as well (Mara 2017). Odor control is also of concern (Hashemi & Han 2017).

Ammonia-based sanitation in composting latrines

ABS consists of the addition of ammonia (in the form of urine) to the feces in the latrine pit to help in the biodegradation and feces sanitation process. As of yet, ABS has not been applied to large-scale sanitation interventions and has only been studied in laboratory studies (Nordin *et al.* 2009; Fidjeland 2015). ABS depends on the presence of uncharged or un-ionized molecules, NH_3 , to create a toxic environment for microorganisms or, for these purposes, pathogens through the disintegration of the protein membrane of the cell wall. The NH_3 molecule has the freedom to travel between this membrane and alkaline properties might raise the internal pH and cause this cell disintegration. This has an added benefit to biosolids or compost in that the process does not consume ammonia, but rather increases its nutrient potential (Nordin *et al.* 2009; Fidjeland 2015).

Goals of the research

The goal of this research is to find a sustainability-inspired CL design through ‘economic’ (the use of less expensive

ferrocement instead of block vaults), ‘technical’ (the use of ABS through the addition of urine and ash), and ‘social’ (the incorporation of users’ preferences for washing) aspects. The combination of economic, technical, and social aspects are the definition of sustainability used here.

MATERIALS AND METHODS

Study site

Valle de Riscó, Panama (population 1,500) is located in the northwestern portion of the Bocas del Toro region of Panama. Valle de Riscó is a town of small family clusters, the five households that participated in this study are in reality just two large family clusters that can trace back their start to two different patriarchs. Valle de Riscó is approximately 35 minutes away by small bus to the much more urbanized city-center of Almirante. Valle de Risco’s connection to Almirante is evident in the relatively higher incomes compared to other communities in the region reported to the National Census Institute of Panama. In 2010, 56% of those living in Valle de Riscó made at least \$175, with almost 20% making between \$400 and \$800 per month.

Ferrocement vaults

To test the feasibility of using ferrocement for the CL vaults, ferrocement was utilized to create two 1,136-L vaults to serve as an alternative to the typical 90-concrete block design used previously. The walls were approximately 50 mm thick. Each of the two vaults had a capacity of 1.14 m³, 0.91 m high and 1.17 m diameter, designed for eight users (Kierys 2016).

Compost degradation testing using ammonia-based treatment

An experiment was designed to determine the role of ash in ABS using intrinsic ammonia found in stored urine collected from dual-vault, urine-diverting CLs. Eighteen reactors composed of matrices of compost and urine obtained from three CLs and varying amounts of ash were assembled in 9.46 L plastic containers (Kierys 2016). Every 2 weeks,

measurements of pH, temperature, and ammonia concentration were obtained from the 18 matrices for 12 weeks.

The six matrices were composed of compost, urine, and ash with one control group and five treatment groups made up of different combinations of ash, stored urine, and fresh urine. *Ascaris* ova viability was determined microscopically and using a linear regression method. *Ascaris* ova presence is being used as an indicator of pathogen reduction since *Ascaris* ova are the most persistent contaminant. This was the first study to show promising potential for the application of ABS as a primary or on-site treatment method.

Ash was collected from three stone hearths from each respective household. All matrix components were measured volumetrically and added to identical containers that had been modified with the addition of a spigot commonly used for household water use to diminish the effects of ammonia volatilization. Because of the addition of the spigot, ammonia levels steadily rose up to the 12th week of the experiment. Each of the compost treatment reactors were then placed outside on concrete platforms raised off the ground and were covered to keep out of direct sunlight, as would be the case in an actual CL.

Measurements of pH and sample temperature were obtained using an Oakton pH 5+ Handheld Meter with pH Probe (Oakton 2017). Samples were taken in 15 mL test tubes, which facilitated the ammonia concentration testing developed by Trimmer using Seachem Multitest: Ammonia Test Kits (Hach 2017). The ammonia testing required dilution of each sample by 1,000 and, in some cases, 1,500 to fit within the manufactured range of 6.0 mg-NH₃-N/L, and used a color-changing disk to determine ammonia levels. Additionally, ambient temperatures were taken on all days in which samples were measured, as well as some of the days in between.

Since it is unfeasible for users to control the urine tank temperature as this would require energy usage for heating or cooling, the authors did not control temperature in the study.

Ethnographic research

To improve the use of CLs, an ethnographic survey was taken from five families in the town. Many households

were observed to own some type of ISF including flush toilets and pit latrines, yet others had none at all, according to some residents. Five families have habitually operated and maintained CLs for more than a decade after receiving initial construction and training from Peace Corps volunteers. Three of these five families were also asked to participate in the complementary technical investigation.

The interviews were conducted with key informants decided by the family to be the household leader, and they knew the details associated with the CL project, the operation and maintenance of it, and had knowledge of previous Peace Corps volunteers (Kierys 2016). Informed consent was received from all participants prior to any formal questioning. There has been considerable interaction between the community and Peace Corps volunteers either directly within or indirectly around the surrounding area of Valle de Riscó and this had considerable influence on the participants of this study. Households that had adopted CL use for the past 12–14 years were asked to participate in this study to fill in some gaps in the literature on EcoSan and provide preliminary knowledge on the still experimental ABS process. The researcher used open coding in the *in vivo* method, when possible, to develop common ideas and differences into overarching themes. Institutional review board (IRB) approval was obtained from Michigan Technological University.

RESULTS AND DISCUSSION

Ferrocement vaults

After some training of the local townspeople on ferrocement construction techniques, ferrocement vaults were built in a demonstration project. It was found that the ferrocement vaults could be built in approximately 32 hours instead of 96 hours for traditional block vaults and for a cost of \$80 (in 2016 dollars) compared to \$400 (Kierys 2016). The cost savings came from not needing a skilled mason and the three-fold decrease in cement volume. The cost of the proposed design in this village in Panama was estimated to be \$140, which is 6% of the annual income of these villagers. A typical CL costs 33% of the annual income.

Compost degradation testing using ammonia-based treatment

Data showing the biweekly temperature, pH, ash%, moisture content, un-ionized and total ammonia and calculated inactivation time calculated from [Fidjeland \(2015\)](#) were collected ([Kierys 2016](#)). Certain findings were consistent with the literature, such as the fact that the groups that received more alkaline amendment (ash) produced more basic (pH <7) readings. An unforeseen outcome was that the group receiving the most ash by volume of compost only slightly outperformed the other less-alkaline groups, especially the control group that was un-amended. This group averaged a pH of 9.77, the highest of all the groups, but had an average uncharged ammonia concentration of 348 mg-NH₃-N/L, not far from the intrinsic uncharged ammonia found in the control group. Uncharged ammonia concentration is positively correlated with *Ascaris ova* inactivation ([Trimmer 2015](#)).

The discrepancy between the pH and corresponding NH₃ values in the group with 75% ash could be explained by the lack of mixing and the resulting moisture content upon ash amendment. Perhaps the combination of a lowered moisture content and heterogeneous distribution of aqueous NH₃ produced a highly volatile concentration and inhibited movement of hydroxide ions ([Nordin et al. 2009](#)). The ammonia production performance of the group consisting of compost and urine was the highest after 12 weeks.

These findings suggest that for ABS treatment a lack of a desiccant or cover material is not inhibitory as is the case for both composting and alkaline desiccation – two widely used EcoSan methods. Sawdust availability is dependent on the success of sawyers and on an optimistic rate of deforestation. Ash is less widely found due to the change towards the use of propane and improved cooking stoves in light of the correlated effects open fires have on pulmonary disease and also the former phenomenon of deforestation that causes families to search for wood further and further away. If neither process can explicitly improve health outcomes or even be found to eliminate pathogens or the vector from human excreta then more commonly-available and practical dry materials such as grass should be promoted to diminish smells and create a biological barrier to fend off vectors.

Testing was performed using microscopy at a local clinic laboratory. The clinic performs routine stool sample analysis and for this reason, viability or log reduction determination was not possible. Thus, the initial samples showed either the presence or absence of *Ascaris ova*. Samples taken at the end of the 12-week experimental period showed that only five of the 12 treatment matrices had no presence of viable *Ascaris ova*.

As the data imply, there is not an obvious correlation that could be drawn between ammonia concentration and pathogen inactivation. There are several matrices that outperformed or were in line with their more successful counterparts, only to yield a positive reading. Most notably, Matrix B5, which had readings near the absolute bottom of the groups, yet was still able to provide inactivation. Matrix temperature was found to correlate to ambient temperature and result in the highest uncharged ammonia concentration at approximately 30.5 °C ([Kierys 2016](#)).

Ethnographic research

The answers to the survey questions generally revealed a positive opinion of CLs ([Table 1](#)). More details are given in [Kierys \(2016\)](#).

Applicability to other cultures

While this ABS design should be applicable to most developing-world cultures, estimating building costs and surveying the potential users as to their preferences will increase the likelihood of successful use.

Table 1 | Ethnographic survey summary of CL design-affecting responses ([Kierys 2016](#))

Question	Response summary
Why don't others have CLs? Problems?	High expense Lack of sawdust as a desiccant Inaccessibility of toilet paper Want water washing bidet
Feelings towards urine use for ABS	Willing to do more to operate urine valves if the compost was degraded faster

CONCLUSIONS

Sustainability-inspired CL design

The objectives of the study were accomplished since a sustainability-based CL was realized. Based on the results of the cost (less-expensive ferrocement), technical (ABS experiments showing successful contaminant removal), and social (ethnographic survey giving washing preferences) noted above, the sustainability-based CL should be employed (Figure 1). The design consists of two ferrocement compost vaults to save money over conventional vaults, urine storage tanks to improve ammonia conditions in the compost, urine control valves for urine control, a water-washing bidet for personal washing (as preferred by the users), and a hand-washing station within the latrine superstructure for convenience.

The operation of the latrine would be identical to that of a traditional CL in terms of urine diversion, avoiding the entry of water, and proper desiccant use. However, every three months, the tank would have to be sealed and become a reactor for the ABS process to begin. Two valves control the influent urine from entering the vault, but once urine does enter the urease in the compost will begin ureolysis and the second vault would have to be

primed with desiccant and begin being used. Once another three months has passed, another valve controlling the effluent of the reactor would have to be opened to drain and release the leachate, preferably into a soak pit. The disposal of this nitrogen-rich effluent is key to not making ABS another contributor to eutrophication and other environmentally-detrimental anthropogenic actions. Next, the false floor would be raised and the tank unsealed after several hours to allow the residual ammonia gas to disperse before the compost is shoveled off for agricultural use. Also, 3.81 cm PVC pipes were used to avoid clogging. There must be a gap between the house superstructure and the top of the ferrocement compost vaults to avoid any vault collapse. Urine diverting cups are used inside the toilet. Both toilets drain into a common urine storage tank located in between the two toilets. Only one urine storage tank is needed since only one toilet is used at a time. The feces go into the ferrocement compost vault. The urine should drain out through the effluent release, after which the compost would be harvested by shovel from the top of the vault for use as fertilizer. The ferrocement compost vaults were each designed for the collection of six months' worth of feces for the number of users desired, or approximately 1,136 L. Other CL details are given in Mihelcic

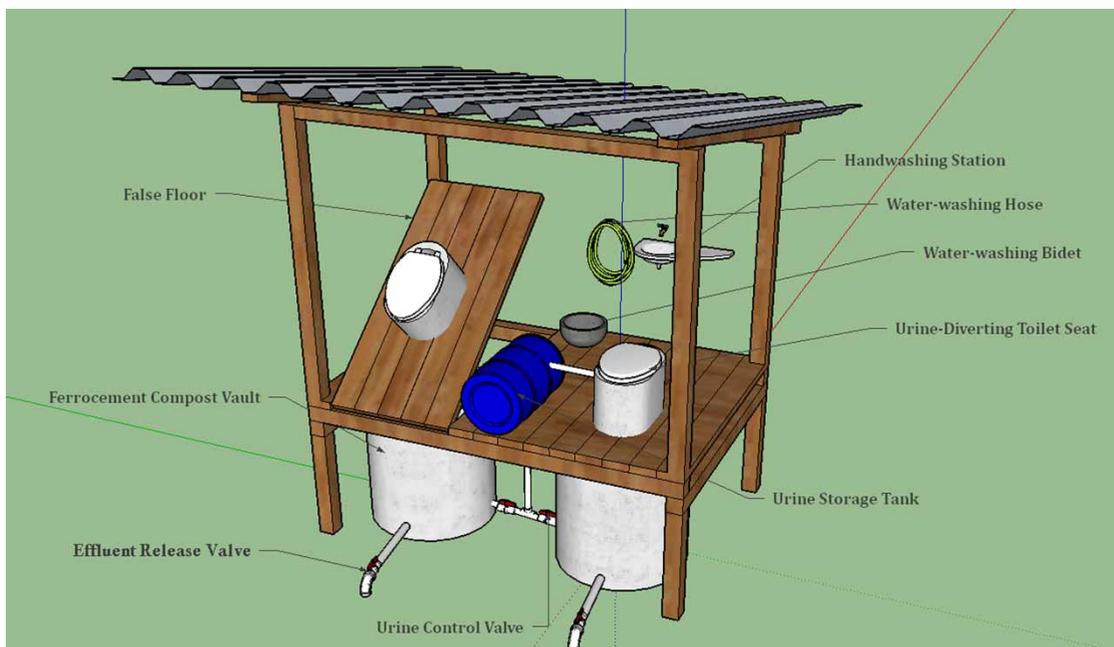


Figure 1 | Conceptual model of ABS latrine design (the ABS is fully enclosed even though the walls and door are not shown here).

et al. (2009). Urine scale formation is not a problem on the smooth walls of the PVC pipe specified here, but could be in the ferrocement compost vaults. Therefore, periodic clearing of any deposits is recommended. The durability and robustness of the proposed design is comparable to the traditional CL. In addition, the ABS odor was deemed by the authors and villagers to be no worse than the traditional CL.

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