FSM4

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Development of Integrated Reactor Systems for the Combined Biological and Electrochemical Treatment of Faecal-Sludge and Wastewater Without Discharge to the Environment

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Abstract

With support from the Gates Foundation, we have developed transportable facilities that have been designed for the onsite treatment of domestic wastewater. After pre-treatment with a mixed anaerobic/aerobic baffled bioreactor, the effluent is processed sequentially through electrochemical arrays and a micro-filter before recycling of the treated black water into a flush water reservoir without discharge to the surrounding environment. Human wastewater can be clarified with the elimination of suspended particles along with > 90% reduction in chemical oxygen demand (COD). In addition, total enteric organism disinfection is achieved for bacteria and viruses via anodic chlorine generation coupled with cathodic hydrogen generation. The biochemical and electrochemically treated wastewater is recycled internally as toilet and urinal flushing water. Improvement of the performance and durability of the core semiconductor anodes along with materials modifications to lower their production costs is a continuing objective. Second-and third-generation prototypes are undergoing field-testing in several locations that lack conventional urban infrastructure for wastewater discharge and treatment; the system can operate without an external source of electricity or fresh water. Extensive field-testing in India and China is underway. A Caltech-China joint-venture company, EcoSan, has been established in Yixing, China to manufacture units for the developing world, while at the same time industrial collaborations have been established in India with ERAM Scientific and the Kohler Company (USA/India) for production of units to be used in urban environments in India. The latest basic research results on semiconductor anode development, field-testing results, and plans for future development manufacturing, and implementation will be presented. At the current time, larger-scale units are being constructed for use in South Africa, Peru, Cambodia, and the Philippines.

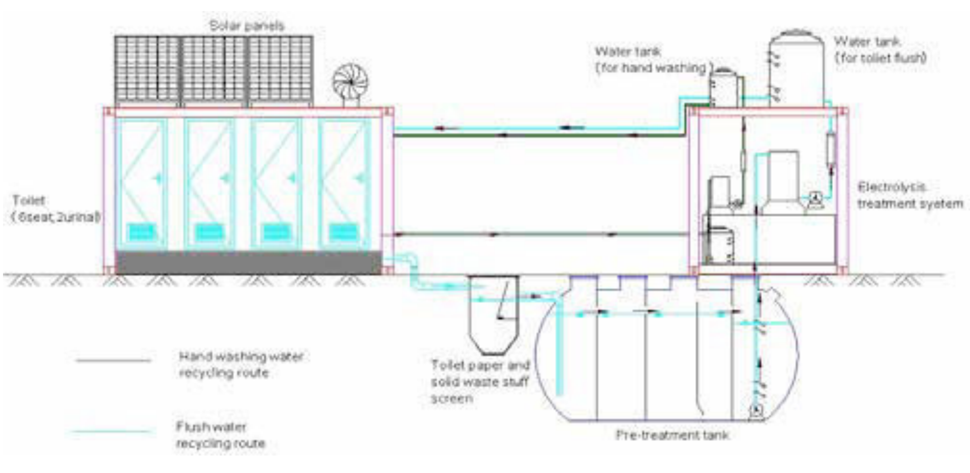

Figure 1. A schematic flow diagram of the Caltech-EcoSan PV-powered solar toilet system is illustrated in an elevation perspective.

Figure 2. Beta prototype PV-powered solar toilet system used at an elementary school in Yixing, China.

Figure 3. Left Panel: Alpha prototype showing the electrochemical reactor arrays, the baffled anaerobic reactor, flush water tank, and the biochemical reactor effluent holding tank. Right: Smartphone monitoring and control systems for operational control, maintenance, and repair directions.

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Urine-tricity Project

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Keywords: Microbial fuel cells; urine treatment; electricity generation

Conference Track: (1) Research Track
Track Topic: *Technologies for the collection, transport, treatment, disposal and use of faecal sludge*
Personal Preference: *oral presentation*

In the context of sanitation and public health, waste management and environmental pollution are the two biggest challenges faced by humanity, especially in Developing World countries. The lack of appropriate water treatment and hygiene initiatives, which usually require an established and expensive infrastructure, means that new technologies that offer effective and low cost solutions, are much sought for. While untreated waste is contaminating water and causing water-borne diseases, the society is constantly searching for sustainable energy sources. The Microbial Fuel Cell (MFC) technology tackles both challenges, offering a bio-electrochemical system capable of producing electricity while treating different types of organic waste, including urine.

An MFC usually consists of an anodic and a cathodic chamber separated by a semipermeable membrane. In the anode chamber of the MFCs, microorganisms break down the organic matter contained in urine and directly convert it to electricity. In the cathode chamber, the oxygen reduction reaction (ORR) takes place by consuming oxygen from the air to generate water or hydrogen peroxide, depending on the catalyst used. The use of MFCs also allows valuable nutrient recovery from urine, including catholyte generation, struvite precipitation or ammonia stripping. However, in order to manufacture an affordable large scale MFC system, it is necessary to minimize the materials cost without sacrificing the power generated. Ceramic membranes and carbonaceous cathode electrodes have recently been proposed as low cost materials for a more applicable MFC technology (Winfield et al. 2016, Gajda et al. 2015).

It has been previously reported that the overall power production can be increased by stacking multiple MFCs into modules that are inter-connected in series and parallel electrical configurations (Ieropoulos et al., 2008). In order to assess the feasibility of the technology outside the lab, it was necessary to scale up the MFCs and test these in real world settings. This was recently demonstrated in the trials conducted on the University of the West of England campus (Frenchay, Bristol) and at the Glastonbury Music Festival 2015 (Worthy Farm, Pilton), which demonstrated the feasibility of the system to power internal lighting while reducing the COD levels (Ieropoulos et al., 2016). These field trials demonstrated that stacks of 288 (UWE) and 432 MFCs (Glastonbury), respectively, can offer a decentralized urine treatment unit, which at the same time is capable of producing electricity to power lights, or in different settings power portable devices. This shows potential for power generation and sanitation improvement in remote locations or emergency areas, including refugee camps.

However, the MFC efficiency in terms of power production and urine treatment can be improved by further miniaturizing the individual ceramic MFC units and multiplying them into modules. In this work, the MFC unit size has been reduced 3-fold in height and 2-fold in width before being fabricated into smaller modules of approximately 1.7 L capacity each. These have been tested and showed an increased power density, generating up to 22 mW per 22-MFC-box. This means that the same absolute power as with the previously used large MFCs, was achieved with the smaller MFCs. Figure 1.1 shows the improvement in power density of the smaller improved design in comparison with that used in the first field trial on campus. These improvements were also due to the use of a different terracotta ceramic membrane. There are several parameters to evaluate in the type of ceramic used, including porosity, wall thickness and composition, since they can considerably affect the MFC power performance. MFCs with a more porous earthenware membrane (16.6% water absorption) have shown higher power output than those with an iron-rich terracotta (9.1% water absorption) membrane (Winfield et al. 2013). Further analysis needs to be performed in order to fully understand the effect that the ceramic composition, porosity, slip-casting and kilning has on the power generation of the MFCs, to achieve a high efficiency for low cost effective urine treatment systems.

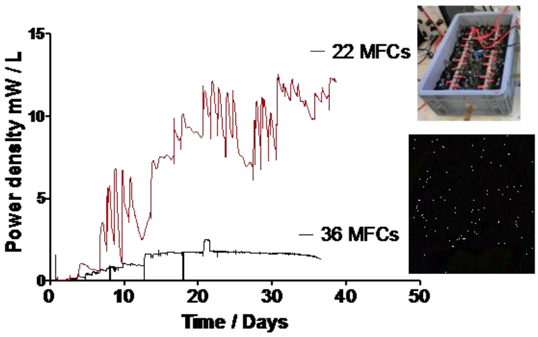

Figure 1.1 Comparison of the improvement in the power density using improved design and materials.

Combining MFCs with other rapidly developing technologies such as microelectronics, supercapacitors and smart energy harvesting systems would enable integration into existing wastewater treatment plants and validate the suitability of MFCs for practical applications. Tin this work, an off-the-grid bio-electrochemical system, which decontaminates urine by utilising the organic compounds locked in urine to produce direct electric current, is presented. This applicable technology offers a low cost Decentralized Wastewater Treatment solution for countries, where the lack of wastewater infrastructure and the scarcity of water leads access to unsafe sanitation and waterborne diseases.

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Market Insights For The Reinvented Toilet, India

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Keywords: value proposition; business model; market entry

Conference Track: (1) Research Track
Track Topic: *Economics & Business*
Personal Preference: *oral presentation*

Background and Context

Understanding the market segments, customer profiles, and various go-to-market considerations for a new product category is essential to designing systems and business models that will succeed in the marketplace. This research was supported by the Bill and Melinda Gates Foundation and was designed to glean important insights for Reinvented Toilets (RTs) across a range of use cases and system designs to help inform the implications of targeting different customer segments and their associated needs in India. The insights from the research can be used by both technology developers designing, prototyping, and testing systems and commercial partners working toward scale-up and market entry. For technology developers, the research defines performance characteristics and features that will drive acceptance and adoption within a particular customer segment, which can be used to direct research funding and technology development efforts to the most essential performance attributes. For commercial partners, the research defines the benefits an RT must deliver to be adopted by a specific customer segment and provides high-level go-to-market strategies for those customer segments.

Specifically, this study provides in-depth customer and market insights regarding urban sanitation solutions as they relate to two principle factors (a) design of systems and (b) the associated use cases. We are exploring drivers that will influence system designs ranging from in-home units to those distal to point of use, and for example, exterior to structures. Also specific uses cases and structures are being considered, including commercial buildings and residential housing, such as apartment buildings, multi-building low-income housing complexes, and slum housing.

Research Approach

To develop customer segments and define characteristics required for adoption of the RT in India, extensive primary research was undertaken over the course of five months running from June to October 2016. The effort included:

- 254 customer interviews, including but not limited to homeowners, builders, architects, contractors, and homeowners' association.
- 59 value chain actor interviews, including manufacturers, retailers, and distributors.
- 21 experts from more than 18 organizations.

The research was conducted in four Tier 2 cities, Coimbatore, Lucknow, Patna, and Pune.

Based on interviews, key drivers that may lead to the adoption of the RT were identified and used to determine customer segment variables. The variables were screened for appropriateness, the degree to which they can help explain variance in adoption drivers, and executability, the viability of using the variable for segmentation based on available data. A customer segmentation frame was developed based on variables and internally homogeneous and externally heterogeneous segments were defined. For each segment, drivers and barriers to adoption of the RT were highlighted. Using insights from the segmentation, implications for the adoption of the technology into that segment elucidated. Market size estimates were calculated for each segment using publically available data.

Outcomes

Nine segment were identified for RT systems that are designed for single homes using the following variables: new versus existing construction, toilet ownership, access to a drain, age of construction, occupation of the chief wage earner serving as a proxy for awareness of sanitation solutions, and highest education achieved in the family as a proxy for openness to new technologies.

Eight segments were identified for RT systems that are designed to process waste from multiple homes using the following variables: new versus existing construction, usage of the structure, e.g. commercial versus residential, the price category of the land, and hours of electricity supply as a proxy for willingness to install amenities.

For each segment, observations and insights from the field were translated into implications for the RT technology. Acceptable ranges for technology parameters such as electricity, footprint, requirements for additives and consumables, and acceptance of by-products were explored with users. For select customer segments, go-to-market strategies were developed. Technology implications, technology parameter ranges for each segment, estimates of segment size, and potential go-to-market strategies are currently being refined and will be presented in detail during the FSM4 conference.

Significance and Impact

The insights from this presentation will offer valuable input for all technology developers and commercial partners interested in developing and commercializing systems in the India market. The research method and approach, based on category-level analysis, may have important applications for defining similar studies in other markets.

India Field Testing of an Integrated Sanitation Platform with Electronic Public Toilet (eToilet) and Off-grid Anaerobic Membrane Bioreactor (NEWgenerator™)

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Keywords: Onsite treatment, water recycling, biogas
Conference Track: FSM Research Track
Track Topic: *Technologies for the collection, transport, treatment and disposal of faecal sludge*
Personal Preference: *oral presentation*

Background and Introduction

Public and communal toilets serve an important role in providing complete sanitation coverage, especially in high-density and low-income urban communities. However, improper design and maintenance of public toilets often renders them unhygienic and underutilized after implementation. Improvements in the design of public toilets, along with automation of their functions can improve user acceptance of these facilities and decrease the long-term operational costs of sanitation provision. These objectives have been met through the development of a fully automated electronic toilet called the eToilet. However, many urban environments present additional challenges including ridged space constraints, absent or ineffective water and electricity infrastructure, and high usage rates. These constraints render traditional decentralized wastewater treatment infrastructure inoperable due to their dependence on water, electricity, and low to moderate usage rates. In this study a novel decentralized treatment technology, the *NEWgenerator™* anaerobic membrane bioreactor (AnMBR), is combined with an eToilet to investigate the combined system's ability to provide sanitation coverage to high density urban areas. The combined system is able to provide onsite water, nutrients, and energy recovery with a small footprint. The ability of the combined systems to operate off-grid, and to recycle a large portion of the water needed for flushing allows the system to be implemented in a greater variety of contexts demanded by high density environments.

The Technology: Electronic Toilet

Traditional public toilets, which form a vital link in providing complete urban sanitation coverage, have a legacy of being poorly maintained and often lead to disuse due to foul smells and service quality. Automation of public toilets can help to improve the hygienic properties of public sanitation while maintaining lower maintenance costs. A fully automated and smart toilet has been developed by the Eram Scientific Solutions group based out of Trivandrum, India. Their product, the eToilet, is a modular, pre-fabricated toilet with remote monitoring capabilities and web-connectivity. The company has gained notable success throughout India with more than 1,800 installations of eToilets in 19 Indian states. All toilets are remotely monitored which helps to decrease maintenance costs while still providing satisfactory toilet cleanliness.

The Technology: Anaerobic Membrane Bioreactor

The coupling of membrane filtration with anaerobic digestion delivers a process that is robust and resilient to fluctuations in environmental conditions and wastewater characteristics. The use of ultrafiltration membranes also helps to guarantee pathogen containment within the system. These advantages have made AnMBRs appealing for use in decentralized wastewater treatment applications. Due to their low energy use, AnMBRs can be combined with decentralized and renewable energy systems, such as photovoltaics, to form self-powered and off-grid sanitation systems. This combination affords the technology the potential to be readily deployed and implemented in countries where grid power is often unreliable.

The Field Test

This study presents recent data from an integrated sanitation platform testing for a year at a school in Kerala, India. The *NEWgenerator*^{TM} AnMBR was housed in a portable shipping container and was connected to two eToilets which had been customized for communal sanitation. Waste produced by the eToilets was then treated by the AnMBR and electrochlorination. The treated water was used for toilet and floor pan flushing. While the AnMBR was originally designed to treat the waste for 100 users per day, there were days when the usage exceeded 400 user/day. Despite large fluctuations in wastewater characteristics and volumes, the treatment performance of the system remained high throughout the study period. This was even during times when the influent COD was low (below 250 mg/L). With such low strengths, traditional anaerobic digestion would be easily overwhelmed. During the field test energy usage was also lower than expected and membrane fouling was adequately prevented through operational conditions. The results of the field trial suggest that *NEWgenerator*^{TM} AnMBRs have great potential for addressing the sanitation needs of many urban areas in developing countries.

Figure 1: Site picture showing final system as installed at the site. The two orange eToilets can be seen with their associated sinks. The AnMBR housed in a shipping container and PV system can also be seen.

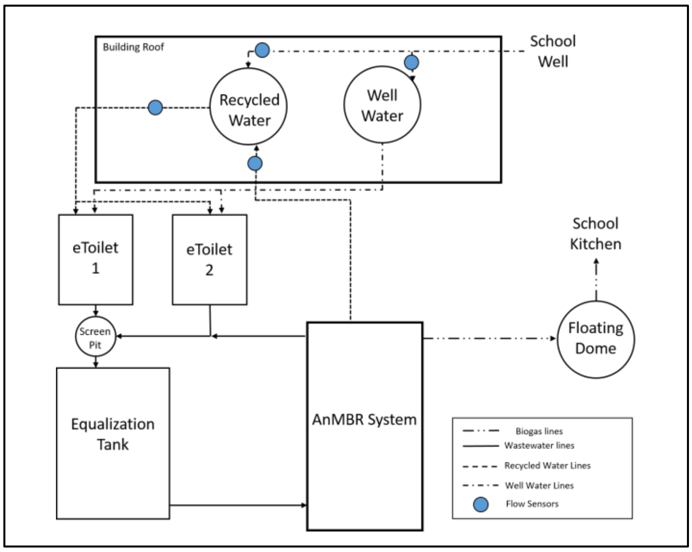

Figure 2: Site layout for field unit. Layout only shows generalized pipes and flows. Sensors and wiring omitted.

Financing Citywide FSM Services

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Keywords: FSM Financing, Bond Market, Municipal Finance

Conference Track: FSM Research Track
Track Topic: Economics and business
Personal Preference: Oral presentation

Introduction

In most discussions on FSM the aspects related to financing are relegated to background. It is assumed that since FSM is a “public good” with high externalities, it is the responsibility of the government to provide for FSM service. However, the onus of providing FSM service is typically on local governments. These local governments usually do not have sufficient funds or technical capacity to provide FSM services. As a consequence, a large number of informal service providers have emerged to fill the service gap. Given the fact that these service providers are unregulated, they do not follow proper practices of emptying pits/septic tanks. These operators dispose fecal sludge in open grounds or water bodies causing serious environmental and health hazards.

FSM Landscape Analysis

In our research, we have done a landscape analysis in India to assess the potential funding requirement of FSM services. This is done on the basis of available information from Census 2011 and PAS data at (www.pas.org .in)[1]. The research shows that the information base on FSM in cities is extremely poor. Most local governments do not have any information on the number of pits/septic tanks being emptied/to be emptied every year. One of the outcomes of our research was to develop an Android based application – SANITAB - for developing a quick information system on FSM at city level.

Financing Full Service Chain

The full service chain of FSM includes septic tank emptying, conveyance, treatment, and possible reuse or resource recovery. For each of these activities, there is a one-time capital cost and recurring operating costs. Some of these costs can be funded either by local governments through its own budget (e.g. emptying service) or by private sector through a contract with local government or user fees. Likewise, the capital costs, of emptying trucks can be met by grants from government or by private enterprise funds. Treatment facilities have been usually funded by public sector with grants, as the revenues from resource recovery are usually not sufficient to recover the capital costs.

Potential Sources of Financing – Bundled and Unbundled Approaches

When governments finance FSM – both capital and operating costs – there are various options. We have explored possible sources of capitals funds, viz.: Grants from National/Provincial government, municipal budget surplus, municipal borrowings (either through loans from financial institutions or public borrowing in terms of municipal bonds. For each of these sources, the pros and cons are assessed. Similarly for financing operating costs – we have explored user fees, sanitation tax, revenues from resources recovered etc.

[1] The Performance Assessment System (PAS)

When private finances are sought for FSM, it is important to first decide on a bundled contract, i.e. the entire service chain or an unbundled contract, i.e. for each of the activities in the service chain. In a country like India, where most private enterprises in the FSM sector are informal enterprises, an unbundled approach to FSM is desirable. This will not place heavy demand for capital mobilization on the private sector. Given that there are very high standards for discharge of treated waste water in India, it is quite likely that the private sector enterprises may not come forward to finance both the capital and operating costs of septage treatment. This is partly true also because of the high subsidy for chemical fertilizers and low charges for electricity and gas in India. This renders revenues from treated septage difficult.

Way Forward

We have already done some background studies and developed tools for PPP/PSP based approaches for FSM. Based on this framework, appropriate procurement procedures and contract documents for private sector participation have been developed. Tenders are invited for PSP in a small town in India and the contract has been awarded. We will track the performance of the private enterprise and study its business model.

We are also working on different aspects of sanitation financing. As a part of this, we plan to explore the demand and opportunities for financing toilet construction in India.

Increasing institutional and regulatory support for private sector

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Keywords: private sector, FSM, institutional

Conference Track: (1) Research Track or (2) Case Study Track
Track Topic: (1) Economics and Business or (2) *Emerging FSM - policy and institutional*
Personal Preference: *oral presentation*

Role of private sector

To achieve the improvements in faecal sludge management (FSM) required for the sustainable development goal of "safely managed sanitation", both scale up and improvements in the quality of current FSM services will be required. In most countries the private sector are the main provider of emptying services (Chowdhry and Kone 2012) and is typically unregulated (World Bank 2014). As cities promote septic tank emptying, such service provision will need to significantly increase, and in many cities increased private sector involvement will be required to meet this demand. This paper discusses the challenges faced by private sector in providing safe emptying services and recommends regulatory and institutional support to create an enabling environment for private sector to provide a safe, sustainable and equitable service as FSM is scaled up.

Challenges for private sector in Indonesia and Vietnam

This paper draws from field research conducted by the authors on private sector roles in FSM in nine cities in Java, Bali and Kalimantan in Indonesia and six rural districts in the Red River Delta in Vietnam (Murta et al. 2015, World Bank 2016a, World Bank 2016b). While both countries have public sludge emptying services, the private sector is the main provider in the research cities and will play a major role as FSM scales up, in particular the regular emptying programs proposed in some Indonesian cities. The research included household surveys (240 Indonesia and 30 Vietnam), interviews with private sludge emptying providers (40 in Indonesia and 4 in Vietnam) and government agencies and found the following four key challenges facing the private sector.

Low demand: Due to non-standard and typically unsealed on-site sanitation and a limited understanding of the need to regularly empty, demand for emptying is low. 67% of the 24 enterprises interviewed in Indonesia reported that low or lack of demand was a major challenge, as well as 71% reporting market saturation and 79% finding competition the main challenge (Murta, 2015). In Indonesia many cities are investigating regular emptying programs and in most cases private sector will provide the service. Demand creation is still required for regular emptying programs with households still able to refuse emptying, making the program unviable as occurred in Dumaguete Philippines (Murta et al 2016) or costly to the private operator who is only paid per successful emptying (World Bank 2016a).

Unregulated: There is uncertainty on both sides about the legal requirements for private sector with 63% of the 24 surveyed enterprises in Indonesia reporting unclear or lack of government regulation. While some cities register private operators (Ho Chi Minh Vietnam), or have memorandum of understanding (Bandung and Jakarta, Indonesia) official registration or licencing of private sector operations in rare. 63% of enterprises in Indonesia were informal and small private emptiers in Vietnam expected not to have a business licence. Licences typically do not have technical requirements such as safe transport or discharge to treatment plants and MOU are difficult to sanction. A lack or uncertainty of regulations was found to create a perception of needing to hide services from government, emptying at night, not discharging to treatment and unregulated tariffs. In Indonesia operators were interested to establish a formal agreement with government to permit their operation, use treatment plants and regulate poor quality providers.

Unsafe practices: Some cities do not permit private sector to discharge at sludge treatment site, others charge unregulated disposal fees and, where they exist, most plants are located far from the city causing high transport costs. These disincentives contribute to the very small proportion of emptied sludge, both public and private trucks, that is safely treated. Hygienic emptying practices or wearing safety equipment is also rare.

Challenges with equitable service provision: While private sector were the main service provider in the surveyed Indonesian cities (62%), they typically charged higher fees than government (30% higher). However households reported a preference for private sector due to faster response, better access to tanks due to longer hose and better trucks and willingness to extend services such as unblocking the toilet. In rural Vietnam government serves the provincial capital but only private sector serve the rural areas. Private sector's increased ability to service difficult to access households can be seen as beneficial for serving the poor, most operators reported no incentives for poor. Sludge emptying enterprises had a lower sense of social responsibility compared with water and sanitation enterprises and less likely to offer flexible payment arrangements.

Local government roles to support and regulate private sector

Recognising the important role of private sector, we suggest minimum local government roles to support private sector engagement and achieve safely managed sanitation.

Regulatory oversight: A balance between supporting private sector engagement and regulating poor practices will require a considered and staged approach from the current unregulated market toward smart compliance. Key roles could include:

- Monitoring current status of private sector moving to tracking emptying and safe discharge.
- Licencing/registration to create service standards, encourage or sanction practices.
- Regulate tariff to improve cost recovery, transparency, equity and reduce cost cutting.

Market Facilitation: Increase demand by government lead promotion of improving on-site sanitation, educating or enforcing regular emptying and linking private sector with this market. The sludge emptying sector typically doesn't receive enterprise support such as business and financial skills training, however these will be vital in the context of the accounting and reporting requirements in regular emptying.

Equity: If sanitation is to serve disadvantaged and low income households, support is required to ensure private sector provides equitable services. The needs of the marginalised groups should be assessed to understand what support private sector may require to avoid exclusion of these groups.

Conclusion

As private sector has a major role in the improvement of FSM, more support is needed to ensure they achieve safe and equitable sanitation aims. It will be important to balance the support to private sector engagement with regulation and will likely require a step-wise approach. This paper highlights that the allocation of responsibility to private sector must be supported by increased local government roles to achieve safe sanitation goals.

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Title: Sanitation Credits: A New Financing Model To Scale Investment In Fecal Sludge Management

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Keywords: sanitation, credits, economics
Conference Track: Research Track
Track Topic: *Economics and business*
Personal Preference: *oral presentation*

Abstract

Market-based approaches to controlling environmental pollution rely on the establishment of rights and pricing. One well-known example is carbon, where the public has acknowledged rights to the common resource of climate, and prices for carbon emissions – to account for detriment to the common good – can be established via a market exchange mechanism. Similarly, economist Ronald Coase (1960) argued that principles of rights and pricing can apply in reverse: where polluters own the right to contaminate a common resource, parties who are negatively impacted may pay the polluter compensation to control pollution.

Consider the case of sanitation, where individuals own the right – even the biological necessity – to contribute contamination to the environment. This pollution results in well documented health, economic, and environmental costs borne by society, suggesting a possible market-based mechanism for controlling fecal contamination. This mechanism would require setting a price for fecal waste and establishing a vehicle to pay individuals, communities, or third parties who engage in activities to control it, with pricing determined by the value of this service in protecting public health and the environment. In advanced economies with developed infrastructure, governments protecting the common good directly manage or pay to have managed the containment and treatment of fecal wastes through centralized sewerage. Ultimately, the costs to society are borne by society, largely through public financing.

In settings with poor sanitation, sewerage is often not feasible for financial or logistical reasons, yet governments or other parties with interests in protecting sanitation-affected common goods can contribute payments to actors who safely manage fecal wastes, including but not limited to operators of infrastructure, processes, and technologies. Pricing may be based on a system of accounting for the negative externalities of the contribution of feces to environments that may lead to human exposure and degradation of the environment, through straightforward albeit potentially complex application of principles of environmental economics.

A mechanism that makes explicit use of rights and pricing in the control of fecal waste could represent a compelling model for investment in sanitation in settings where effective sanitary infrastructure does not exist and public financing is insufficient to offset the incurred cost to society of poor sanitation.

Valuation of feces is not a completely new concept in the public health arena. For example, non-governmental organizations focusing on ecological sanitation value feces for its future use in fertilizer, and thereby ensure its safe containment, transport, and reuse. Further, as recently as 2015, the local government in Ahmedabad, India provided small financial incentives to encourage use of public toilets, thereby encouraging “good behaviors.” Though not directly paying for the health costs of sanitation, these models still show that value can be placed on (the lack of) fecal contamination.

We propose a basic unit of exchange – a *sanitation credit* – to facilitate transactions in this space, based on the mass of fecal waste safely managed/treated, similar to the mass-based unit used in the carbon-credit exchange. As an illustrative example, we estimate that a fecal waste credit for a village of 200 households, all lacking access to toilets, could be worth around USD 54,000, based solely on the health

costs of poor sanitation[1]. The economic/societal value conveyed in this example is in the same order of magnitude as running a comprehensive fecal sludge removal service for such a village.

Advantages of the model may include:

- **catalyzing participation** by a broad range of investors in scaling sanitation, including private, donor, and civil society actors;
- **increasing flexibility** to support innovative, small-scale, or more sustainable FSM solutions; and,
- **driving** cost **efficiencies**.

Sanitation credits based on "mass of fecal waste safely managed" could also incentivize the development of technologies, services, and infrastructure that are effective in meeting the primary sanitation goals under SDG 6, which explicitly names *safely-managed excreta* as the ultimate outcome for properly-managed sanitary services.

Challenges include:

- **determining proper pricing** among stakeholders;
- **defining the** spatial-temporal **scale** of the impacted resources (i.e., defining the common good and who is impacted across scales); and,
- **mitigating** the potential for **unintended consequences**, including negatively influencing existing public financing models for FSM.

From an operational perspective, another challenge would be creating robust measuring systems since the value-density of waste within such a credit scheme would be much higher than soil, potentially leading to incentives to game the system by FSM system operators and sludge collectors.

This presentation considers the pros and cons of establishing a system of sanitation credits and outlines, through illustrative examples, how it could be effectively applied to stimulate both public and private capital investment in this sector.

[1]Assuming an annual loss of USD 54 billion due to poor sanitation, with 700 million people contributing to harmful sludge and 71% of this (i.e., USD 39 billion) being the net health cost, with the remaining being the time cost.

Financial Feasibility Analysis for FSM business in Thailand Case Study

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Keywords: Net Present Value (NPV), Internal Rate of Return (IRR), Fecal Sludge Management (FSM), Fecal Sludge (FS)
Conference Track: *Case Study Track*
Track Topic: *At scale city-wide or nationwide FSM services - Financing and tariff structure*
Personal Preference: *Oral presentation*

Background

Current Fecal Sludge Management (FSM) services in Thailand are concentrated in collection and transportation. Although sanitation service is a public responsibility granted by local administration organizations (LAOs), private companies are involved due to lack of FS collection capacity from the LAOs (AIT 2014). But only few of the service providers, public or private, have operational treatment plants, due to high operational and maintenance cost. Thereafter raw FS is dumped in agricultural lands, disposal ponds, land fields and others without safe treatment procedures. FS problems should be properly managed to minimize significant impact on public health and the environment (Taweesan 2015). Thus, sustainable profit making business is an opportunity to address untreated effluents and its disposal into landfills, plantations and rivers.
This paper therefore aims to show the overall FSM business with scientific, technical and marked facts on Thailand FSM; with clear understanding of the current business components and proposes a profit making FSM business concept based on financial feasibility analysis.

Methodology

This study was carried out in regions located at north, north-east, central and south of Thailand. From the regions, quantitative and qualitative data was obtained to better understand the collection, transportation and treatment trends of faecal sludge.
To find general information of service area such as resources and working condition of FSM activities, questionnaires were distributed and surveys were conducted in 131 LAOs. Also for financial information such as revenues, tax, personnel, operation and maintenance cost information were collected by questionnaires and field investigation was conducted for 28 FSM public and private businesses.

Key Findings

This study analyzed 13 service providers from public and private sectors. Financial indicators such as net profit, net present value (NPV) and internal rate of return (IRR) were calculated, to identify key

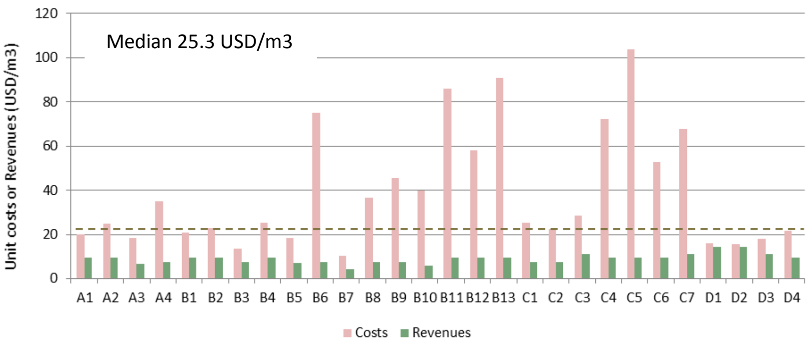

Figure 1: Unit cost and revenue

success factors and limitations of each FSM financial models. NPV and IRR shows the attractiveness of business,
in the case of high IRR and positive NPV values the project can be accepted (Erményi 2015). This analysis found that for both public and private service provider, IRR was less and NPV was negative. As shown in Figure 1, the median unit cost is approximately 25.30 USD/m^3 while the revenues ranged from 4.33 -14.33 USD/m^3.
In order to make a positive NPV, IRR need to be higher than the required rate of return, other revenues should be added. We suggest here, three scenarios for profitable FSM businesses. **Scenario 1**: By introducing FS treatment fee together with the currently existing emptying fee could result in positive NPV and IRR. The current fee (4.33 -14.33 USD/m^3) is suggested to be raised by 63 USD/m^3. However, raising revenues by adding FS collection fee or collecting FS treatment fee may not be a sustainable solution because customers are not willing to pay FSM service fee more than 12 USD/desludging.
Scenario 2: FS by-product price needs to be increased up to 6,324 USD/tons to get positive NPV and IRR of FSM project. But it is an extremely high price compared to commercial chemical fertilizer cost (i.e. 400-700 USD/ton).
Scenario 3: If the FS collection fee cannot be increased from 8.33 USD/m^3, service providers need to collect FS approximately 23,000 m^3/year (63-88m^3/day), or approximately 401.16 m^3 per km of traveling distance to cover operating cost of FS collection, transportation, treatment and reuse. Therefore, appropriate technologies and management may need to be considered to increase efficiency of FSM service.

Conclusions

This study shows that FSM business operated by private and public sectors in Thailand are under loss, which is mainly caused due to low service fee, inefficient logistic operation, less product utilization and inappropriate management (Chowdhry 2012). Therefore, complete solution may need to be identified such as: increasing service fee, improving FS collection performance with the current revenues, cost reduction by using new technology and utilization of faecal sludge. The possible solutions for FSM in Thailand is illustrated in Figure 2.

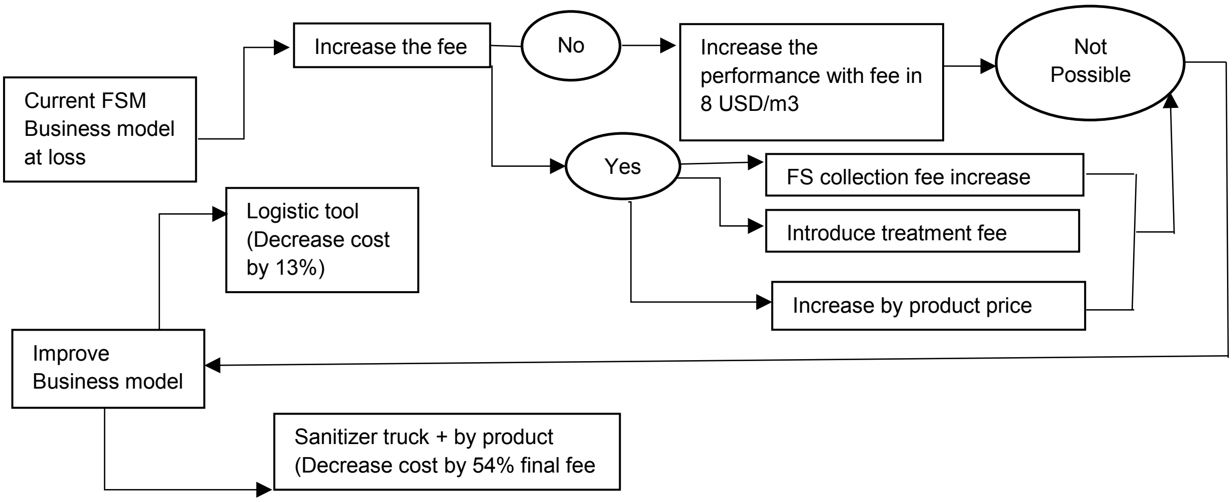

Figure 2: Decision tree of possible solutions for FSM in Thailand

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Performance Evaluation of DRDO Based Anaerobic Biodigesters for Blackwater Treatment

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Keywords: Blackwater treatment; DRDO based Anaerobic Biodigester; onsite sanitation system

Conference Track: Research Track

Track Topic: Technologies for the collection, transport, treatment, disposal and use of faecal sludge

Personal Preference: O*ral presentation*

Background

Faecal contamination of water resources remains a major concern, especially in developing countries. 99.8% of death in developing countries is due to sanitation, water and hygiene-related problems (WHO, 2003). In India, faeco-orally transmitted enteric pathogens registered about 10% of total transmitted diseases (WHO, 2008). Blackwater contains pathogens of faeces and the nutrients of urine that are diluted in the flush water (Tilley et al., 2014). Proper treatment of blackwater through the use of appropriate sanitation systems acts as the primary barrier to prevent the spread of pathogens in the environment. Onsite sanitation system is desirable in rural and peri-urban areas, where the treatment of blackwater takes place at the same location where it is generated. Defence Research and Development Organisation (DRDO) has developed an anaerobic biodigester technology, which is a modified form of conventional septic tanks for onsite black water treatment (DRDO, 2016). DRDO based anaerobic biodigester technology has two components: anaerobic microbial consortium and specially designed fermentation tank. The microbial consortium has been made by acclimatization, enrichment and bioaugmentation. The fermentation containers are commonly made of FRP/concrete, with rectangular or cylindrical shape. The main aim of this present study was to evaluate the existing DRDO based anaerobic biodigesters installed by DRDO licensee vendors in different parts of South India for blackwater treatment.

Methodology

To evaluate the performance of DRDO anaerobic biodigesters, existing biodigesters installed by DRDO Licensee vendors namely Banka BioLoo Pvt Ltd., MAK India Ltd., Eram Scientific Solutions and Shubra Biotech Pvt Ltd., were selected. For the study, 15 number of anaerobic biodigester units installed in different parts of South India (Tamil Nadu, Karnataka, Telangana and Andhra Pradesh) were chosen (Table 1) and evaluated for a period of 6 months. Performance assessment of anaerobic biodigesters was carried out in terms of its system performance, usability and acceptability/demand in urban and rural settings in South India. Grab and composite sampling techniques were adopted for a period of 5 months and one month, respectively. Raw wastewater, treated water and tap water samples were collected and analysed for pH, DO, temperature, COD, BOD, solids, nutrients and fecal coliform (FC) as per standard methods (APHA, 2005). A questionnaire was prepared and evaluated for assessing the socio-economic and institutional condition on the existing onsite bio-digester system.

Table 1. DRDO based anaerobic biodigesters selected for the study

Vendor	Location	Installation	Users	Units after Biodigester
MAK	Dindigul	May'15	100	Sandfilter
	Karur	March'15	100	Reed bed
	Coimbatore	May'15	1	-
	Madurai	May'15	150	Sand filter
	Ramanathapuram	June'15	60	Gravel bed (Not operational)
ERAM	Rajiv Nagar Park	October'14	20-30	-
	Tirumalai Nagar Park	October'14	25-30	-
	ELCITA 1	March'15	30-35	Reed bed (Not operational)
	ELCITA 2	March'15	30-35	Reed bed (Not operational)

BANKA BIOLOO	Bangalore	July’14	150	-
	Nellore	July’15	2-3	-
	Ongole	December’14	15	-
	Hyderabad 1	November’14	12	-
	Hyderabad 2	November’14	3	-
SHUBRA	Seva Tirupati	June’14	30	Sand filter

Results

The performance of all the 15 DRDO based biodigester units in terms of removal efficiencies of organic matter, TSS and FC is show in Figure 1.

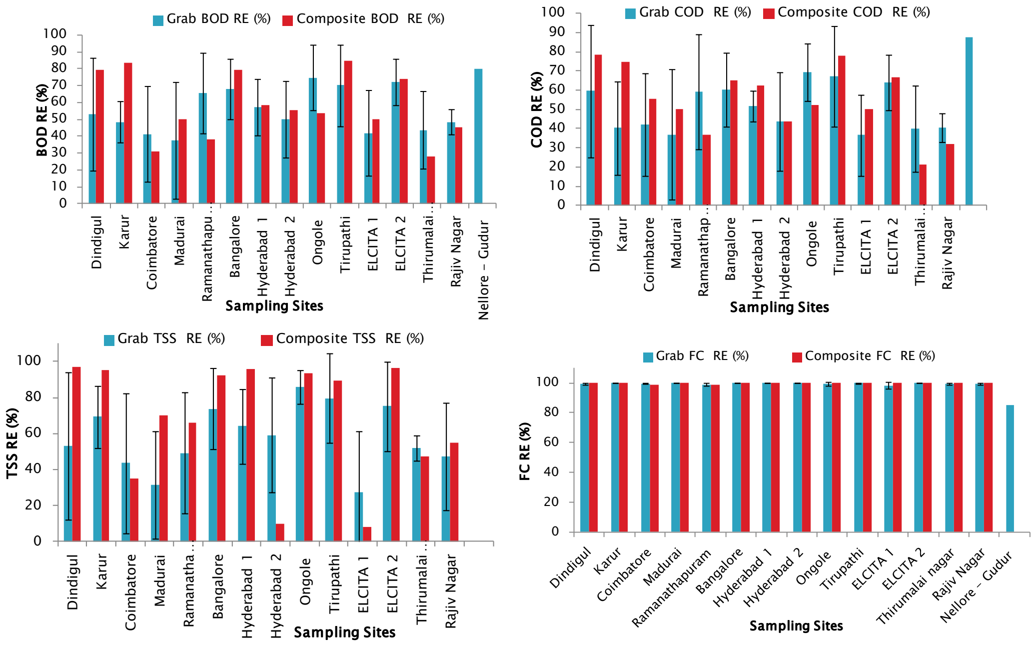

Figure 1: Comparison between grab and composite sampling of DRDO based anaerobic biodigesters

Variations between the grab and composite sampling were less than 2% for FC removal, 50% for BOD and COD removal, and 65% for TSS removal. It is indicative that the characteristics of the treated water depended upon usage of toilets, amount of feces coming in and number of users and location (Metcalf and Eddy, 2002). Presence of Reed bed / Sand filter bed (Tirupathi, Dindigul and Karur) enabled better outlet quality compared to system employed only with Biodigester. Units with regular use performed better (Karur and Bangalore). Sludge washout was observed in new units (< 6 months). It was observed from the study that treated water quality from none of the selected units met the discharge limit of CPCB (2015) with respect to concentrtaions of TN, TSS, FC and BOD values.

Conclusion

The results from the present study indicate that performance of DRDO based anaerobic biodigesters varied upon no. of users, regular usage and treatment units installed after biodigesters (sand filter and reed bed). There was no significant difference observed between performances of anaerobic biodigesters installed by different DRDO licensee vendors in South India.

Acknowledgement

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Design of Sludge Treatment Facilities in Indonesia: Learning from the Past to Design a Better Future

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Keywords: sludge; treatment; design

Conference Track: (1) Research Track
Track Topic: *Technologies for the Collection, Transport, Treatment and Disposal of Sludge*
Personal Preference: *oral presentation*

Background

The use of septic tanks (both closed and open) is extremely wide spread in Indonesia with over 85% of the urban population relying on this form of sanitation. The septage collection is typically done on an ad-hoc basis and in most cities carried out by small, unregulated private sector companies. Technical Assessments done by the Ministry of Public Works and Housing (MPWH) show that 85% of the existing 185 septage treatment plants (STP) are not functioning as planned, due to various, mostly techncial factors, explained further below. The Government of Indonesia (GOI) is furthermore striving to provide universal sanitation access to all by 2020 and has developed plans and budgets to both renovate the existing STPs as well as build 200 additional STPs for cities and regencies which currently do not have a STP. The MPWH then realized that the strategies for designing, construction and operating these 200 STP need to change drastically from the current 185, especially because Indonesia, supported by various international donors including USAID, has started to roll out an ambitious program of introducing routine desludging for all sanitation facilities in urban areas across Indonesia, which will greatly increase the amount of septage requiring treatment. For this reason USAID (IUWASH PLUS and MWH) in collaboration with WSP/Worldbank, initiated a quick review of the current STP designs and operation, followed by recommendtions for future improvement through a guide as well as initial training of Government staff, design engineers and STP operators

Review of Existing Septage Treatment Facilities

During 2016 reviews were conducted for eight different sludge treatment facilities. The facilities were in the cities of Medan (1), Bogor (1), Malang (1), Bekasi (1) and Jakarta (4 spread over two locations). The reviews included site visits, measurements and process engineering review and were supported by a septage quality sampling regime. Lessons learned related predominantly to design and technology selection were documented from the reviews and general challenges that are currently experienced which contribute to the low rate of success were identified. Some of these challenges included:

- Selection of treatment processes that are not suitable for the high solids loading experienced with septage treatment
- Incorrect sizing of treatment processes
- Failure to understand the range of flows that a treatment facility will see through its lifetime, including initial low flow and subsequent future flow
- Failure to provide redundancy
- Failure to provide appropriate pre-treatment
- Failure to understand the required synergies between different treatment processes

- Failure to plan for and execute transfer of knowledge to operators to allow correct operation of treatment facilities

Solutions Identified

To combat the challenges identified in this study a plan was put in place to build capacity for better design of future facilities. One of the components was the creation of a written manual focussing on septage treatment in the Indonesia context. The manual includes description of a methodology for planning and designing a septage treatment facility; discussion of phasing and how it can be planned and designed for; a detailed discussion of an approach to redundancy and a model to systematically conduct process selection for a new septage treatment facility; documenting data gathered to date on septage quality in Indonesia; and an introduction to the design of a wide range of treatment process that can be used for septage.

In addition to this manual, trainings were held for various stakeholders including national and regional technical staff of the MPWH, operators of existing STP and consultants engaged in the design of STP. Other steps are being made to support the design of future STP include assistance in early trial of example facilities, improving Terms of Reference for consultants for designing STP and engaging local (and pssibly US-based) universities in further development of curriculum and research specifically for septage treatment in Indonesia.

Presentation Content

The presentation will summarize the lessons learned from the initial studies of 8 existing facilities and describe with illustrations the general challenges which were identified, results of 160of septage quality samples which were collected across Indonesia, the methodical approach that was developed and how this information is disseminated throughout the Indonesian septage industry to help ensure that all future septage treatment facilities meet a sufficient techncial standard allowing for successful treatment of the growing amounts of septage collected in Indonesia. Special attention will be provided how engineering designs of the appropriate treatment processes can be phased combining a modular approach with similar equipment and adaptiing simple treatment technologies into more technological sophisticated and complex process as the demand on the treatment facility grows and both operator capacity and revenue from user fees increase.

Technological Options For Fecal Sludge Pelletization In Ghana

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Keywords: Fecal sludge, pellets, compost, pelletizer

Introduction

Feacal sludge management (FSM) interventions at various levels and scales are being implemented in various developing countries to combat/augment the inadequacies in treatment of feacal sludge (FS) to acceptable levels. All these interventions are being rolled out to reduce the amount of unserved population. In the last millennium development goals (MDGs), sub-Saharan African countries recorded 30% of improved sanitation coverage being the least at the global level (UNICEF and WHO, 2015). In the new sustainable development goals (SDGs); goal 6 which touches on clean water and sanitation for all by 2030, certain technical challenges if not managed well could lead to slow progress. In Ghana, one of the FSM which is being implemented is the WAFO Project, out of which came the Fortifer plant. The Fortifer plant is a 500-ton annual capacity plant which treats FS from public toilets and households combining with organic fractions of market waste (MW) or municipal solid waste (MSW) to produce compost. Value is further added to the compost by enriching with inorganic nitrogen sources and pelletizing to reduce the bulkiness of compost and to reduce costs in transportation. There is currently wide acceptance of pellets but what are the guiding principles in choosing a pelletizer and what are the quality criteria best looked out for in a FS-based pellets? The aim of this paper to evaluate various technological options with regards to choosing a pelletizer as well as technical challenges that faces in general recycling of FS developing countries based on lessons learnt, solution packages experienced with Fortifer plant as a case study in Ghana.

Description of the Fortifer process

Solids in the FS are recovered using sand filter (drying beds) and then composted or co-composted with other organic wastes such as market or household wastes or sawdust, usually for a period of 60 – 100 days. A mixing ratio of dewatered FS and municipal organic waste or sawdust at 1:3 w/w is recommended, informed by the earlier research (Cofie et al., 2009). To reduce compost application rates (volumes) and increase available N levels at the time of application, enrichment is performed, raising the compost nitrogen content from 1-2% to typically 3% through addition of e.g. inorganic N sources such as urea and ammonium sulphate. To reduce the bulkiness of composts, which is mainly responsible for most of the difficulties associated with handling, especially storage and transport, palletization can be done to increase bulk density by 20 – 50% compared to the powdered composts. Pellets are produced from composts, to which appropriate amount of water and binding material such as cassava starch are added, using a pelletizer (Nikiema et al., 2013). The Fortifer production process is shown in Figure 1 below.

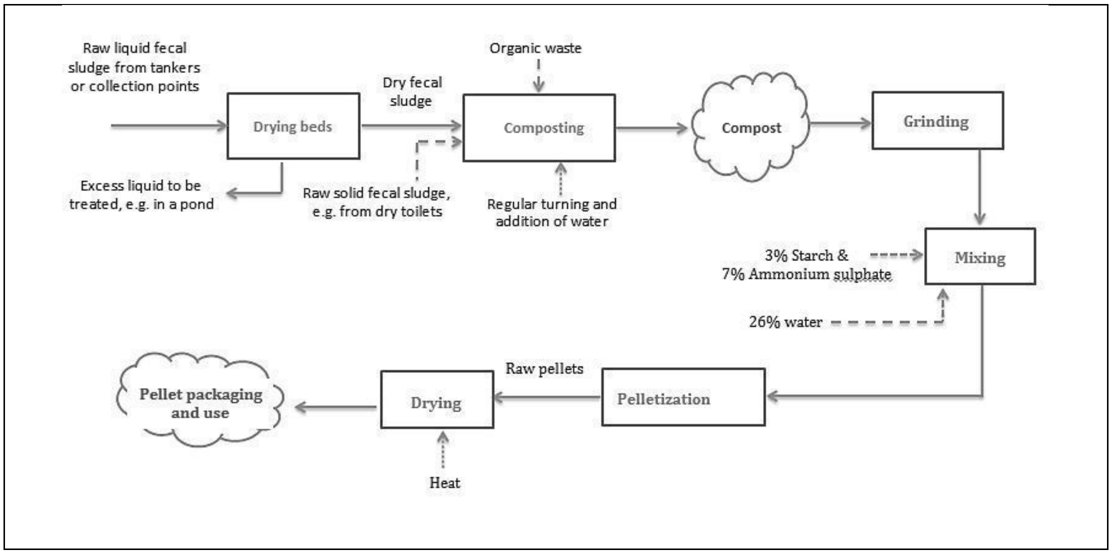

Figure 1. Fortifer Pellet production process developed by IWMI

Three different pelletizing machines were studied and the pellet quality as a function of the machine type/material was evaluated. The pelletizer machines included: a 380-V pelletizer locally manufactured by CSIR with an average capacity of 80 kg/h; a Pellet Mill IOTA25 from Italy; and a 415-V pelletizer locally fabricated in Sri-Lanka. The machines had the following effect on the quality of pellets produced in Table 1 below

Table 1. Effect of pelletizer machine on product quality of pellets

	380-V pelletizer	Pellet Mill IOTA25	415-V

Technical Challenges

- ***Quality/impurities of FS characteristics***

FS characteristics vary widely according to location and cultural practices of the people. What is increasingly becoming a concern is the high levels of impurities in the sludge to hinder recycling. The first is the level of plastic materials (condoms, sanitary pads etc.) found in the raw sludge. This increases the cost of treatment and recycling as a considerable amount of time and energy is spent removing these impurities. In smaller scale treatment plants, where removal cannot be done mechanical, manual sorting is done putting the health of those workers at risks and not promoting zero contact of FS. Other impurities may include oil, kerosene, acid etc.

- ***Long haulage distances***

For some FS treatment and recycling centers in developing countries, the haulage of wastes tends to be rather long. Sometimes traffic congestion further aggravates the problem and renders haulage to designated recycling areas/sites uneconomical and financially unattractive.

SASTEP: Lessons Learnt from Phase I of the SASTEP EarthAuger Demonstration in South Africa

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Keywords: Compost Toilet; EarthAuger

Theme: Case Studies Track
Track Topic: Pilots showing promises
Personal Preference: Oral presentation

Introduction

Stimulated by the Bill & Melinda Gates Foundation (BMGF) Water, Sanitation and Health Programme's *Reinvent the Toilet Challenge* initiative, many off-the-grid sanitation solutions have undergone rapid development since 2011. Although many of the technology processes are not new conceptually, the integration of the technology components into a self-sufficient unit in the context of providing sanitation solutions, is an untested approach. Globally, there currently exist no due diligence criteria or standards for the function, operation, and performance of the technologies, due to their recent emergence in the sanitation sector. Thus, rigorous demonstration as considered to be a primary pipeline to comprehensively determine technical performance of the technology solutions in their intended environment of operation, as well as ascertain and address social acceptance.

The South African Department of Science & Technology (DST), with support from BMGF, have initiated the South African Sanitation Technology Demonstration Programme (SASTEP), a demonstration programme implemented by the Water Research Commission (WRC) to holistically evaluate, and develop procedures for, appropriate new sanitation technologies. Phase I of the SASTEP sees technologies stress tested in a single rural environment, where phase II includes further widespread demonstrations, after learnings and improvements to the technologies have been incorporated, to better simulate demonstration conditions representative of diverse global communities, and therefore provide evidence on the performance of technology solutions not limited by local contexts.

The first technology to be demonstrated in SASTEP is the Critical Practices LLC EarthAuger. The EarthAuger is a composting toilet, a technologically primitive concept which features urine separation and a residence chamber with airflow for solid waste, which provides a controlled environment for effective natural microbial action to stabilise faecal matter and bulking agents.

Demonstration

200 EarthAuger toilets are currently being demonstrated in 200 households in Ida, a rural agricultural community in Eastern Cape, South Africa. For the duration of the demonstration, the following criteria are monitored and investigated: unit performance, user preferences social acceptance, maintenance requirements, operational requirements, implementation costing, and business opportunities for local entrepreneurs and community uptake of entrepreneurship opportunities through implementation of the technologies.

An existing commercially available Low Flush Toilet / Ventilated Improved Pit-Latrine (VIP) superstructure design was adapted for the first EarthAuger demonstration, where prefabricated, rapid-assembly features allowed for a community-based assembly process. This assembly process was the core element in a community empowerment and local job creation component of the demonstration programme, which saw employment in the skill areas of project management, assembly, transportation, security, education, and social facilitation. The total cost for each unit was R 11 292.84 per unit, for all expenses and activities under the implementation programme, including development, community employment stimulation, and social facilitation and education.

User behaviour monitoring indicated that successful user adaption was high with intensive social facilitation and training, and follow up inspections. Traditionally, household onsite sanitation facilities in South Africa are located as far away from the homestead as is feasibly possible, and preparatory user education was successful in combating this stigma, as home owners generally provided consent to have EarthAugers installed closer to their homes than hypothetical VIP solutions. Further social acceptance monitoring, to be captured at the closure of the demonstration programme, will provide qualitative and quantitative results with regards to user behaviour and social acceptance.

Social facilitation and training has, however, ensured that operational requirements of the EarthAuger are adhered to. Thus far, the EarthAuger units have performed without mechanical failure, or notable mechanical maintenance requirements. The composted faecal matter-bulking agent product of the composting process was subject to beneficiation practices, where local households use the product for personal subsistence farming and/or sales.

Formal commercialisation and localisation events have already been conducted for the EarthAuger technology, along with other SASTEP-partnered technologies, as a part of the localisation and uptake component of SASTEP. These engagements have lead to interest in the commercial and investment sector for uptake and localisation opportunities. One community based example has seen the Rotary Club of Lukhanji Sunset develop a business model for plastic recycling programmes from local schools to be incorporated into a local EarthAuger component manufacturing programme, for localisation of manufacturing and supply, and local employment stimulation.

On completion of the six month demonstration programme, all findings and results will be captured and reviewed, to determine a holistic understanding of unit requirements and acceptance in additional communities in rural agricultural communities in South Africa. Thereafter, the design and implementation of the unit will be improved based on learnings from the programme, and incorporated into the broader second phase of demonstration.

Dissemination of the results and learnings of the first phase of demonstration of the EarthAuger composting toilet under SASTEP is a key activity in the interests of advancing knowledge and understanding of the function, value and impact of demonstration when technologies transition from prototype to commercial product. This case study, one of the first of it’s kind regarding BMGF funded sanitation technolgoies, and the learnings thereof, may serve as a guidline for technology developers and partners at FSM4 on demonstrating technologies to promote focused and informed development towards commercialisation.

Carbon Neutral Electrical Generation from Human Solid Waste: Developing the Energy Balance and Identifying Suitable Electrical Generation Solutions Capable of Harnessing Thermal Energy

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Keywords: Septage Management, Faecal Sludge Management, Energy Balance, Power Generation, Pyrolysis, Biochar, Resource Recovery and Reuse,

Introduction

In 2015, 2.5 billion individuals did not have access to proper sanitation services (WHO 2016). Although access to toilets is increasing, human solid waste treatment services are often unavailable or are too expensive, resulting in untreated human waste being discharged into pits or surface water. Building treatment infrastructure for human waste in these areas is difficult as roughly 1.2 billion individuals do not have access to electricity, with even more people suffering from a supply that is poor quality and unreliable (IEA 2016).

One of the proposed solutions to alleviate this problem has been to develop a pyrolysis unit that is self-sustaining, carbon neutral, and off-grid, that could transform raw human waste to energy and biochar. This has several advantages, including: 1) destruction of all pathogens and organic toxins present in the human waste due to the temperatures achieved in the pyrolysis process, (Laird et al.,2009); 2) significant mass reduction of human waste (88-95% reduction in mass); 3) production of a net energy output, which could be used to generate heat or electricity in rural or low-income applications, allowing for the creation of a complete off-the- grid pyrolysis unit (Liu et al., 2014); and 4) creation of a useful product, biochar, which can be used for carbon sequestration (Lehmann 2007), as a surrogate for activated carbon (Mohan et al., 2014), fuel for heating or cooking (Ward et al., 2014), or to enhance the soil's fertility, crop productivity, water holding capacity, and biota (Van Zwieten et al., 2010).

To develop the first off-grid carbon neutral human waste pyrolyzer, the Bill & Melinda Gates Foundation has funded this research to: 1) develop a complete energy model for a carbon neutral human solid waste pyrolyzer capable of handling the human waste of 500 to 10,000 individuals; and 2) identify and evaluate technologies that could harness the thermal energy from the pyrolysis process to generate the electricity needed to operate the pyrolyzer.

Objective

To calculate the energy output from a human solid waste pyrolyzer, and to identify electrical generation products that could harness the thermal energy from the pyrolyzer, ultimately developing an off-grid product for remote applications that is carbon neutral.

Methods

A theoretical energy model was developed to determine the energy output from the pyrolyzer system accounting for fuel input, supplemental fuel, and water reduction processes. The results were compared to observed data from pyrolyzer prototypes. A systematic search was conducted to identify and evaluate all generators that could harness the excess thermal energy from the pyrolyzer to generate electricity to create a self-sustaining off-grid unit. Steam, Stirling, thermoelectric, organic Rankine cycle, and thermoacoustic heat engines were explored.

Results

Analysis of the energy model shows that using human solid waste from urine-diverted dry toilets, the pyrolyzer is capable of producing 20% biochar (by weight) and enough thermal energy to generate the electricity to power the unit, with 0% supplemental fuel. With 50% supplemental fuel by weight and 0% biochar production, the pyrolyzer system can power itself when processing high moisture waste (up to 85%). Seven steam engines and eight organic Rankine cycle engines were identified that met all of the inclusion criteria, were commercially available, and could generate sufficient electrical power to operate the pyrolyzer system.

Conclusions

The development of a self-sustaining human solid waste pyrolyzer is possible. As pyrolyzer technology and thermal transfer efficiencies improve, a self-sustaining pyrolyzer will become increasingly more feasible. Future studies should focus on improving pyrolyzer technology and integrating the identified electrical generation technologies into the pyrolyzer system to begin optimizing a carbon neutral off-grid unit that does not depend on supplemental fuel.

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Temperature and Shear Rate Dependent Viscosity Model for Feces Simulant and Computational Fluid Dynamics Analysis of a High-Throughput Viscous Heater to Process Feces

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Keywords: Viscous heating, CFD, High-throughput

Conference Track: (1) Research Track
Track Topic: Technologies for the collection, transport, treatment, disposal and use of faecal sludge
Personal Preference: poster presentation

Viscous heating technology relies on conversion of mechanical energy to heat through viscous dissipation. The mechanical energy required is often present in the pumping and transportation sub-systems used to treat and transport waste. No additional burning or electric heating is required, although available waste heat may be incorporated. Viscous heating provides an additional benefit of uniform temperature distribution and mixing.

Advanced computational tools, such as Computational Fluid Dynamics (CFD), allows simulation of reactor geometry, fluid properties and other process variables; and can benefit process design. However, changes in fluid viscosity with variation in shear rate and temperature are critical in using an appropriate viscosity model. (Podichetty et al. 2015) described the effect of reactor geometry on design of a high-throughput viscous heater to process feces using a shear-rate-dependent viscosity model. In this study, a temperature and shear-rate-dependent viscosity model from rheometer experiments is developed over the range 25 to 75°C. The viscosity model was validated using a thermodynamic model and experimental results from the viscous heater in Belcher et al. (2015). Scale up studies were performed to optimize viscous heater design for a high-throughput flow rate of 1000L/hr.

A shear-rate-dependent viscosity model was developed using rheometry data for potato paste with 88% moisture. Shear-rate viscosity data were fitted using the Sisko equation,

$$\eta = \eta_\infty + k * \gamma^{n-1}$$

where η_∞ is the infinite-shear viscosity, k is the consistency coefficient, and n is the flow behaviour index. The Sisko equation combines power law and infinite-shear viscosity for shear thinning fluids. An infinite-shear viscosity of 0.3 Pa·s was selected based on data from (Canet et al. 2005) and adjusted per reactor operating conditions. Temperature dependency was incorporated within parameters k and n. Rheometer studies on potato paste were performed at 25, 40, 60, and 75°C. The expression for parameter k, k = 168 - 1.06*T(°C), and constant value for parameter n, n = 0.56, were obtained from experimental data. The value of n did not vary significantly over the range of temperature; hence, an average value for n was calculated.

A simplified thermodynamic model with an energy balance was used to determine the minimum power required for a specified temperature increase,

$$\dot{W} = \dot{m}[h_{in} - h_{out}] = \dot{m}C_p\Delta T$$

Where, $\dot{m}$ is the mass flowrate, h_{in} is inlet enthalpy, h_{out} is outlet enthalpy, C_p is heat capacity, and T is temperature. The viscous heater model used dimensions and settings from experiments (Belcher et al. 2015). Viscous heater power requirement was calculated by multiplying shaft torque by rotational speed,

$$\dot{W} = 4\pi * \eta * \omega * \frac{k^2}{1 - k^2} * r_o^2 * l * \omega$$

Where, ω is rotational speed, k is the ratio of inner to outer radius, r_o is radius of the outer cylinder, and l is the length of the viscous heater cylinders. Table 1 compares results from the thermodynamic and viscous heater models. The viscous heater model was able to satisfactorily predict power requirement at different flow rates.

Table 1 Thermodynamic validation of temperature and shear rate dependent viscosity model

	Power requirement (kW)	
Flow rate(L/h)	**Thermodynamic model**	**Viscous heater model**
37	2.57	2.46
42	2.64	2.53

The viscosity model, geometry, and fluid properties were input into CFD simulation to determine outlet temperature for comparison with experimental results. Table 2 compares experimental with CFD results, and demonstrates that the model satisfactorily predicted outlet temperature from performed experiments with the viscous heater.

Table 2 Outlet Temperature Comparison

	Outlet Temperature (°C)	
Flow rate(L/h)	**Experimental Results**	**CFD Results**
37	84	82
42	78	78

The variation between the viscosity model and data can be attributed to the infinite-shear rate viscosity value used in the model. A temperature dependent infinite-shear viscosity relationship from rheometer data at 25, 40, 60, and 75°C, similar to k and n, would improve predictions. The scale up study for 1000L/h was optimized for two different geometries. The ability of the viscosity model to predict outlet temperature was evaluated using CFD. Table 3 gives the geometries, outlet temperature, and power requirements used in simulation accounting for annular flow only. The rotational speed for both simulations was 1500 rpm.

Table 1.3 1000L/h scale up geometries and viscosity model validation

Length (m)	**Inner Radius (m)**	**Gap Space (mm)**	**Average Outlet Temp (°C)**	**Required Power (kW)**
1.5	0.064	3.4	82.4	66.4
1	0.071	3.1	78.5	62.3

Comparison of outlet temperature showed that the viscosity model is satisfactory. Comparison of the power from simulation matched well with the thermodynamic model. CFD models provide an excellent tool to design and optimize reactors that can be used to process feces. In this study we developed a temperature and shear-dependent viscosity model that can be used for optimized design for high-throughput viscous heaters.

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Smouldering and Catalytic Conversion for Fecal Treatment

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Keywords: Smouldering, Household Toilet, Catalytic Oxidation

Conference Track: (1) Research Track
Track Topic: *Technologies for the collection, transport, treatment and disposal of faecal sludge*
Personal Preference: *either poster presentation or oral presentation*

Overview

We are developing a household scale off-grid sanitation system that separates free water from solid waste using simple gravity separation, incinerates solid waste by smoldering, and pasteurizes liquid waste using heat generated from smoldering. Significant recent advances include: development of a way to smolder in a cyclically continuous manner without the need for re-ignition as long as there is a consistent influx of fuel - thus minimizing energy requirement for ignition, incorporation of post-smoldering catalytic process to increase conversion - thus increasing heat generation and reducing emissions, and efficient use of high temperature post-catalyst emissions for in situ drying of incoming feces.

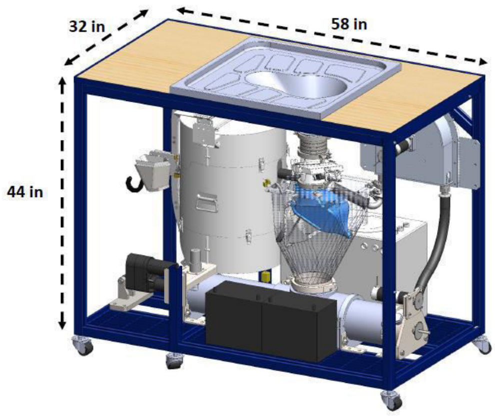

Figure 1 The integrated system

Solid treatment

The core reactor of the process consists of a column of approximately 3 inch diameter and 15 inch height; encapsulated by an annular “donut” packed with catalyst around the smoldering zone - which is maintained within a fixed vertical zone in our cyclic-continuous process, and an annular heat exchanger extending upwards from the catalyst zone. The vertical co-location of the smoldering zone and the catalyst module facilitates thermal synergies between the two processes.

The column is filled with a packed bed of feces mixed with hard granular medium, smoldering occurs as air flows through the bed to bring oxygen to fuel surfaces in the smoldering zone, and the smoldering front moves upwards as smoldering progresses. The post-smoldering emissions stream, which includes significant amounts of incompletely converted fuel in the form of CO, VOCs and hydrocarbons, is directed through the catalyst zone, and further converted to near completion, generating additional heat and increasing the temperature of the gas stream by as much as 250°C. The hot post-catalyst emissions stream then flows upwards along the outside of the smoldering column to provide heating and in situ drying of the feces/medium mixture above the smoldering zone.

For a pseudio-continuous operation, the smoldering front is maintained within a fixed vertical zone, when the smoldering front reaches the top of the zone, a fixed amount of media is discharged from the bottom of the reactor - thus lowering the bed and dropping the smoldering front to the bottom of the designated zone. The discharged media is transported up and recycled back into the top of the reactor. At the same time a set mass of new fuel is pumped into the top of the reactor. The feces and media are mixed in situ, and the cycle repeats. Temperature readings at thermocouples located at various positions along the column, catalyst zone, and post-catalyst heat exchanger show the cyclic nature of the process, and increased temperatures through the catalyst zone (figure 2). Most notably, smoldering of full moisture human feces is demonstrated to be feasible and sustainable for long hours without the need for a separate pre-drying step and equipment. Gas analysis of the post-catalyst emissions shows low CO and CO/CO_2, indicating increased conversion in the catalyst zone.

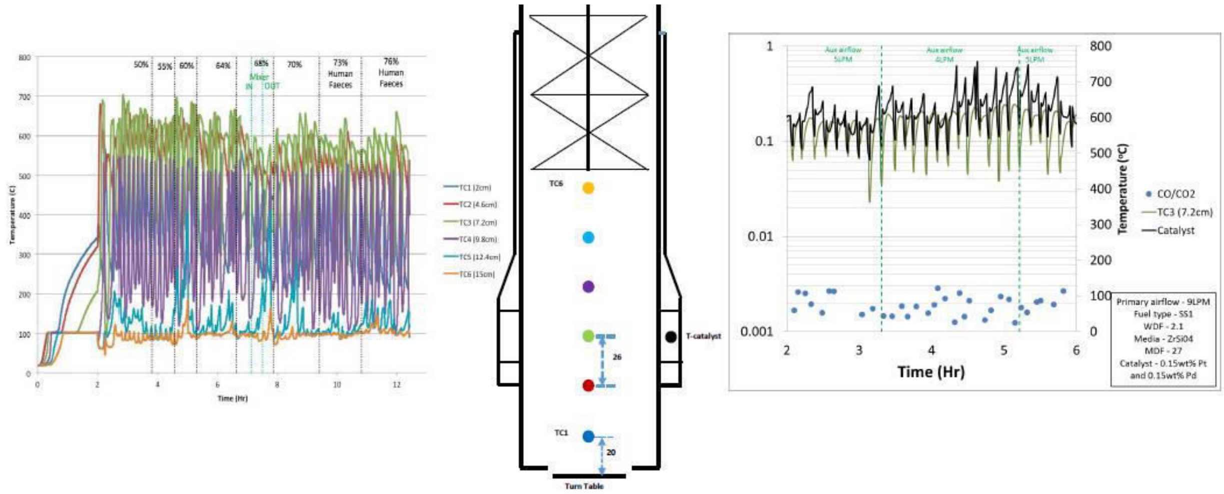

Figure 2 Smouldering temperature results (left) and Catalyst temperature and CO/CO_2 ratios (right)

The smouldering front velocity can be controlled by the superficial air velocity; or for a given column cross-sectional area, fecal destruction rate can be controlled by air flow rate. Smaller diameter columns will reduce fecal destruction rate correspondingly. Media to dry fuel ratio and moisture content also influence fecal destruction rate, but to a lesser extent. A wide range of fecal destruction rates suitable for a household scale system, ranging from about 10 to 200 g/h of dry fecal mass, has been demonstrated.

Liquid treatment

Pasteurization of the liquid stream of urine/washwater requires appropriate temperature/time combinations, increasing temperature reduces required residence time and can thus reduce system size. At 70°C, residence time of about 1 minute is sufficient to kill 6 logs of Helminth eggs. An energy efficient way to heat the liquid is by flowing the liquid through coils wrapped around the smouldering column and make use of heat radiated from the reactor. A layer of insulation between the column and the coils prevents excess heat transfer. This concept has been shown to be effective in treating at least 1 L/hr of liquid flowing continuously in the coils.

Conclusions

We have demonstrated: (a) the ability to treat full moisture content human feces without a separate drying step, separate drying equipment, (b) CO concentration in emission in the 100 ppm range, and CO/CO_2 well below 0.5%, and (c) fecal destruction rates ranging from 10 g/h to 200 g/h of dry fecal mass (10 person scale ~ 30 g/h) - thus allowing for variability in input rates expected in a household scale system. With the energy efficiencies we have achieved, external energy requirement is expected to be very low once operations and equipment design have been optimized. Multiple iterations of prototypes have been made and tested. With the support of STeP, we are preparing for field studies in Coimbatore early 2017.

Continual Flow Heat Treatment System for Container-based Toilets

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Keywords: container-based sanitation, solar thermal treatment, pathogen inactivation

Conference Track: (1) Research Track
Track Topic: *Technologies for the collection, transport, treatment, disposal and use of faecal sludge*
Personal Preference: Oral Presentation

Background

The SDGs call for 100% universal access to safe sanitation and water by 2030, while also halving the proportion of untreated wastewater and increasing safe reuse. In Kenya, less than 5% of fecal sludge is properly treated before disposal, causing health and environmental burdens[1]. Traditional treatment systems focus on safely disposing fecal sludge into the environment without much consideration towards reuse or cost recovery. Furthermore, space can be a limiting factor for building more treatment systems, particularly in rapidly urbanizing communities and in refugee camps.

Sanivation, a sanitation social enterprise based in Naivasha, Kenya, is using a novel and financially sustainable approach to impact one million people in the next five years with improved sanitation services. They are deploying a model where they install modern container-based toilets in people's home for free and then households pay a monthly subscription for the toilet to be serviced. The waste is taken to a centralized processing site, where it is rendered safe for reuse, according to WHO guidelines, and transformed into charcoal briquettes. As Sanivation scales its services, new treatment technologies have been designed to process more fecal sludge to create value-added reuse products.

Goal and Aims

There is a need to develop effective fecal sludge treatment systems at a low cost to alleviate disposal of untreated waste into the environment in Kenya. To this end, Sanivation sought to develop a waste treatment system that could be scalable, replicable, and effective in various settings, including peri-urban communities and refugee camps.

Specifically, Sanivation addressed the following aims:

- To design a cost-efficient solar thermal continual flow treatment system that can treat 200 kg/day of human waste for use in peri-urban communities.
- To create a mobile system that combines treatment and reuse of fecal waste inside of a shipping container to reduce cost and space needed for permanent on-site waste treatment infrastructure for use in refugee camps.
- To determine the microbiological effectiveness of this solar treatment system, as measured by log-reductions of *E. coli* and *Ascaris suum.*

Methodology

Sanivation opted to utilize solar thermal energy for heat-treating the feces to keep operational expenses and environmental effects low. In order to evaluate different design options, Sanivation calculated solar energy potential in Naivasha, characterized feces inputs and developed a matlab model . A similar methodology was applied to the mobile plug-and-play treatment technology in a shipping container, while accounting for different inputs that pertain to Kakuma Refugee Camp.

Sanivation will assess microbiological effectiveness of the solar treatment system using two indicators: *Escherichia coli (E. coli)* and *Ascaris suum (A. suum)*. To determine inactivation of *E. coli* over treatment time, waste samples will be collected at select time points from the center location within treatment containers and assayed for *E. coli* concentration using IDEXX® Colilert™-18 methodology. Total solids analysis (EPA Method 1684) will be performed on an aliquot of each sample. Back-calculation will provide an estimate of E. coli per gram of total solids for each time point. Prior to treatment, viable *A. suum* ova will be seeded into 20 µm nylon mesh bags ("tea bags") and multiple bags will be embedded into waste material at the center location (center and edge) within treatment containers. To determine inactivation of ova over treatment time, a tea bag will be removed at select time points from the container and viable and non-viable *A. suum* ova will be enumerated via microscopy following 28 days of incubation at 28°C.

Results

Sanivation has begun operating the new treatment system in Naivasha, a peri-urban community. With the solar thermal continual flow heat treatment system, Sanivation can treat 200 kg/day (or 500 toilets). Over a five-year lifespan, this system has an estimated capital cost of $0.4/ton treated and $0.55/ton operational cost for a total cost of $0.95/ton. The system has a footprint of 12m^2 and only requires one full-time operator. Below is a schematic of the patent-pending continual flow treatment system.

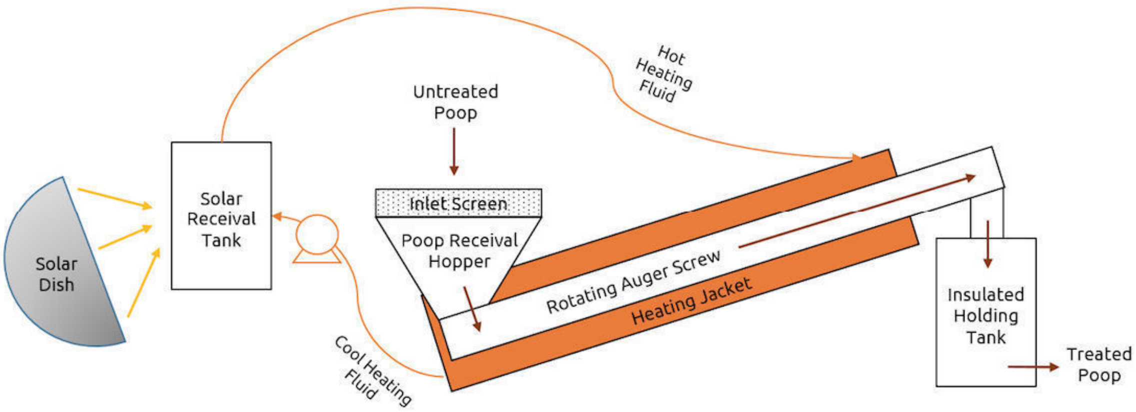

Figure 1.1 Continual flow heat treatment design.

This system is currently being scaled up to treat up to 15 tons/month (or 750 kg/day) of feces in the containerized treatment and reuse system in Kakuma Refugee Camp. Within the system, up to 200 tons of fuel per month can be created. The containerized treatment and reuse system will only cost ~$200 per month for operational expenses, including power, labor, maintenance, and PPE and is expected to be operational by December 2016.

By January 2017, the microbiological effectiveness evaluation of the treatment system in Naivasha will be complete, where Sanivation will have data on time and temperature needed to inactivate *E. coli* and *Ascaris suum* ova by a 4-log reduction.

Conclusion

As Kenya strives for universal sanitation, there needs to be alternatives for waste collection, transportation, treatment, and reuse options in the private sector to ensure that sanitation is being safely managed. The results from Sanivation's research provide alternative solutions for fecal sludge management that are cost-efficient, microbiologically effective, and scalable for a variety of contexts, including peri-urban communities and refugee camps.

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Scalability of underground drainage and faecal sludge management – a financial perspective from India

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Keywords: FSM costing; FSM economics India; comparison of cost of UDG and FSM; Indian sanitation budget analysis

Conference Track:(1) Research Track
Track Topic: *Economics and business*
Personal Preference: *oral presentation*

The government of India has promised to build toilets for approximately 1.45 crore households by the year 2020 (Swachh Bharat Abhiyan, 2016). In order to fulfil this promise, the toilets are being built at an unprecedented speed and scale. 33% of urban households in India are connected to sewerage,and 45% of urban households depend on on-site facilities (Water Aid, 2016). This on-site system has limited or no facilities for safe transportation, treatment and disposal, which poses public health and environmental risks. In order to safely manage the faecal matter and wastewater that is generated from these toilets, the three main options before decision makers are to build (1) centralised wastewater treatment system with sewerage (2) decentralised wastewater treatment with small pipe networks (3) faecal sludge management. One of the most important factors effecting the decision of treatment system selection is the cost and economics involved in each of the three options. There is a dearth of literature focused on the cost and economics of the aforementioned three systems. Further, there is a need to analyse the viability of each option given the current state of the Indian economy and budget allocation for sanitation.

In the above context, this research aims to (1) estimate and compare the capital and operational costs of centralised wastewater treatment plants with sewerage networks, decentralised wastewater treatment plants with small pipe networks, and faecal system management (FSM) systems in India and (2) analyse the scalability of each solution - given the cost of different systems and the current budget sanctioned by the Government of India. Although access to good quality data was a major challenge due to multiple factors, the research team was able to collect data from around 215 systems comprising of all the three options. Of all the three systems mentioned, acquiring data on FSM systems was the most challenging, as fewer than 5 FSM systems are fully operational in India.

Based on the above stated data collected across 23 towns and cities in India, the Capex and Opex for the different systems were quantified as in table 1.

Table 1: Capital and operational expenditure per capita per year.

Options	Capex (Per capita)	Opex (Per capita/year)
Centralised system	INR 13,000- 17,000	INR 1,000-1,800
Decentralised system	INR 4,500- 9,000	INR 50-800
FSM[1]	INR 200-400	INR 20-300

The GDP of India for the financial year 2015 was INR 138.42 trillion. The per capita expenditure of the Union government in 2015 was INR 14,698.18 (www.data.gov.in, 2015). Out of this sum, expenditure on sanitation and health combined is INR 4,072. The per capita budget allocated for the Swachh Bharat Mission is INR 69. The budget allocated for two

[1]The data for FSM systems have been gathered from CDD Society's work.

central sponsored schemes for urban infrastructure development - Atal Mission for Rejuvenation and Urban Transformation (AMRUT) and 'Smart Cities' Mission for the year 2016-2017 is INR 7,296 crore (per capita INR 55). The budget allocated for highly strategic sector life defence is INR 2,000 per capita.

As reflected in the table above, the first two options cost between INR 4500- 17,000, while the budget available is lesser than INR 100 per capita per year. If payment will be made over the course of 10 years, taking a staggered payment approach, the budget available would approximately be INR 1,000 per capita.

In addition, we also look at the negative externalities associated with implementing a centralised wastewater treatment system with sewerage networks in terms of disruptions to traffic, air pollution, and inability to reuse treated water and nutrients. Further, centralized systems take several years to implement and suffer from several execution risks, chief among which is the unwillingness or inability of users to make the last mile connection from household to sewer network. FSM systems, on the other hand, rely as much as possible on existing infrastructure to achieve quick pollution alleviation.

Relying on existing infrastructure makes FSM very cost effective. In fact, the incremental cost of implementing FSM versus a centralised system is therefore only about 10%. We also provide an absolute cost comparison of the two systems. From the above analysis, it is clear that the centralised system is far beyond the available means of the government, hence they are not really an option before decision makers. It is, however, interesting to note that FSM is an option that governments can afford with the existing budget trend. Because the transportation component of FSM is already a thriving market, a smart structuring of finances through public private partnership can make FSM viable. As we move from the choice of centralised sewerage to FSM, the nature of the problem changes from bring purely public good to more private good. This enables shifting a large part of the FSM investment need to the private sector. Hence, FSM not only enjoys a huge cost advantage but importantly, it shifts the problem to the segment which holds the largest share of the national income.

One limitation of FSM is its narrow scope and hence inability to address treatment of greywater. This is considered a serious drawback of this approach and is the single biggest criticism levelled against FSM. It is true that most FSM systems are not designed to address the greywater problem. However, we argue that the health and environmental benefits of treating faecal sludge are well justified by the costs incurred.

Overall, although centralised and decentralised are technologically much superior and successfully implemented in large numbers across the country, these two systems are not really an option before decision makers for addressing the country-wide management of sanitation problem at scale. Hence, FSM is the only viable option for addressing the country's sanitation problem in medium term perspective.

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Determining the Economically Optimal Capacity Of A Decentralized Faecal Sludge Treatment Plant

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Keywords: economics; scale; decentralized

Conference Track: (1) Research Track
Track Topic: Economics and business
Personal Preference: Oral presentation

Introduction
A critical product design question for a new decentralized faecal sludge treatment technology is its capacity – i.e. how much faecal sludge should a plant be able to process on a daily basis? This presentation will discuss how we determined the economically optimal capacity for a faecal sludge treatment plant based on an illustrative Omni Processor (OP) technology – a new product category envisioned by the Bill & Melinda Gates Foundation. We will also discuss the product design and go-to-market strategy implications of this analysis. While the focus of this presentation is on the OP technology, the approach taken is highly relevant to sizing any faecal sludge treatment technology, particularly those requiring vehicular conveyance of sludge.

Capacity Matters
Determining optimal capacity a faecal sludge treatment plant (FSTP) is critical because it has a significant impact on the total cost of faecal sludge management (FSM). This includes both the cost of collecting and transporting faecal sludge and the cost of treating it. Minimizing the costs of FSM is clearly in the best interests of society – not least of all because it makes FSM service provision more affordable, and therefore, more likely to happen.

An obvious mechanism by which the costs of FSM are minimized is simply ensuring a treatment plant is not oversized given a city's needs. Understanding the optimal capacity (or capacities) of a faecal sludge treatment technology can also reduce FSM costs by enabling the technology supplier to reduce "non-recurring engineering" expenses. Small scale, decentralized faecal sludge treatment technologies offer an opportunity for suppliers to develop a relatively standardized product portfolio of pre-engineered solutions. Developing such a portfolio of options requires an understanding of the economically optimal capacity of a treatment plant.

Analytical Approach
To determine the optimal product portfolio (in terms of processing capacity) we established the economically optimal capacity for the OP on a city-by-city basis. We then synthesized this information to establish which capacity OP's could serve a significant share of the market. We conducted this analysis for around 4,000 urban areas in 13 countries across Asia, Africa and Central America. These 13 countries had been (separately) identified as potentially attractive markets for the OP based on system economics and political economy for faecal sludge management.

For each city, the economically optimal OP was established on the basis of the processing capacity that would minimize total FSM costs – including both treatment and faecal sludge collection and transport. By optimizing for this metric, we were able to take into account a key trade-off:

- Faecal sludge treatment costs decrease with as processing capacity increase – due to economies of scale in processing plant equipment.
- Faecal sludge collection and transport costs increase as processing capacity increases – since truck operators will have to travel further to collect sufficient faecal sludge for the plant.

This trade-of is inherent to any decentralized system reliant on a distributed input – such as most biomass to energy plants.

A key factor to consider when exploring this trade-off is a city's population density. In a city with relatively low population density, increasing plant capacity will have a much greater impact on transport distance than a city with a relatively high population density. Clearly a range of other city and country-specific factors will also influence this analysis. Table 1.1 summarizes the main factors we were able to capture in an analysis of this scale.

Table 1 Operation of the CLASS systems in Coimbatore, India as of September 2016.

	Faecal Sludge Collection & Transport*	Faecal Sludge Treatment
Country-specific factors	• Typical labour requirements and labour costs • Typical truck capacity and fuel efficiency • Typical transport speeds • Truck capital and maintenance costs • Diesel costs	• Electricity prices • Water price • Labour cost
City-specific factors	• Population density	• Target FSM population (i.e. population requiring desludging of on-site sanitation systems).

* Where available.

Results

We will present the key findings of our analysis and discuss their implications for product development and go-to-market strategy, including:

- What capacity FSTP / OP systems make sense? What would be the relative market share of these different capacities across the countries of interest?
- What implications does this analysis have for which markets should be pursued first for an FSTP / OP?
- What are the characteristics of the cities that fall into different product capacity categories? Can these characteristics effectively be used to target or guide marketing?

In addition, we will present more generalized findings that could guide the development of technologies any FSTP or OP technology. In particular, we will share findings about the distribution of urban areas by target FSM population size (i.e. the number of people who are currently reliant on on-site sanitation), and population density.

Significance and Impact

The direct impact of this work is to help identify an optimal product and market strategy for OP technologies. The methodology described is applicable to any other faecal sludge processing technology. As a result, this presentation could help technology developers optimize their own product and market strategy – which would lead to more cost-effective and wider deployment of faecal sludge treatment technologies.

Sub Saharan Africa Stakeholder Perspectives And Early Thoughts On Macro Business Model Implications

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Keywords: stakeholder perspectives; business model; market entry

Conference Track: (1) Research Track
Track Topic: Economic & Business
Personal Preference: poster

Background and Context

The need for improved sanitation in Sub-Saharan Africa is clear--only 30% of individuals have access to improved sanitation services and nearly half of all people using unimproved sources live in Sub-Saharan Africa. However, for a technology developer or commercial firm considering how to address this significant challenge, the task can seem overwhelming; after all, Sub-Saharan Africa is comprised of 48 independent countries with different environments and unique cultures.

Given the large need for sanitation solutions, the Sanitation Technology Platform (STeP), supported by the Bill and Melinda Gates Foundation, undertook research to understand how the Sub-Saharan Africa sanitation market might best be analyzed to provide actionable insights and model markets that answer where and for whom Reinvented Toilets (RT), a new product category, might be deployed and designed by technology and commercial partners. This study also establishes important qualitative foundations for subsequent, more in-depth studies designed to support customer segmentation, market insights, and design specifications for RT's in target countries in Africa.

Research Approach

To start, the approach included analysis of secondary data, including country specific data, World Bank Worldwide Governance Indicators, eThekwini commitment progress scores, and USAID CSOSI data, to define the opportunity space and identify markets that are attractive individually and/or serve as models for other markets. This analysis included diversity in the types and sizes of urban contexts considered. The "model market" approach reduced analysis of Sub-Saharan Africa from 48 countries to four--Kenya, South Africa, Senegal, and Nigeria, specific cities including Mombasa and Kisumu in Kenya, Durban and Cape Town in South Africa, Dakar and Thies in Senegal, and Lagos and Jos in Nigeria.

Over the course of five weeks, these highly targeted "Stakeholder Perspective" studies were undertaken in each city to better understand potential use cases, stakeholders, and context. The qualitative research approach included 15 – 18 key informant interviews in each city with the goal of characterizing and mapping specific use cases including community toilets, school toilets, and residential toilets, analyzing stakeholders in each use case to define the user and customer and map the buying process, and characterize the context in which the systems will be adopted. In total, approximately 120 interviews were conducted with various sanitation stakeholders including home toilet users, home owners, multi-unit apartment building tenants, public toilet operators, public toilet users, builders, plumbers, sanitation product distributors, and others. For the toilet user interviews, a key stakeholder group for this study, the qualitative interviews were conducted utilizing an ethnographic approach to understand how personal contexts like family, occupation, education, peer pressure, and societal norms impact decision making around sanitation.

Key informant interviews focused on three areas:
- Fit of the individual into the local sanitation ecosystem
- Current state of the sanitation product in his or her daily environment
- Issues interviewees wish to see resolved in regards to his or her interaction with the sanitation product and the technical features of most value in a future sanitation product

While this study is ongoing, we expect insights to be gained from exploring the focal areas that inform both product design and the business model development for technology developers and commercial partners interested in the Sub-Saharan Africa market. Potential outcomes include identifying and characterizing drivers of product adoption that must be considered during both product and business model design.

Outcomes

When complete, the study will address a number of questions at varying levels of depth including, but not limited to:
- How do users of sanitation products utilize the product in their daily life such as frequency and maintenance?
- What issues do users most frequently face with their sanitation product?
- Which stakeholders drive purchasing decision-making for new sanitation products?
- What factors impact new toilet technology adoption such as price, acceptance by peers, and formal ministry approval?
- What product features are valued and not valued by different stakeholders and why?
- What mental contexts of stakeholders need to be taken into consideration when commercializing a new sanitation product (risk aversion, value placed on health, capex purchasing behavior, etc.)?

Significance

This study has the potential to offer technology partners and commercial entities additional insights into the African market to support technology development and market insights. The study will also be used to inform more comprehensive market segmentation and characterization studies. In addition, while this specific study was designed to explore Reinvented Toilet technologies, the learnings could inform the design and adoption of any decentralized sanitation solution for Sub-Saharan Africa. By developing an understanding of potential use cases, deep diving into stakeholder perspectives about the value and benefits desired, and characterizing the context in which a system might operate, organizations seeking to develop and/or commercialize a sanitation product will have a new resource to consider technology and business requirements and features. For companies, understanding use cases, stakeholders, and context can help de-risk investments and provide insight into which markets to enter. For technology developers, this effort may uncover new technology features that should be further developed for specific use cases.

Strategies and lessons for achieving scale in Sanitation

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Keywords: Scale, pit emptying,

Conference Track: (1) Research Track
Personal Preference: *oral presentation*

Introduction

Although it is not always an exact fit, one of the closest methodologies Water for People follow within its sanitation work is that of Market System Development. A good guide to this can be found on the BEAM exchange and following https://beamexchange.org/resources/167/ . In his report 'Getting to Scale', Gareth Davis describes the accumulative experiences of the market systems development sector in taking initiatives to scale and this forms the framework for analysing Water for Peoples sanitation initiatives across nine countries. Gareth Davis outlines five strategies to scale and each of these is briefly described with a reflection on their relevance to scaling sanitation beyond the 'pilot' stage.

Strategy 1: Achieve scale through 'big' actors

"The simplest strategy for getting to scale is to work with one or two market actors that by themselves have the ability to reach large numbers of poor men and women"

The applicability of this strategy in sanitation is limited as there are simply too few large companies interested in either latrine construction or pit emptying. Sanitation is what is referred to as a 'thin market', that is one where there are low numbers of buyers and sellers and where the total number of transactions are low. It is particularly thin when introducing a brand new type of service, such as using the Gulper to empty pits. As the market improves and demand increases the better companies operating within the sector should grow and it may become Water for People role to make the linkage between these companies and impact investors.

Strategy 2: Work with 'first movers' to create a demonstration effect

"Another commonly deployed strategy for getting to scale is to work with a small number of 'first movers' in order to demonstrate the viability of the innovation to other market actors. The hope is that this demonstration effect will then lead to spontaneous or organic 'crowding-in' by other market actors ('second movers')"

This strategy is based on the Diffusion of Innovation theory developed by E M Rogers where the adoption process goes through innovators, early adopters, early majority, late majority and finally the laggards. This is a familiar strategy for sanitation in Water for People, but only in Muzaffarpur, India has the strategy worked. In this area 8 cement ring manufacturers were facilitated to start selling toilet components, the project stopped, but 18 months later, with Water for People doing absolutely nothing, they had increased to 22 manufacturers producing an estimated 1600 latrines a year.

Strategy 3: Actively support 'second movers'

"If Strategy 2 fails to promote the desired crowding-in, the programme can provide more direct support to second movers. The aim is to either reach scale through a combination of the first and second batch of programme-supported actors, or to create a further demonstration effect or reach a tipping point that will lead to scale through the spontaneous crowding-in of a third wave of actors"

Whilst there have been good primary movers within each country program, these has been a distinct lack of secondary movers. For the *demonstration effect* to works the first movers has to be visible to the second movers, second movers have the incentives, capacity, and resources to copy the first movers, barriers to entry are low, and that second movers are able to access the know-how in order to replicate and adapt the innovation. These area the areas where Water for People has not been paying enough attention and been too passive in its belief that crowding-in will somehow magically occur.

Some of the reasons for the lack of second movers two also be attributed to the nature of the sanitation markets, such as thin markets, very new markets and pit emptying being an unattractive disgusting job. Nicaragua is an example of where Water For People is actively working to get secondary movers into the market.

Strategy 4: Create or strengthen supporting functions

"Rather than the programme directly providing support to second movers to promote the uptake of an innovation (Strategy 3), it may be possible to create or strengthen a set of service providers to do the job for you"

This strategy did not work for Water For People when it employment of a series of five Business Development Service providers in India, Rwanda, Uganda, Malawi and Bolivia. Six months after the end of the project, all the country programs had terminated the relationship and not one is now active in the sector.

Strategy 5: Strengthen or reform rules and regulations

"Seek to change the rules and regulations in the wider system in a way that supports or incentivizes the uptake of a given innovation… putting in place regulations that provide greater certainty to firms,"

This option may appear to be a quick and tempting solution for scaling sanitation, feacal sludge after all is a highly pathogenic material and is a threat to public health. However, in all Water for People countries, laws already exist designed to ensure latrine provision and safe emptying, but these are not enforced and usually blatantly and openly ignored. Passing legislation and then not enforcing it may actually make things worse.

Combined use of the strategies.

In practice a combination of the five strategies is used over the time span of an intervention nurturing process, with one being dominant at any particular time.

In Blantyre the initial strategy for growing pit emptying businesses was to identify the prime movers an accordance with Strategy 2, and this moved on to Strategy 3 when crowding-in failed to occur and with the formation of the Pit Empties Association designed to attract and support more second tier movers. An element of Strategy 4 is included with the PEA offering business support services and may become the more dominant strategy in the future. In the meantime Water For People is working with the city sanitation coordination team at the city assembly, which one day may result in changes in rules and regulation as in Strategy 5.

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San Benchmarks: Citywide Assessment of Sanitation Service Delivery - Including On-Site Sanitation

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Keywords: Assessment; Indicators; on-site sanitation

Conference Track: Research Track
Track Topic: Characterization and quantification of faecal sludge
Personal Preference: Oral presentation

Background

Most cities in India depend fully on onsite sanitation systems, or have mixed sanitation (sewerage and onsite) systems. Only a few cities have 100% sewerage system. As per census 2011, around 40% households with toilets are connected to sewer network while 60% households with toilet are connected to onsite sanitation systems, mainly septic tanks. Despite this wide prevalence of onsite sanitation systems, no benchmarking framework captures onsite sanitation services (For example, IBNET). The Service Level Benchmark (SLB) indicators of the Government of India also focus only on conventional underground sewerage systems. Such measurement frameworks imply that cities without sewerage system are non-sanitised.

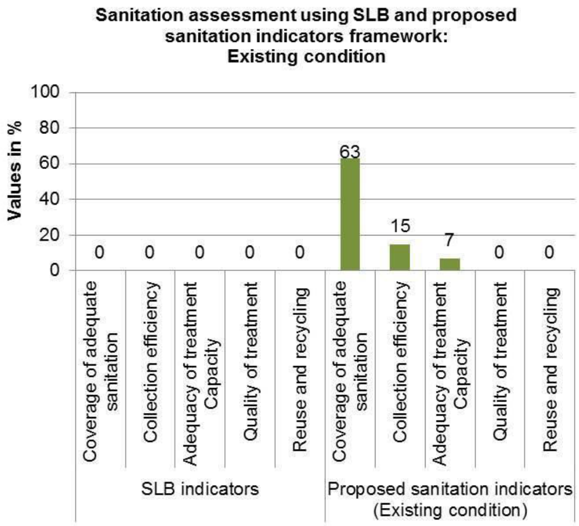
However, it is obvious that a well-managed onsite sanitation system can also provide good public health and environmental outcomes. A similar recognition of onsite sanitation systems is also available in the new CPHEEO Manual on sewage and sewerage treatment (2013) and the advisory note on septage management in urban India (2013) issued by the Ministry of Urban Development. The recently launched Swachh Bharat Mission (SBM) and AMRUT schemes of Government of India, also talks about onsite sanitation system as an acceptable sanitation system. It is in this context that CEPT University has prepared a new set of SLB indicators to capture the ground realities of more widely prevalent onsite sanitation systems.

Proposed framework for citywide sanitation assessment

San Benchmarks provides a new framework for performance assessment of citywide sanitation by capturing the onsite sanitation systems along with the conventional sewerage systems. The basic premise is that a well-managed onsite sanitation system can also help in achieve the goal of a totally sanitized city. The approach of San Benchmark is more outcome based rather than technology based. A framework with new indicators has been developed to capture the full sanitation service chain from access, collection/storage and conveyance to treatment and reuse/disposal. This new framework captures a more realistic picture of the sanitation situation as well as helps identify improvement areas in sanitation services at local level. This framework has been tested in 400+ cities of Gujarat, Maharashtra, Chhattisgarh and Telangana.

The use of the San Benchmarks framework will help state and city governments in monitoring sanitation improvement. It also helps cities choose various options for sanitation improvement planning based on local priorities and availability of finance. Importantly, the framework makes it possible to assess the improvement in service performance by making smaller investments in onsite sanitation system.

Sinnar Municipal Council is a point in case - a city that is fully dependent on onsite sanitation system. The SLB indicators consider this city as fully “non-sanitized” with zero performance on each wastewater management indicator, because the SLB framework does not capture service performance of onsite sanitation systems. Using San Benchmarks, however, the city sanitation performance improves considerably. It also shows that the proposed improvement measures for onsite sanitation system by the local government are not captured in the SLB framework. However, the new indicators help to show the higher performance level achieved after such improvements.



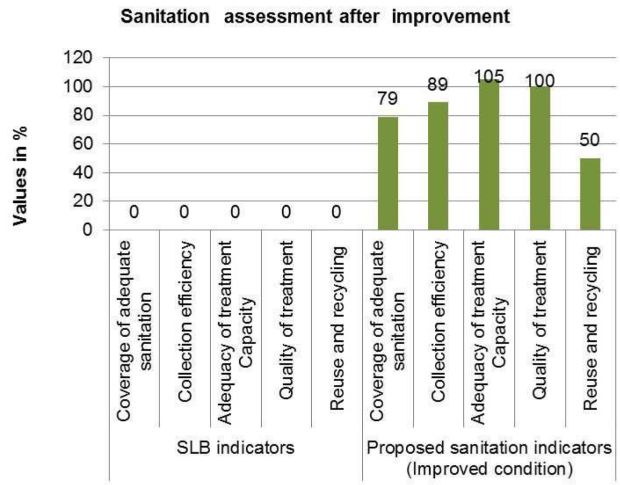


Figure 1: Sanitation assessment using SLB and San Benchmark framework (Proposed sanitation indicators) for Sinnar city

Addressing the data challenges

A major challenge in using San Benchmarks for assessing performance is the availability, or lack thereof, of adequate information. Based on an assessment in a few cities of Maharashtra, a number of measures have been identified to improve information of onsite sanitation systems. For example, appropriate questions for onsite sanitation were included in the existing property tax assessment form, and activities of private septic tank emptying agencies were tracked to measure and improve information for on-site sanitation systems.

The Way forward

Many cities aspire to provide sewer networks in their cities but this is beyond the capacity of most cities and is not financially sustainable. A well-managed onsite sanitation system is likely to play an important role in providing safe sanitation, and should be an integral part of the performance assessment system. The San Benchmarks framework provides a more realistic picture of on-ground situation as well as facilitates identification of improvement areas at the local level. It can be used for better decision-making and policy intervention at the state level and to prepare improvement plans at the city level.

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Development and Testing of Faecal Sludge Simulants

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Keywords: synthetic faeces, faecal sludge simulant, artificial poop

Conference Track: (1) Research Track
Track Topic: Development and Testing of Faecal Sludge Simulants
Personal Preference: *Oral presentation*

Background

The need for novel, cost-effective, sustainable and efficient technologies for faecal sludge management is emerging mostly in developing countries where the current onsite sanitation technologies do not satisfy or provide any safe discharge and treatment of the human excreta. The sanitation needs of about 2.7 billion people worldwide are served through onsite sanitation facilities (Strande et al. 2014), however the need for novel, cost-effective, sustainable and efficient technologies for faecal waste management is emerging mostly in developing countries where many pit latrines, flush toilets and sewage systems do not safely discharge human waste or properly treat them (Niwagaba et. Al., 2009). The excreta, particularly the faecal matter, often remains open to the environment which causes breakout of infectious diseases such as diarrhoea. Diarrhoea is the primary cause of the death of children under the age of five in the developing world.

The entire FSM chain as it currently stands, requires handling or often direct exposure during use to pathogenic faecal by the toilet users or the pit emptiers. This suggests that the current onsite sanitation technologies should be improved to provide safe collection, transport, treatment and disposal with minimum risks to the public health. On the other hand, during field and laboratory studies in the process of developing innovative technologies for faecal sludge treatment, high health hazards are present due to strong probability of pathogen contamination.

All of these limitations suggested the need to develop faecal sludge simulants, as analogues of human faeces or faecal sludge to serve the testing stages of innovative technologies for treatment of human excreta with no risk of pathogen contamination.

Materials and Methods

At the Pollution Research Group, three initial recipes were used to mix FS simulants and some of their properties were analysed and compared to “real” faecal sludge. Where required, these recipes were modified in order to match closer to the properties of the faecal sludge. All the simulants were tested by the following properties: moisture content, total, fixed, volatile and suspended solids, sludge volume index, chemical oxygen demand, pH, density, thermal conductivity, heat capacity, calorific value, rheology and particle size distribution, and compared to the same properties of faecal sludge and fresh faeces (Figure 1). Ten different simulants as variations were prepared and analysed in total. The comparative properties were selected on the base of the advertised technology prototypes under the Transformative Technologies programme run by the Bill & Melinda Gates Foundation. The “real” faecal sludge samples were selected from on-site sanitation facilities (dry and wet ventilated improved pit latrines, community ablution blocks and urine diversion toilets) in the eThekwini Metro area around Durban, South Africa. Standard operational procedures were followed for all the analysed properties and repeated for all samples in order to ensure compatibility.

At a later stage, further studies were carried for provision of simulants of fresh faeces, following Wignarajah et al. (2006).

Results

The comparative results between "real" and "syntactic sludge" are presented in **Figure 1**. On the base of these results, the simulant that indicated the closest match to real FS - Synthetic Sludge 9 (Table 1) was the recommended simulant for the Bill & Melinda Gates Foundation's Reinvent the Toilet Fair: India 2014. A standard procedure of the mixing procedure was developed.

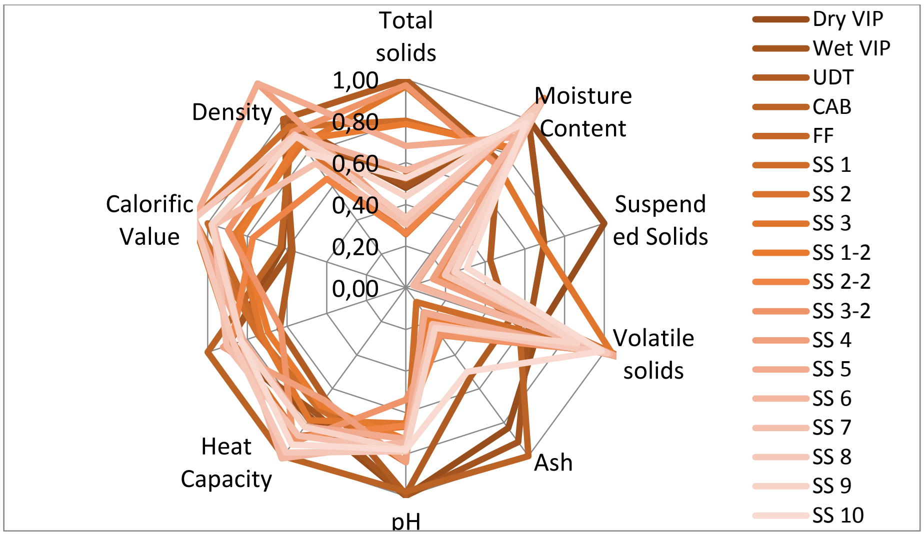

Figure 1: Comparison of properties of synthetic sludge simulants (SS1-SS10)

Table 1. Proposed simulant recipe

Recipe 9 FINAL SYNTHETIC SLUDGE RECIPE					
Ingredients	***% Wet Mass***	***Mass for 1 kg***	***Mass for 500g***	***Mass for 250g***	***% Dry Mass***
Instant yeast	7.3	72.80	36.40	18.20	32.49
Water	77.6	776.10	388.05	194.03	
Psyllium	2.4	24.30	12.15	6.08	10.84
Peanut oil	3.9	38.80	19.40	9.70	17.31
Miso	2.4	24.30	12.15	6.08	10.84
PEG	2.7	27.20	12.15	6.08	12.14
Inorganic Calcium phosphate	2.4	24.30	12.15	6.08	10.84
Cellulose half cotton linters/ half tissue -shredded	1.2	12.40	6.20	3.10	5.53
Total Mass	100.0	1000.20	500.10	250.05	100.00

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Engineering Design Approach for Selection and Design of Treatment Technologies

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Keywords: faecal sludge; resource recovery;
Conference Track: Research Track: Characterization and quantification of faecal sludge

Introduction
Faecal Sludge Management (FSM) is a relatively new and rapidly growing field. There is a great need in FSM for practical and reliable approaches that allow engineers to select and design treatment technologies. Presented here is how research conducted in the department Sandec (Sanitation, Water and Solid Waste for Development) at Eawag addresses and is filling gaps toward a sound engineering design approach.This presentation will provide an update of our recently conducted, but not yet published, research in this area. All of our published research is available for download at www.sandec.ch/fsm_tools.

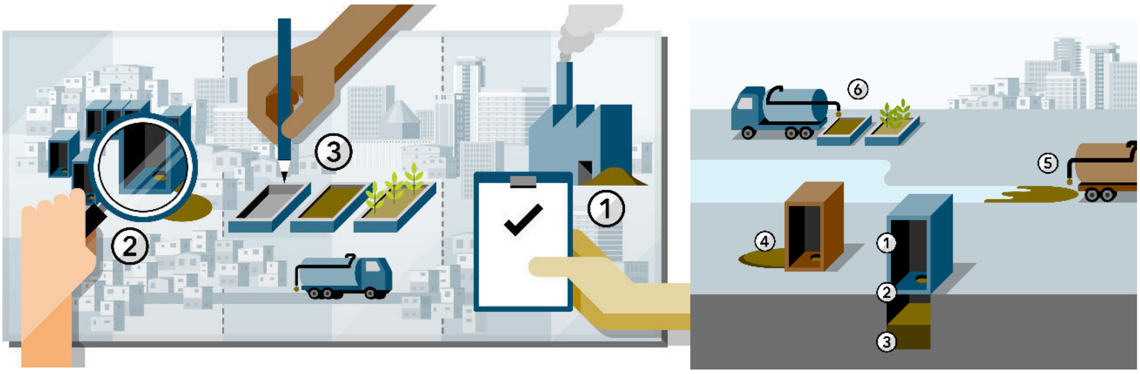

Figure 1: Left – Schematic of Engineering Design Approach, including: 1) Treatment Objectives and Resource Recovery; 2) Faecal Sludge Quantification and Characterization; and 3) Treatment Technologies for Resource Recovery. Right – Schematic of Quantification and Characterization, including: 1) excreta produced; 2) FS produced; 3) FS accumulated; 4) FS emptied (but not collected); 5) FS collected (but not delivered to legal discharge); and 6) FS delivered to legal discharge.

Treatment Objectives and Resource Recovery
The definition of engineering design is the formulation of a plan that allows an engineer to build a product with a specified performance goal. Unfortunately, performance goals and the specific local context are all too commonly ignored in low-income countries when designing treatment technologies. Decisions are frequently based more on what has worked in different contexts that are not relevant, or on available project funding. The number one performance goal is protection of public health. In the case where resource recovery is possible, the intended enduse can inform the performance goal, for example pathogen reduction for use in agricultural, or dewatering for use as a dry fuel. Designing for the specific enduse is critical, as under-designing treatment technologies do not provide adequate protection of human and environmental health, and over-designing wastes money and resources. Resource recovery can also increase financial flows to help offset treatment costs, and provide an incentive for the efficient operation of treatment plants.

The Market Driven Approach methodology was developed jointly between engineers and experts in economics and business development to assist in the identification of FS treatment endproducts that are appropriate for local contexts and have the largest market potential for volume and growth (Schoebitz et al. 2016).

Faecal Sludge Quantification and Characterisation

Prior to the design of full-scale treatment plants, engineers first need to know the quantities and characteristics of the FS that will be treated (see Figure). However, no reliable methods currently exist to determine the quantities and characteristics of FS on this scale. Reliable estimations are quite complicated due to the informal nature of FSM, and the high variability of FS characteristics. Our recent research on understanding what will be delivered at treatment plants includes identifying reliable predictors of FS characteristics, GIS analysis of collection and transport trucks, and reliable and reproducible standard methods for laboratory analyses. We placed GPS trackers in 34 faecal sludge collection and transport trucks and followed their activity over a period of three months in Kampala, Uganda (Schoebitz et al. submitted). Through this analysis we were able to collect quantitative data about collection frequencies, and areas of the city that are lacking service provision. To develop an understanding of reliable predictors of FS characteristics, we collected180 faecal sludge samples in Kampala (Schoebitz et al. in preparation), and 60 in Hanoi, Vietnam (Bassan et al. in preparation) and analysed them for statistical correlation to spatially available demographic data. This analysis is working towards reliable and reasonably accurate methods for the quantification and characterization of FS on a scale relevant for the design of semi-centralized FS treatment plants.

Treatment Technologies for Resource Recovery

After the definition of performance goals and deriving estimations of FS quantities and characteristics, then treatment technologies can be designed. Because available space in urban areas is very limited, and most current FS treatment technologies are space intensive, our research in this area focuses on how to increase the treatment capacity of existing technologies. This can increase the amount of sludge treated, and/or reduce the required footprint of treatment plants, in addition to optimizing technical aspects of resource recovery. Our recent work in this area has included FS as fuel for brick production and oil regeneration, pyrolysis of FS for char production, identification of indigenous plant species for use in planted drying beds, technology development to increase treatment capacity of unplanted drying beds.

One of the most important treatment objectives in FSM is dewatering. FS is mainly comprised of water, and water is heavy and expensive to transport. Discharging polluted water into the environment also has significantly negative human and environmental health impacts. Dewatering FS is required prior to its being used in resource recovery applications, such as composting or combustion as a fuel. Our recent research in this area has included evaluating locally available natural resources as conditioners for dewatering of faecal sludge (Gold et al. 2016). We are actively conducting dewatering research from the fundamental to applied level at our facilities in Switzerland and Dar es Salaam.

Sustainable Implementation

Most importantly, one must keep in mind that the engineering design of treatment technologies is only one aspect of sustainable FSM. This also must include integrated planning and management schemes. For more information, please refer to the book, Faecal Sludge Management: Systems Approach to Implementation and Operation, and other publications available at www.sandec.ch/fsm_tools

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Linking Microbial Communities to Degradation Processes Occurring in a VIP and Pour-Flush Latrines

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Keywords: microbial communities, decomposition, VIP, Pour flush, latrine

Conference Track: (1) Research Track
Track Topic: *Characterization and quantification of faecal sludge*
Personal Preference: *Oral presentation*

Introduction

One of the most common onsite sanitation technologies is the Ventilated Improved Pit latrine (VIP), which was considered an improvement over the traditional pit latrine due to better odor and insect control (Mara, 1984). Millions of VIPs were installed in Zimbabwe, Botswana, Ghana, Tanzania, South Africa, and other countries since the 1980s. As these pits started to fill up, the problem of pit emptying led to consideration of improved onsite sanitation technologies. In South Africa, the pour-flush toilet (PF), adapted from traditional Indian design, was tested in the outskirts of the Pietermaritzburg area. In this case the existing VIP pits were converted into PF leach pits. The PF toilet was seen as bridging the gap between basic on-site sanitation technologies and water-borne sewerage that people aspire to (Byrne, 2016), and the initial results were encouraging with respect to performance and user satisfaction (Still and Louton, 2012).

It is important to note that the VIP and PF latrines are not simply storage mechanisms for faecal sludge (FS): degradation of faecal sludge occurs in VIPs and PF leach pits. A general understanding of the processes occurring in the VIP was presented by Buckley et al. (2008), which states that aerobic and anaerobic processes occur depending on the position of the material within the pit. In PF toilets, water that is used for flushing carries the faeces to the leach pits, where the liquid portion of the faecal material leaches out through the bottom and sides of the pit, allowing solids to settle at the bottom. In a dual-leach pit situation, the FS in the unused pit becomes biologically stable and safe to handle after 2-3 years (Tilley et al., 2008). Previous research, mostly conducted at the UKZN, using chemical and physical characterization has in general confirmed this basic understanding in VIPs (Zuma et al. 2015). However, research on the microbial communities in a VIP is rare, and to our knowledge there has been only one study using DNA sequencing to analyse the microbiology in pits, conducted in Vietnam and Tanzania (Torondel et al, 2016). To our knowledge, the metagenomic analysis of the VIP in South Africa and PF latrines anywhere in the world has not been performed.

In this study, we report the 16S rRNA gene metagenomic analysis of the different layers of a VIP, and the standing and active leach pits of several PF latrines in South Africa. The resulting microbial community analysis will help provide more insight into the degradation processes occurring within these onsite systems.

Methods

A VIP in Bester's Camp, eThekwini municipality, was sampled such that 8 representative FS samples from 4 different depth layers from the front and back of the pit were obtained (Fig. 1). Similarly, 12 samples from 6 PF leach pits (standing and active) were sampled. DNA was extracted from the samples at the UKZN laboratory, and these were freeze-dried and transported to NC State University. A DNA

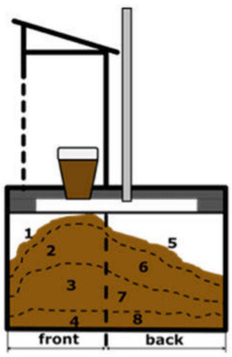

Figure 1 Sample locations in VIP (Zuma et al. 2015)

fragment of approximately 460 bp length flanking the V3 and V4 regions of the 16S ribosomal RNA (rRNA) gene of bacteria and archaea was amplified. Library preparation, quantification, normalization, and pooling were performed according to the Illumina 16S metagenomics protocol and pooled libraries were run on an Illumina MiSeq platform. Amplicon sequences were analysed following the QIIME pipeline, using principal coordinate analysis (PCoA), NMDS, and analysis of taxa abundances.

Results and Discussion

Clear differences in the bacterial communities are observed in the analysed samples (Fig. 2). They clearly show anaerobic processes occurring in the deeper layers of the VIP, in accordance with the Buckley (2008) model. Differences between the samples collected from the front and back of the VIP are also evident. In the PF leach pits, the differences are related to whether the pits were active or standing. PCoA (Fig. 3) shows that the VIP samples were more similar to each other than to the PF samples, suggesting that the different onsite technologies resulted in different microbial communities. In addition, several pysico-chemical parameters were correlated to the microbial composition.

Figure 2 Taxon profile abundance (genus level) for VIP (pit) and PF (TLT) samples

In this paper the findings and insights are discussed further and related to the microbial function and degradation processes occurring within the VIP and leach pits. They seem crucial to understand how FS is degraded in pits, and how different onsite technologies promote different microbial functions.

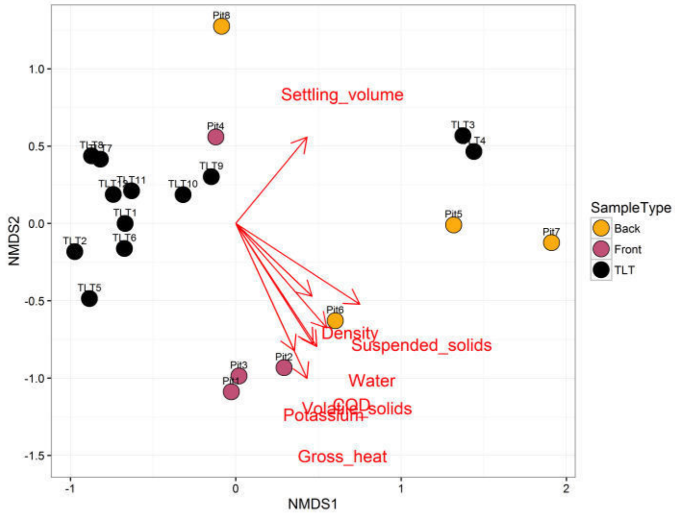

Fig. 1.3. Principal Component Analysis (PCoA) showing how communities are different from each other, and relationship to physico-chemical characteristics

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Continued development and field testing of a decentralized, self-contained toilet that converts human waste into burnable fuel and disinfected liquid waste

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Keywords: reinvented toilet; electrochemical disinfection, combustion

Conference Track: (1) Research Track
Track Topic: *Technologies for the collection, transport, treatment, disposal and use of faecal sludge*
Personal Preference: O*ral presentation*

Background

Research and development continues on sustainable, off-grid toilet solutions to meet the needs of the over 2.6 billion people lacking proper sanitation. RTI International has been developing a decentralized system that treats human waste without sewer, water, or electrical infrastructure. The RTI system receives mixed waste and separates them into solid and liquid streams. The liquid stream is treated by an electrochemical process to standards that allow the processed water to be reused as flush water. The solids stream is dried into a burnable fuel, then combusted to generate heat to dry incoming solids and thermoelectrically power the liquid processing.

The *alpha* version of the toilet was installed at the WiC Research Lab (WRL) at CEPT University in Ahmedabad, India in September 2015. The system was open to users including students, workers, and community members to collect user feedback on the design in addition to long term technical data. This alpha unit reliably disinfected liquid that was reused for flushing and produced dried fecal pellets that were successfully combusted. The testing also highlighted the need for some design improvements including improving the solids mass throughput and the resulting energy balance. This paper discusses the design changes and field testing of the RTI Toilet during the transition from the *alpha* to *beta* system at field site at CEPT University.

Overall Design

The RTI toilet receives mixed sold and liquid waste from a low-flush (1.5 L) squat plate. When flushed, the mixed waste enters a solid/liquid separator. The liquid system utilizes an electrochemical process that creates mixed oxidants including chlorine containing species from the salts naturally present in urine. These oxidants disinfect the liquid and provide a chlorine residual that allows the liquid to be recycled as flush water. The solids process first extrudes the material through a macerating unit. The solids are then moved into a “mini-extruder” that extrudes a fixed volume onto a drying plate. The solids are dried into burnable flakes through a batch process before being scraped into the fuel hopper. The fuel hopper feeds a small combustion unit that burns the fuel which provides the heat that dries the incoming wet solids on the plate.

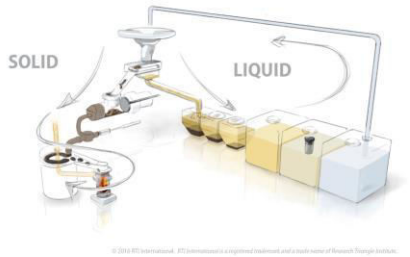

Figure 1. Schematic of the RTI Toilet treatment system.

Design Improvements

The transition from the *alpha* to the *beta* unit focused mainly on the reduction of the solids combustion rate to the rate of solids dried ratio. The *beta* system incorporated a new drying unit that increased the mass throughput ratio. Figure 2 shows the improvement in the total system electrical energy. A 1:1 solids mass balance ratio is within reach with supplemental solar power. Preliminary data has shown the new drying system to achieve a 8:1 mass balance ratio while producing burnable flakes of less than 25% moisture.

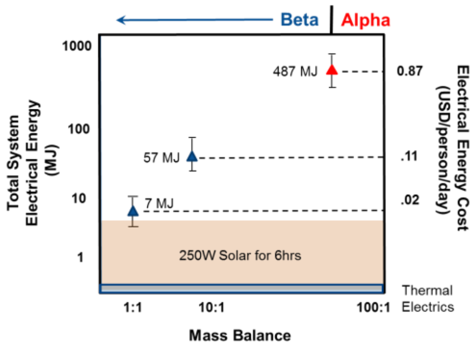

Figure 2. Total system energy vs solids mass balance ratio.

The efficacy and reliability of the liquid system was also improved in the *beta* design. Long term testing of the *alpha* system showed that disinfection was not always achieved at the normal 24 volt setting once the system had reached steady state. Several iterations of voltage settings and timings on the electrochemical cell were studied on the lab system. It was discovered that a combination of running the cell at 24 and 32 volts would reliably disinfect even at steady state. Long term, live use of this configuration is currently being tested with the newly installed *beta* unit at CEPT University.

The RTI Toilet system is a focal point for social science research for technology adoption. Findings from surveys are used with strategies to mitigate risk and improve technical performance to inform technology development cycle. Research conducted through 60 focus groups with over 700 men and women from low-income urban areas has been completed in 2015-16, as well as a household survey with over 1,200 participants. The findings provide insights into technology demand and sanitation practices in urban Gujarat, and influence further technology development for the unique waste treatment strategies. The surveys also provide input on broader adoption issues related gender and menstrual hygiene management, water reuse practices and preferences.

Conclusions and Next Steps

The *beta* version of the RTI Toilet has demonstrated improvements in both the liquid and solids treatment streams. A 10 fold improvement in the solids mass throughput was observed while still producing a reliably shaped, burnable fuel. The disinfection process of the liquid was also made more robust. Live user testing of the system is ongoing at CEPT University in Ahmedabad, India and continues to provide feedback for future design.

Field Testing Of Onsite Wastewater Treatment Technologies With 100% Pathogen Removal

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Keywords: electrochemical; flush toilet; water reuse;

Conference Track: (1) Research Track
Track Topic: Technologies for the collection, transport, treatment, disposal and use of faecal sludge
Personal Preference: oral presentation

Introduction

The Sanitation Technology Platform (STeP) helps move transformative sanitation technologies from prototype to product by enabling collaboration with partners, implementing field testing and supporting commercialization. A key performance criterion for onsite wastewater treatment is to achieve complete pathogen removal from the effluent versus the conventional log reduction in bacteria count.

STeP conducts field testing of prototypes to demonstrate operation in the relevant environment, ensure safety of the treated effluent, track performance and reliability and inform improvements in design.

The Closed Loop Advanced Sanitation System (CLASS) developed by Kohler is one of the transformative sanitation technologies supported by the Bill & Melinda Gates Foundation to address global sanitation challenges.

The CLASS system is intended for use in multiuser, apartment-type living environments, and treats black water from flush toilets. It relies on a treatment technology developed by Caltech as part of the Gates Foundation Reinvent the Toilet Challenge. The black water is separated from solid waste using settling tanks, and the liquid is treated in a batch process in an electrochemical reactor with custom electrodes that generate chlorine from the chloride salts present in the wastewater. The treated water is connected to the toilet cisterns and used for flushing only (Figure 1A). A prototype was designed to serve as an external back-end unit to 3-5 apartments with 10-20 users in India. Three CLASS units (Figure 1B) have been installed in Coimbatore, India and are being field tested by STeP.

Methodology

STeP identified and secured testing sites and established a MOU with the organizations (a private senior living facility and PSG Institute of Medical Sciences and Research). Institutional Review Board approval was obtained, and an informed consent was signed by a representative of each of the 22 households enrolled in the study. Field testing is set-up so that there was no disruption in the water or wastewater services to the residents; the toilet cisterns are supplied through a connection to tap water until the water treated by the CLASS unit is adequate for reuse. The system has an overflow to sewage which is also used for the treated water until adequate quality is achieved. The criteria for reuse is disinfection as demonstrated by removal of E.coli, total coliform and helminth eggs to below the detection limit of the measurement assay. Since installation, the CLASS systems have received regular influx of faecal sludge that enabled extensive testing and upgrades of the systems (Table 1).

Table 1. Operation of the CLASS systems in Coimbatore, India as of September 2016.

	Unit 1	Unit 2	Unit 3
Hours of Operation	3307	1918	4396
Volume of waste water treated (L)	71350	42300	86280

The system has produced up to 600 L of treated water/day, which is collected in a tank on the building rooftop and is adequate for the residents' needs. Sampling taps enable liquid to be collected at various points for testing, particularly before and after the electrochemical reactor.

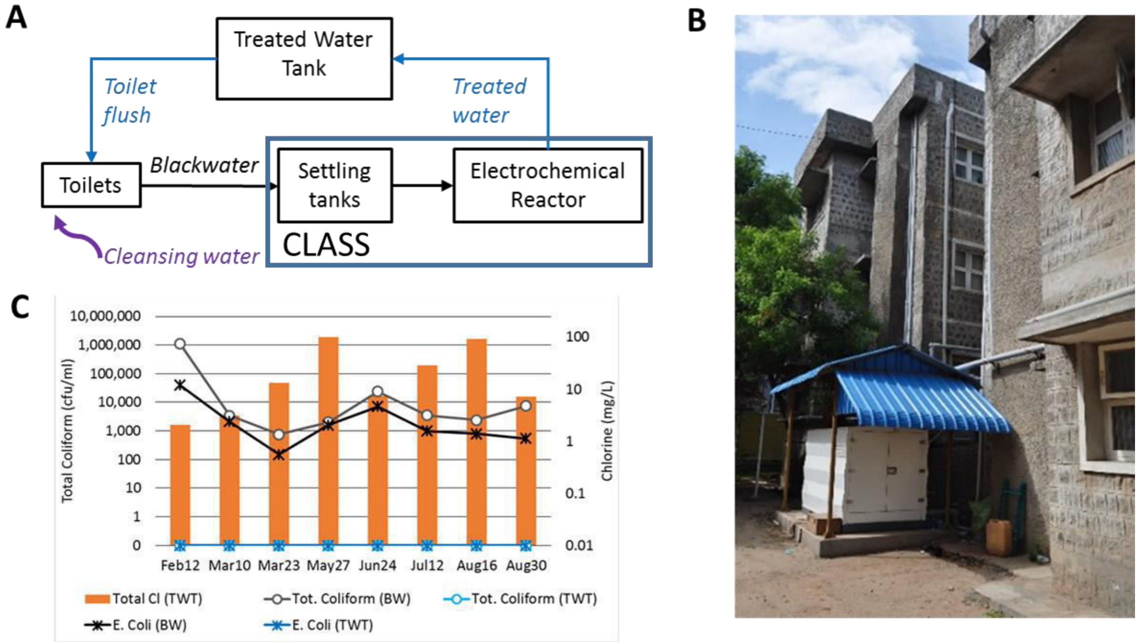

Figure 1. A. Schematic of the installation and operation of the CLASS system for black water treatment for re-use for flush. **B.** A picture of the one CLASS unit installed outside an apartment complex in Coimbatore, India. **C.** Bacteriological analysis conducted on sample before (BW, black water) and after (TW, treated water) the electrochemical reactor and electrochemically generated chlorine concentration in treated water.

Results

Water quality is monitored daily in the field using measurements of free and total chlorine, electrical conductivity, and pH. Blackwater and treated water samples are also periodically sent to independent certified laboratories for a suite chemical and bacteriological analysis including physicochemical parameters (total suspended solids, COD, nitrogen, chloride and others). Analysis of total coliform and E.coli in the treated water demonstrated routine achievement of 100% pathogen removal (count below the sensitivity of the assay) due the chlorine produced in the electrochemical reaction (Figure 1C). Samples are also collected to screen for helminth eggs using a well-established method of isolation and enumeration by STeP partner, PSG Institute for Medical Sciences and Research. The treated water has consistently been found to be free of parasite eggs (<1 egg/2L sample).

In addition to analytical measurements of wastewater, STeP is responsible for maintenance of the system, tracking the use of consumables, troubleshooting and reliability assessment. One of the biggest challenge observed in some of the sites is related to the high water hardness. This results in mineral deposits on the surface of the electrodes and on the bottom of the electrochemical reactor tank, causing performance and maintenance issues.

User studies to capture perceptions and behaviour associated with CLASS technology

Recognizing the critical link between technology and human behaviour, STeP conducted user-focused research as part of field testing. This work examines the technology's impact on stakeholder perceptions, knowledge, and behaviour, which in turn influences initial adoption and sustained use. Residents using wastewater treated by the CLASS technology for flushing were interviewed throughout field testing to understand user reactions and behaviours that changed or introduced challenges to the technical operation of the CLASS system. Thus far, the study has been conducted on one unit and suggests high acceptability among most users of the system.

Catalytic pyrolysis of human feces for biofuel production

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Summary Abstract

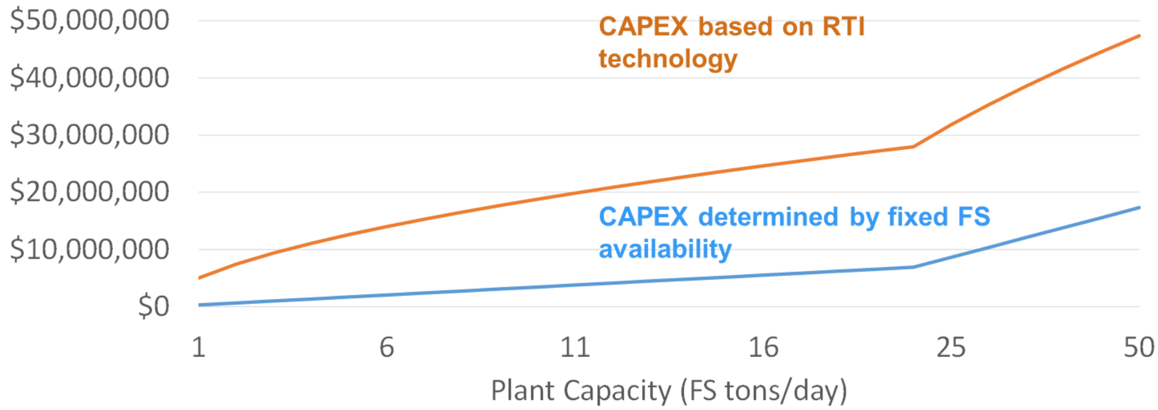
More than 2.5 billion people in the world live without access to safe and effective sanitation and in many of these same regions, economic and social development is hindered by limited access to clean, reliable, and affordable forms of energy. At the intersection of these two global challenges lies an opportunity to adapt advanced biofuels technology to locally produce energy, fuels, and products from feces-derived feedstocks. Pyrolysis is the rapid thermal decomposition of organic material in the absence of oxygen to produce a liquid intermediate. Bio-oil typically has high acidity and poor thermal stability, caused by high concentration of reactive oxygenated hydrocarbons, that makes upgrading to finished products a challenge and impedes the broader utility[1,2]. Catalytic fast pyrolysis has been applied to a wide range of biomass feedstocks[3] but never for conversion of faecal sludge. Here we show the production of oil from human feces using a novel catalyst proven to have excellent deoxygenation activity during catalytic fast pyrolysis of lignocellulosic biomass. The study demonstrates the production of value-added products including organic bio-crude and char without foul odor. The bio-crude yield (32.2 wt.%) was nearly twice that for pine, however, the nitrogen content was approximately 5.7wt% compared to less than 0.1 wt% in the pine bio-crude. Post-treatment methods will eventually be required to remove the nitrogen to produce more viable biofuels. The results suggest that catalytic fast pyrolysis may serve as a value-added recovery process for faecal sludge management while also providing broader access to energy in the developing world. Further results include analysis of the economic feasibility of this technology in developing world settings and the broader impacts of leveraging faecal waste as a valuable commodity in delivering both energy and improved sanitation to the world's poor.

Feedstock	Loblolly Pine	Sewage Sludge
Product yield (wt%)		
Bio-crude (Organic)	9.3	**13.7**
Aqueous	42.3	26.0
Gas	25.2	17.7
Solid	25.4	**35.8**
Gas breakdown (wt%)		
CO	10.4	1.5
CO_2	8.1	8.5
CH_4	1.4	0.6
C_2	0.6	0.5
C_3	1.5	1.5
C_4+	3.0	5.1

Biochar Aqueous ESP organics Light organics

- Higher yield of organic liquid indicates the greater potential for liquid transportation fuel production from sewage sludge.
- Higher yield of carbonaceous solid (biochar) due high ash content of the sewage sludge feedstock.

Gap in break-even points between fixed CAPEX (RTI technology estimate) and CAPEX based on fixed FS availability



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A Life Cycle Perspective on Scaling Up Sanitation in India

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Keywords: life cycle assessment; sanitation; India

Conference Track: (1) Research Track
Track Topic: *Characterization and quantification of faecal sludge*
Personal Preference: *oral presentation*

Introduction

Nearly 800 million people in India lack access to adequate sanitation facilities. In 2014, Prime Minister Modi announced the “Swachh Bharat” (Clean India) mission with the aims to fully eradicate open defecation by 2019 and significantly increase the number of individual household latrines. If each Indian household is ultimately provided with an individual latrine, this would require the construction of nearly 170 million new, fully functioning toilets (own calculations based on World Bank 2016). It is inevitable that such large scale infrastructure projects will have sustainability implications. Challenges include the need for vast amounts of construction materials for toilets and wastewater treatment infrastructure and energy for operation of wastewater treatment. Opportunities include tapping into valuable resources that can be recovered from human waste. In this study we used Life Cycle Assessment (LCA) methodology to analyse and compare the range of environmental impacts and nutrient recovery benefits from applying different technologies for scaling up sanitation in India.

Methods

Life Cycle Assessment (LCA) is a science-based approach allowing for holistic comparison of environmental impacts of products, processes and systems along their whole life cycle (Hellweg & Milà i Canals 2014). The analysis was conducted according to the principles of ISO14044 standard (ISO 2006). The following four scenarios were analysed:

1. Connecting everyone in India who currently does not have access to improved sanitation to centralised wastewater treatment facilities
2. Providing twin-pit latrines and reusing the compost in agriculture
3. Constructing twin-pit latrines with separation of urine and faeces at source and reusing recovered nutrients
4. Building source-separating latrines connected to household scale biogas plants

The scope of the assessment covered all the impacts related to the construction of toilets, their operation and the disposal of the sludge, including all the supporting infrastructure (e.g. pipeline and wastewater treatment plants), direct emissions to air from latrines and impacts of various sludge disposal routes. The value of recovered fertilisers was accounted for through the avoided need for production of a portion of fertilisers currently used in India, based on their nutrient content. The benefits of biogas recovery were considered through substitution of cooking fuels.

Results

Fig. 1. Presents comparison of estimated two environmental impacts (greenhouse gas emissions and fossil energy use) for a single household. We estimate that connecting all households in India to centralised wastewater treatment facilities would require construction of around 8943 new wastewater treatment plants. Results of the analysis suggest that closing the sanitation gap with source separating toilets at this scale can provide on average 3885 ktonnes of plant available nitrogen and 378 ktonnes of phosphorus every year. This is a significant amount, corresponding to around 18 % of the total annual projected nitrogen

demand in India in 2019 and 4.9% of the demand for phosphorus. The conservatively estimated net greenhouse gas emissions at the scale of the whole country ranged from just 3 M tonnes CO2eq per year for source separation and biogas to +189 M tonnes CO2eq per year for twin pit latrines. These are significant numbers. The study suggest that the annual direct methane emissions from pit latrines alone would have the potential to increase the greenhouse gas emissions of India by 6% compared to the 2012 levels.

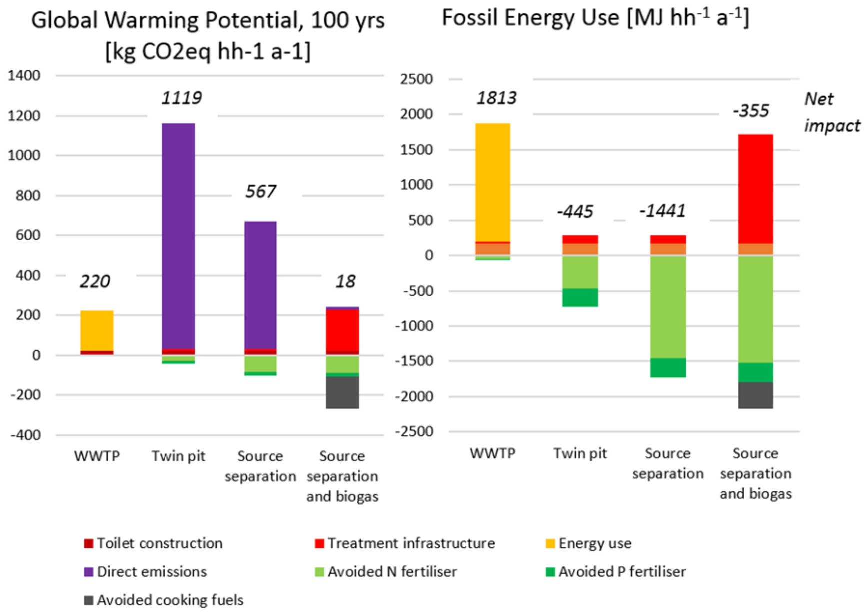

Figure 1. Environmental impacts of sanitation systems at the household (hh) level per annum. Full life cycle including the construction of toilets and wastewater treatment infrastructure. Bars allow for the distinction between the estimated impacts (positive numbers) and estimated potential avoided impacts due to the use of technology (negative numbers). The net aggregated impacts are provided numerically in italics above the bars.

Conclusions

Sustainability implications of scaling up sanitation in India can differ substantially depending on technology choice. Providing source-separating toilets with biogas could lead to a near zero net greenhouse gas impact, while continuing building pit latrines would lead to a significant increase in net greenhouse gas impacts among the other potential negative implications, eg. water pollution. Closing the sanitation gap with nutrient recovery systems can potentially offset greenhouse gas emissions while satisfying a significant portion of the fertiliser requirements of India. Although the practical approaches to recover the full amount of nutrients may not yet be available, innovations that can recover portions of the nutrients should be supported. Results of this study can help inform organisations working to improve access to sanitation in India to identify trade-offs and opportunities. Our methodology can be applied to evaluate other sanitation technologies and systems both at the household and country levels.

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The Inactivation of *Ascaris suum* Eggs by Short Exposure to High Temperatures for the Purpose of Sanitizing VIP Latrine Sludge by Viscous Heating.

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Keywords: *Ascaris suum*, inactivation, temperature.

Conference Track: Research Track

Track Topic: Technologies for the collection, transport, treatment, disposal and use of faecal sludge

Personal Preference: Oral presentation

Lack of improved water, sanitation and hygiene (WASH) is directly associated with the "silent epidemic" of infectious diseases that burdens approximately one third of the world's population (Bardosh, 2015). The inability to provide WASH results in diarrhoeal disease prevalence, which manifests generally as a symptom of bacterial and viral infections, but can also be a symptom of infection by helminths, the most common being *Ascaris sp.* (Brownell and Nelson, 2006; Fewtrell et al., 2005). Pit latrines are found in many rural communities and are regarded as improved sanitation by the South African government. The usefulness of a pit latrine is finite; as once full, they must either be sealed or emptied (Bhagwan et al., 2008). Pit contents need to be treated or disposed of safely to minimize any risk to human health.

Temperature has proved to be one of the most effective and promising treatment options for sanitising sludge. Previous studies have found that, at temperatures above 60°C, *Ascaris* eggs may be inactivated in a few minutes, but can survive for more than a year at 40°C (Brownell and Nelson, 2006). Viscous heating occurs when a thick fluid is passed through a narrow gap, where the outer shell remains stationary and the inner cylinder rotates rapidly (Belcher et al., 2015). This may be used to inactivate *Ascaris* sp. eggs in sludge (Podichetty et al., 2014). A viscous heater was designed for the processing of faecal sludge and is currently housed at the University of KwaZulu-Natal.

Previous studies, using both simulated and sieved VIP pit sludge have indicated that the residence time of sludge within the heater is low (seconds), allowing for short exposure of the helminth eggs to high temperature (up to 85°C) (Belcher et al., 2015). The present study was therefore aimed at determining the effects of high temperatures at short contact times on the survivability of *Ascaris* eggs. The outcomes of this study can be used by designers and operators of all types of sanitation equipment, when deciding how to treat and dispose of sludge safely. *Ascaris suum* eggs were procured, and exposed to 60°C, 70°C, 75°C and 80°C for 5, 10, 15, 30 and 45 seconds, and 1, 2, 3 and 4 minutes. Eggs were pipetted into plastic test tubes containing water, which had been preheated to the required test temperature. Eggs were exposed for the respective times, and either washed directly onto a 20 µm sieve (placed under an open tap to allow for rapid cooling to room temperature), or first transferred into a beaker containing iced water (to allow for rapid cooling) and then washed onto the sieve. Eggs were immediately analysed via light microscopy, and washed back into the test tube, and incubated for 28 days in order to determine if further development occurred.

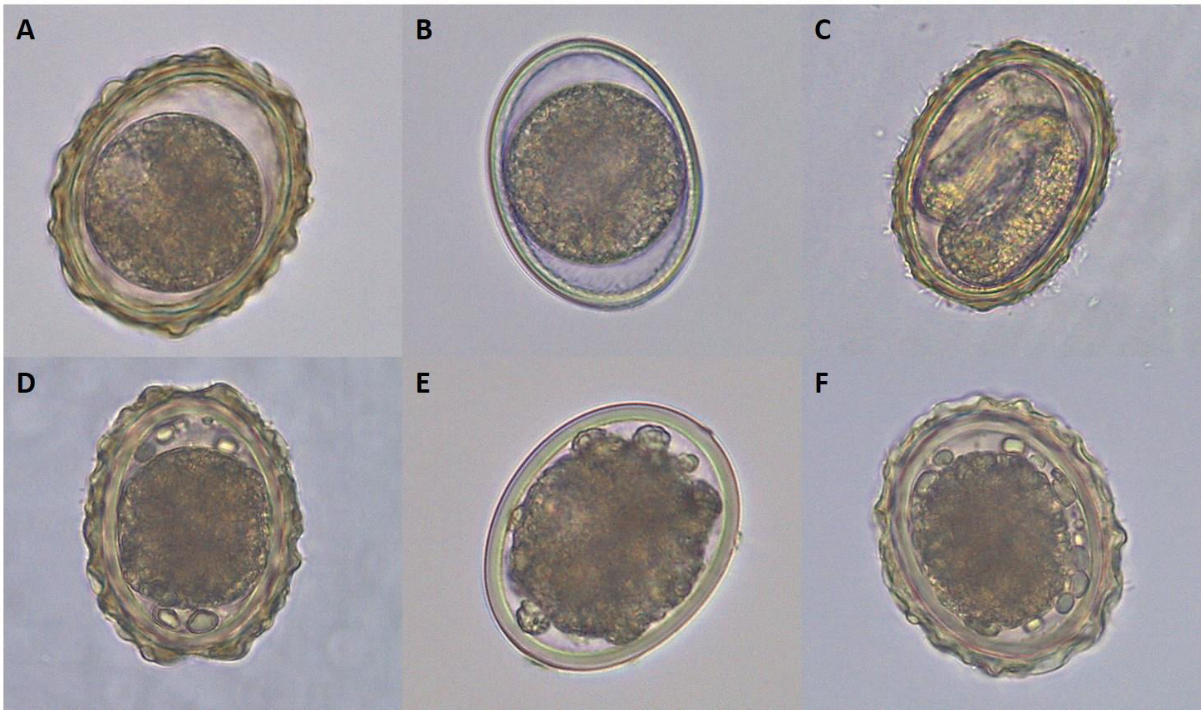

Figure 1: Untreated (A, B and C) and treated (D, E and F) *Ascaris suum* eggs. (A) Viable, undeveloped egg at the one-celled stage. (B) Viable, decorticated, undeveloped egg at the one-celled stage. (C) Viable, embryonated egg with visible larva. (D) Damaged egg at the one celled stage (still a regular shape) showing globule formation. (E) Non-viable egg (One-celled mass is irregular in shape) treated at 80°C for 5 seconds, pre-incubation. (F) Non-viable egg (One-celled mass is irregular in shape and very globular) treated at 80°C for 5 seconds, post-incubation.

At contact times of a few seconds, a treatment temperature of 80°C proved to be sufficient, with < 11% viable eggs recovered pre-incubation and < 1% viable eggs recovered post-incubation. Figure 1 shows the difference between eggs before and after treatment at 80°C. Treated eggs appear globular, and the one-celled mass appears darker in colour. Eggs that appeared undeveloped but globular did not develop further during incubation, indicating successful inactivation. Lower temperatures required longer contact times, and the die-off mechanism appeared different from a visual examination of egg morphology via light microscopy, post-treatment. Currently, 60°C and 75°C require testing at all contact times, and samples being incubated currently need to be analysed. These results will be included in the full paper. Further work is required in order to understand the mechanism of inactivation of the eggs when treated by the viscous heater.

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METHOD FOR THE DETECTION AND QUANTIFICATION OF SOIL TRANSMITTED HELMINTH EGGS IN FAECAL SLUDGE

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KEYWORDS: Faecal Sludge; Soil Transmitted Helminths; Sewage

Conference Track: Research Track
Track Topic: *Health, Safety and Hygiene*
Personal Preference: O*ral presentation*

Background

Soil Transmitted Helminths are of major health concern globally, especially in tropical and subtropical regions (Stolk *et al*., 2016). Infections are mostly a result of exposure to faecally contaminated water, soil or through contaminated crops (Keraita and Amoah, 2011). Faecal sludge from public toilets is estimated to contain between 2, 500 to 60,000 eggs/L, however from septic tanks the concentrations are reported to be from 600 to 16, 000 eggs/L (Yen-Phi *et al.,* 2010), Trönnberg *et al*., (2010) reported 103 eggs per gram (EPG) for *A. lumbricoides*, 27 EPG for *T. trichiura* and 55 EPG for *Taenia* spp from UD toilets.Therefore exposure to faecal sludge could result in a high risk of infection, and treatment or containment is needed to reduce this risk. Exposure to faecal sludge could be during the collection, conveyance and treatment or during its application in agriculture. Due to exponential population growth and declining agricultural land, there is high pressure to increase productivity, as well as alternate ways to increase soil fertility. This has led to an increase in the application of fecal sludge in agriculture among other factors. Determination of STHs egg concentration in sludge is therefore very important for treatment technology validation as well as classification of faecal sludge for reuse purposes. However, the detection of soil transmitted helminths in environmental samples is a major challenge globally (Collender *et al*., 2015). As part of an on-going Bill and Melinda Gates Foundation funded project a revised and harmonized methodology has been proposed for the detection of STHs ova in environmental samples, such as wastewater, fecal sludge, soil, compost etc. The results from validation tests performed to determine the performance of the method for the detection of STHs in raw sewage and faecal sludge are presented.

METHODOLOGY

Faecal sludge and raw sewage samples were taken from a wastewater treatment plant in Dakar, Senegal. The concentration of STHs eggs in these samples was determined using the revised methodology. Briefly, 50 g of fecal sludge portions were measured into beakers containing 500 mL of distilled water and 0.1% Tween80 was added to the 1000 mL mark. The mixture was blended and poured through a 200 µm sieve unto a 20 µm sieve. The contents on the 20 µm sieve were carefully washed into 50 mL centrifuge tubes and centrifuged for 10 minutes at 3000 rpm. The supernatants were discarded and 15 mL of $ZnSO_4$ solution (specific gravity of 1.30) added. The mixture was centrifuged again at 3000 rpm for 10 minutes. The supernatant was then poured through the 20 µm sieve and the contents of the sieve washed with a water bottle or under running water into a 50 mL centrifuge tube and centrifuged at 3000 rpm for 10 minutes. Supernatants were discarded and the pellets viewed under the microscope at X10 magnification. All eggs were counted. The 'split-spike technique' (Bowman *et al.,* 2003) was used in determination of the accuracy of the method.

RESULTS AND DISCUSSION

Ascaris spp, *Trichuris* spp and hookworm eggs were detected, with higher concentrations in the sludge than the raw sewage samples. The table below shows the concentration of STHs eggs recovered from the samples. Raw sewage samples were also spiked with 4000 eggs of *Ascaris suum.*

Table 1: Mean concentration of STHs in sludge and raw sewage samples

	SLUDGE (eggs/g)			RAW SEWAGE* (eggs/L)		
	***Ascaris* spp**	***Trichuris* spp**	**Hookworm**	***Ascaris* spp**	***Trichuris* spp**	**Hookworm**
1	1250	19500	340	570	1080	90
2	1065	17600	160	570	1500	120
3	1180	18500	280	3780	1950	30

***The split-spike technique was used to determine the recovery percentage of *Ascaris* spp eggs in the raw sewage samples.**

The split-spike technique showed that over 80 % of *Ascaris* spp eggs were recovered from raw sewage using the new revised method. The results obtained indicate that the proposed method could be effectively used to recover STHs eggs from sewage samples, however its recovery in sludge samples needs to be further assessed related to a recovery analysis for sludge samples. In addition the extended tests would help to determine the applicability of the method in recovering eggs of different STHs species in sludge. The consistency of this method has also been used to detect eggs of five different STHs (*Ascaris* spp, hookworm, *Taenia* spp, *Trichuris* spp, *Toxocara* spp and *Hymenolepis* spp) in wastewater samples from Durban, South Africa.

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Disinfection from freshly separated fecal matters by applying heat and chemicals

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Keywords: Disinfection; Fresh fecal matter, Heating

Conference Track: (1) Research Track
Track Topic: *Technologies for the collection, transport, treatment, disposal and use of faecal sludge*
Personal Preference: O*ral presentation*

Introduction

To mimic the function of a dry toilet, mechanical devices such as "solid and liquid separator" are increasingly being used in a wet toilet system, which could separate solid and liquid from toilet wastewater. In this regard, Asian Institute of Technology (AIT), Thailand, has invented an efficient separator which is being used in the Zyclone cube toilet. Freshly-separated fecal matter still contains high level of pathogen and needs to be properly treated before discharging. The reuse of nutrients from human excreta without appropriate treatment of fecal matter can increase the risk of health impacts in food and feed production (WHO 2006). Lack of an appropriate treatment system is a crucial barrier to overcome for enabling safe use of such freshly separated fecal matters.
Effective and fairly prevalent, heating is a tried and tested method for pathogen inactivation. However, when it comes to fresh fecal matters, there is still only limited information on pathogen inactivation by heating. This study thus aims to determine temperature-time relationship of heating for pathogen inactivation in fresh fecal matters. In addition to this, it is also concerned on evaluating the potential of applying chemicals (lime and urea) to inactivate pathogen in fresh fecal matter.

Materials and methods

For *E. coli*, Heat inactivation tests were performed under temperatures of 50°C, 60°C and 70°C for different time durations (*50°C for 30, 60, 120, 180, 240 and 300 min); (60 °C for 5, 10, 15, 20, 25, 30 and 60 min) and (70°C for 2.5, 5, 7.5, 10, 15, 20 and 30 min).* The initial level of *E. coli* were varied by adding mixed cultures of *E. coli,* grown separately overnight at 37°C in 20 ml of Luria Broth (LB). The pathogenic indicator *E. coli* and eggs of Ascaris were selected for this study *E. coli* tests were done by drop plate methods and converted in to CFU per gram of dry solid. Meanwhile, the effect of 3% and 5% lime and urea on *E. coli* was also studied.
In case of *Ascaris* eggs, heat inactivation at of viable eggs at 60°C, 70°C and 80°C was performed with contact times of 0, 15, 30, 60, 120 and 240 minutes. The viability of eggs for this test was determined after 28 days of incubation time, at the end of which all eggs with motile larva, when observed under a microscope, were counted as viable while those with inactive larvae were deemed non-viable. At the same time, studies on the effect of 5% and 7% lime and urea on *Ascaris* eggs were also performed.

Results and discussion

Inactivation of *E. coli*

Inactivation of *E. coli* in relation to temperatures and time with different levels of initial *E. coli* is presented in Figure 1. It shows that at 50°C, depending upon the initial concentration, 240

and 300 minutes were required to completely inactivate the *E. coli*. A decrease in this time was markedly prominent as the temperature increased. At 60°C, the cultures were inactivated in 15 and 25 minutes, and the discrepancy in time for inactivation was in accordance with the initial *E. coli* levels. Nevertheless, when the test was conducted at 70°C, the cultures were inactivated within 15 minutes and this complete inactivation seemed to be indifferent to the initial *E. coli* levels. The results suggested that the time durations required for inactivation varied with initial *E. coli* level at moderately high temperatures of 50°C and 60°C but were similar at 70°C.
The inactivation of *E. coli* by chemical disinfection showed that 24 hours were required for complete inactivation by 5% lime and urea (w/w basis) while 3% of urea and lime required 66 hours to attain the same level of inactivation.

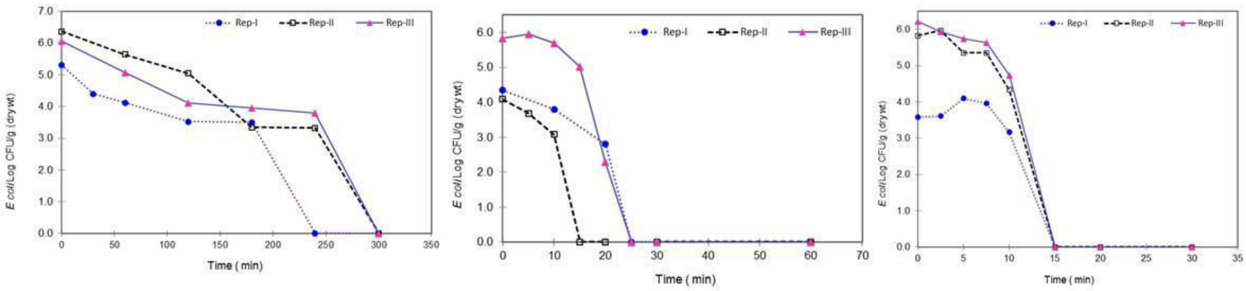

Figure 1 *E. coli* inactivation at different temperature and times

Inactivation of *Ascaris* eggs

The inactivation of *Ascaris* eggs was found to be dependent on temperature which is in close agreement with earlier studies. The results showed 100% inactivation after the eggs were subjected to temperatures of 70°C and 80°C for 15 minutes. While at 60°C, inactivation of 80% eggs was achieved. A total success rate of 100% could be achieved only after a contact time of 240 minutes. The *Ascaris* eggs subjected to 5% and 7% of urea and lime were found to be viable for 28 days of contact time.

Conclusions

- Complete inactivation of *E. coli* from fresh feces was obtained at 300, 30 and 15 min under 50°C, 60°C and 70°C temperature respectively. The effects of initial load was preserved for low temperature and not effective for higher temp (50°C, 60°C and 70°C).
- *Ascaris* eggs from fresh feces were inactivated by heating for at 70°C and 80°C for 15 minutes.
- Lime and urea applied at 3% and 5% (w/w basis) could inactive *E. coli* completely in 66 hours and 24 hours, respectively but its application was not found effective for *Ascaris* egg inactivation.

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Fermentation of Human Faecal Waste to Produce Carboxylic Acids and Inactivate *Ascaris* Eggs

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Keywords: *Ascaris*, Carboxylic acids, Pathogen reduction

Conference Track: Research track
Track Topic: *Technologies for the collection, transport, treatment, and disposal of faecal sludge*
Personal Preference: *Oral presentation*

Introduction

The development of inexpensive and efficient processes to reduce pathogens remains a major challenge for recovering resources and creating value-added products from faecal waste. Within the carboxylate platform, open cultures of microbial consortia (also referred to as microbiomes) convert complex organic wastes to a mixture of carboxylates under anaerobic conditions (Agler *et al.*, 2012). Traditional anaerobic digestion is one example of a carboxylate platform technology because reactor microbiomes produce methane from short-chain carboxylates (*e.g.*, acetate, propionate, lactate, *n*-butryate with 2, 3, 3, and 4 carbons in its chain, respectively). However, mesophilic anaerobic digestion alone does not sufficiently reduce the pathogen load in faeces (Feachem *et al.*, 1983). When methane production is inhibited or methanogens are absent from the microbiome, the carbon chains of acetate can be elongated to produce *n*-butyrate and *n*-caproate (6 carbons), which are toxic to pathogens in their undissociated acid form. Here, our objective was to investigate whether the *in-situ* production of *n*-butyrate and *n*-caproate in anaerobic fermentation of human faeces can be high enough to inactivate a model pathogen.

Batch fermentation to produce *n*-butyrate and *n*-caproate: Batch experiments were performed in triplicate in 1-L reactors using human faeces as a substrate. Each reactor contained 205 g (+/- 2.5 g) of faeces and 20 g of inoculum. The inoculum was derived from a well-characterized reactor microbiome that produced *n*-caproate for several years (Agler*, et al.*, 2012). Reactor headspace was sparged with nitrogen gas to produce anaerobic conditions. Solid samples were removed from the reactors every four days for the first 20 days of fermentation and then after longer intervals for days 20 through 78. Carboxylate concentrations were measured using gas chromatography with a flame-ionization detector.

***Ascaris* inactivation by *n*-butyric acid and *n*-caproic acid:** *Ascaris suum* eggs were used as surrogates for the human roundworm *Ascaris lumbricoides* to test inactivation by *n*-butyric acid and *n*-caproic acid. Eggs were suspended in 1.0 mL of a carboxylic acid solution and stored in anaerobic conditions at 30°C. Four different exposure times (2, 6, 12, and 20 days) with eight different concentrations of *n*-butyric acid and *n*-caproic acid were tested. Concentrations were chosen to simulate those observed from batch fermentation. The pH was set at 2.0 to maintain over 99% of the carboxylates in their undissociated carboxylic acid form (pK_a ~4.9), which is the form able to cross the lipid membranes of cells and eggs to become toxic (Brul & Coote, 1999). After the designated exposure time, eggs were washed to remove residual carboxylic acids and transferred to aerobic incubation at 28°C. After three weeks, eggs were examined microscopically, and the viability was calculated. The results were used to calculate regression equations to predict exposure time required to achieve a 3-log reduction in viability given the *n*-butyric acid or *n*-caproic acid concentration.

Results and Discussion

Production of *n*-butyrate and *n*-caproate: After 46 days of fermentation, *n*-butyrate reached a maximum concentration of 240 mM, and *n*-caproate reached a maximum concentration of 27 mM (**Fig. 1**). The average pH initially decreased from 6.7 to 5.1 in the first four days of fermentation but then steadily increased back to 6.7 during the remainder of the experimental period due to the breakdown of proteins into ammonium (data not shown).

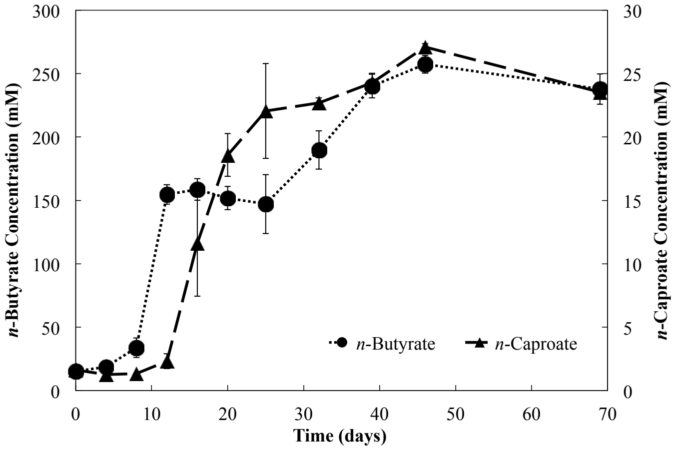

Figure 1. Accumulation of *n*-butyrate (●) and *n*-caproate (■) from batch fermentation of faeces at 30°C.

***Ascaris* inactivation by *n*-butyric acid and *n*-caproic acid:** The maximum concentrations of *n*-butyrate and *n*-caproate observed in batch fermentations (**Fig. 1**) were sufficient to achieve a 3-log reduction of *A. suum* viability when exposed at 30°C (**Fig. 2**). However, an artificial reduction in the pH was required to maintain a high enough concentration of the undissociated carboxylic acids. Based on the calculated regression equations, exposure to 240 mM *n*-butyric acid for 19 days or 27 mM *n*-caproic acid for 10 days is predicted to cause a 3-log reduction in *A. suum* viability when exposed at 30°C (**Fig. 2**).

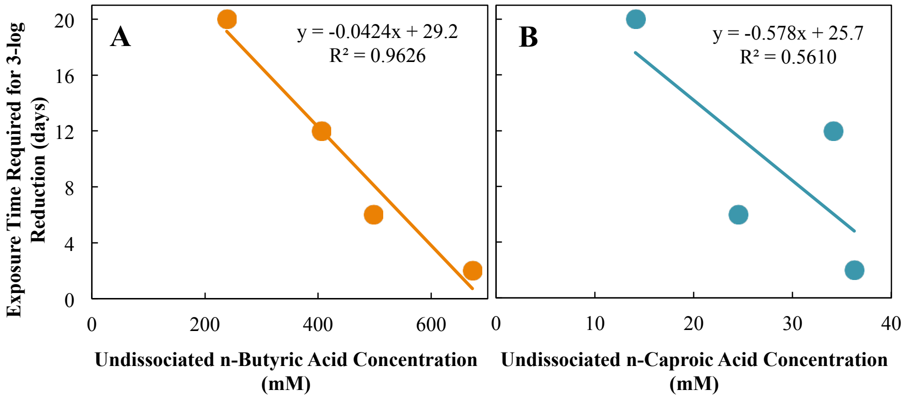

Figure 2. Time required for a 3-log reduction of viable *A. suum* eggs as a result of exposure to undissociated *n*-butyric acid (A) and *n*-caproic acid (B) at 30°C.

Conclusions and Future Work

This work successfully demonstrated that *n*-butyrate and *n*-caproate could be produced from fermentation of human faecal waste and then utilized for *in-situ* pathogen inactivation. This novel process has many potential applications for management and treatment of faeces. It may be used as onsite treatment to provide sludge that is safe to handle and apply to land. Alternatively, it may be used as a pretreatment step for further processing such as composting, drying, and anaerobic digestion. Further work is focused on understanding the other factors that affect *Ascaris* inactivation including the faeces matrix, temperature, and exposure time.

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Integrating lifecycle carbon, energy and water impacts into decentralized sanitation infrastructure planning

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Keywords: life-cycle assessment; resource recovery; FSM; DEWATS

Conference Track: Research Track
Track Topic *Technologies for the collection, transport, treatment, disposal and use of faecal sludge*
Personal Preference: *Oral presentation*

Introduction

By mid-century, urban populations of sub-Saharan Africa (SSA) and South Asia (SA) will increase to 1.1 billion and 1.2 billion, respectively, representing a three- and two-fold increase of the current figures (UN-DESA, 2015). These regions also have some of the lowest rates of urban sanitation coverage with only 41% in SSA and 67% in SA estimated to have access to improved sanitation (WHO/UNICEF, 2015a).

Major sanitation investments will be necessary for this growing unserved population. In line with the proposed Sustainable Development Goals (SDGs), which focus on the safe management of faecal waste, a greater proportion of investment will be directed to the entire sanitation service chain (SSC) in the coming decades. Given the considerable resource requirements of sanitation infrastructure, coupled with increasingly variable climatic conditions and resource scarcity, it is essential that water and energy requirements are integrated into planning for such investments. At a global level, it is also critical that infrastructure decisions seek to minimize carbon emissions.

Conventional sewerage and wastewater treatment will not be feasible for the vast majority of low-income countries. In recent years, non-sewered faecal sludge management (FSM) and decentralized wastewater treatment (DEWATS) approaches have gained traction as sanitation alternatives. This research presents a model to quantify the lifecycle carbon, energy and water footprints of FSM and DEWATS approaches. The model is demonstrated using case studies in Zambia and India.

Methods

A life cycle assessment (LCA) approach is used to quantify resource use and carbon emissions over the lifespan of the sanitation infrastructure. The SSC from storage/collection through disposal/reuse is included in the analysis scope. Construction and operations phases are included in the analysis, with an assumed infrastructure lifespan of 20 years. The functional unit of the analysis, used to compare systems on an equivalent basis, is defined as: *lifecycle management of excreta, urine and wastewater associated with sanitation, per-capita per-year*. The extent to which resource recovery may offset impacts is investigated through interactions with conventional resource flows.

Carbon emissions, energy and water use were quantified for a DEWATS and FSM system in Zambia and India. Three scenarios were considered, in which the extent of energy recovery, replacement of conventional fuel use, and pit latrine conditions were varied: (1) baseline (2) most favourable and (3) least favourable (Table 1).

Table 1 Parameter variables and descriptions for scenario analysis

Parameter	Baseline[1]	Most favourable	Least favourable
Percent of biogas recovered at primary treatment	80%	100%	0%
Ratio of conventional fuel replacement to biogas use	Charcoal = 1:1 LPG = 1:1	Charcoal = 2:1 LPG = 1:1	Charcoal = N/A LPG = N/A
Pit latrine condition (MCF)[2] (IPCC, 2006)	ZM: dry, communal IND: wet[3]	ZM: dry, small family IND: wet	ZM: wet IND: wet

[1] Baseline scenario assumptions are according to observed system conditions
[2] The IPCC (2006) defines a 'methane correction factor' (MCF) to describe the degree to which a system is anaerobic. Pit latrines are characterized as: dry (MCF=0.1); communal (>5 users) (MCF=0.5); and wet (MCF=0.7).
[3] India case study pits are designated as 'wet' in all scenarios as primarily pour-flush toilets are used.

Preliminary findings

Preliminary findings indicate that under the baseline and most favourable scenarios, both the Zambia and India DEWATS systems analysed produce less carbon emissions *per-capita-year* in comparison to the FSM systems. Moreover, in the most favourable scenario, the Zambia DEWATS system results in negative annual carbon emissions (-26 kgCO2-e/cap/year) due to the replacement of charcoal as a conventional cooking fuel. However, in the least favourable scenario, in which no biogas energy is recovered, DEWATS systems in the two countries produce higher carbon emissions when compared to the FSM systems.

Annual energy use is higher for the DEWATS systems analysed as compared to FSM systems under the baseline and least favourable scenarios, primarily due to the greater *per-capita* infrastructure requirements of the DEWATS systems. For the most favourable scenario, both the Zambia DEWATS and FSM system result in a net annual energy savings (-18 and -3 MJ/cap/year, respectively) resulting from the replacement of charcoal. Finally, greater quantities of water are used by the DEWATS systems in all scenarios.

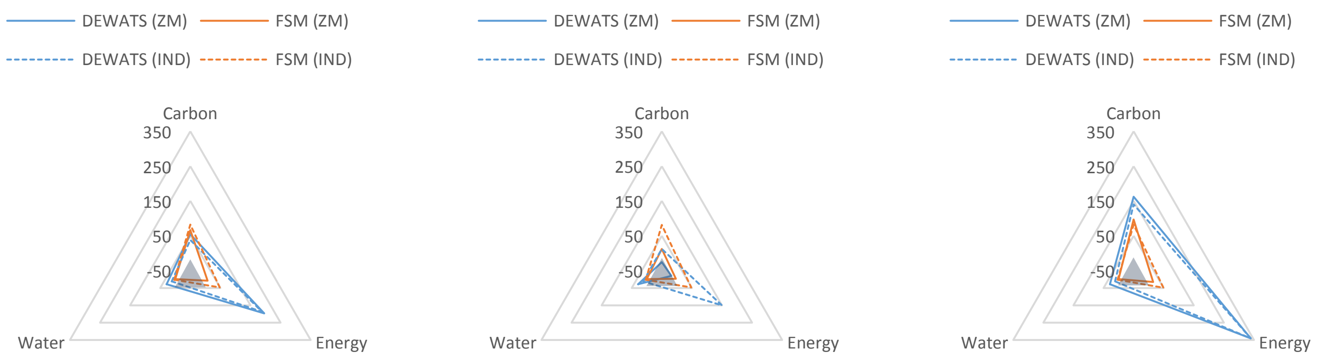

Figure 1(a) Baseline scenario Figure 1(b) Most favourable scenario Figure 1(c) Least favourable scenario

Figure 1(a) – 1(c) Annual *per-capita* carbon emissions (kgCO2-e/cap/year), energy use (MJ/cap/year), water use (m3/cap/year) for Zambia and India DEWATS and FSM systems analysed (grey indicates negative region)

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Is it Possible to Continually Produce Fodder on Planted Drying Beds Treating Faecal Sludge?

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Keywords: Forage-Faecal sludge-Planted drying beds

Conference Track: Research Track
Track Topic: *Technologies for the collection, transport, treatment, disposal and use of faecal sludge*
Personal Preference: O*ral presentation*

Introduction

Climate change, environmental degradation and unsustainable consumption of resources are increasingly putting a strain on the Earth's natural wealth. This mean that cities need to adapt and implement more resource efficient systems. More sustainable and ecological-based treatment technologies could help alleviate the strain on resources. Planted drying beds are a promising technology for the treatment of faecal sludge in low-income countries, and research is ongoing for adapting and optimizing resource recovery of the technology for this context (Sonko et al. 2014, Gueye et al. 2016). However, planted drying beds have still not yet been widely implemented. Performance data on the use of indigenous plants that are adaptable to conditions of planted drying beds could improve the scaling up of this technology (Alexander K. Anning et al. 2013). The objective of this study was to identify indigenous plants throughout Senegal for potential use in planted drying beds, and evaluate the optimal production and forage quality with four selected species.

Methods

Based on the superior growth performance of *E. crus-galli, E. pyramidalis, P. geminatum and P.vaginatum* (Gueye et al. 2016), they were selected for analysis of the effects of several harvests on forage production and quality. Plants were grown in 200 L barrels at the Cambéréne wastewater treatment plant in Dakar as pilot-scale planted drying beds. Barrels were filled with ten cm layer of coarse gravel (10–40 mm diameter), a ten cm layer of fine gravel (5–10 mm) and a 15 cm layer of sand, and planted with nine shoots in each barrel. A four cm diameter perforated PVC pipe was placed at the bottom for drainage. The study was conducted over a seven month period, including four months for acclimatization and three months for loading the beds. The acclimization period consisted of watering with tap water and effluent from faecal sludge settling thanks for one month, and then gradually increasing faecal sludge loading rates to 50, 100 and 150 kg TS/m2*year over a three month period. During the loading period, barrels were loaded weekly at a rate of 200 kg TS/m2*year. During this period, the plants was harvested to a height of 60 cm at the end of each month.TS,TSS, BOD, and COD were monitored in the faecal sludge and leachate with Standard Methods (APHA et al. 2005), forage production by shoot density and shoot height, and forage quality by mineral content, crude protein and fiber content with Standard Methods (AFNOR 1993, AOAC 1995)

Results

Monthly harvesting of plants influenced plant production, and different trends were observed for the species. *E. pyramidalis, P. geminatum, P. vaginatum* had increased biomass production, whereas *E. crus-galli* had less tolerance to repeated harvesting. After the second harvest, *E. crus-galli* growth in shoot density and shoot height was affected, with a reduction in density of 8.84%. Jinadasa et al. (2008) reported similar results and noted the shoot heights of *Typha angustifolia* were lower at the third and fourth harvestings compared to the first and second harvestings. In contrast, *E. pyramidalis, P. geminatum,* and *P. vaginatum* density increased by 5.53; 6.90; and 7.55% respectively after the second harvest. Shoot height followed a similar pattern during the harvesting period. Monthly harvesting of plants also increased nutrient yields, which was also observed by Lounglawan et al. (2014). Crude protein and mineral content increased, and fiber content decreased. This is due to the frequent harvesting resulting in younger, leafier plants. Based on these measurements, all of the plants grown in this study meet recommended nutritional requirements of livestock, and were well below levels of toxicity (NRC 2001).

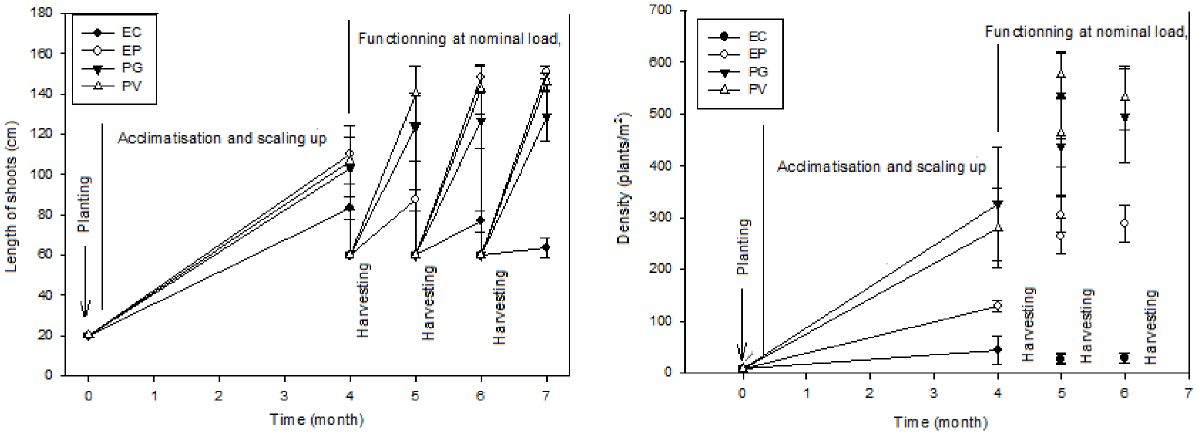

Figure 1.1 Total height of plant shoots and density as a function of time and harvesting period: (EC) *E. crus-galli*; (EP) *E. pyramidalis*; (PG) *P. geminatum*; (PV) *P. vaginatum*.

Conclusions

E. pyramidalis, P. geminatum, and *P. vaginatum* all appear to be suitable plants for use in planted drying beds treating faecal sludge for sustainable biomass production with repeated harvesting based on plant biomass and quality. All four plants were suitable for livestock feed, and the sale of these plants could help to offset treatment costs.

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Treatment of faecal matter – A product value comparison of four treatment options

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Keywords: faecal treatment; black solider fly, biogas

Conference Track: (1) Research Track
Track Topic: Technologies for the treatment of faecal sludge
Personal Preference: oral presentation

Introduction

In low and middle-income countries, collection and treatment of faecal matter is a costly business; the uncontrolled disposal of faecal matter can create health risks and lead to environmental pollution (Massoud et al., 2009). It has been suggested that the way to solve the sanitation crises and to reach out to the most vulnerable is with resource oriented sanitation (ROS), in which the nutrients in our excrements are captured and recycled back into the food cycle (Langergraber & Muellegger, 2005). In ecological sanitation, the urine and faeces can either be collected and treated together or separately and should be treated in a manner as to guarantee hygienic conditions and highest degree of nutrient capture (Austin, 2005). If the treatment can yield valuable products, the generated value can shift the value-chain of excreta and thereby cover the cost of the treatment (Diener et al., 2014).

In this study, four faecal treatment options were compared in terms of generated products: thermophilic composting (TC), black soldier fly composting (BSF), anaerobic digestion (AD) and black soldier fly composting followed by anaerobic digestion of the treatment residue (BSF+AD). An estimation of the value of the generated products was conducted in order to evaluate the viability of the treatment option.

Methodology

Materials

Faeces were collected daily in plastic bags and kept at -20 °C until use. Inoculum for AD was collected from the sewage sludge digester at the local waste water treatment plant (Kungsängen, Uppsala, Sweden) and was left to degas for three days at 37 °C under anaerobic conditions.

BSF composting

Approximately 10,000 five days old black soldier fly larvae were added to 5800 g thawed and homogenised faecal material and left for 14 days at room temperature. Upon finishing the composting, the larvae were separated from the treatment residue and both were stored at -20 °C.

Biogas potential

Anaerobic digestion of faeces and BSF-composted faeces was carried out in 600 mL serum bottles filled with 1.2 g VS sample (2.4 g VS/L), 3.6 g VS inoculum (7.2 g VS/L) and tap water to a final volume of 400 mL. The headspace was flushed with N_2. Triplicate batch test for each sample and a blank for the inoculum were conducted for 16-22 days at 37 °C under stirring (130 rpm). The methane production was continuously monitored. The methane production attributed to the inoculum was subtracted when calculating the accumulated methane production.

Results and discussion

The process was evaluated for the treatment of 1000 kg faecal matter (Table 1); using the values in Rose et al. (2015) this is the total mass defecated by around 10 people in a year in low-and middle-income countries whereas it is the amount defecated by just over 20 people in a year in high-income countries. BSF+AD had the overall highest material reduction on a VS basis, while thermophilic composting had the lowest. The methane potential of the BSF-residue was considerably lower than that of untreated faeces. The BSF system yielded the highest economical value, followed by BSF-AD. Thermophilic composting generated the product of least value.

Table 1. The values of the different treatments options assuming the treatment of 1000 kg faecal matter: thermal composting (TC), black soldier fly composing (BSF), digestion (Dig), black soldier fly composting followed by digestion of treatment residue (BSF+AD).

	TC[a]	BSF	AD	BSF + AD
VS reduction (%)	30	56.6	69.2	74.5
Larval biomass generated (kg DS)		78.3		7.8
Digestate volume (m^3)			79.4	34.4
Methane generated (kg)			44.0	11.4
Compost/digestate generated (kg VS)	133.5	82.8	69.2	41.4
Value larval biomass (US$)[b]		123.5		12.3
Value methane (US$)[c]			84.3	21.9
Value compost (US$)[d]	89.7	55.6	3.9	3.2
Total value (US$)	90	179	124	145

[a]Treatment process parameters taken from Niwagaba et al. (2009).
[b]The value assumed to be comparable to dried fish meal, European import prices used (YCharts, August 2016).
[c]Assuming gas vehicle grade, price for vehicle gas at gas stations in Sweden (September, 2016) used (US$ 1.9/kg).
[d]A value of €300/tonne compost (US$168/tonne) was estimated: assuming 50% dry solids and 50% volatile solids an estimated price per kg VS was attained (US$ 0.7/kg VS).

In this evaluation the cost for the actual treatment as well as the processing cost of the products was not included. The value estimated for the products yielded from the treatment of 1000 kg faecal matter can thus be seen as a ballpark figure of how much the treatment can cost while still being economically viable. In this comparison, the European import price for fishmeal was used to estimate the value of larval biomass, while the retail vehicle grade gas price was used to estimate the value of the generated methane. The cost for refining biogas to vehicle grade gas is major; the cost of drying fly larvae on the other hand should be considerably smaller. Furthermore, the BSF technology is far less complex than digestion, thus the investment and running cost could be expected to be smaller. From this perspective, BSF technology was found to be the most attractive option for treatment of faecal matter.

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Effect of Environmental Parameters on the Treatment of Human Fecal Waste by Black Soldier Fly Larvae

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Keywords: Faecal waste, Black Soldier Fly Larvae, Waste reduction

Conference Track: (1) Research Track
Track Topic: *Technologies for the collection, transport, treatment, disposal and use of faecal sludge*
Personal Preference: *oral presentation*

Abstract

On-site sanitation systems such as dry pit, flush Pit, dual pit-latrines and septic tank are widely used around the globe. Due to the absence of any effective technology for the treatment of the septage generated from these sanitation systems, in most of the cases the contaminated septage is dumped in landfills or dumping yards without any treatment. There has been as such no effective development of Faecal Sludge treatment technology to ensure safe fate of the contaminated septage and in most of the occasion they have been found crudely disposed off in landfills or dumping yards and left untreated. The septage or its leachate has potential to cause serious health effects when drinking water gets contaminated. This extended abstract reports some of the results obtained when we employed black soldier fly larvae (BSFL) as a biological agent for the treatment and reduction of the amount of fresh human feces which forms a part of the septage. BSFL is a voracious eater of organic wastes and has been reported in literature to be very efficient agent for waste reduction and conversion into their body weight (Diener at al. 2011, Banks et al. 2014, Paz et al. 2015). Generally, the BSFL has a larval life of 14 days during which they consume food and gain weight before they turn into a prepupae wherein they avoid food. They turn into pupae and eventually, in a fly. Just like many other biological agents, these larvae are sensitive to environmental conditions such as temperature and humidity so that the most efficient waste reduction may take place at an optimum temperature and humidity. In this research our objective is to study the effect of the environmental parameters such as temperature and humidity on the substrate (human feces) reduction and weight gain by the BSFL. We performed a set of experiments involving BSFL put in fresh human feces under different environmental conditions. The temperatures were 25, 30 and 35 deg C which is within the prevailing temperature range (25-35 deg C) in most parts of India. For each temperature, relative humidity (RH) was varied between 55-85%. For each experiment, 50 numbers of 6 day old larvae were kept inside a box inside which 200 g of fresh human feces collected from a septic tank was spread at 2 cm thickness. Three replicates (human feces and BSFL) along with control (only contains human feces and no larvae) were made and each box was maintained at specific temperature and relative humidity inside an incubator. The BSFL as well as the substrate were weighed every other day till they kept on gaining weight. Figure 1.1 shows the Percentage weight gain of the BSFL and Percentage reduction in the substrate for the experiments run at 30^0C and at different levels of relative humidity as an example. Due to brevity, we have included only the results obtained from the experiments run at Temperature,T=30^0C and Relative Humidity (RH)= 55, 65, 75 and 85%.

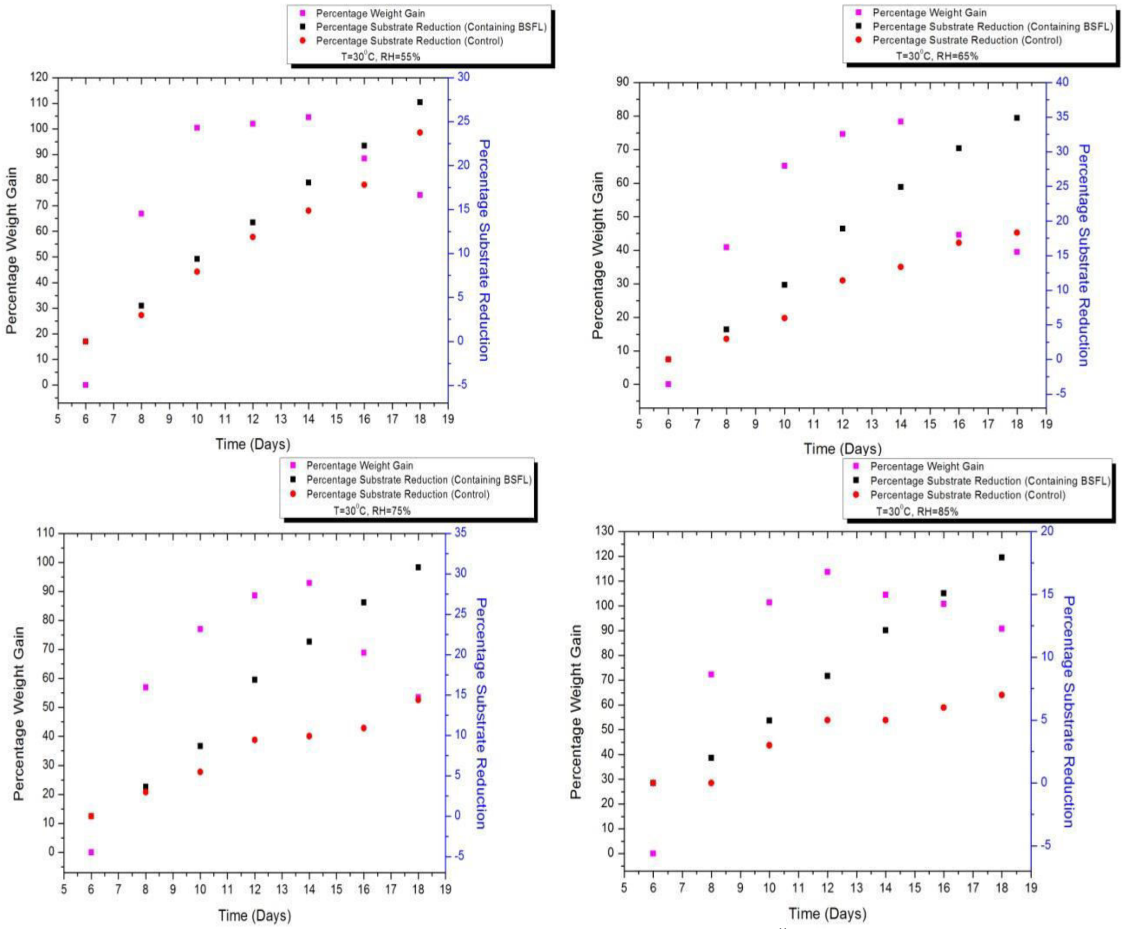

Figure 1.1 Percentage Weight Gain and Substrate Reduction at T=30^{0}C and RH= 55, 65, 75 and 85%

The substrate reduction was found to be in the range of 3-17%, the highest being at RH of 65-75%. The weight gain of BSFL was observed to be in the range of 39-91%, the highest being at 85% RH. The results indicate that at 30^{0}C, the optimum utilization of food takes place at 65-75% RH. However, larval weight gain follows a different trend, monotonously increasing with respect to the relative humidity. The logical inference is that the larvae are most active in feeding as well as metabolising (catabolising) the substrate at RH of 65-75 %, while at higher RH the feeding rate is lower and the rate of metabolism (catabolism) is even lower. The weight gain of BSFL per unit substrate reduction for each larvae at RH=55, 65, 75 and 85% was calculated as 1.521, 0.983, 1.361 and 2.031 mg/gram. Hence, there is a net gain in weight of the BSFL at high humidity where, due to reduced activity, they cannot catabolize even the food they consume. As a result, there is a weight gain, which may at once look as anomalous result. The substrate consumed by each larvae was 0.613, 0.666, 0.656 and 0.579 g at RH=55, 65, 75 and 85%, respectively. This means that approximately 1500 numbers of BSFL may be required to consume 1 kg of human feces at 65-75% RH. Overall, BSFL showed a promising agent for the treatment of fecal sludge management.

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Abstract for FSM 4

Design and implementation of integrated electrochemical wastewater treatment and recycling systems for onsite sanitation in the developing world

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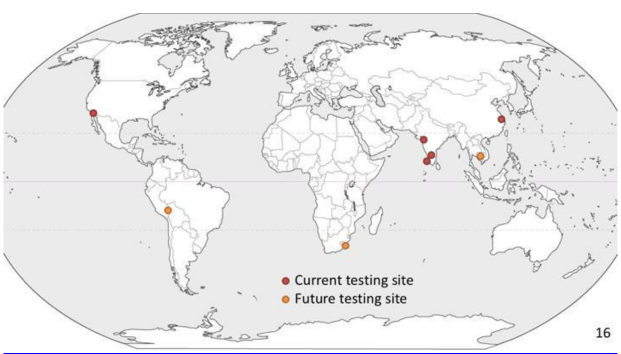
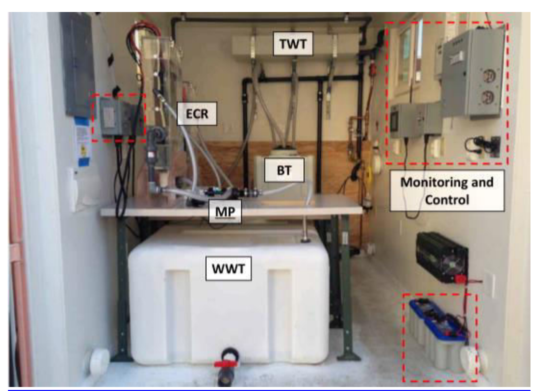
Abstract:

Self-contained wastewater treatment system prototypes based on electrochemical oxidation of feces and urine have been designed, constructed, and implemented in regions where access to sanitation is contrived. Integrated designs in shipping containers for an average 40-person daily load have been chosen in order to minimize the footprint and maximize the flexibility of installation and the security of the users. First tested in the United States, the system has been installed in India and China in semi-controlled public testing environments. Successes and challenges from semi-controlled field testing environment will be presented as well as our strategies for the "next steps" in the technical development and social adoption of this treatment technology.





Left: testing sites (current and planned) of the Caltech Toilet Systems. Right: interior of the treatment room of one of the Caltech Toilet prototypes.

A Neighbourhood Faecal Sludge Treatment System Using Supercritical Water Oxidation

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Keywords: faecal sludge treatment; container-based sanitation; full-scale system

Conference Track: (*choose one*) (1) Research Track – (2) Case Study Track – (3) Industry and Exhibition Track
Track Topic: *(2) Case Study Track*
Personal Preference: *oral presentation*

Heading

Our team has designed and built a technical scale prototype supercritical water oxidation (SCWO) system to treat the faecal waste produced by roughly 1000-1200 persons daily. The unit is housed in a standard 20 ft shipping container and has been undergoing testing at Duke since early 2015. The process, while high-tech is relatively simple. After moderate preheating, the waste slurry is mixed with supercritical water (~600 C) and air (which serves as oxidant), which rapidly brings the waste undergoing treatment to supercritical conditions (~400 C, 240 bars). Under these conditions, all organics are rapidly (i.e., within seconds) oxidized to CO2, with the corresponding heat of combustion released in the reaction medium. After the reaction, heat is recovered in a 39 m long heat exchanger and used to preheat the incoming slurry, supercritical water and air. The system is well instrumented and operation is controlled using a programmable logic controller. Experiments were first conducted with isopropanol as a model fuel, prior to treating various faecal wastes and sludges. Procurement of enough faecal material to run experiments (300-500+ person equivalent per run) has been a challenge, since the system is operated on the Duke University campus and is not connected to actual toilets. Thus experiments were conducted with fresh dog faeces and secondary municipal sludge. To date, over one hundred hours of operation have been accumulated.
Typically, over 99.9% removal of COD, over 98% removal of total nitrogen and total phosphorous removal were observed. The effluent water was clear, odourless (Figure 1) and would be suitable for reuse in a number of applications (e.g., laundry, possibly hot showers). The system also produced large amounts of low grade heat in the form of hot water effluent which could be monetized. Energy balances highlighted the importance of minimizing heat losses around the reactor in order to achieve autothermal operation. Detailed system performance under selected conditions, the fate of nitrogen and phosphorous, energy balances and process economics will be presented and discussed at the conference. The project is funded by the Bill & Melinda Gates Foundation.

Figure 1 Pictures of the prototype system, influent faecal sludge (dog faeces) and treated effluent.

The Nano Membrane Toilet

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Keywords: Toilet, membrane, combustion

Conference Track: (1) Research Track
Track Topic: *Technologies for the collection, transport, treatment, disposal and use of faecal sludge*
Personal Preference: *oral presentation*

Introduction

The Nano Membrane Toilet will be able to treat human waste on-site without external energy or water. It is designed for single-household use (equivalent to 10 people) and will accept urine and faeces as a mixture. It is still under development and this paper provides an update on progress.

System configuration

The Nano Membrane Toilet uses a unique rotating mechanism to transport the mixture into a holding tank without using any water whilst simultaneously blocking odour and the user's view of the waste.

The solids then settle to the bottom of the tank, while the liquids float on the top. The solids are transported out of the tank by mechanical screw (Mercer at al 2016, Mercer et al 2017, a paper at this conference) into a gasifier or combustor which will convert them into ash and energy. The energy will be used to power essential toilet processes, and any residual energy used for charging mobile phones or other low voltage items.

The liquids pass over a weir in the holding chamber and into the membranes bundle. The unique nanostructured membrane wall facilitates water transport in the vapour state rather than as a liquid which yields high rejection of pathogens and some odorous volatile compounds. The clean water will be collected for reuse at the household level in washing or irrigation applications. An overview of this configuration can be found in Figure 1.

Developing the business model will be a key focus in the coming months of the project. One possibility is that the Nano Membrane Toilet will be rented by the households and maintenance will be undertaken with a trained operative responsible for the franchised area.

Developing the membrane and gasifier modules

Ensuring the membrane works as efficiently as possible to separate clean water from pathogens and other liquid contaminants is vital. Experimental work has defined the tube-side mass transfer coefficient derived in hollow fibre membrane contactors of different characteristic length scales (equivalent diameter and fibre length) under the slow flow conditions that are expected in the toilet (Wang et al 2016). This provides vital information to the membrane module design.

To power the membranes, energy needs to be recovered from the faeces combustion. Modelling showed that the maximum recoverable exergy potential from average adult moist human faeces can be up to 15 MJ/kg (Onabanjo 2016a). Experimental work has also showed that dry human faeces had a higher energy content than wood biomass which is promising for the development of the combustor. Simulant faeces can be successfully combusted even if the moisture levels are as high as 60% by weight (Onabanjo 2016b).

Energy modelling suggests that the Nano Membrane Toilet will be a net exporter of energy and power, and can be optimised for either water or energy recovery. If optimised for energy recovery its output could be equivalent to a USB port (Hanak et al 2016).

Further development of these modules forming the “back end” is planned over the coming period and will be necessary before full system integration can take place.

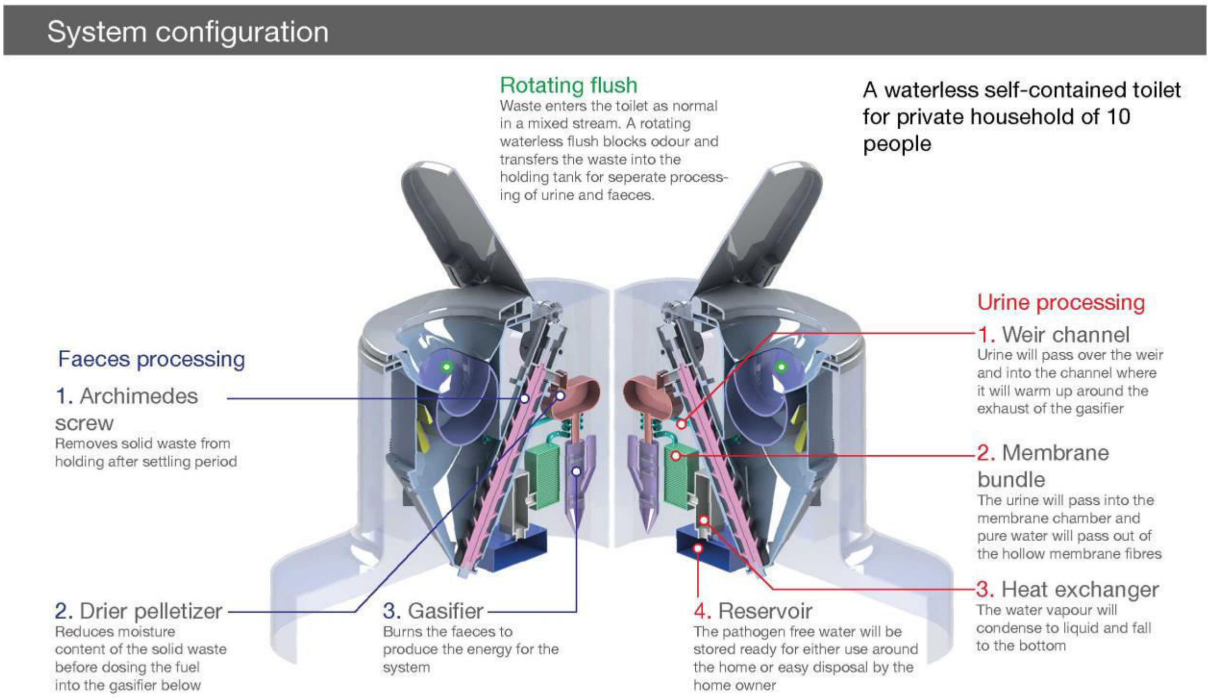

Figure 1 Overview of the system configuration, credit R. Tierney and M. Collins

Human User Tests

The flush, screw, tank and weir modules were combined into a “Front End” prototype for human testing in summer 2016. This successfully demonstrated the concept and highlighted areas for improvement. More extensive user trials of the Front End will be carried out in the UK and Africa in early 2017.

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From TRL5 to TRL7: Development of the *NEWgenerator™* Anaerobic Membrane Bioreactors for Decentralized Wastewater Treatment

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Keywords: AnMBR, resilient treatment, waste variability, water recycling
Conference Track: FSM Research Track
Track Topic: Technologies for the collection, transport, treatment and disposal of faecal sludge
Personal Preference: oral presentation

Background and Introduction

Decentralized and onsite wastewater treatment offer the potential to minimize many health and environmental impacts associated with faecal sludge management in developing countries. However, many existing onsite treatment technologies are low-tech and can only guarantee pathogen destruction or removal under optimal conditions. This often leads to many technologies serving as holding tanks with little to no removal or concentration of pathogens. These solutions often do not minimize sludge volumes and thus serve to exacerbate the frequency and need for faecal sludge collection and treatment. New decentralized technologies, particularly ones aimed at pathogen destruction and containment, are needed to address the challenges of urban sanitation in developing countries. This study follows the development of a novel treatment technology, the *NEWgenerator™* anaerobic membrane bioreactor (AnMBR), for onsite waste treatment. The particular focus is on the system's ability to handle adverse conditions, including low strength wastewaters, temperature fluctuations, and large fluctuations in wastewater production and characteristics.

The Technology: Anaerobic Membrane Bioreactor

AnMBRs have demonstrated in lab and field trials to have high quality effluents, small footprints, and low energy requirements. The coupling of high performance ultrafiltration membranes with anaerobic digestion creates a treatment system that offers reliable performance and is resilient to many changes in environmental conditions. These advantages make it appealing for use in decentralized wastewater treatment applications where variability in operating conditions is often greater and where constant operator oversight would be cost prohibitive. Due to their low energy consumption, AnMBRs can be combined with decentralized and renewable energy systems, such as photovoltaics, to form an autonomous, self-powered and off-grid sanitation system. This combination affords the technology the potential to be readily deployed and implemented in a variety of challenging settings worldwide. The high quality of the effluent (multiple log removal of pathogens) produced by AnMBRs also allows for water to be recycled and reused for toilet flushing, saving any available water of higher purity to be used for human consumption (e.g., drinking and cooking).

Technology Development and Notes:

This study follows the development of the *NEWgenerator*^{TM} technology from initial lab-scale (TRL5) trials to pilot testing (TRL6) to field testing (TRL7). The TRL7 *NEWgenerator*^{TM} is the world's first portable AnMBR entirely powered by solar energy. Lessons learned including system performance under temperature variations, and large fluctuations of feed concentrations are presented. Additionally, the system's performance under field conditions in a relevant setting (Southern India) are presented. The potential for *NEWgenerator*^{TM} to be used for post-disaster emergency sanitation is also discussed.

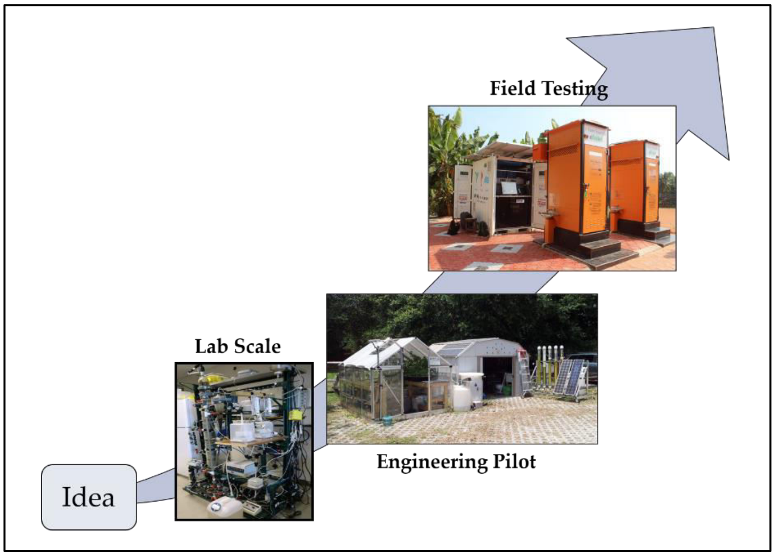

Figure 1: Development and testing stages over time. Early stage was proof of concept and developed in the lab. A subsequent engineering scale pilot was developed and tested process resilience to variable feed and environmental conditions.

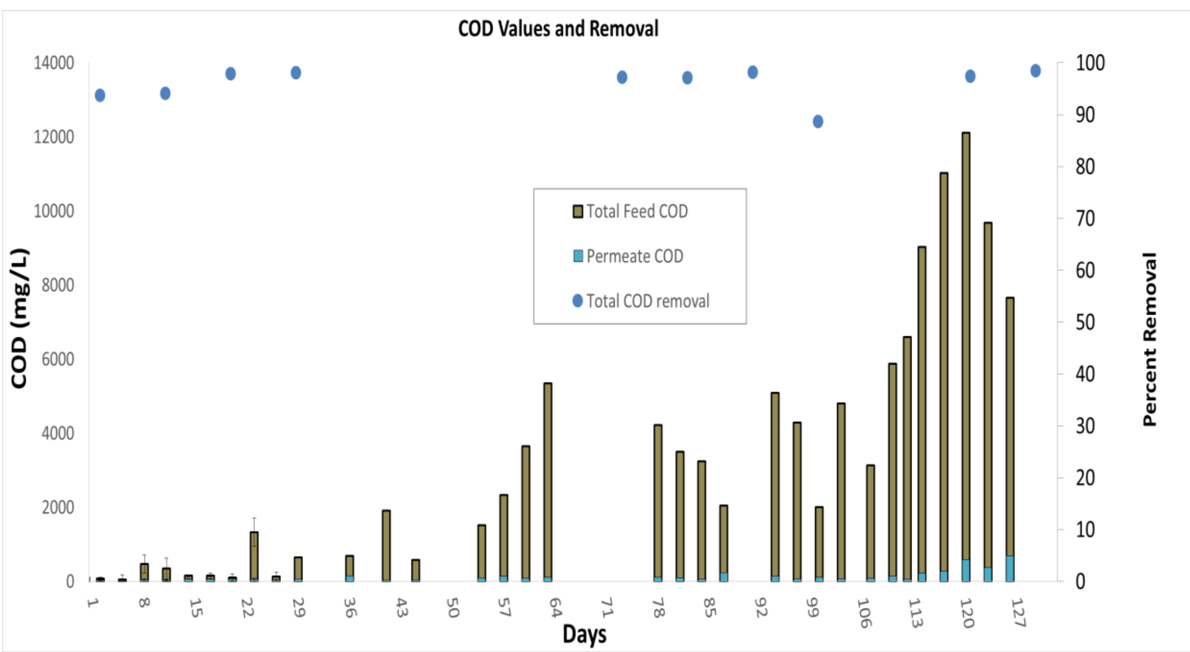

Figure 2: Engineering scale system performance when subjected to a range of incoming waste strengths. Plot show high chemical oxygen demand (COD) removal efficiencies by the *NEWgenerator*^{TM} AnMBR.

Why do Women in India not use Public Toilets?
Patterns and Determinants of Public Toilet Usage by Women in Warangal City

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Keywords: Women, Public Toilets, Behavior
Conference Track: Research Track
Track Topic: Health, Safety and Hygiene
Personal Preference: Oral Presentation

Introduction

Greater Warangal Municipal Corporation (GWMC) has taken several initiatives towards improving sanitation in Warangal, the second largest city in the state of Telangana. One of the key interventions is providing Public Toilets (PTs) in areas with high population density (market areas, bus terminals, railway station, intersections, near hospitals etc) to address open defecation/ urination. Thirty eight (38) PTs were built through Public Private Partnership model with well defined service level standards and user charges for cost recovery. These toilets have provision for WC, urinals, handwashing stations, soap and bathing arrangement for men, women and people with special needs. The maintenance of the facilities is being monitored regularly by GWMC to ensure compliance with service standards.

It was observed that the number of women visiting PTs is extremely limited vis-à-vis the predicted demand. This evaluation study is carried out by ASCI to understand the patterns and determinants of PT usage by women.

Objectives of the Study

This study aims to understand the barriers and enablers for usage of PTs and to identify access, design and service related improvements for enhanced usage by women. The first part of the study was a quantitative dip stick study undertaken to understand the usage and satisfaction levels amongst women with the existing PT facilities in the City. It also identified the attributes of a ‘good’ PT facility as described by the respondents. The dipstick study included 197 women from all strata of society and different occupations. The second part of the study, based on these insights was a series of in-depth interviews.

Methodology and Results

The dipstick study identified the following:

1. Older women had higher awareness of sanitation hygiene issues while occupational difference did not make a difference to awareness levels. While a majority of the women were aware of the hygiene issues, they were unable to point out or name specific hygiene issues such as diarrhea and urinary tract infections.
2. Women who over 10 min away from their homes used PTs and hence distance away from home was a reason for use of PT.
3. Less educated women used the PTs more often than more educated women. This is perhaps women who worked in public spaces were often less educated than those who had access to offices and places where they worked.

4. About 52.8% of sample use PTs. Most of the users stated good experience. All of them pay over Rs.5 for the use of PT. Most (70%) do not wash their hands with soap after use of PT.
5. Some reasons for not using Public Toilets was lack of cleanliness, inappropriate location, presence of too many men near the entrance, presence of male caretaker.
6. Trained Caretaker, Caretakers' behavior and availability of western toilets seems to make a difference to those who don't use toilets.
7. Colours in the toilet, caretaker and fees makes a difference to usage frequency of women using toilets.

Based on these results, in-depth interviews were executed to understand the specific needs, experience and preference of women in using PTs. Statistical tools (non-metric multi-dimensional Scaling (NMDS) based co-occurrence (Sorensen's coefficient) and similarity analysis were used to drawn inferences. This data was further analysed using network analysis, which revealed strong relationships among some of the concepts.

The 21 women respondents from various income groups, educational qualifications and belonging to various strata of society ranging from street vendors to museum managers have indicated that they require certain exclusive facilities and feel that having women caretakers makes them feel more secure. The access from main roads and in locations such as petrol bunks/bus-stops/railway stations where they stop during travel appear to be important locations for such toilets.

Analysis and Conclusion

The analysis of linked concepts and narratives indicate that women looking for sanitation facilities in public are quite distressed with the existing state of facilities, location and infrastructure. Despite an understanding of the negative externalities of lack of proper sanitation facilities for women, little work exists in understanding the nature of women's need in sanitation.

Conclusions from the ongoing study are being used in setting up sanitation facilities for women in Warangal city and in other cities in Telangana State. Also, the experience gained would inform provision of sanitation facilities for women in other cities in India. The results of this study will be used as an initial framework to reconstitute behavior change models appropriate to the region.

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Smart compliance in faecal sludge management: Strategies to achieve health and environmental outcomes

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Keywords: regulation; compliance; incentives

Conference Track: (1) Research Track OR (2) Case Study Track
Track Topic: *Regulatory and legislative development*
Personal Preference: *Oral presentation*

Introduction

This paper aims to contribute to global debate on approaches that can assist local governments to develop and implement effective enforcement strategies for faecal sludge management (FSM) in the context of onsite sanitation. For urban sanitation, setting regulations and standards is critical to ensure that both faecal sludge and liquid effluent (or leachate) are managed safely and that as a result, public health and environmental outcomes can be achieved. However, ensuring compliance with these standards and rules can be difficult. Compliance challenges are frequent across the sanitation service chain and across different actors; households constructing and emptying septic tanks, operators managing decentralised community-scale wastewater treatment systems, and private service providers emptying, transporting and disposing of sludge. In this paper we focus on compliance challenges in relation to FSM emptying, transport and disposal.

Key concepts in achieving compliance

The conventional regulatory approach is one of "command-and-control" that involves a regulatory agency setting rules, monitoring actions, and punishing those who do not comply. But the reality in many contexts is that this inspection-penalty approach is not effective. Beyond 'command-and-control' approaches, and at the other end of the spectrum, are behaviour change communication (BCC) approaches that seek to educate and change attitudes and behaviours. Whilst success stories exist, in practice there are limits to only appealing to the collective sense of "public good" and people's willingness to prevent harm to the environment and the health of the wider community. Hence the need to develop cost-effective, 'smart' ways to achieve compliance by combining approaches and instruments.

Methods

This paper identifies four principles to inform "smarter" approaches to regulation, enforcement and compliance to deliver outcomes in FSM. It draws on key concepts and approaches used both within and beyond FSM and urban sanitation, and provides examples that illustrate these approaches. The examples were sought through a snow-ball sampling approach based on key contacts within the urban sanitation sector and through a literature review of examples from other sectoral contexts.

Results: principles that can support 'smart' compliance

The following principles can inform 'smart' approaches to compliance. They are illustrated with brief examples in relation to FSM.

Principle 1: Apply a responsive regulation approach: Responsive regulation recognises that there are different attitudes to compliance, and applies a progressive set of compliance strategies from low to high severity. Many regulators apply responsive regulation as a staged approach – e.g. first non-compliance might involve receiving a warning or information letter, and then progressively stricter approaches for subsequent noncompliances. As an example, in some cities in the Philippines (Alabel, Marikina and Dumaguete) there exist a clear set of enforced local ordinances for emptying. Initially households not adhering to the regulations are given written notices. Further non-compliance is addressed by fines (AECOM and Sandec-Eawag 2010, OXFAM 2016).

Principle 2: Identify and leverage compliance motivations: The responsive regulation model considers motivations in relation to aligning the "strength" of regulatory penalty to the "willingness" to comply. A more comprehensive application of responsive regulation seeks to understand individual and organisational motivations, to develop specific compliances strategies that respond to these. For example, in Marikina City, Philippines built on compliance motivations comprising community pride and peer-pressure. To promote participation in the desludging program, window stickers were provided for participating customers to engender a sense of pride and exert peer-pressure. This was combined with an awareness raising campaign that tapped into pride for healthy, clean waterways, and emphasised links between desludging and local environmental conditions (Robbins 2012).

Principle 3: Apply risk-based thinking: An essential factor for allocating resources to compliance efforts is the potential degree of harm from non-compliance, which for FSM comprises the risk to public health and the environment. Risk-based thinking ensures that the regulatory efforts and resources spent by a regulatory authority are proportionate to the risk of harm posed by non-compliance. Potential behaviours to regulate can be mapped on a "likelihood-consequence" matrix, for instance to determine, in a given context, which activity (amongst emptying, transport and disposal) non-compliance leads to greatest risks.

Principle 4: Combine approaches and instruments: Combining and mixing policy instruments has long been advocated to achieve the goals of environmental management and policy. A range of instruments may be combined, including voluntary approaches, command-and-control regulation, self-regulation and market-based instruments. For example, in Patong city, Thailand, government subsidies support emptying and treatment and were combined with market-based tax incentives (Taweesan et al 2015). In another example, in Bandung, Indonesia, a compliance strategy included licencing 17 private providers and giving them access to dispose of sludge in sewer manholes rather than drive lengthy distances, using citizen monitoring with smart-phones to report on illegal dumping, and involving police in monitoring the licenced providers.

Significance and conclusion

Many reasons exist for why simple 'command-and-control' regulation is unlikely to be effective in the first instance in achieving compliance in FSM emptying, transport and disposal. These include that local governments and regulators rarely have sufficient resources for inspection, monitoring or enforcement; the local political and community appetite for applying penalties may be weak; and poor accountability, governance and institutional systems mean there is a high risk of "regulatory capture". This paper has therefore provided four key principles that can inform smarter approaches to compliance in FSM, namely (i) applying a responsive regulation approach; (ii) identifying and leveraging compliance motivations; (iii) applying risk-based thinking and (iv) combining approaches and instruments. Application of these principles could support improved approaches to compliance in the urban sanitation sector and deliver improved FSM outcomes.

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FSM is not just an urban issue: findings from a rapid assessment in rural Vietnam

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Keywords: Rural; FSM; Vietnam

Conference Track: Research Track
Track Topic: *Technology, Economics and Business (Institutional)*
Personal Preference: *Oral presentation*

Introduction

Since 2013 the World Bank has supported the Government of Vietnam through the Results-based Rural Water Supply and Sanitation under the National Target Program (the Program) in eight provinces in the Red River Delta. In relation to sanitation, the Program aims to provide 130,000 new toilets and 1.275 million people benefiting from commune-wide sanitation from 2013 to 2017. With this significant expansion in sanitation systems, the Program wanted to understand whether the management of faecal sludge would not compromise the health and environment benefits of increased access to improved sanitation.

In the eight provinces, there is between 50-80% hygienic latrine coverage and these are predominately septic tanks (62%) (MARD 2015). While FSM often focuses on urban sanitation needs, the filling and management of sludge from sanitation systems is relevant to rural areas, particularly as sanitation in rural Vietnam moves away from pit latrines and agricultural reuse. Previous research in rural Vietnam focused on specific topics such as degradation processes and reuse from dry latrines (Nguyen, 2015), sanitation markets (PSI, 2014), and latrine costs (Do, 2014).

Rapid Assessment

A rapid assessment was conducted in March 2016 to understand the current practices, operations and issues associated with FSM in rural Vietnam; and to provide recommendations on practical solutions to reduce potential public health and environmental risks. The scope included 10 days research in Phu Tho, Ha Nam and Thanh Hoa provinces, conducting in-depth discussions with representatives from provincial, district and commune levels, 56 household and 12 institution surveys, interviews with 6 pit emptying providers and assessment of sludge disposal sites. A workshop with representatives from the eight provinces was conducted in June to discuss the findings and recommendations.

Key Findings

Regulations and Institutional Responsibility: Existing regulations regarding the management of FSM (Decree 38 and Decree 80) were not well known and not yet implemented in the surveyed provinces. Although the new Decree 38 specifies MOC is responsible, there was limited and unclear responsibility for FSM in the program provinces. Additionally the application of domestic wastewater standards to septic tank sludge is unclear, particularly whether standards govern sludge treatment or discharge.

On-site systems and Emptying Frequency

Septic tanks were the main type of latrine found, with biogas digesters and improved and unimproved pit latrines also common. Most septic tanks and biogas did not have a soak pit and discharged to drains and waterways. There was limited knowledge and no guidelines on the need to regularly empty septic tanks. Commune leaders reported emptying was growing but not yet common, with only a few systems emptied each year. The sampling focused on emptied systems and of the 27 septic tanks surveyed 12 were emptied after an average 11 years operation and 7 of 11 biogas surveyed were emptied after an average 10 years operation. For dry latrines, government and households had some knowledge on safe practices and some guidelines existed and was promoted, however not always practiced.

Emptying Methods and Service Providers: Septic tanks and biogas were typically emptied with a vacuum or manual pump, however there were some reports of manual emptying. One private operator entered inside a biogas digester to empty hardened sludge which is a major safety risk. Low cost emptying methods using manual pump appeared suitable for rural areas, however the current practice of disposing sludge to adjacent land was unsafe. Although the state owned enterprises had licences to empty, it was not an obligation and private sector were the main provider in rural areas, although they are not monitored or registered. While public and private sectors reported emptying was a profitable business, most government departments thought it was too costly to establish as a public service.

Treatment, Disposal and Reuse: There were no sludge treatment or safe disposal sites in the surveyed provinces. Untreated sludge was discharged to private land, farms and waterways. Sludge reuse practices varied, with reuse of fresh sludge or effluent water on rice, maize and vegetables common and there was limited knowledge of health risks. Unclear responsibilities and no guidelines for the acceptable options to treat or reuse sludge limits its management or the inclusion of FSM in planning.

Key Recommendations

A key outcome of the workshop was the urgency with which provincial representatives feel that FSM should be improved as it is seen as a growing issue. Recommendations included:

Provincial Government

- Clarify and allocate responsibilities for each stage of FSM, including for monitoring and enforcement, enact regulations and include FSM in provincial planning.
- Expand sanitation promotion to include the need to regularly empty septic tanks and biogas, emptying triggers and risks of manual emptying or untreated disposal or reuse.
- Promote safe emptying, transport, disposal and reuse to public and private pit emptiers.
- Assess applicability of FSM business models including expanding existing solid waste or public-private partnerships, and promote FSM business opportunities to private sector.

National Government

- Develop guidelines on regulation of private sector (responsibility, licensing, enforcement).
- Develop options for FSM business models suitable for rural areas and promote to state owned enterprise and private sector, including support for pilot programs to trial models.
- Sludge treatment guidelines for rural areas (simple, low-cost, optimise reuse potential).

Conclusion

Although a brief and small scale assessment, the research identified that while FSM is not currently a major health or environmental risk due to low emptying demand, it is recognised as a growing issue, particularly with the low levels of understanding about FSM, limited regulation or planning. It is predicted there will be significant increase in demand for emptying in the next years due to the surge in septic tank and biogas construction 7-10 years ago. Based on these findings the international FSM sector could support rural FSM through: including FSM in rural sanitation education programs; urgently educating pit emptiers about the risks of entering biogas; promoting emptying business opportunities to sanitation masons; developing and piloting low cost and low tech sludge disposal options including how risk management can be applied where strict discharge standards can't be met.

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Studies on the impact of anthropogenic wastes on growth and yield of maize and cowpea, major nutrients and pathogen load in soil

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Keywords: Ecosan toilet; Maize; Fertilizers

Conference Track: (1) Research Track
Track Topic: *Characterization and quantification of faecal sludge*
Personal Preference: *Oral presentation*

Background

Increase in population and huge density of human settlements, have led to generation of huge quantities of human wastes in the form of digestive refuse material known as faecal material and urine which pose the onerous task of their disposal. India produces around 17.9 million cubic meters of sewage and 4 million tons of sludge every year with a combined nutrient contribution of 2.4 lakh tons of nitrogen (N), 1.3 lakh tons of phosphorus (P_2O_5) and 1.2 lakh tons of potassium (K_2O) besides 12 lakh tons of organic carbon. But most of these nutrients and organic carbon pollutes soil and water bodies. In this direction an eco-friendly design of toilet called 'ECOSAN' needs to be popularized which help in source separation of human urine and faecal matter in a hygienic way. To exploit the huge potentiality of anthropogenic wastes as a supplement to fertilizers, research on use of anthropogenic wastes has been attempted to study the impact of humanure, pit toilet sludge and sewage sludge on growth and yield of Maize (*Zea mays*) and Cowpea (*Vigna unguiculata*) and on soil major nutrients with emphasis on pathogen load in soil during 2014-15.

Methodology

Three different sources of anthropogenic waste materials were collected from different sources viz decomposed human excreta from ecosan toilets (humanure), human excreta from pit toilets and sewage sludge from sewage treatment plant. These materials were dried, powdered and analysed for nutrient composition and for isolation of pathogens. Characterization of the waste reveals that ash mixed with humanure was rich in potassium (2.27%), medium in phosphorus (0.58%), other nutrients were in appreciable amounts. Whereas, human excreta from pit toilets and sewage sludge from sewage treatment plants were found to be rich in phosphorus (0.77% and 1.06%, respectively) and nitrogen (0.45% and 0.44%, respectively) as compared to potassium. After characterization, the faecal sludge from three sources were used as nutrient sources along with three levels of recommended dose of fertilizers (RDF) of 75%, 100% and 150%, which were then compared with RDF + Farm Yard Manure (FYM), RDF alone, FYM alone and control. The field experiment was conducted during 2014-15 with maize and cowpea as test crops. The quantity of humanure was added based on the potassium content and the quantity of pit toilet sludge and sewage treatment plant sludge were worked out based on phosphorus requirement of crops. The balance quantities of nutrients required in each treatment were supplied through inorganic fertilizers.

Results and discussion

The results of laboratory study revealed that all the three anthropogenic human wastes contain the pathogens viz E.coli, Staphylococcus aureus and Bacillus species. The field experiment on maize, significantly higher plant height (203.65 cm) and number of leaves per plant (14.25) were recorded with 150% Potassium (K) through humanure + balance N and phosphorous (P) through fertilizers to supply 150% N and P and lower plant height (117.11 cm) and number of leaves per plant (8.19) were recorded in control. Similarly, the test weight (31.50 grams), grain yield (87.52 q ha^{-1}) and stover yield (93.93 q ha^{-1}) recorded were significantly higher in treatment which received 150% K through humanure + balance N and P through fertilizers to supply 150% N and P. The increase in grain yield was to the tune of 16.99%, 34.34% and 88.90% over RDF (100% NPK + FYM), RDF alone and FYM alone treatments. The test weight (27.29 grams), grain yield (38.96 q ha^{-1}) and stover yield (42.55 q ha^{-1}) were lower in absolute control. Similarly higher plant height (92.51 cm) and number of branches per plant (10.28) were recorded in 150% K through humanure + balance N and P through fertilizers to supply 150% N and P and lower plant height (37.02 cm) and number of branches per plant (6.30) were recorded in control. Similarly, the test weight (11.92 grams), seed yield (1.94 t ha^{-1}) and haulm yield (3.20 t ha^{-1}) recorded were significantly higher in treatment which received 150% K through humanure + balance N and P through fertilizers to supply 150% N and P.

Table 1.1 Higher available nutrients in Maize and Cowpea through humanure + balance N and P through fertilizers to supply 150% N and P

Nutrient level in kg ha^{-1}	Maize	Cowpea
N	407.39	202.52
P_2O_5	64.63	49.12
K_2O	339.94	156.37

Table 1.2 Lower available nutrients in Maize and Cowpea on a control plot without nutrients or fertilizers

Nutrient level in kg ha^{-1}	Maize	Cowpea
N	309.24	78.32
P_2O_5	31.93	18.93
K_2O	167.95	77.26

The pathogens viz, E.coli, salmonella, Bacillus and Staphylococcus were present in soil after harvest of Maize crop but it was absent after harvest of Cowpea due to soil chemical reactions and also life span of survival of pathogens to the environment.

Conclusion

From these results, it can be concluded that use of faecal sludge can solve the problem of their disposal and also reduces the reliance on scarce/costly fertilizers for crop production and also help improve soil fertility with greater crop yield.

Characteristics of Faecal Sludge generated from onsite systems located in Devanahalli

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Key words: Faecal sludge, Pits, Septic tank, Solids, Organic content
Conference Track: (1) Research Track
Track Topic: Characterization of faecal sludge
Personal Preference: Oral presentation

"Faecal sludge is the solid or settled contents in pit latrines and septic tanks. The main contents of faecal sludge are - faeces, urine, anal cleansing material (paper, plastic, rags), washwater, detergents and disinfectants" (Foxon et al., nd). The characteristics of Faecal Sludge (FS) differ widely between different households, cities and countries; and are influenced by user practices, duration of storage, temperature, soil condition, intrusion of groundwater or surface water in septic tanks or pits, design and performance of septic tanks/pits and tank emptying technology and pattern (MOUD, 2013). Research also shows that heterogeneous factors during collection and transportation using desludging vehicles influence the characteristics to a great extent. Further, at a town or city scale, there is limited data available, especially in India, to predict or estimate values of FS characteristics in order to select and design appropriate treatment modules. The objective of this study is to assess the characteristics of FS samples collected that are collected at the faecal sludge treatment plant (FSTP) that receives FS from pits and septic tanks in Devanahalli, to estimate the values for the faecal sludge can be derived, which help designers choose appropriate design parameters to select the treatment methods.

The methodology for this study is based on primary data collected through a sampling campaign at the FSTP. Samples are collected at the inlet of the treatment system at the time the desludging trucks are discharging FS into the treatment plant. Samples are collected during the discharging process at three intervals (beginning, middle and end) from the inlet of the treatment plant. A composite sample is prepared from these samples for analysis. These were then analysed at a laboratory for pH, Total Solids (TS), Total Volatile Solids (VS), Ammonical Nitrogen, Phosphates, Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD) using APHA standard methods. Data related to the type of containment system, specifications of containment system, desludging practices, usage of water, time at which the containment system was built, time since the previous emptying and so on have also been documented. This paper represents the results of 115 samples collected at the FSTP. The data has also been statistically analysed to understand how the variability and variance in influencing factors impacts the characteristics of FS. .

All the collected samples show high concentration of BOD, COD, TS and VS and all the parameters are highly variable from one source to another. As per Strauss, 1997, the faecal sludge samples analyzed fall under the category of Type "A" high strength (highly concentrated). pH ranges between 7 to 8 for all the measured samples. The measured COD values for all the samples range between 0.02- 1.67kg/l. These values are higher than the range estimated by Strauss of 20,000-50,000mg/l for public toilet and 15,000 mg/l for septic tank. The measured TS values for all the samples range between 0.015- 1.27kg/l and VS values range between 0.006 to 0.7kg/l. The ammonia content of the faecal sludge samples analysed has values between 1.0-3.0g/l of NH_4–N which is lower than the range estimated by Strauss. The faecal sludge generated from onsite sanitation systems present at commercial establishments also has high solids content compared to institutes and households.

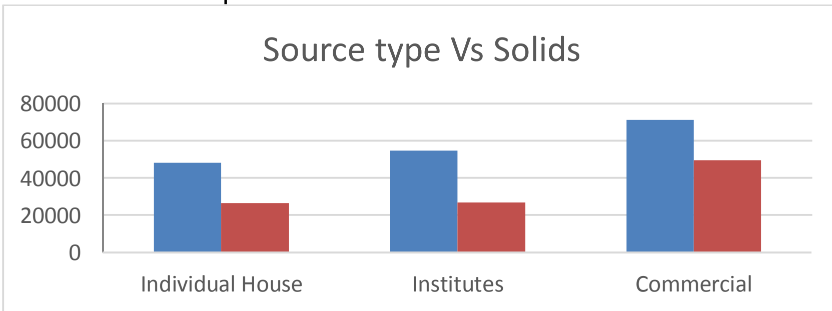

Figure 1 Solidcontent of faecal sludge with respect to desludging frequency

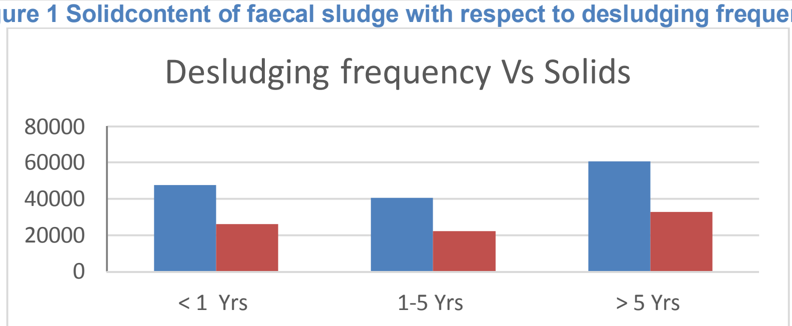

Figure 2 Solid content of faecal sludge as against source of faecal sludge generated

As shown in above figures, the high solid content values are indicators of long desludging intervals, use of single pits, unlined pits, pour flush toilets, low water supply, low water table, no grey water infiltration and low rainfall instances. In most cases, water used for flushing percolates into the ground from the unlined bottom or joints of the containment systems; only solids get accumulated in the pit/septic tank which results in high solids and organic content of the FS brought to the FSTP. Heavy metals content of dried treated FS has been analysed, and its presence is a concern, but with the results clear conclusions could not be drawn. The high ammonical nitrogen values are attributed to the discharge of only black wastewater to the onsite systems.

While a few similarities were observed between sources of samples from the same town, a larger number of variations were found. Variations in characteristics were observed in relation to age of sludge, amount of water used for desludging, type of buildings (commercial, household, institutes) and design of containment units (lined/unlined). As a result, any statistical correlation between characteristics and influencing factors has not been established with the current data set. The current sample size of 115 is just an indicator of the characteristics at a town level; more data would need to be collected over time to get a better understanding. Further characterization in relation to biodegradability, pathogen and heavy metal content in dried sludge should also be conducted. More data should help in estimating values for FS characteristics, especially in relation to influencing factors, that will help choose technology options for appropriate treatment.

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Septage Characterization in Indian Urban Centres and Standalone Treatment Options for Septage Handling & Disposal

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Keywords: Septage; Sanitation; Standalone

Conference Track: Research Track
Track Topic: Characterisation & Quantification of Faecal Sludge
Personal Preference: Oral Presentation

Background:

With Government of India's program on Swacch Bharat Mission, state governments are strongly competing to declare their respective states as open defecation free and the resultant is that India is finally on course to provide toilets for all. About 17 million urban households lack adequate sanitation facilities in India, with 14.7 million households having no toilets. Majority of these urban households will be provided onsite sanitation systems such as septic tanks. The treatment capacity exists for only 30% of the wastewater generated in the cities and only 22% of the wastewater is actually treated before disposal. However, for technical reasons it is challenging to use wastewater treatment facility for treating faecal waste from septic tank. Septage management largely remains a neglected component of urban sanitation. Onsite facilities have become major sources of groundwater and surface water pollution with significant environmental, public health and economic impacts.

With majority of households rapidly getting access to toilets through onsite sanitation system, there is immediate need to plan and construct septage treatment facilities. However, there is limited data on septage characteristics in India in literature. Reliable data on septage is critical for research, planning and design of septage treatment facilities. The data would also enable resource management tools such as nutrient loading models, ecosystem sustainability analyses, and also for resource managers and regulatory decision makers charged with setting and/or verifying compliance with treatment standards.

Study Process

A study for characterization of septage waste was undertaken in 2015 across ten urban centres across different zones of India – Anekal and Nelamangala (Karnataka), Bhopal & Indore (Madhya Pradesh), Kolkata & Howrah (West Bengal), Ahmedabad & Nadiad (Gujarat) and Gaziabad & Gurgaon (National Capital Region). 3 samples were collected from Septage hauling trucks at each of the centres and analysed for a set of 16 parameters covering Physical, Chemical, Biological parameters including helminth eggs using Standard Methods. A data sheet on the septage collection and transport vehicles was also undertaken.

Our paper will report on data collected at all locations by all the 16 parameters and discuss similarities and differences in constituents among the study sites.

Based on the analysis a set of technical options for septage management was prepared for standalone treatment of septage based on modular capacity. The standalone handling & disposal options for onsite sanitation includes six technologies identified on having immediate availability and relevance. The treatment components and applicability of the technologies is discussed for size of the cities/ towns. The comparative analysis of the options would also be presented.

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Maximising the Value of Fertilisers Derived from Source-Separated Human Waste in Antananarivo, Madagascar

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Keywords: human waste derived fertiliser; digestate; nutrient cycling

Introduction

Achieving global food security is one of the major challenges we face for the near future: with the current rate of population growth it is estimated that by 2050 global food demand will double (Tilman et al. 2011). Higher crop productivity will be needed worldwide, requiring higher volumes of fertilisers while ensuring soil health is maintained. Mineral nutrient reserves are finite and the need for closing nutrient loops by returning waste nutrients to soil is recognised as a key factor to ensure food security (Cordell et al. 2009). Rapid rates of urbanisation add further pressures to this issue with cities currently behaving as nutrient ‘sinks’. Nutrients are transported from rural areas and consumed in cities but not returned to soil, creating additional demand for chemical fertilisers. Urbanization accounts for more than 90% of future population growth in developing countries and Africa holds highest urban growth rate at 3.5% per year (Ncube 2012). Rapid expansion of urban areas without parallel economic growth creates environments which feature a lack of adequate waste removal, water and sanitation services (Scott 2013). Transforming human waste into soil conditioners is one way to create an economic incentive for treating and valorising toilet waste while achieving full nutrient recycling and improving soil fertility.

In Antananarivo, the capital of Madagascar (pop. 2.3 million), 82% of latrine sludge is dumped or overflows in urban waterways and courtyards, while 17% is dumped directly into the Ikopa river (Gilbert 2015). A project is underway in Madagascar partly funded by Loowatt (a UK SME which has designed a novel dry toilet and pioneers human waste composting in Madagascar), investigating the feasibility of full nutrient recycling of human wastes into soil by producing a soil conditioner and fertiliser that is attractive to the farmers of the area in which it is produced. The treatment process aims to maximise the energy and nutrient recovery from human waste through anaerobic digestion. Human waste is first anaerobically digested, biogas is used to generate electricity and the digestate is further treated to produce two additional soil amendments: compost and vermicompost.

Methods

A pot trial under controlled conditions was undertaken between April and August 2015 at Cranfield University, UK. Six different fertiliser treatments were applied (compost (C), vermicompost (V), chemical inorganic fertiliser (I), a mix of compost and chemical fertiliser (C+I), a mix of vermicompost and chemical fertiliser (V+I) and control) with three replicates for each treatment. The organic fertilisers (C and V) were derived from digestate issued from anaerobic digestion of human waste derived fertilisers (HWDF) and were produced by Loowatt in Antananarivo using human waste collected from their toilets. The initial soil and fertiliser content of Potassium and Magnesium are shown in Table 1. Maize was chosen as a test crop with one plant grown to maturity in each pot.Soil samples were taken from each plot after harvesting of the plants and the concentration of several nutrients was analysed: Magnesium, Potassium, Zinc and Copper.

Table 1 Initial soil and fertiliser nutrient concentrations

Parameter	Initial soil conditions	Compost	Vermicompost
Available Potassium (mg/L)	<20	15958 $\pm$ 903	15734 $\pm$ 398
Available Magnesium (mg/L)	<15	122 $\pm$ 13.2	224$\pm$ 2.33

Results

Factorial ANOVA statistical analyses were carried out on the data obtained. Highly significant differences ($P<0.001$) were observed with respect to the concentrations of Mg and K between control pots and pots treated with fertilisers. Pots treated with vermicompost had the highest Potassium concentration, which was 2.3 times higher than the next highest concentration observed for the V+I treatment. The highest concentrations of Magnesium in this experiment were also found in pots treated with vermicompost. Pots that received V+I had the highest concentration of Magnesium in soil, 14% higher than the next highest concentration, which was found in pots treated with vermicompost alone. The following highest Magnesium concentration was 1.6 times lower for pots treated with C+I. These results suggest that vermicompost provides higher concentrations of micronutrients and provide a residual concentration in soil after crop harvest, improving the nutrient content of soil in the long term. An interaction between inorganic fertilisers and compost and vermicompost is also suggested by these results, improving the residual micronutrient content of soil.

Heavy metal concentrations on the other hand were not influenced by the fertiliser applied. No significant differences ($P > 0.05$) were observed for Zinc or Copper concentrations between control pots and pots treated with fertilisers or between the different fertiliser treatments, showing that no residual heavy metals remained in soil as a result of fertiliser application. Zinc and Copper are considered trace elements for plant growth: they are essential for healthy growth but are required in very small quantities and can potentially contaminate soil if present in high concentrations.

Conclusions

These results show the potential of digestate derived from human waste as a source material for producing compost and vermicompost and highlight the differences in nutrient content between compost and vermicompost. The benefit of mixing HWDF with chemical fertilisers was also highlighted in this experiment, showing an opportunity for combining organic and inorganic fertilisers for optimising plant growth and long term soil health. Low heavy metal concentrations in soil in all the pots treated with HWDF showed the benefits of producing fertilisers from source-separated human waste, free from contaminated industrial effluent that might be found in conventional wastewater streams.

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Rheology of faecal sludge from VIP latrines

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Keywords: shear thinning; viscoelasticity; pit emptying

Conference Track: (1) Research Track
Track Topic: *Characterization and quantification of faecal sludge*
Personal Preference: *oral presentation*

Introduction

Considered as a basic form of sanitation, ventilated improved pit (VIP) latrines are widespread in rural and peri-urban areas from developing countries. The sustainable management of VIP latrines is important in order to mitigate the health risk and pollution issues from faecal sludge. Ideally, after the pit is full, faecal sludge has to be removed in the safest possible way and disposed for disinfection and resource recovery.
The rheological characteristics of faecal sludge are relevant for the design of pit emptying devices and treatment processes. They determine the flow behaviour of the sludge as a function of the applied shear stress. Nevertheless, the rheology of faecal sludge has been barely explored in literature. Up to now, only a couple of investigation (Woolley, Cottingham, et al. 2014a; Woolley, Buckley, et al. 2014b) has been carried out for fresh faeces.
Arising from the need of rheological data, this work aims at characterizing the rheological properties of faecal sludge from VIP latrines and their implication on pit emptying.

Materials and Methods

Faecal sludge was sampled from VIP latrines located in the eThekwini municipality (Durban, South Africa). Sampling was done at different positions within the pit. For each of the samples, experiments in the rheometer were performed in order to determine their viscous and visco-elastic properties, and the moisture and ash content were measured. A n-power law was used to model the viscosity of faecal sludge as a function of the shear rate, and the parameters from the model were correlated to the moisture content, based on the experimental results obtained from samples with altered moisture content in the range 77 to 90%. The model was employed to calculate the pumping requirements for pit emptying, based in the criteria set in the Omni-Ingestor project (project initiated by the Bill & Melinda Gates Foundation in order to improve pit emptying).

Results and discussion

Faecal sludge exhibits a shear thinning behaviour, i.e. a decrease of viscosity by increasing the shear rate. The damping factor of the faecal sludge was lower than 1, highlighting the higher elastic than viscous response after application of a low shear stress. This explains the yield stress that has to be exceeded in order to overcome the elastic resistance and then to induce the flow of sludge.
Similar viscosities were found for the samples from different pits (Figure 1), irrespective to the position within the pit (Figure 2). The exception was the sample from the bottom of one of the pits, for which it was not possible to induce flow during the rheometer experiments. Indeed, this sample had a solid-like behaviour with a lower moisture content (67% wet basis) and higher ash content (60% dry basis) with respect to the other samples (moisture content: 78 to 80% wet basis; ash content: 30 to 50% dry basis). This sample should then correspond to an aged sludge which has undergone a higher biodegradation level compared to the other samples.
The model developed in this work predicted with accuracy the shear thinning behaviour of the sludge and the decrease of viscosity as moisture content of the sludge is increased.

According to the model, the pumping requirements during pit emptying will decrease as the moisture content of the sludge will be higher.

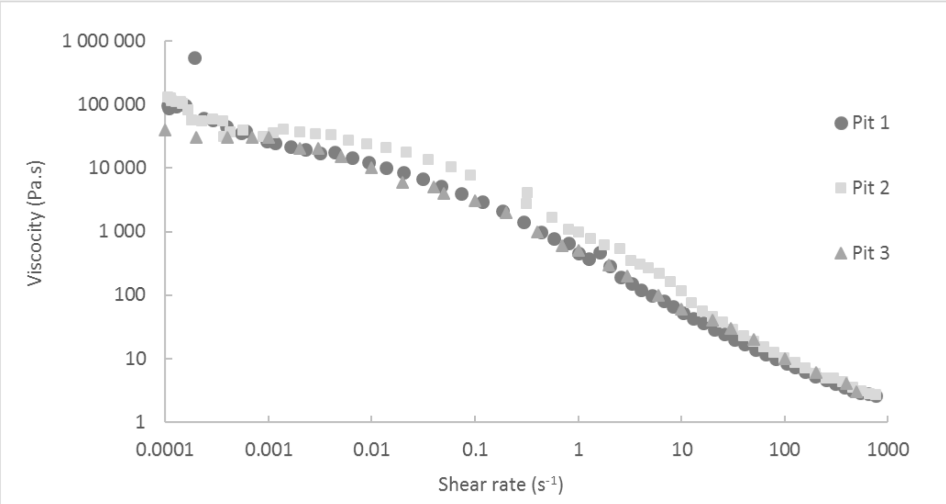

Figure 1. Viscosity versus shear rate for the average of three pits

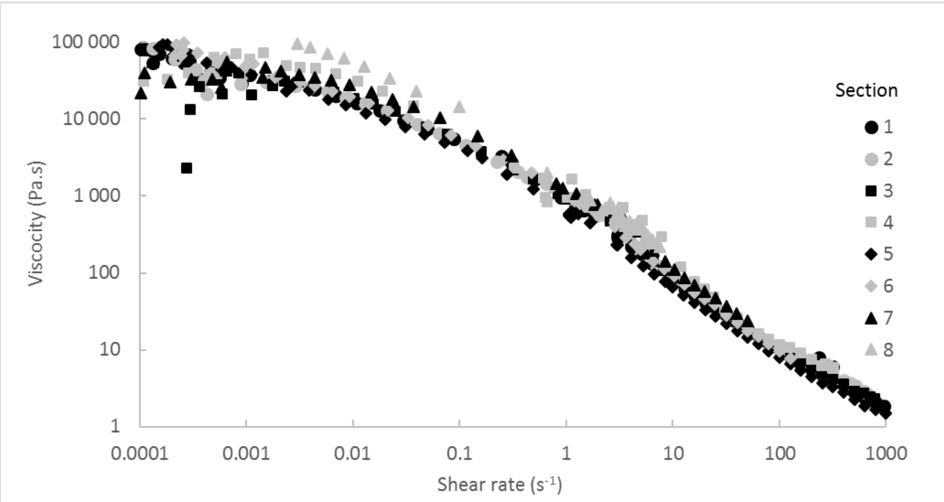

Figure 2. Viscosity versus shear rate for the samples from different sections of one of the pits

Conclusions

Faecal sludge is a viscous material with an elastic resistance to overcome in order to induce flow. As the applied shear is increased, the viscosity of faecal sludge decreases. The rheological properties of faecal sludge seem quite homogeneous within the pit, and similar between different pits. Nonetheless, the faecal sludge from the bottom of the pit may be different due to its higher age. The addition of water to the pit would facilitate considerably the pumping during pit emptying. However, this practice would require to handle higher volumes of sludge and lead to longer pit emptying times.

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‘LaDePa’ process for the Drying and Pasteurisation of Faecal Sludge from VIP latrines by the means of IR Radiation, and Reuse of the Product

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Keywords: faecal sludge; drying; reuse

Conference Track: (1) Research Track
Track Topic: *Technologies for the collection, transport, treatment, disposal and use of faecal sludge*
Personal Preference: *oral presentation*

Introduction

In Durban, South Africa, the ‘Latrine Dehydration and Pasteurization’ (LaDePa) machine has been installed for the treatment of faecal sludge from ventilated improved pit latrines into a pathogen-free product for reuse (Harrison & Wilson 2012). In this process, pellets from faecal sludge are produced through an extruder and are then convoyed into an infrared heating chamber for drying and pasteurization. This paper gives an overview of the performance of the process and characteristics of the dried products for its reuse. This includes: (i) the study of the drying and pasteurization performance of the process using a laboratory scale prototype; and (ii) an evaluation of the use of the processed pellets for agriculture or as a biofuel based on chemical and physical analyses.

Materials and Methods

The sample was faecal sludge from ventilated improved pit (VIP) latrines. The experiments were performed in a laboratory scale LaDePa (Figure 1), situated in the Pollution Research Group, at the University of KwaZulu-Natal, Durban, South Africa. The design of this prototype is based on the full scale LaDePa machine, with a scaling factor of 1:10. The intensity of IR radiation from the emitters was varied between the experiments, while the other operating conditions were kept constant. The diameter of the pellets was 8 mm.

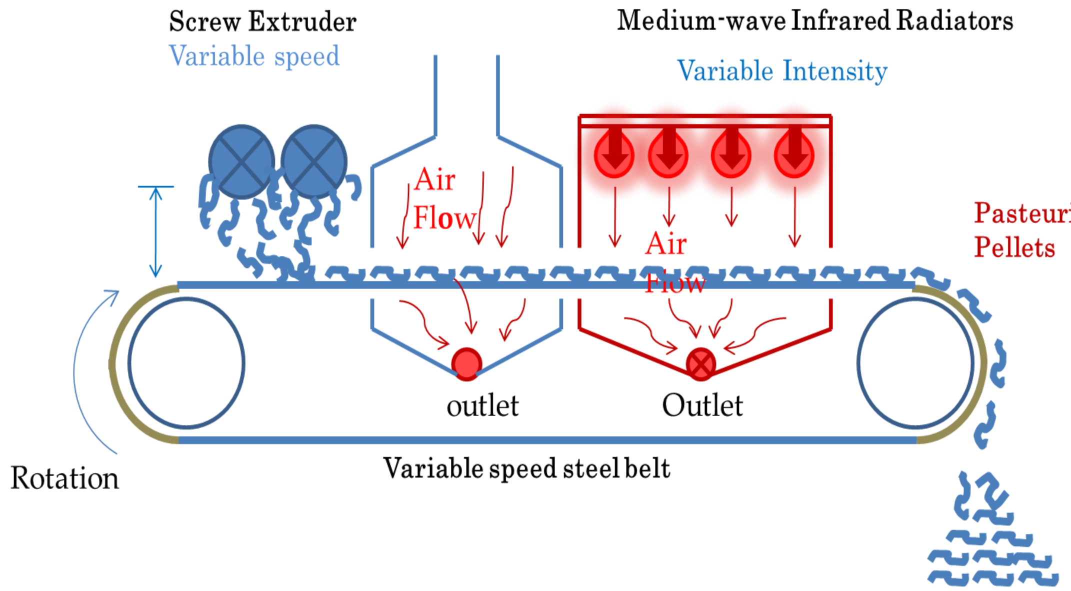

Figure 1. Schematic diagram of the laboratory scale LaDePa

The extent of drying and pasteurization of the samples was determined based on moisture content and the presence of viable Ascaris eggs respectively, for pellets sampled at different residence times.
The potential reuse of the pellets for agriculture and as a biofuel was evaluated through the fallowing analyses of the content of valuable nutrients (C, N, P, K, Ca, Mg, soluble N, soluble P) and thermal properties (calorific value, thermal diffusivity heat capacity, thermal conductivity).

Results and discussion

As the intensity of infrared radiation was increased, drying temperature was higher, resulting in a faster moisture removal and more efficient process in terms of energy consumption (Figure 2). However, the pellets were thermally degraded at temperatures above 200°C. After processing, Ascaris eggs were deactivated or severely damaged so that they would be unlikely to develop.
Drying does not affect the chemical composition of the dried solid in terms nutrients (C, N, P, K, Ca and Mg) nor does it affect the calorific value. However, thermal properties (heat capacity, thermal conductivity, thermal diffusivity) and the content of soluble N changed during drying. The results also showed that the processed faecal sludge have interesting characteristics for reuse: similar nutrient content than manure and compost (P, K, Mg, Ca, N and C concentrations approximately 85, 10, 15, 30, 15, and 380 g / kg of dry solid), and similar fuel characteristics than wood (calorific value of 18 Mj / kg dry solid; thermal diffusivity in the order of 10^{-7} m^2/s).

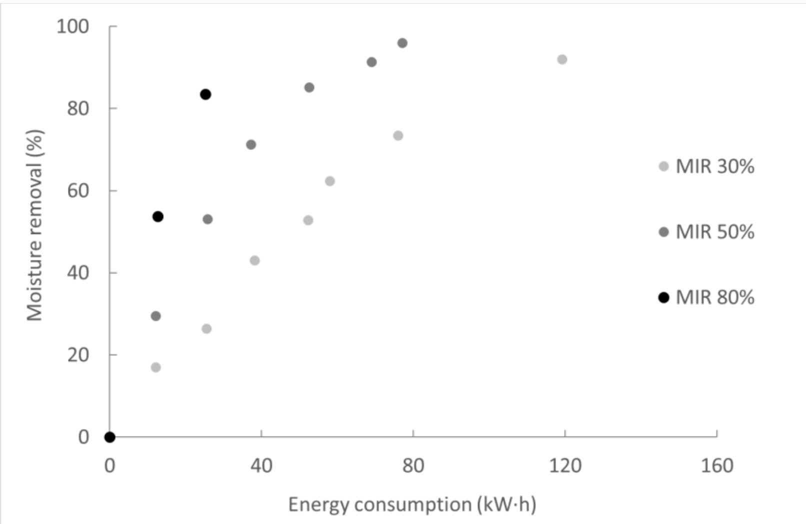

Figure 2. Moisture removal versus energy consumption at different MIR intensity

Conclusions

The experiments in the laboratory scale LaDePa demonstrated that this process is an interesting alternative for the treatment of faecal sludge from VIP latrines. The final product are pellets that demonstrates to be suitable for use in agriculture or as a biofuel.

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Integrated Digestion and Nutrient Recovery to Enhance Value Extraction from Faecal Sludge Treatment

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Keywords: Anaerobic digestion; nutrient recovery; value chain
Conference Track: Research Track
Track Topic: Technologies for the treatment and reuse of faecal sludge
Personal Preference: Oral Presentation

Background

Poor sanitaiton allows faecal pathogens to contaminate food and drinking water. The 'Transforming Waste Project' (TWP) is a consortium seeking a robust and high-impact solution to protect water in peri-urban areas (PUAs) by transforming faecal sludge (FS) to high-value products. The solutions proposed by the TWP team are designed for Kanyama, the largest PUA of Lusaka, Zambia. The approach underpinning the project is that technologies for FS management (FSM) must be locally-appropriate, feasible and – importantly – desirable for end-users. Anaerobic digestion (AD), when used as a core FSM technology, incorporates many sustainable benefits, especially for PUAs. AD converts biowaste into a combustible biogas and a soil fertiliser. Relative to aerobic treatment processes, AD is low-cost, energy-efficient and low-tech. Integration of AD with sludge drying beds modified for nutrient (N, P & K) recovery shows promise.

Site Investigations

Kanyama is not yet serviced by a centralised sewage network (Kennedy-Walker *et al.,* 2015). The Kanyama Water Trust (KWT) estimates a major deficit in the availability of pit latrines and that a majority is in poor condition. Partnering with the UK-based NGO, Water and Sanitation for the Urban Poor, the KWT implemented an FSM service for Kayama in 2013. It is a model system and has revolutionised FSM in Kanyama. The treatment stage comprises a fixed-dome digester and conventional drying beds (WSUP, 2015). Following extensive investigations of the socio-technical dynamics of the sanitation situation in Kanyama, the TWP designed and tested a treatment system – making small, modifications to the system managed by the KWT (**Table 1**). The new system focuses on enhanced recovery of energy and nutrients, the value of which would help underwrite less lucrative stages of FSM, such as FS containment, collection and safe transport.

Laboratory-scale Technology Proof-of-Concept

The transforming waste digester (TWD) comprised a 20-l cylindrical bioreactor operated at 37°C. FS were manually fed to the TWD, and was retained by a strategically placed, descending baffle. By the final 10 days of the start-up period, the TWD was facilitating a 17%-reduction in both total solids (TS) and volatile solids (VS). Biogas was produced immediately after start-up. The biogas methane concentration increased over the trial, and the average concentration was 55% during the final 10 days, equating to a methane yield of 0.88 l $CH_4/gVS_{removed}$.

The modified drying bed design incorporated a fixed, non-regenerative medium, clinoptilolite. To assess design and scale-up parameters, dynamic column experiments were done at a range of flow rates (referred to as empty bed contact time (EBCT)), NH_4-N concentrations and TS concentrations. Operation at low hydraulic loading rates (EBCT of 354 min) was most efficient with respect to NH_4-N capacity (60 g NH_4-N/kg clinoptilolite). Operation of the drying bed at long EBCTs would, however, require a significantly larger footprint (17.7 times greater) than a system with a lower (20-min) EBCT. Additionally, though, the media capacity would be lower (5 g NH_4-N /kg clinoptilolite) in a system with a short EBCT. The full saturation of the clinoptilolite in the configuration outlined (**Fig. 1**) would provide a fertiliser product with a grade of 5.9 wt.% NH_4-N.

Table 1. Comparison of current digestion operational conditions in Kanyama with the proposed combined digestion and nutrient recovery system

	Component	Design Comparison		Reasoning
		Current	Proposed (TWD)	
Digester	Feeding Mechanism	Semi-continuous, manually	Semi-continuous, manually	The feeding relies on the number and size of collections in a given day
	Sludge Removal	Roughly bi-weekly, pumped out	Simultaneous displacement of stabilized sludge and liquid effluent during feeding	Reduces the need for pumping and secondary transport
	Retention Time	45-60 days	30 days	Faster retention time means that for a given digester size, more waste can be treated in a set time period
	Mixing	Not mixed	Intermittent (minimal) mechanical mixing	Increased microbe-substrate contact, more thorough stabilization and higher biogas yields
Drying Bed	Nutrient Capture	Unknown	N & K upon non-regenerative media: Clinoptilolite and P & C in the sludge cake	Recovers key nutrients, which can be lost during percolation
	Nutrient Reuse	Organic fertilizer	Mixing at appropriate C:N:P ratios for use as nitrogen-rich fertilizer	Produces a consistent, high-value end-product

Project Conclusions

- The developing world is in a unique position to implement sustainable sanitation technologies, and AD has clear potential.
- The use of revenue generated from the revovery of valuable end-products from FS to underwrite less lucrative stages of FSM should be investigated further.
- The adaptation of sludge drying beds is a feasible method for the recovery of key macro-nutrients (N, P, K) required in agriculture. Clinoptilolite has great potential as a non-regenerative media for the drying bed application**.**

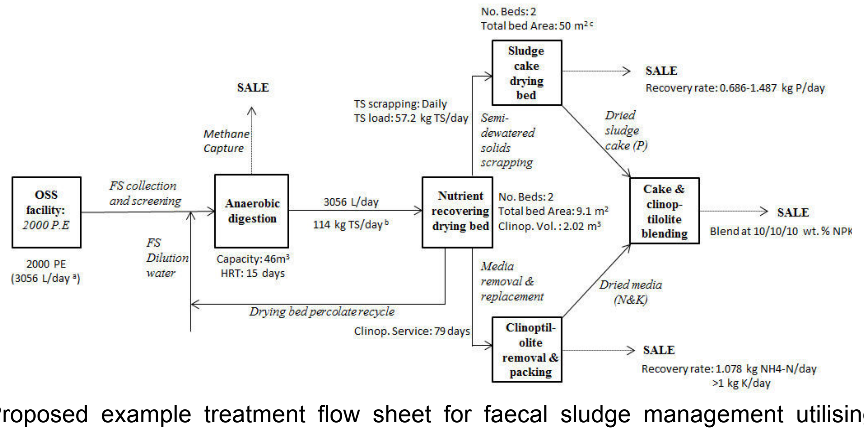

Figure 2. Proposed example treatment flow sheet for faecal sludge management utilising AD and nutrient recovery drying beds. Population equivalent (PE) of 2000 utilised for faeces and urine production rates

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Dewatering Pre-Treatment of Faecal Sludge in Urban Slums

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Keywords: Decentralized; Dewaterability extent; Pit latrines faecal sludge.
Conference Track: (1) Research Track
Track Topic: Characterization and quantification of faecal sludge
Personal Preference: Oral presentation

Introduction

The use of on-site sanitation technologies is high in many urban areas of low income countries (Strande 2014). However, faecal sludge management (FSM), once the facilities are full still remains a challenge. Less than 50% of the faecal sludge (FS) quantities generated is collected, of which 25% is received at centralized plants for appropriate treatment (Blackett et al. 2014). The rest is either unemptied or disposed of indiscriminately onto surrounding land, water courses or unsafely used in agriculture/ aquaculture (Klingel et al. 2002; Murungi & van Dijk 2014). The uncollected FS is mainly found in urban slums, the densely populated areas in cities, often located on marginal land and inhabited by the poor. Some of the challenges of collecting FS from these areas are high emptying costs due to long haul distances and/or high density of housing units, which limits access by emptying equipment such as vacuum trucks. Consequently, the affected slum dwellers resort to unhygienic practices of emptying FS into the living environment or disposing it into nearby open drains (Murungi & van Dijk 2014), posing high risks to human health and environmental pollution. These challenges necessitate modified emptying equipment such as the *gulper*. More so, the challenge of transportation and treatment of emptied FS could be solved by treating FS at or near the point of generation (decentralized) (Semiyaga et al. 2015).

Since FS is over 90% water, dewatering it presents an important first step of managing it effectively. This study linked relevant characteristics of FS from pit latrines (the most common sanitation technologies found in urban slums) to two dewaterability measures; that is dewaterability rate (rate at which water filters out of the sludge) expressed in terms of capillary suction time (CST) and dewaterability extent (percent dry solids in the sludge cake) (Peng et al. 2011). In this context, lined pit latrines consist of cement-mortar sealed containment pits that prevent liquid loss, while unlined pit latrines permit infiltration into the surrounding soils.

Materials and Methods

The study was carried out in three typical urban slums of Kampala (Uganda), with limited access to vacuum truck emptying. A total of 22 and 10 FS samples were collected from lined and unlined pit latrines, respectively, using a multi-stage sampler (Semiyaga et al. 2016). FS from these pits was measured for TS, conductivity, COD, moisture content, TVS, crude protein, ash, sand content and particle size distribution. Particle size distribution was determined by sieving FS samples under a water jet. The relationship of these parameters to the two dewaterability measures (CST and % cake solids) within and between FS from each pit latrine category was established.

Results and Discussion

The presented findings are based on a published article (Semiyaga et al. 2016). The average dewaterability extent of FS from unlined pit latrines (31.8%) was significantly higher than that from lined latrines (18.6%) (p = 0.000), while the dewaterability rate (1122 and 1485 seconds of FS from lined and unlined pits, respectively) was not significantly different (p = 0.104) (Figure 1).

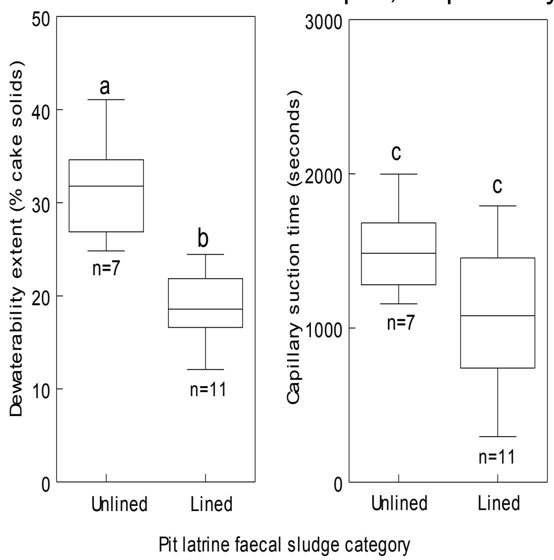

Figure 1 Dewaterability extent (left) and dewaterability rate as CST (right) of FS from lined and unlined pit latrines.

Differences in dewaterability extent between FS from lined and unlined pit latrines was largely related to initial TS, TVS and sand content. Dewaterability extent of FS from lined pits significantly decreased with increasing TVS (R^2 = -0.459, p = 0.016), but this was not the case with FS from unlined pit latrine. Based on the results in this study, TS values of FS from lined and unlined pit latrines in Kampala slums (51.4±29.2 and 177±78.1 g/L, respectively) are similar to reported values of mixed FS (from pits and septic tanks collected in Accra and Dakar) after thickening

About 38% and 48% solids in FS from lined and unlined pits, respectively, were of diameter > 0.1 mm, hence settleable and can be removed by sedimentation pre-treatment. Additionally, FS from lined pits had higher proportion of fine solids (true and supra colloids). Change in particle proportions had no significant relationships to dewaterability extent for FS from all pit latrine categories with the exception of size > 1mm in FS from unlined pit latrines, where increasing size significantly reduced dewaterability extent (R^2 = -0.7524, p = 0.005).

Conclusions and Implications

The results from this study suggest that FS from pit latrines in Kampala can be conveniently dewatered without thickening, thereby reducing costs of FS management. The pit latrine FS from studied slums can then be directly loaded to drying beds, thereby saving time, costs and space required for FS thickening. After decentralized dewatering, the liquid stream can join sewer lines (for slums which straddle sewer lines), while the reduced solid stream can be transformed into useful products within slums or less expensively transported to treatment plants, where it can be directly loaded to drying beds.

The results further show that to maintain high dewaterability extent; TVS should be reduced and sand content increased in FS from lined pit latrines while the particle sizes should be ≤ 1 mm in FS from unlined pit latrines.

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Faecal Sludge Dewatering: Two New Research Facilities for a Multi-Directional Approach

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Keywords: treatment; dewatering; on-site sanitation
Conference Track: (1) Research Track
Track Topic: Technologies for the collection, transport, treatment, and disposal of faecal sludge
Personal Preference: oral presentation

Introduction

Separation of solids and liquids before faecal sludge (FS) treatment is essential for safeguarding public health and environmental safety. FS collected with vacuum trucks commonly comprises more than 95% water, making it heavy and expensive to transport. Efficient dewatering is an essential step in increasing the feasibility of FS transport, treatment, and resource recovery. In contrast to treatment of wastewater sludge, knowledge of FS dewatering is lacking at both fundamental and empirical levels. In 2016, Eawag in Switzerland and the University of Dar es Salaam in Tanzania started conducting research on dewatering of FS at two new research facilities, working together towards closing these knowledge gaps.

The goal of this collaboration is to approach FS dewatering from the fundamental level to applied field testing and to employ iterative problem solving for the testing and piloting of new, innovative dewatering and resource recovery technologies. Current research assesses the influence of urine and solids concentration on FS dewatering at the WaterHub in NEST and the use of conditioners to increase dewatering efficiency on drying beds at the University of Dar es Salaam.

Figure 1. Left image: The NEST building with a residential research module installed on the second floor; Centre image: Pipes leading into the WaterHub laboratory, separately transporting FS, urine, and greywater to research stations; Right image: The FS dewatering facility in Dar es Salaam.

Dewatering research facilities

The NEST building at Eawag provides experimental space and a living laboratory for applied research on building materials, energy, and water. Individual housing unit sized research modules can be installed into the NEST building in order to test innovative construction concepts (Figure 1). Liquid waste streams from the building are separated at the source and FS, urine, and greywater are piped separately to the basement, where resource recovery-oriented sanitation technologies, starting with dewatering, are being tested in the WaterHub laboratory. This facility allows for the laboratory research with focus on fundamental knowledge. The dewatering facility at the University of Dar es Salaam has been designed for pilot-scale experiments. FS is dewatered there with settling-thickening tanks and drying beds. Effluent is co-treated with wastewater in waste stabilization ponds. This facility allows for the empirical testing of findings from laboratory research.

Materials and methods

FS collection and storage facilities are currently under construction at the WaterHub in NEST. In order to simulate incoming FS while construction was underway, synthetic FS was developed based on (Colón et al., 2015) and (Penn et al., in preparation). FS at different concentrations of synthetic faeces (4 wt% and 25 wt%) was mixed with different urine concentrations (0% v/v, 7% v/v, and 100% v/v). Capillary suction time (CST) and sludge cake TS after centrifugation were used as indices for dewatering rate and efficiency, respectively. Samples were also analysed for chemical oxygen demand (COD), total nitrogen (TN), ammonia nitrogen (NH_4-N), pH, electric conductivity (EC), total solids (TS), total suspended solids (TSS), total volatile solids (TVS) and viscosity. At the University of Dar es Salaam, FS from septic tanks and pit latrines was collected from vacuum trucks. Jar test, Imhoff cone and CST analysis based on (Gold et al., 2016) were used to identify the optimal dosage for FS conditioning with chitosan in Dar es Salaam. FS was conditioned with dosages between 0 and 5 mg/g TS. Samples were also analysed for TS, TSS, TVS and COD.

Results

Results from the WaterHub in NEST indicate that FS dewatering rate and dewatering efficiency decrease with increased TSS. Increased urine concentration resulted in decreased viscosity of synthetic FS. There was no observable influence of urine concentration on dewatering rate, but urine addition decreased dewatering efficiency. Results from conditioning experiments in Dar es Salaam indicate that chitosan increases FS dewatering rate between 30 and 90% depending on the dosage, with influent total solids (TS) of 0.05-0.1%(Kimwaga et al., 2016). Results appear to be comparable to results from Dakar (Gold et al., 2016) and Kampala (Sandec, unpublished data). The optimal conditioner dosage will be a trade-off between increased dewatering efficiency and cost.

Conclusions

Optimal chitosan doses and several important parameters governing FS dewatering have been identified. Presented results will include ongoing research. An Aquatron passive solids-liquids separator is being evaluated to concentrate incoming FS, which will be collected and used for future experiments at the WaterHub in NEST. Trials of conditioning with chitosan and characterization of leachate are underway in Dar es Salaam.

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Urban Risk Factors Associated With Enteric Infection In Children: The Role Of Toilets, FSM, And Flooding In A Low-Income Neighborhood Of Vellore, India

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Keywords: enteric infection, open drains, sanitation
Conference Track: Research Track
Track Topic: *Health, safety, and hygiene*
Personal Preference: *oral presentation*

Background and context

Poor sanitation conditions contribute to pediatric enteric infection and longer-term health outcomes. In low-income urban settings, coverage of toilets is often poor, open drains are common, and thus fecal sludge management is an issue. However, the effects of exposure pathways through which these conditions affect child health have not been quantified, including the effects of the density and geography of an area and a child's frequency of contact with fecal contamination both inside and outside the home.

Nature of the issue addressed

This study examined the contributions of the household and neighborhood environments to pediatric enteric infection risk. Specifically, we evaluated how a young infant's risk of enteric infection varied with the presence of household toilets, the type of fecal sludge management associated with a toilet (e.g. toilets discharging to an open drain vs. ones containing feces onsite), and the presence of flooding in the neighborhood.

Scale and time-frame of the project

The scale of this study was in a single, low-income, urban neighborhood in India. Data was collected over 5 years. Children were followed from birth to 2 years of age over a 4 year follow-up period, with exposures assessed at the conclusion of the follow-up period.

Methodology, lessons learned, recommendations

Over their first two years of life, diarrheal and routine (monthly) stool were collected from 230 children and assayed for enteric pathogens as part of a large, multisite cohort study (The MAL-ED Network Investigators, 2014). Exposures, including the presence and type of household sanitation and physical and spatial attributes of the neighborhood, were assessed using spatial data and interviews with caregivers in 100 of these households. Exposures associated with infection risk were evaluated by mixed effects logistic regression.

Household toilet coverage and FSM were poor (33% coverage of toilets, of which 82% discharged to open drains) and open drains were ubiquitous in the study neighborhood. Household toilet presence was associated with lower risk of any enteric infection overall (OR: 0.73, 95% CI: 0.55-0.97). However, this protective association varied by season for households with a toilet discharging directly to drains: compared to households without toilets, the presence of this type of toilet was associated with 39% lower risk of enteric infection during the dry season (OR: 0.61, 95% CI: 0.41-0.91), but no difference in enteric infection risk during the northeast monsoon (OR: 1.10, 95% CI: 0.66-1.85). Within the neighborhood, residence in the spatial cluster of reported drain flooding, regardless of the frequency of reported contact, was associated with significantly higher risk (OR: 2.39, 95% CI: 1.24-4.63) during the northeast monsoon compared to the dry season (Figure 1).

Lessons learned and recommendations are at both the household- and neighborhood-levels. At the household, direct discharge of toilets into drains—a lack of effective FSM—may prevent toilets from being functional during periods of heavy rain and flooding, inhibiting the protective effect of toilets on children's health. Thus, planning for containment of fecal sludge in household tanks with construction of toilets, rather than *de facto* connections to open drains, is necessary. At the neighborhood-level, low coverage of household toilets, most with poor FSM, combined with prevalent open drains may increase the health risk for children in "downstream" households. Effective FSM, in this case, includes mitigation of flood risks to contain fecal sludge and prevent open drain flooding.

Significance and impact of project on fecal sludge management

This study's results show some of the first evidence of the important intersection between urban environments, types of fecal sludge management associated with household toilets, and health risk in young children. This study both confirms some previous hypotheses about the risks from poor FSM and provides new insight into how this risk manifests in low-income, urban settings. Poor FSM at a household can have health implications beyond that household, especially where neighborhood-level FSM is poor and open drains are prevalent. In such areas, risk from these drains is present regardless of the frequency of contact because the levels of fecal contamination are so high.

Conclusions

While household toilet use may protect against enteric infection, poor FSM conditions can influence exposures in the household and neighborhood environment, with implications for children's health in that and other downstream households. Many of these exposures are not controllable by the household alone, necessitating FSM interventions to reduce fecal contamination in the public domain as well.

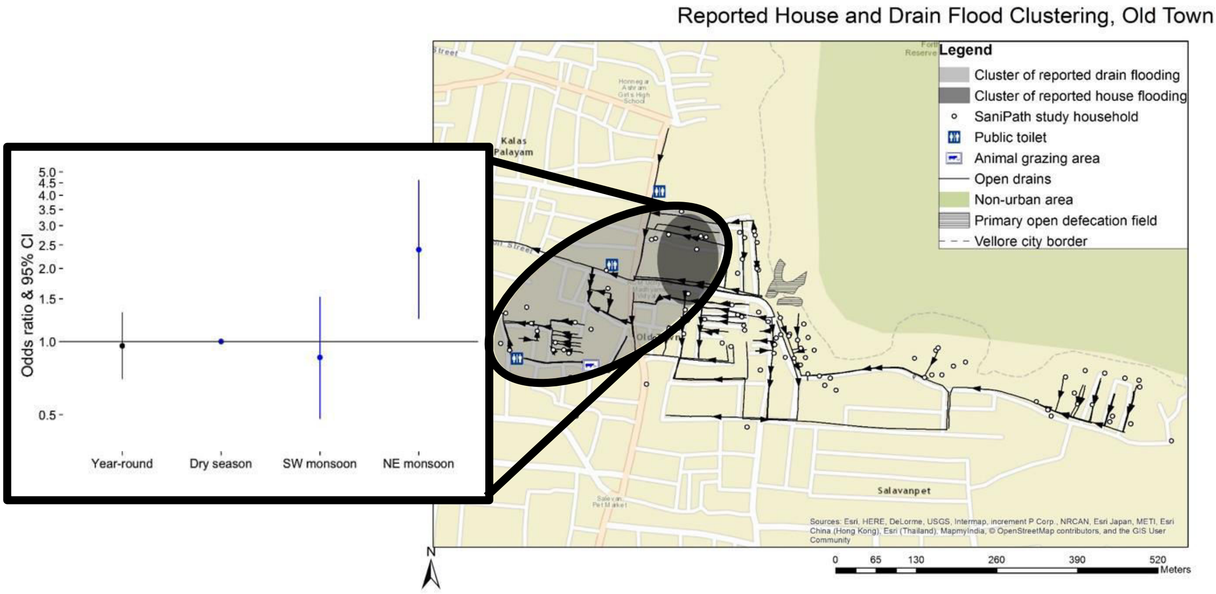

Figure 1: Seasonal associations between clustered drain flooding and enteric infection risk. Children living in the spatial cluster of drain flooding (identified by the large, gray ellipse on the neighborhood map) had more than twice the risk of enteric infection during the northeast monsoon season than in the dry season, while the risk of enteric infection for children living elsewhere in the neighborhood did not vary by season.

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Faecal Sludge Management in Urban and Peri-urban Areas of LMICs: Challenges and Sustainable Solutions

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Keywords: faecal sludge management; business models, innovation

Conference Track: (1) FSM case Study Track
Track Topic: *At scale city-wide or nationwide FSM services*
Personal Preference: *oral presentation*

The Joint Monitoring Programme's update on the Millennium Development Goals progress (WHO/UNICEF, 2015) reports that 53% of the urban population in low and middle income countries (LMICs) still rely on on-site unimproved sanitation. These sanitation systems accumulate faecal sludge, which needs to be safely emptied, transported, treated, disposed of and/or reused (Peal et al. 2014). The problem of managing faecal sludge in informal and densely populated areas of LMICs is exacerbated by high urbanisation rates and lack of space for mechanically emptying pits, which makes of faecal sludge management (FSM) an urgent environmental and public health issue to be tackled.

Providing sustainable and safely managed sanitation in the rapidly-growing urban settlements and peri-urban areas of LMICs requires solving a complex nexus of problems (Chowdry and Kone, 2012). FSM is not merely a technological problem linked to a particular type of sanitation or emptying technology, but it strongly relates to other soft issues such as appropriate planning and management, the establishment profitable business models and appropriate governance mechanisms. The current state of FSM in LMICs suggests that a lot is yet to be done to increase demand for FSM products and services among consumers, to design and market better sanitation technologies, improve maintenance, emptying and transport of products/services, and to get treatment, re-use and final disposal of faecal sludge.

We conducted a review of organisations/ventures, which provide technologies and services along the FSM chain and operate in LMICs. We searched the grey and academic literature for reports, web resources and peer-reviewed publications ad identified 40 organisations/ventures providing products/services and business models along the FSM in LMICs. Fourteen of these organisations/ventures have reportedly reached scale (i.e. they have proven to work in different settings and contexts), 19 have been piloted at various level and three of which are still at prototype stage.

We then contacted the organisations/ventures which reported to be at scale and conducted interviews gathering information concerning a) Target customers; b) Demand generation models; c) Product/technology details; d) Business Model; e) Costs and f) Enabling environment.

The organisations/ventures reviewed were classified in two categories of innovation. The first category relates to innovative technologies/product and services offered by the screened organisations/ventures. Under this category, four types of innovative products/services were identified. The second category of innovations which emerged from our review relates to the business models proposed by the organisations/ventures in delivering the sanitation and FSM improvements. Under this second category we identified four types of innovative business models. An important consideration which emerged from our study is that the majority of the models investigated are still not financially sustainable. These in fact are unable to generate revenues that go beyond the recovery of operational costs and being supported by external funds for start-up and scaling-up activities or internally by other more profitable areas of business within the same organisation/venture.

The significance of our study to the advance of knowledge of FSM is twofold. Firstly, our study allows to characterise problems and bottlenecks in the FSM chain, which are typical to many urban and peri-urban areas of LMICs, thus highlighting knowledge gaps and future research and development needs. Finally, our study provides an overview of the most up to date state of the art in terms of products and services to address the FSM chain.

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Assessment Of Public Health Risks From Unsafe Fecal Sludge Management In Accra, Ghana

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Keywords: public health risk; unsafe fecal sludge management; fecal exposure pathways

Conference Track: Research Track

Background

The SaniPath tool (SaniPath.org) is a rapid assessment decision making tool for local government and development partners designed to assess public health risks related to unsafe fecal sludge management in low resource urban settings and help prioritize sanitation investments based on exposures that have the greatest public health impact. The SaniPath tool has been used previously to evaluate fecal exposure pathways in some poor neighborhoods of Accra in Ghana, Vellore in India and Maputo in Mozambique. In this study, the SaniPath tool was deployed in Accra, Ghana in order to evaluate whether the tool can be used to characterize city level exposure to fecal contamination using a sub set of representative neighborhoods with varying sanitation coverage, population density and socio-economic status.

Methods

Data collection took place from April to August 2016. Four representative neighborhoods of varying sanitation coverage, population density and socio-economic status were selected using Ghana Statistical Service 2010 census data and Accra Metropolitan Authority poverty map. The 4 neighborhoods were classified using a score scale into “very poor”, “poor”, “moderate” and “good” sanitation neighborhoods. The SaniPath tool is a 2-4 week assessment per neighborhood including a) behavior surveys to understand how frequently people come into contact with fecal contamination from different environmental sources and b) environmental sampling and analyses to quantify *E.coli* concentration in these different environments.

In each neighborhood, three key informant interviews and transect walks with community leaders were conducted. The transect walk involved mapping key sanitation related facilities to inform environmental sampling. Subsequently, 100 head of household surveys, 6 community surveys with male and female groups and 2 schools surveys with children were conducted in each neighborhood. Relevant samples in each neighborhood from ocean water, open drains, produce, drinking water, soil, public latrines and flood water were collected and analyzed. Data from the surveys and environmental samples collected were combined to determine the risk profiles of each neighborhood using Bayesian methods.

Results

Results show that the produce pathway has the greatest risk of exposure to fecal contamination irrespective of the sanitation classification of the neighborhood. The proportion of people exposed did not vary significantly, ranging from 93% to 96% exposed across all four neighborhoods. In addition, there was no significant difference in the level of average *E.coli* concentration of produce across all 4 neighborhoods. The average *E.coli* concentration was high, ranging from about $10^{6.18}$ CFU per 100ml to $10^{7.14}$ CFU per 100ml across all 4 neighborhoods. The driver for the greatest risk of exposure to fecal contamination is the reported high frequency of eating produce and the high *E.coli* concentration of produce across all 4 neighborhoods.

Conclusions

Unsafe fecal sludge management can lead to exposure to fecal contamination resulting in increased burden of diarrhea diseases if pathways of fecal transmission are not identified and interrupted. Decision makers need evidence to better plan and prioritize sanitation investments at the city level in resource poor settings. Using publicly available data may assist decision makers at the city level aggregate risk of exposure to fecal contamination from representative neighborhoods and plan city wide interventions that may reduce the associated public health risks irrespective of the population density, socio economic status or sanitation coverage.

Exposure to Fecal Contamination in 3 low-income urban settings: Results from the SaniPath Tool

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Keywords: Urban Sanitation, Exposure Assessment, Tools

Conference Track: (*choose one*) (1) Research
Track Topic: *Health, Safety, and Hygiene*
Personal Preference: *Oral Presentation*

Background and Context

The SaniPath Exposure Assessment Tool is designed to estimate risks of exposure to fecal contamination in low-resource urban settings. The Center for Global Safe Water, Sanitation, and Hygiene at Emory University used the lessons learned from an in-depth, 2-year, investigation in Accra, Ghana to develop the SaniPath Tool. The tool is a simplified, yet informative, means of characterizing the risk of exposure to feces from multiple transmission routes in the public domain in order to inform advocacy, prioritize investments, and respond to complex urban sanitation needs. This presentation details the results of using this tool in three different cities: Accra, Ghana; Vellore, India; and Maputo, Mozambique.

Nature of the Issue Addressed

Rapid urbanization has led to a growing sanitation crisis in urban areas of low-resource countries. However, there are little data to inform strategies to mitigate risks of exposure to fecal contamination. Each of the three cities that are described in this presentation grapple with multiple urban sanitation challenges that are experienced by many cities in low-income countries.

The Greater Accra region is the most populous in Ghana with over 4 million inhabitants and an estimated rate of urbanization of 3.4%.This rapid urbanization has exacerbated problems with the poor provision of sanitation services and fecal sludge management (FSM). Less than 15% of the fecal sludge generated by Accra and other large cities in Ghana is effectively treated (Government of Ghana, 2010) and the remainder flows into open drains or is discharged directly onto the beach by tanker trucks.

Maputo, Mozambique is a rapidly urbanizing city on the south east coast of Africa. The majority of urban residents who lack access to basic sanitation live in peri-urban unplanned communities surrounding Maputo. Approximately 90% of households use on-site sanitation, and between 8-25% of total fecal waste is safely managed). A 2001 WHO report indicated that diarrheal disease was the third leading cause of death in Maputo, accounting for 10% of all deaths.

Vellore is located in the state of Tamil Nadu in south India. It is a city of approximately 500,000 people in a “dry sub-humid to semi-arid” climate). Gastrointestinal disease is the second most common pediatric illness in this study area and accounts for approximately 27% of all reported illness. 51% of households in the recent MAL-ED study of pediatric enteric infections in Vellore had no sanitation facility and 35% had a toilet that flushed to an open drain.

Scale of the Study

Data were collected from 5 neighborhoods in Accra, 2 neighborhoods in Vellore, and 2 neighborhoods in Maputo. Cross sectional data were collected April-June 2016 in Accra, February- March 2014 in Vellore, and April-May 2016 in Maputo.

Methodology, Lessons Learned, and Recommendations

The SaniPath Tool provides a standardized methodology, with a customizable format, that guides the user through a rapid 4-6 week assessment that includes both behavioral and environmental microbiology components. The behavioral survey was used in households, schools, or community groups and assesses the frequency of behaviors of children and adults that may bring them into contact with fecal contamination. Simple microbiology methods were employed to quantify the concentration of *E. coli* (as an indicator of the magnitude of fecal contamination) in environmental samples from various exposure pathways. Pathways of exposure include: contact with surface waters, contact with public latrine surfaces, ingestion of raw produce, contact with drains, contact with flood water, and ingestion of municipal drinking or bathing water. Behavior and environmental data are combined, along with other parameters, and analysed using Bayesian methods to develop risk profiles. The risk profiles illustrate the estimated percentage of the nieghborhood population that are exposed to fecal contamination in a particular pathway and the mean dose (average amount of *E. coli* ingested per month). The risk profiles can be used to compare exposure pathways, compare neighborhoods, or compare age groups (adults/children). The dominant exposure pathways are the pathways that likely pose the greatest risk of exposure to fecal contamination within a neighbourhood.

Results indicate that the dominant exposure to fecal contamination in Accra was through ingestion of raw produce (mean log10dose=6.0-7.1 cfu *E. coli*/month). Ingestion of raw produce (mean log10 dose= 7.9-14), and exposure to flood waters (mean log10 dose= 6.5-8.6 cfu *E. coli*/month), were the dominant pathways in the study neighbourhood in Maputo .In contrast, in Vellore, the dominant pathways were piped drinking water (mean log10dose=4.2-4.9 cfu *E. coli*/month) and drain water (mean log10dose=3.7-4.1 cfu *E. coli*/month).

Overall, the greatest variability in exposure to fecal contamination between the 3 cities was in the drain pathway. The study found moderate levels of fecal contamination in municipal drinking water and that a high proportion of population were exposed to contaminated drinking water. Finally, our results indicate that produce consistently had high levels of fecal contamination, but the proportion of the exposed population varied by city due to cultural differences in diet. Sanitation planners can use this information on geographic differences and pathway differences to target investments to areas/pathways of greatest risk.

Significance

Despite the considerable sanitation needs of urban and peri-urban communities, there are little data to inform strategies to mitigate risks of fecal exposure in low-income countries. There is a need for site-specific evidence to inform decisions about sanitation investments. The impact of poor urban sanitation services and FSM on food safety, and the risks from fecal contamination of the food supply have been under-recognized by water and sanitation professionals and municipal governments. The widespread practice of wastewater irrigation of food crops in urban and peri-urban areas can threaten the safety of food supply and health of the whole urban area as contaminated produce moves throughout the city.

Conclusions

The SaniPath Exposure Assessment Tool can assess public health risks from exposure to fecal contamination due to inadequate sanitation services and FSM. The risk profiles generated show how exposure to fecal contamination varies across neighborhoods in a single city and across pathways for three different cities. These exposure assessments can inform advocacy, prioritize investments, and promote evidence-based responses to complex urban sanitation needs.

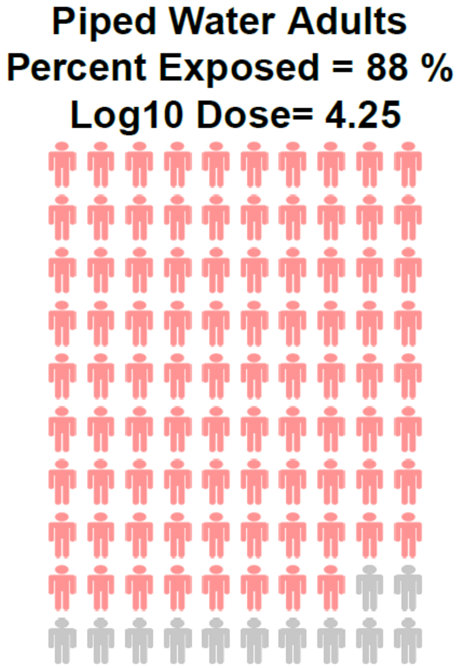

Figure 1.1 Example risk profile. The percent exposed to fecal contamination is represented by the number of red people, while the darkness of the red color represents the estimated mean dose (average *E. coli* cfu ingested per month)

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Decentralized Treatment Strategies For Septage Management

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Keywords: Septage dewatering; Co-composting; Sustainable treatment

Conference Track: FSM Research Track
Track Topic: Technologies for the collection, transport, treatment and disposal of faecal sludge
Personal Preference: *Oral presentation*

Motivation for the study

In developing countries like India, where majority of the population depends on septic tanks as their sole wastewater treatment facility (Census,2011), the septic tank waste (septage) are mostly letting out untreated which cause groundwater and surface water sources contamination (Daughton and Christian, 2011) and lead to serious health threats. Even though septage is harmful, it's rich in organics and nutrients. A decentralized treatment strategy will help in reusing septage waste as a resource like fertilizer once properly treated. Though the National Urban Sanitation Policy (NUSP, 2011) suggests composting as a sustainable septage treatment option, there exists no description about the proper mechanism for septage composting. Therefore there arise a pressing need for sustainable treatment for septage.

Approach

The septage collected from different parts of Chennai city were pooled together to get representative samples. Since septage contains larger volume of water rather than solids, direct treatment is not advisable. A solid liquid separation (dewatering) approach can reduce the pollutant load in the filtrate to a significant level which can be either send to existing sewage treatment plant (STP) or constructed wetlands/similar systems for further treatment while the septage solids can be hygienised to get useful product like humus.

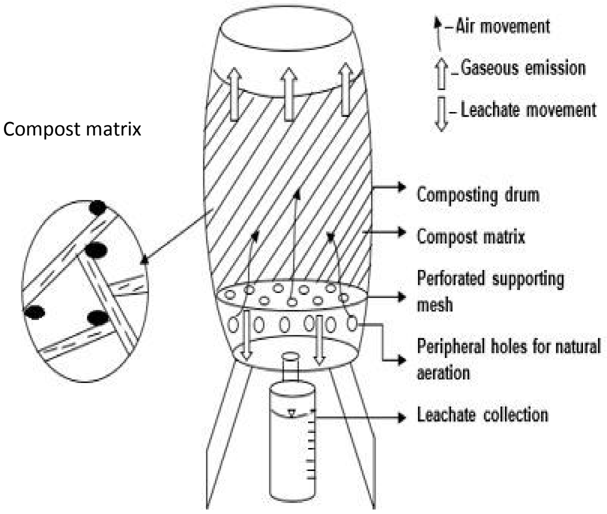
Septage dewatering

Four sustainable dewatering options like i) sand drying bed, ii) reed drying bed, iii) solar drying and iv) alum coagulation were evaluated. Among these methods, sand drying bed and reed drying bed were found to be better options as they are less time consuming, economical, eco-friendly and suitable for wide range of pollutant load. The efficiency of alum coagulation depends on total solids concentration and solar drying depends on prevailing climatic conditions, which are highly variable in nature.

Septage co-composting in laboratory scale in-vessel system

The dewatered septage solids obtained from drying beds were subjected for composting. Since the septage has low carbon to nitrogen (C/N) ratio, it need to be blended with higher C/N ratio materials to have effective composting. Mixed organic waste which comprises of green vegetables, cooked waste, paper waste, cow dung, coir pith (as bulking material for moisture reduction and to increase C/N ratio) and wood chips (structural material that resists compaction and maintains air filled porosity) were used as co-composting material.

Figure 1 shows the laboratory scale in-vessel system for septage co-composting. The feedstock composition were found to be optimum for co-composting as the temperature profile (Figure 2) of the composting pile initially attained mesophilic stage and later developed thermophilic stage. The retention at higher temperature i.e., >55^{o}C for more than 3 days as shown in Figure 2, ensured significant pathogen reduction. The characteristics of initial compost mixture and final compost, after 20 days of treatment are given in Table 1.



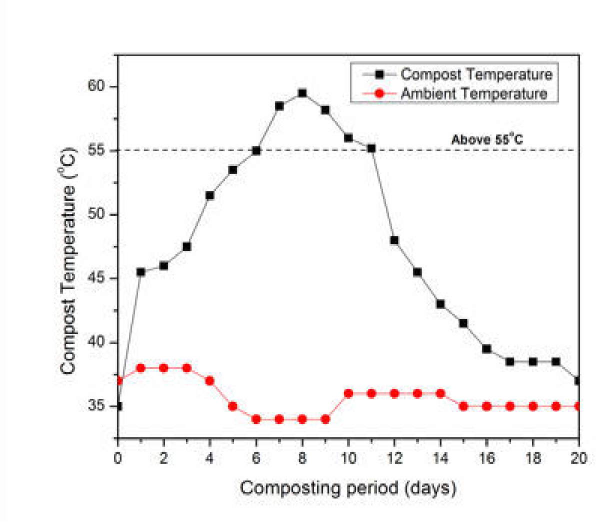


Figure 1. Laboratory scale in-vessel co-composting system

Figure 2. Temperature profile

Table 1. Chemical properties of the compost before and after the in-vessel co-composting.

Parameters	In-vessel co-composting	
	Initial	Final
pH value	3.9±0.5 [a]	7.9±0.5
EC (dS/m)	1.9±0.8	1.5±0.7
Moisture content (%)	78±0.5	69.7±0.3
Total Carbon (% dw)	38.7±1.4	34.1±2.5
Total Nitrogen TN (% dw)	1.9±0.2	2.9±0.3
Total phosphorous TP (g/kg dw)	2.3±0.6	3.1±0.5
C/N ratio	20.1±1.4	11.7±0.4
Faecal coliforms (CFU/g)	2.9×10^3	3
Total coliforms (CFU/g)	7.3×10^3	8

a- Mean ± Standard deviation (n=3), dw- dry weight or total solids, CFU- Colony Forming Units

The results showed that the in-vessel co-composting helped in rapid degradation (within 20days) and yielded good quality ripened compost with enough nutrient content suitable for using as a fertilizer.

Conclusion

Proper mixing of feedstock materials resulted in obtaining the final ripened compost within 20 days of composting operation. The final compost have an average TN of 2.9% and TP of 0.31%. The low temperature (37-39°C) and low C/N ratio (11.7) confirms the stability of final compost. The seed germination test results of the compost extract showed a germination index above 100% which indicates a matured compost. Therefore the selected feedstock composition is suitable for effective septage treatment via co-composting and the final product is suitable for the application as a soil conditioner.

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Development of On-site Faecal Sludge and Septage Treatment Techniques

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Key words: On-site faecal sludge treatment; leach pit life extender; mobile treatment unit.
Conference Track: (1) Research Track
Track Topic: Technologies for the collection, transport, treatment and disposal of Faecal Sludge
Personal Preference: *Oral presentation*

Abstract

Sanitation facilities are broadly classified as on-site and off-site systems. In on-site systems, the excreta is retained, confined, and treated at the site of defecation, whereas in off-site systems it is taken away (typically through a water-based underground sewerage network) for treatment and disposal in distant sewage treatment plants. On-site sanitation systems (leach pit and septic tank) demand handling and disposal of partially stabilized/treated excreta (septage) to ensure hygiene.

Of the 247 million households in India, about 123 million have sanitation services. Out of these about 55 million have installed septic tanks and 19 million have leach pit latrines (Govt-India-Census, 2011). A conservative estimate indicates about 64 million household toilets require faecal sludge management (FSM) across the country. There are challenges with leach pits which fill frequently and hence require frequent removal - especially in water logged areas. There are any elements in the conventional practice of faecal sludge emptying/collection: transportation, treatment and disposal; and transportation is a major factor in determining the profitability (and therefore sustainability) of the Faecal Sludge Management (FSM) business. A consequence of this has been unsanitary "dumping" of waste resulting in contamination of water bodies in and around urban areas.

In general, the sewage transport through underground drainage and using septage treatment units for treating and disposal requires too high an investment and the majority of urban Indian households use septic tanks which lack proper effluent disposal such as dispersion trench. In addition, every 2 to 3 years (depending on the capacity) the septic tank will require emptying. Due to lack of FSM policy guidelines and strict enforcement, there are number issues in emptying the septic tanks, transportation, treatment and disposal of sludge.

Analysing the gaps and understanding the need for hygienic on-site treatment, the WASH Institute developed a technical design to innovate appropriate products and with funding from Bill & Melinda Gates Foundation via Water For People were able to pilot the design. The WASH Institute then continued work on the design and testing after the maturity of the grant, and Population Service International provided advice on social marketing of the resultant products.

The products developed are an on-site treatment methodology for leach pits (a leach life extender called Septguard) and a mobile treatment technique for emptying, treating and disposing of faecal sludge.

Septguard consists of an effluent extract unit with fabric filter and a membrane filter unit. It accommodates a solid-liquid separation arrangement and effluent treatment part. Field tests have been conducted by WASH Institute over a 9 month period and the treated effluent from the Septguard is meeting the standards laid out under Indian national pollution control for disposal of treated effluent.

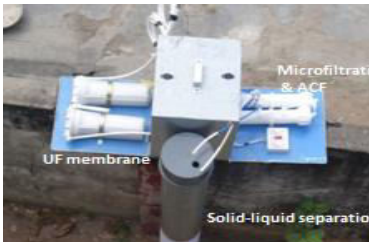

Photo 1. Septguard - Pit Life extender

Photo 2. Mobile faecal sludge

The Mobile Treatment Unit incorporates a sewage pump, a collection tank, solid-liquid separation, effluent treatment unit and centrifuge for decanting sludge.

The analysis of treated effluent for Biological Oxygen Demand (BOD) indicates value below 30 mg/L for both products. The average coliform count in the Septguard model is 540 Nos/100 mL, while it is 490 Nos./100 mL in mobile unit. Both BOD and coliform values are within the Pollution Control board norms of 30 mg/L.

Both the products have shown excellent results during the field tests and now the WASH Institute is planning to tie-up with Duke University, a US based academic institution, to go for systematic testing to develop a standard operating procedure and also customize the products to make them more attractive to consumers. The targeted cost for the Septguard unit is Rs.5000/- ($75) and Rs.650,000/- ($10,000) for the Mobile Treatment Unit.

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From Research to Implementation: BRAC WASH Initiative for FSM in Urban Areas

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Keywords: Market, Organic, Treatment

Conference Track (1) Research Track
Track Topic: *Technologies for the collection, transportation, treatment, disposal and use of faecal sludge*
Personal Preference: *Oral presentation*

Background

Since 2006 BRAC Water, Sanitation and Hygiene (WASH) programme has helped over 41 million people gain access to hygienic latrines and 2.3 million people gain access to safe water across 250 sub-districts of Bangladesh. BRAC WASH has helped to bring about a social transformation in areas where it works, with significant progress on rural sanitation particularly for the poorest families. Success has been achieved over a nine year period not only in the provision of hygienic household latrines, but also in their use by all members of the family. Under the programme, ultra poor households received grants from BRAC, covering the cost of a hygienic household latrine, while poor households qualified for loans. Around 15% of the total number of people reached received grants, and 2% received loans from BRAC WASH. About 31% were motivated to install latrines through self-financing, and 38% were motivated to simply convert unhygienic latrines to hygienic ones. In addition, 14% were reached by mobilising funds from government schemes and other agencies.

Context

Action was required to deal with human waste once hygienic latrines became full. Environmentally safe collection, transport, treatment, and productive re-use of treated human waste within a well-constructed and well-managed sanitation service delivery chain has the potential to safeguard the environment, improve public health, and provide financial benefits to users and service providers. BRAC WASH has done research to develop protocol for reusing the double pit content as organic fertilizer (Dey et al., 2016). The programme has developed and widely circulated this sludge reuse protocol (including information on safe storage and handling) through field trials, leaflets, and posters. From 2016, the programme has started working in urban areas – 35 small towns mostly located in the southern region of Bangladesh. Since the context of faecal sludge management is different in urban areas, BRAC WASH has done two action research studies with BioSol Energy BV and University of Leeds. Based on the findings of these two studies, BRAC WASH is commencing its urban faecal sludge management activities.

Method

The two action research studies focused on few different issues. The one led by University of Leeds focused on small scale co-composting with special emphasis on collection and transportation of faecal sludge. The study analysed the quality of faecal sludge from single pit, double pit and septic tank based latrines. It checked the scope of using different pumps to collect faecal sludge from the pit/tank. Pre-treatment and post treatment of faecal sludge including introduction of bio-drying was part of the research. The study also checked the potential for faecal sludge reuse in the form of compost by doing a plot trial on spinach (Balasubramaniya et al., 2016). Additionally, health and safety issues, financing and tariff structure, market research and institutional factors analysis were done through interviews, focus group discussions and document review.

Table 1.1 Physical and chemical characteristics of FS sample

District	Moisture (wt%)	pH	Conductivity (mmho/cm)	TVS (wt%)	TOC (wt%)	TN (wt%)	C/N	PO_4-P (wt%)
Gazipur	83.68	7.35	3.34	68.56	36.38	3.70	9.52	2.10
Noakhali	88.10	7.08	5.02	68.65	37.23	3.91	10.09	2.13
Khulna	91.34	7.94	4.76	74.37	39.32	3.66	10.91	2.25
Mymensingh	90.54	7.73	3.51	68.09	54.34	3.15	12.83	1.67
Feni	90.54	7.81	4.58	77.88	41.19	3.98	11.12	2.49
Mean	88.84	7.58	4.24	71.51	41.69	3.68	10.89	2.13

TVS = Total volatile solids; TOC = Total organic carbon; TN = Total nitrogen; C/N = carbon to nitrogen ratio

The action research done by Biosol Energy BV focused on collection and processing of faecal sludge at large scale. It used vacutugs of different sizes for collection test. The study checked the feasibility of collection and processing of corn stovers and poultry manure to mix with faecal sludge for biogas production through anaerobic digestion. This research presented a model where the initial feedstock would be 7,000 Mg of corn stovers/year and 3,000 Mg of chicken manure. However this would gradually (over a period of 3 to 4 years) change to 1,000 Mg faecal sludge (content of 40,000 pit latrines), 6,000 Mg of corn stovers and 3,000 Mg of chicken manure.

Present Work

Based on the findings of this action research, BRAC WASH is currently working on starting faecal sludge treatment plants in two different towns of Bangladesh. One of the towns is in southern Bangladesh and the other one is in the north. Programme has done an early survey on the need for FSM in those towns. Based on the survey, the programme has conducted dialogues with the respective town municipalities to seek support and mobilization of logistics from their end. A working plan has been developed in coordination with the municipality to carry out full scale faecal sludge management in these towns.

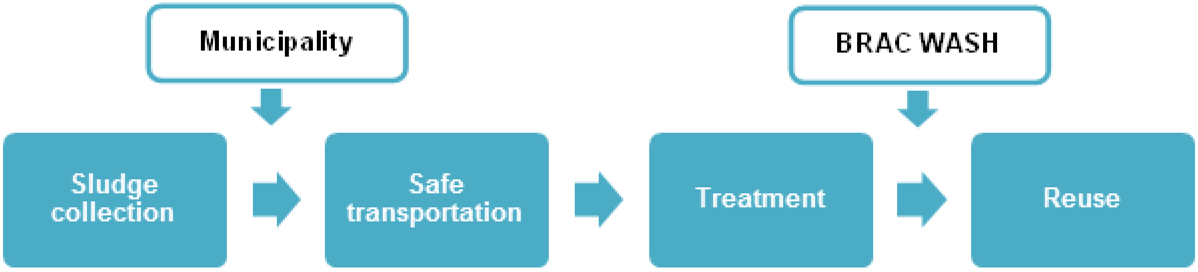

Figure 1.1 Work plan on FSM for BRAC WASH in urban areas

Alongside this, BRAC WASH is working to develop a tariff structure for desludging, transportation and price for the end product. The programme is also working to develop an incentive-based model for emptying trucks. The first one year of full scale operation will optimize these issues and develop a continuous operation cycle for FSM, which will then be scaled up to the rest of the urban areas that the programme is operating in.

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Faecal Sludge Biorefineries based on a Volatile Fatty Acid Platform

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Keywords: biorefineries, process platforms, beneficiation, volatile fatty acids, carbon recovery

Conference Track: (*choose one*) (1) Research Track
Track Topic: *Technologies for the collection, transport, treatment, disposal and use of faecal sludge*
Personal Preference: *Oral presentation*

Abstract

Recovery and reuse of resources present in various feedstocks, including waste streams such as faecal sludge can be a viable pathway and one component towards realization of the circular economy. Widespread adoption and implementation of resource recovery depends on several factors including engineering feasibility, technology maturity and reliability, capital and operating costs, recovered product resale value and environmental impacts. From an elemental composition, the major constituents of faecal sludge can be classified under carbon, nitrogen and phosphorous. Of these, in general, organic carbon is present in most waste streams at an average oxidation state of zero, C(0). During traditional waste treatment processes, a fraction of this organic carbon is converted to biomass while the remainder is oxidized to carbon dioxide (CO_2) either aerobically, anoxically or anaerobically. As a substrate, CO_2 contains less energy and flexibility for conversion into commercially attractive products. In contrast, the influent organic carbon and/or biomass can be reduced under anaerobic conditions to generate methane (CH_4), which is a source of heat and power. Indeed, generation of CH_4 has emerged as a principal endpoint for readily usable energy around the globe. Yet, methane is only one possibility as an endpoint for carbon recovery through microbial platforms and pathways.

On the other hand, the use of short chain volatile fatty acids (VFA) produced during fermentation might be regarded as an alternative and advantageous channel to facilitate resource recovery from waste streams. In this sense, the fermenter output could also be manipulated to produce the most favorable VFA composition for the downstream process.

VFA based platform for the production of commodity chemicals

Currently existing bio-based pipelines depend upon carbohydrates (glucose, sucrose) or food crops making them unsustainable for large scale production. However, most of these production pathways include few key intermediates such as acetyl-CoA and pyruvate, which can be readily produced from VFA (**Figure 1**). Therefore, research efforts are now being focused to 'retrofit' the existing bio-based pipelines to incorporate VFA as a cheaper and alternate carbon substrate to replace the more expensive carbohydrates or unsustainable food and agricultural commodity based bio-substrates with varying degree of success. For instance, the use of VFA for microbial lipid and polyhydroxyalkanoate (bio-plastics) production has been extensively studied and the costs of such processes have reduced dramatically. The cost of bio-plastics produced through fermentation of wastewater was reported to be 0.75-1.45 $/Kg (Fernández-Dacosta et al., 2015) which is comparable to the market price of various commercial plastics (0.5-1.2 $/Kg). Similarly, we have shown that the cost of biodiesel production from food waste fermentation was reported to be 0.81-2.53 $/L(Vajpeyi & Chandran, 2015) compared to the average price of gasoline in the US and the EU (0.5-1.5$/L). VFA can be channelled to various pathways towards the bio-based production of certain building-block chemicals such as adipic acid, butanol, organic acids such as citric, malic and succinic acids. Certain other important chemicals of biological origin, including furans, mixed alcohols, long chain sugars (sorbitol, xylitol), solvents (acetone, formaldehyde) and organic acids (glucaric, levulinic, itaconic acids), could also potentially be produced from VFA.

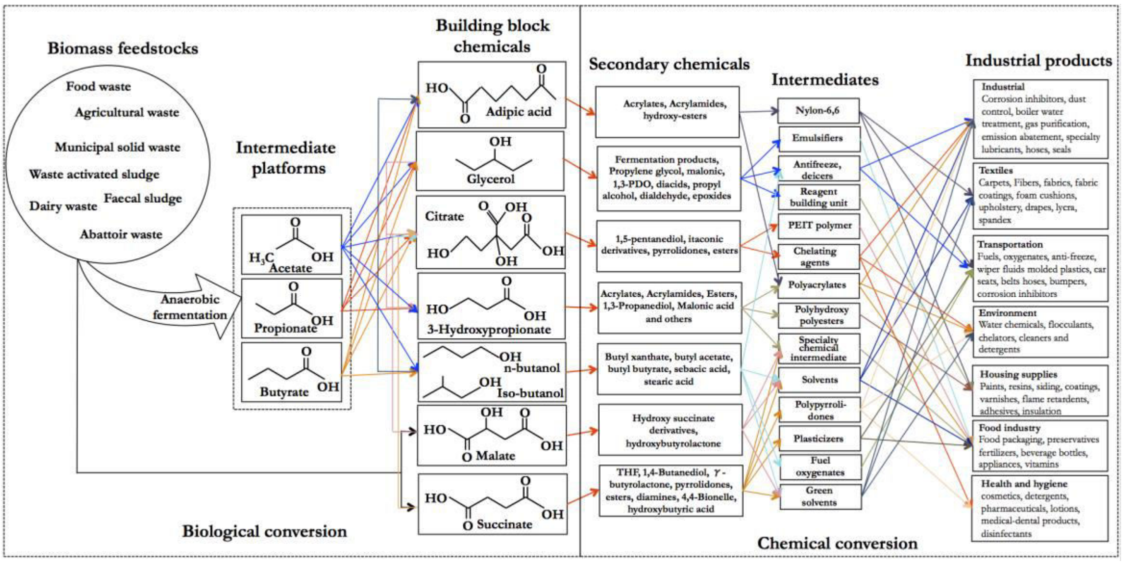

Figure 1. Flexible biorefinery platforms for converting a diverse array of organic feedstocks including faecal sludge to commodity chemicals

Conversion of biogas to biomethanol

Under certain circumstances, it may not be funnel the entire carbon content of faecal sludge towards VFA. In this case, it is still possible to consider higher value products such as biomethanol to enhance the value of biogas. We have recently developed a novel process to convert the methane contained in biogas to methanol biologically using ammonia oxidizing bacteria (Taher and Chandran, 2013) at among the highest rates and yields reported in literature **(Figure 2)**. This process does not require clean up or drying of the biogas (to remove moisture). Further, the methanol produced can be extracted or even directly used for biological nitrogen removal from the treated faecal sludge stream, if needed.

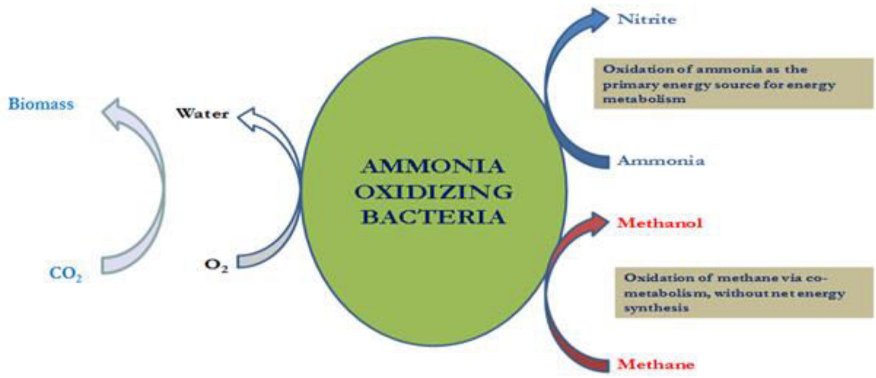

Figure 2. Bio-based process for conversion of methane containing mixtures (such as biogas) to bio-methanol

In sum, VFA based platforms offer an exciting prospect for beneficiation and resource recovery from faecal sludge. While more research on both the fundamental and applied aspects is needed, adopting a biorefinery approach rather than a ‘removal or disposal’ approach could potentially transform the faecal sludge sector to a resource-positive one, bolstered by the products emanating from the faecal sludge streams themselves.

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The Flexcrevator: An Improved Pit Emptying Technology with Trash Exclusion

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Keywords: pit emptying; trash exclusion; *Flexcrevator*

Conference Track: (1) Research Track
Track Topic: *Technologies for the collection, transport, treatment, disposal and use of faecal sludge*
Personal Preference: O*ral presentation*

Background

Sanitary and affordable pit emptying remains a major challenge with an estimated 1.77 billion people using pit latrines worldwide (Graham & Polizzotto, 2013). High waste variability, the presence of large amounts of trash, and access to and within the pit continue to impede the development of a single pit emptying technology that can empty a high percentage of pits at a competitive cost. This paper discusses the continued development of the Flexcrevator (patent pending, previously 'Excrevator'), an auger based pit emptying technology (Rogers et al., 2014). The previous versions of the Excrevator showed promise in field tests conducted in South Africa, Malawi, and India from 2013 - 2015. The compact design was able to access the pit side and empty dense sludge at flow rates of up 0.7 liters per second (lps). The testing also highlighted areas for improvement, including:

1) *More maneuverability within the pit* – the long rigid pipe containing the auger was difficult to maneuver into and within the pit, especially when the only pit access was through the squat hole.
2) *Handling a Wide Range of Waste Viscosity* – Pits were observed to range from extremely dry and soil-like to watery, even within the same community. The auger was able to lift dense sludge but would simply "poke holes" in the dense sludge if it did not flow to the inlet. The system also struggled with very watery sludge due to slippage back down the auger.
3) *Trash Jamming the Auger* – Trash, such as hair, shirts, rocks, bottles, etc. were very common in the African pits. These would frequently jam the auger, sometimes being dislodged by running the auger in reverse but often requiring manual removal.

The current version of the Flexcrevator includes essential design changes to build on the successes and meet the identified challenges with the previous version.

Design Improvements

The new Flexcrevator features a vacuum system, a flexible auger, and trash handling capabilities to improve on the issues observed from previous testing. The new version has switched from hydraulic motors to electric since electric motors are more common in developing areas, local electrical and machine shops have experience with them, and spare parts are more available, making maintenance easier.

Vacuum System

The new system features a vacuum that pulls 12-15 in Hg of vacuum to a mobile 90 L tank resulting in a maximum flow rate of ~ 3 lps. The vacuum system is mounted compactly under the 90 L tank to provide maximum mobility of the machine. With the addition of the vacuum, the Flexcrevator can now empty a higher range of wastes, including very wet material. The waste is pulled into the 90 L tank and then discharged into drums through a 15 cm valve.

Flexible Auger

A major change to the system has been the switch from the straight-shaft 10 cm auger to a flexible, shaftless 7 cm auger. The flexible auger runs the length of a flexible 7.6 cm diameter PVC hose and protrudes approximately 15 cm. This flexibility allows easy access into the pit, even through the squat hole.

Trash Exclusion

The most exciting update to the Flexcrevator is the change in its operation to facilitate a trash handling mechanism. In normal operation, the Flexcrevator runs the flexible auger in reverse while the vacuum system is operated. This allows waste to travel up the inner diameter of the shaftless auger while the auger acts as a self-cleaning screen that provides trash rejection in the pit. This operation has great potential as the trash exclusion will 1) provide on-site separation of trash and waste, 2) improve the efficiency of vacuum systems due to a decrease in clogging, and 3) encourage better pit usage practices as the emptying service can charge separately for waste and trash removal.

Field Testing in Hyderabad, India

The new version of the Flexcrevator was fabricated and field tested on a simulated pit at North Carolina State University before being tested in Hyderabad, India with support from Banka BioLoo. Testing consisted of two pit types: bio-tanks on train cars and household pits. The Flexcrevator provided complete servicing of 10 train car tanks in about 5-10 minutes each, which compares extremely favourably to the current day-long process just to empty one tank. Testing on the local pit latrines, the Flexcrevator's intended purpose, demonstrated an emptying rate of 3 lps (2.25 lps when adjusted for time to empty into drums) while providing trash rejection (Figure 1a). The system demonstrated its trash rejection capabilities by removing waste from a pit with 80-100% trash without allowing any trash to enter the system and preventing clogging (Figure 1b). Testing of the system is ongoing in Hyderabad with operation provided by Banka BioLoo.

a) b)

Figure 1 a) The Flexcrevator unit in Hyderabad, India b) example of a pit with high trash content.

Conclusions and Next Steps

Testing of the new Flexcrevator system has demonstrated easier operation, high ranges of waste removal, and trash exclusion capabilities. Continued field testing is planned for Malawi, and Senegal in late 2016/early 2017. This includes a newly developed unit that will attach to any existing vacuum system and provide trash rejection at the pit side.

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Physical and Financial Performance of Pit Emptying Technologies

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Keywords: Pit emptying technologies; Pump performance; Business model
Conference Track: (1) Research Track
Track Topic: Technologies for the collection and transport of faecal sludge
Personal Preference: Oral presentation

Currently there is a limited understanding of the relative performance of different pit emptying technologies, mostly based on anecdotal evidence or subjective qualitative descriptions. Mikhael et al. (2014) and Goal (2016) present useful summaries of technologies for manually-operated and fully mechanised pit emptying, however there is no quantitative assessment of the strength of sludge that each pump can remove and operating costs crucial to assessing the profitability of a business model are often lacking.

This paper presents a methodology for assessing the relative performance of different PETs, based upon the physical properties of faecal sludge and results from pump testing. This technical data is combined with a business model to assess the profitability of various PETs. To demonstrate the approach we present data for various manually-operated sludge pumps in rural and peri-urban India and Uganda. The results demonstrate clear differences in profitability for each PET in the different markets, and could be used to inform investment decisions by prospective entrepreneurs. The data can also be used to better inform pump development efforts by focusing efforts to increase profitability.

Our approach uses a three-stage process:

1. How strong is the faecal sludge?

The first step is to measure the undrained shear strength to assess the physical characteristics of the faecal sludge. The penetrometer described by Radford & Sugden (2014) has been used to test the strength of 80 pits in three locations in India:

- Rural village in South 24 Parganas District, West Bengal
- Peri-urban area of Muzaffarpur, Bihar
- Peri-urban area of Patna, Bihar

The results are described in a separate paper at FSM4 Conference. These data have been combined with the 30 pits from Radford & Sugden in Kampala, Uganda. Work is ongoing to calibrate manual cone penetrometer data collected by others in Malawi and Kenya.

2. What is the performance of different pumps?

Various manually-operated faecal sludge pumps, including the Gulper 1, Gulper 2 and manual diaphragm pump have been tested using the process described in Radford et al. (2015). The maximum strength capacity of each pump, and an average flow rate at multiple different strengths, is recorded to produce a performance curve. Additional testing has been completed to evaluate the effect of debris on pump performance, and these results are included here. Work is ongoing by partners at Partners in Development and North Carolina State University to evaluate the performance of the eVac and Excrevator pumps and we encourage other developers and practitioners to adopt the same process to produce consistent, comparable results.

3. How does that impact profitability?

The volume that can be emptied from a given pit is calculated by combining the sludge strength profile with the pump performance curves. This feeds into a business model to estimate potential profit for a pit-emptying entrepreneur. The business model was developed from previous work at the University of KwaZulu Natal, with Sanitation Solutions Group data from businesses using Gulpers in Uganda. Scenarios for India were developed from market surveys undertaken by Water for People. The cost model includes labour, transport, sludge disposal, maintenance and depreciation of equipment and financing costs. Payment can be selected as a fixed fee for emptying, or a unit rate per volume removed.

The results from the business model for the three areas in India are shown in Figure 1 below. The depth of sludge in each pit at various strengths (left axis) is shown in grey, with potential profit overlaid (right axis) – in blue for the Gulper 1 and red for the Gulper 2 pump.

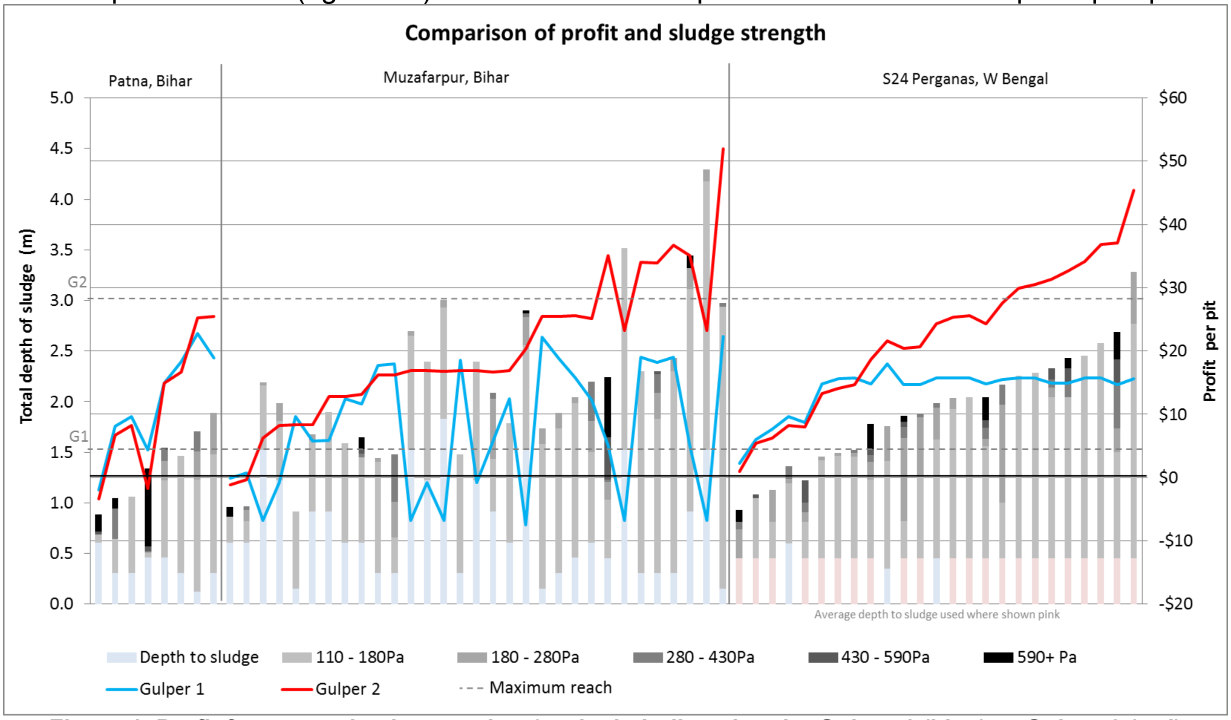

Figure 1: **Profit from completely emptying 65 pits in India using the Gulper 1 (blue) or Gulper 2 (red)**

The results demonstrate significant differences in profitability between two pump designs that are relatively similar – highlighting the value of this approach to inform pump selection. Further analysis also shows that different pumps have higher average profit in different locations, with the Gulper 1 proving best in Patna where most pits are relatively shallow, and the Gulper 2 best in Muzaffarpur and South 24 Parganas. The data have also been used to assess the sensitivity of each pump design to different factors such as reach, sludge strength and debris content. This can help identify priority areas for developing improvements to the pumps, by focusing on factors with the greatest impact on profitability.

The methodology presented here provides a repeatable and quantitative process to assess the performance of pit emptying technologies, linking that directly to profitability for the service provider. As further data are collected we propose to develop an open web portal to support entrepreneurs and other organisations in selecting the most appropriate pit emptying equipment for a given location and business model.

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Designing the Next Generation of Pit Emptying Technologies Using a Workshop Approach

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Keywords: Omni-Ingestor, Pit Emptying, Collaborative approach, Design of technologies

Conference Track: (1) Research Track
Track Topic: *Technologies for the collection, transport, treatment, disposal and use of faecal sludge*
Personal Preference: *Oral presentation*

Introduction

Every day, pit latrines receive an estimated 0.6 billion kg of faeces and 2.1 billion kg of urine from 1.77 billion people around the world (Graham and Polizzotto, 2013). Once pits are full, the faecal sludge has to be removed, transported, and treated/reused. One of the biggest challenges in this sanitation chain is devising a hygienic, efficient, and modern way of emptying pit latrines.

In April and June 2016, the Omni Ingestor Program of The Bill & Melinda Gates Foundation convened two workshops to address the issue of designing the next generation of pit emptying technologies. The participants were selected from a variety of backgrounds-NGOs, private companies, universities, and international organizations - and all were involved in pit emptying technologies, sludge pumping practices, pump design, pit emptying operations, or product and technology design. This paper will present the workshop methodology, highlight the many issues in designing pit emptying technologies, and discuss some of the initial ideas and solutions that resulted from the exercise.

Workshop Approach

The approach was designed to take into account the different pit designs and faecal sludge (FS) characteristics in Africa and in South Asia. To ensure that these conditions were considered, the first workshop was convened in April 2016 in South Africa and included visits to Tanzania and Zambia. The second workshop in June 2016 was held in Bangalore, India. The workshop logistics were handled by the Pollution Research Group of the University of KwaZulu-Natal (UKZN), with support from BORDA-SADC; The University of Zambia; Water and Sanitation Association of Zambia; The Ifakara Health Institute; eThekwini Water and Sanitation; BORDA (India) and CDD (India).

The workshop was designed and led by Jon Shaw, who has led a number of workshops for engineers and technology designers. The following process was followed:

1. *Problem Definition*

   This involved making clear what problems (technical, economical, environmental, cultural) the workshop needed to consider, the scope of the workshop (what is included, and what is not), and how sufficiency is defined.
2. *Current Status/Level Setting*

   This was informed by field visits to observe pit emptying practices in Dar es Salaam (Tanzania), Lusaka (Zambia), Durban (South Africa), and the outskirts of Bangalore (India). In addition, other participants were invited to describe current issues and practices in Malawi, Uganda, Tanzania, South Africa, Madagascar, and Bangladesh.
3. *Objectives and Deliverables*

This focused the workshop on the end products of the workshop. In particular, the “requirements” as defined by the OI program were reviewed and evaluated.

4. *Idea Generation*

   Here, several approaches were employed, including *intuitive* and *formal* methods. The emphasis was on generating all kinds of ideas and solutions, using other ideas as springboards, and communicating the ideas visually using post-it notes. Systematic Inventive Thinking (SIT) was used to generate and explore more ideas.

5. *Evaluation*

   After several solutions were identified, the group was asked to evaluate the different pit emptying technologies/solutions according to several criteria, including feasibility, performance in wet and dry pits, cost, and risks.

Lessons learned

It became clear that the pits in different countries in Africa were different from each other and from the pits in India, and that designing a single technology to handle all pits would be difficult. The participants identified challenges associated with dry vs. wet pits and pits that contained trash. Some of the requirements were deemed to be unrealistic (e.g., with respect to automation and ultra safety). The field visits were illustrative, and showed clearly the issues that were context-dependent and the problems in the field, including transportation and disposal of the collected FS. How different groups were approaching FS collection (e.g., centrifugal pumps in Bangalore) and treatment (e.g., anaerobic digesters in Lusaka) were also enlightening.

The participants, most of whom have been working in the field for many years, were surprised at the effectiveness of the process in generating new ideas and recasting perspectives with respect to pit emptying. The participants were encouraged to avoid structural fixedness, and avoid ownership of any single idea. This led to quite imaginative solutions, for example, of dealing with FS in pits (e.g., eutectic freezing inside the pit, little robots, multiple types of hoses), pumping the FS to the surface, and moving the FS from the pit side to the roadside unit. The idea generation exercises, group activities, and discussions were stimulating and led to several potential technology options. A few of the options were quickly prototyped in the mechanical workshop at UKZN using readily available materials. Initial costing was also performed, and reports on several technologies were prepared. Because of time constraints, the evaluation step was performed quickly, and was acknowledged to be imprecise.

In general, the workshops were successful in bringing together practitioners, workers, and researchers from different countries with different approaches. The highly collaborative atmosphere led to synergy and sharing of ideas (Figures 1.1, 1.2), and these partnerships continued beyond the workshop to pursue some of the pit emptying solutions that appeared to have potential. Admittedly, the cost of organizing a global workshop for many participants is a barrier to replication. It may be possible to conduct future workshops via the internet.

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Fig. 1.1. Collaboration and post-it notes

Fig. 1.2. Discussion and post-it notes

Promoting safe on-site sanitation in urban Tamil Nadu: Case Study of Tiruchirapalli and Periyanaickenpalayam Town Panchayat

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Keywords: Baseline; Construction Practices; On-site systems

Conference Track: (1) Research Track
Track Topic: Technologies for the collection, transport, treatment, disposal and use of faecal sludge;
Personal Preference: Oral presentation

Abstract

Introduction

A Baseline study covering the entire sanitation chain, was carried out in Tiruchirapalli Municipal Corporation and the two Town Panchayats of Periyanaicken Palayam and Narasimhanaicken Palayam. The paper presents some of the salient findings from this Study, and dwells on challenges and prospects of sanitation improvements in urban Tamil Nadu. Among other findings, these studies report practices at considerable variation from design norms, and these pose serious environmental and public health hazards.

Methodology and Scope

A series of baseline study exercises were undertaken in the three urban locations over the Feb-May 2016 period. These studies included household and establishment surveys using structured questionnaires; focus group discussions with households, resident in slums and other groups; thematic case studies documented with select households, establishments, masons and ULB workers. In addition, detailed technical studies were carried out with a smaller sample of households focused on the construction and operation of toilets and their containment structures. Water Quality Samples were also tested from households and other key locations as a part of the above surveys. The above baseline studies covered more than 3,000 households and establishments, situated in about 65 neighbourhoods (number of transects), including 23 transects (predominantly slum locations).

Design and construction practices of on-site sanitation systems

The Baseline Study reveal considerable variations in the design and construction practices of on-site sanitation systems. The construction practices vary a lot depending on the masons' perceptions and understanding of how septic tank is to be constructed; the householder's considerations of space and economy; and the belief that these structures should be built so as to obviate or postpone as much as possible, the need for regular cleaning. As a result, septic tanks were found be very large in size and/or constructed as 'holding tanks' letting out partially treated fluids constantly into the open or into drains. In addition, the practice of marrying the principles of 'leaching' to septic tank form essentially rendered void the water-tight feature of septic tank design, and converted them into large-sized leach pits, severely diminishing their treatment efficiency and posing the hazard of polluting groundwater.

Cleaning or de-sludging of on-site containment systems

The baseline study reports significantly varying cleaning frequencies by households. Most of the cleaning or de-sludging events are reactive and not planned or regular. Such events are generally reactive to blockage of the toilet or exfiltration at the site leading to odour and ambient issues.

The practices followed by sludge operators working in the three towns also suggests lack of awareness amongst both parties – households and operators – of what impact cleaning has on the efficiency of treatment systems. Ad hoc procedures that aim to economise costs and hence 'charges' are resorted to, and common problems like build-up of hardened sludge is seldom rectified.

Making on-site sanitation safe

The findings of the baseline studies in the three towns highlight a complex set of issues that will need to be tackled for making household sanitation solutions safe in these environs. The perceptions and sphere of influence of different key stakeholders – households, establishments, masons, sludge operators – seem to be critical determinants of current design and construction/O&M practices. The knowledge and influence of other stakeholders like ULB officers, appears to have a limited bearing on outcomes at the current juncture.

The study team has developed an engagement plan with stakeholders who are identified as directly influencing on-site sanitation decision-making and practices; and seeks to broaden these by bringing in other stakeholders who are seen as influential but currently not influencing on-site sanitation decision-making.

Summary

The paper will report on some of the salient findings about the current practices in respect of design and O&M of on-site sanitation systems in the three locations. The findings point to considerable variation from design norms prescribed by the Government, and pose health and environmental hazards. At the same time, many of as-built structures may not be amenable to simple solutions. The paper identifies the key stakeholders influencing these practices leading to undesirable outcomes. It also seeks to explore an approach to bring in other potentially influential stakeholders to remedy the situation.

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Financing Non-network Systems For Small Towns[1]: An Exploratory Analysis

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Keywords: Non-network; small towns; financing

Urban India is growing rapidly as revealed by the Census 2011 which recorded a growth rate of 3.2% in the last decade. Presently 377 million or 31.2% of the country's population resides in more than 7,900 towns. Despite impressive economic growth (GDP of 4 – 5% in the last three years) and investments in excess of Rs. 2 billion between 1951 and 2012, only about 200 of the over 7,900 cities and towns (2.5% of cities and 33% of the country's population) have at least a partial sewerage network (Ministry of Urban Development, 2010). A large number of these towns (7400 towns) are small towns with populations under 50,000 with little or no sewer networks and a large number of households in these towns relying on on-site sanitation.

Further, treatment capacity exists for only 30% of the wastewater generated in the cities and only 22% of the wastewater is actually treated before disposal. Household connectivity to the wastewater collection and treatment infrastructure is an issue, as is operation and maintenance, resulting in a lot of sewage being discharged without treatment into the rivers and drainage channels thus contaminating freshwater resources downstream. Performance of existing wastewater treatment infrastructure also needs attention, as treated effluents from 58% of sewage treatment plants assessed (Central Pollution Control Board, 2007) by the regulatory agency failed to comply with the discharge standards (High Powered Empowered Committee 2011). Thus, environmental pollution from untreated sewage is quite widespread and has been estimated to be responsible for contamination of 80% of the nation's fresh water sources.

The High Powered Expert Committee (HPEC) estimates that to improve sanitation through sewerage systems over the next 20 years (2012-2031), the investment required is Rs. 2,427 billion (Report on Indian Infrastructure and Services 2011). This implies a per capita investment of Rs. 4,704 or a household investment of Rs. 23,520 (for a family of 5). This is a significant investment requirement, maybe even unrealistic, considering that the sector attracted investment amounting to about Rs. 2 billion over the preceding six decades, which while being a considerable amount, is insignificant compared to investment estimated developed by the HPEC to ensure complete sewerage coverage in the country. This also compares unfavorably with the estimates of capital investments required for collection, treatment and disposal of septage (septic tank sludge), which is about Rs. 6,000 /household, or about 25% of the cost of sewerage systems.

Despite the cost economics favouring non-network sanitation and Govt. of India releasing an advisory on septage management, government financing of non-network sanitation is only limited to cities with populations of 100,000 and above, which hampers sanitation provisions and improvements in other towns.

[1] Towns with populations under 50,000

With more than 195 million households that rely on on-site sanitation in India and an economic cost of Rs 2.4 trillion per year (6.4% of GDP) due to inadequate sanitation (WSP, 2010), financial and institutional strengthening will be needed to ensure that capital investments into the Sustainable Development Goals (SDGs) translate into effective service delivery. The SDG indicator 6.2.1 under target 6.2 (sanitation and hygiene) emphasizes the importance of “safely managed sanitation services” which goes beyond the “access to improved sanitation” target of the Millennium Development Goals (MDGs).

This paper examines if private sector financing to support non-network sanitation in small towns is a financially viable option and also the regulatory environment to ensure financial sustainability of the investments. The paper also on examining fecal sludge management models from 22 countries presents an appropriate business model and makes a compelling case for private sector financing for non-networked based systems to improve service delivery in small towns.

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Odors and FSM: Impacts and How to Deal with the Stench

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Keywords: malodor; user behavior; odor control

Conference Track: (*choose one*) (1) Research Track – (2) Case Study Track – (3) Industry and Exhibition Track
Track Topic: *1 Research Track*
Personal Preference: *oral presentation*

The provision of sanitation services will accelerate as part of the Sustainable Development Goals with increasing focus placed on fecal sludge treatment and reuse. One common constraint in the sanitation value chain is the malodor present in fecal sludge. Finding cost-effective ways to minimize odor nuisance from latrines to the end user is critical. Adsorption and biofiltration studies are being conducted as part of a project funded by the Bill & Melinda Gates Foundation to understand the many impacts of malodor on FSM, control and mitigate malodors derived from human waste. A broad survey was conducted to define the landscape of odor nuisance along the fecal sludge management chain. The survey highlighted that malodor is a contributor to open defecation, and low toilet maintenance. The results also highlighted the importance of certain toilet features to limit malodor. Detailed results will be presented and discussed. Biochars derived from bamboo wood, manure (human feces, horse, sheep), and Norit ROZ3 activated carbon are being used to evaluate adsorption of malodor. A reconstitution of fecal malodors was used, which comprised a mix of 4-7 compounds including carboxylic acids, sulfur and nitrogen containing compounds shown to be responsible for human fecal odor. Both static and dynamic type adsorption tests were performed. Odor was quantified using olfactometry (dilution to threshold, or D/T), perceived intensity and an H_2S meter. Breakthrough capacities of the adsorbents for both odor reduction (odor units per g of adsorbent) and H2S reduction (mg/g of adsorbent) were determined. It was shown that odor breakthrough for most cases occurred prior to H_2S breakthrough. Initial results show manure based chars (horse and human feces) have a capacity of > 4.2 mg H_2S /g char and an odor reduction of 2550 odor units per g char. In addition, specific compounds representing adsorption challenges and contributing to the earlier odor breakthrough were identified. Biofiltration tests were also conducted in columns with various packing materials, including biochars, zeolite, lava rock, and an typical mix used in odor control biofilters. Removal of odorous air mimicking actual latrine field measurements was determined by using olfactometry as assessed by an odor panel at various odor loadings of the odor control systems. GC-MS measurements were also taken to assess the removal of individual compounds in the odor makeup. Very effective odor rem was observed in the different biofilters with 60-90% removal of odors at gas residence time of 12 seconds, depending on the conditions and the packing material. The biofilters were also subjected to various H_2S challenges of increasing concenentrations. Those packed with pine char and sheep char performed the best with essentially complete removal of H_2S at inlet concentrations as high as 180 ppb.

Odors are intimately connected to fecal sludge management practices and adoption of toilets and it is only recently that one has started to consider the many impacts of malodor on toilet acceptance and adoption. Overall, the results provide baseline engineering data on possible ways of applying and sizing adsorption and biofiltration as malodor control methods to the various fecal sludge management approaches.

From Research to Commercialisation and Uptake of Sanitation Technology Innovations: The WRC Pour and Low Flush Experience

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Keywords: Commercialisation, Toilets

Conference Track: (1) Research Track
Track Topic: At scale city-wide or national FSM services (evolution of services), Emerging FSM services (Beyond pilot and scaling up).
Personal Preference: *oral presentation*

Introduction
Experience to date with dry sanitation in South Africa has shown the many challenges which need to be addressed to support sustainability over the long term. User behaviour and attitudes, as well lack of understanding of the sanitation environment by planners and designers, has resulted in the infrastructure investment of nearly 1 million Ventilated Improved Pit (VIP) latrines being in jeopardy. The problems relate to the high filling rates of dry pit latrines, the significant intrusion of detritus and plastic bags (flying toilets), misuse of the facilities and lack of user acceptance. The emptying of pits has been challenging, unsafe and at many times not economical.

Noting the need for technology that can bridge the technological between on-site dry systems and full waterborne systems, the WRC invested in the development of a Pour Flush latrine, which is standard in much of Asia, but modified for South African users. Sanitation practice differs fundamentally between South Africa and Asia in that in South Africa (as in much of Africa) sitting and not squatting is standard, as is the use of paper (often including newsprint) rather than water for anal cleansing. The Pour Flush latrine was not seriously considered in South Africa, partly because of the water requirement, but also because it was assumed that – given the practice of using paper for anal cleansing - such a latrine would quickly block and become a maintenance burden. However, this assumption had never been tested and in 2009 the Water Research Commission initiated a study to test the feasibility of using the Pour Flush toilet in South Africa. Over a 5-year period – including the research and development phase – the technology has been successfully demonstrated and upscaled with at least two commercial products developed and available on the market. This paper will share as a case study how the rollout and uptake of pour flush is being scaled up in South Africa, through a number of strategic demonstration projects, policy formulations and good awareness creation.

Research and Development Phase
The research challenge was to produce a toilet prototype with the following features: it must be able to flush successfully using less than 2 litres of water; it must look very much like the type of toilet pedestal in use in this part of the world; it must not block when newspaper is used for anal cleansing; it must have a water seal; and it must be robust and affordable. A fibreglass prototype was developed, fabricated and tested based on the design considerations. Flushing was achieved through a pouring action using a jug or other vessels i.e. in a manner similar for Asian toilets. The prototype developed was made for 'sitters' as the majority of South Africans sit on a pedestal while defecating. Externally, the prototype appeared no different to that of a standard flush pedestal. Internally, however, the prototype was more funnel shaped. The water seal in the prototype was 25 mm and compared favourably to 20 mm of Asian variants (Still and Louton, 2012).

The Pour Flush prototype developed was evaluated by Partners in Development using the internationally recognised Maximum Performance (MaP) protocol and required only 1ℓ to flush 4 wads of tissue paper and six synthetic stool samples. Newspaper required almost double the flushing volume. The prototype was able to successfully flush synthetic stools and 4 x ¼ newspaper sheets using 2 litres of flush water (full details can be viewed in Still and Louton, 2012). Once proven successful under controlled conditions, the Pour Flush system was piloted in selected households.

Piloting

Partners in Development piloted the Pour Flush prototype in over 20 rural households in 2010. Post-pilot results indicated that the innovative P-trap developed through the R&D phase allowed significantly less trash disposal into the leach pit compared to VIP units. The results from the first prototype piloting were successful with only one blockage recorded in any of the 20 new low flush systems over 15 months – due to a child flushing a packet into the bowl – and users expressing no problems with flushing in households using toilet paper and/or newspaper. The pilot studies were subsequently extended to other areas where the user behaviour was expected to be different, including high-density settlements (Maluti GSM, 2014) and schools (Still and Louton, 2013). Faecal sludge characterisation of the initial pilot prototypes indicated that physico-chemically, the sludge was similar to VIP latrine sludge but with significantly less trash disposal observed. Further, leachate testing in the same region indicated limited groundwater pollution contamination (Lorentz et al., 2015). With less trash intrusion, emptying is expected to occur after a 5-year period.

Commercialisation, Demonstration and Upscaling

Following the success of the first pilot, the WRC and PiD approached industry to look for support for developing a commercial product. EnviroSan, a locally-based company who had been involved in manufacture of on-site dry sanitation pedestals, saw potential to diversify their portfolio to include low-flush systems. EnviroSan used the research findings to develop a commercial product called the Eazi-Flush for less than US$60. The Eazi-Flush consists of a lockable flange, a pedestal body with a clip-on seat and incorporated child-seat lid. The flushing component is made up of an insert which screws into the seat, and a P-trap which can be plumbed into standard fittings. EnviroSan enabled the Eazi-Flush product to be further upgraded with a low flush cistern which only requires 2 litres of water to transport the deposits. It was this product that was used in the subsequent demonstration programme as part of a partnership with the Department of Science and Technology to deliver services using innovative approaches. Over 500 units have been installed since 2015. In the latest development, the eThekwini Municipality, which saw the potential of technology in the demonstration programmes, has implemented over 600 units of the toilets in a low-income housing project where there is no sewerage connection. The units are installed inside the homes offering convenience and greywater from showers is treated and recycled for flushing and / or re-use in food gardens. From 2009 to now, the WRC has been able to drive an innovative toilet technology from R&D phase to commercialisation and upscaling within an 8-year cycle; it is these lessons that will be shared to the community of practice.

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The Informal Economy of Pit Emptying in Blantyre, Malawi

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Keywords: Malawi; informal emptying; policy

Conference Track: Research Track
Track Topic: Economics and Business
Personal Preference: oral presentation

Introduction
Though attempts have been made to understand the financial challenges facing the oft-ostracized pit emptiers of Africa (Mbéguéré et al, 2010) much remains unknown. Over 75% of Blantyre's 1,000,000 residents, rely on pit latrines which require emptying before they overflow; space limits the construction of new latrines. Despite a seemingly large market for their services, self-employed pit emptiers who serve the urban poor struggle to make a profit: we investigate the reasons why.

Methodology
Despite the existence of an "informal pit emptiers network", members were difficult to locate and contact, though we started our search in this way. To identify a range of entrepreneurs, we employed several strategies: asking known emptiers to refer colleagues, looking for public notices and signs within informal areas and waiting at the treatment plant until the entrepreneurs came to dump their sludge. Over the course of 6 weeks we were able to contact and interview 11 entrepreneurs; more were contacted but they were unwilling to participate in the study. The questionnaire consisted of 40 questions and lasted approximately 1 hour. The questionnaire was administered verbally in the local language, Chichewa. Only those pit emptiers who employed manual techniques, i.e. not vacuum pumps or mechanical tools, were included in the sample.

Ethical approval for the research was obtained from the Republic of Malawi, National Commission for Science and Technology Review Board. Participation was on the basis of informed, written consent.

Results and discussion
In understanding the economics that govern the sustainable business practices of pit emptiers, we identify both enabling factors and barriers to success.

Enabling Factors
Without engaging actively with Water for People (WfP) for this work, the most glaring factor that has fostered and encouraged the pit emptying businesses in Blantyre, is the use of the WfP-developed "Gulper". The Gulper is a manual hand pump that allows the operator to direct the sludge easily into containers to be transported offsite. WfP allowed the entrepreneurs to pay the K 150,000 (USD$200) equipment fee in instalments and offered them the chance to buy (storage) drums at a reduced price. Only 2 of those interviewed were still using buckets and shovels. Additionally, a vehicle has been made available for rent, at K 5,000 (USD$7) per trip, for which the entrepreneurs only provide fuel.

Apart from technical aspects, prosperity is linked to societal support. Specifically, village chiefs allow the entrepreneurs to advertise their services at public gatherings including weddings and funerals. This societal recognition of the profession and access to large numbers of people, are key to the businesses' success.

All of these entrepreneurs have other business. They work as toilet builders and sell toilet pans (flappers), which allows them to promote their pit-emptying to a larger number of potential customers. This diversity of activities acts as a means of informal advertising that is essential to business model.

Barriers to Success

Despite personal outreach activities, knowledge about emptying services available remains limited. Few entrepreneurs have funds to formally advertise (through signs or posters) and the few that do, often find that their signs (posted on trees) are quickly removed or covered. Without large-scale, permanent advertising, contact with customers remains limited.

The fee to dump at the Blantyre City Council's wastewater treatment plant is K 2,000. While not a significant proportion of the total expenses (See Figure 1), the transport required to reach it, combined with the fee acts as a significant disincentive to safe disposal; indeed, some of those interviewed admitting to dumping sludge into pits or the river.

As in all business, customers are not timely with their payments. Customers appeal for credit or price reductions. When customers do not pay the full amount, entrepreneurs are forced to spend what they receive on transport and dumping fees, leaving them with no profit or money for salaries. Tracking down outstanding payments is a time-consuming and often futile task.

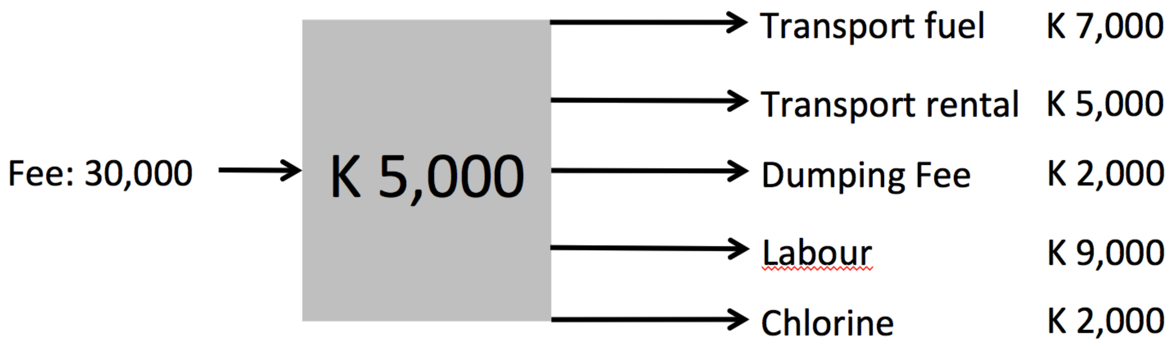

Figure 1. Average cost breakdown per emptying job in Blantyre, Malawi

Conclusion and Recommendations

Despite the widespread and continued support of WfP, the informal pit emptiers in Blantyre face numerous challenges. Most costly to their businesses is the need to pay for transport and emptying fees. Decentralized transfer stations, located in the informal areas, could be filled with sludge by the local entrepreneurs (using only local transport) and then periodically emptied by vacuum truck which would then transport the sludge to the official treatment facilities. City-run transfer stations would have the duel effect of reducing operating costs as well as the incentive to dump in the local environment. Donors who are interested in limiting the number of pits that overflow while encouraging businesses to expand, could distribute full-cost or price-reduction vouchers to be used against the cost of emptying with one of the association members. Manual pit emptiers serve those that cannot be reached by traditional vehicles too large for rocky or narrow roads.

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The Suitability of Specific Methanogenic Activity Test For Modelling the Ammonia Inhibition of Anaerobic Digestion of Faecal Sludge Samples.

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Keywords: Biological methane potential; acetoclastic microorganism; Gompertz model

Conference Track: Research Track
Track Topic: Characterization and quantification of faecal sludge
Personal Preference: *oral presentation*

Introduction

Improved understanding of the degradation mechanisms of faecal sludge collected into latrines would enable the better sizing of pits when optimising the desludging frequency or infrastructure required for the collection transport, discharge sites, treatment plants, and disposal options (Strande et al. 2014). However, pit latrines are usually regarded as mere collection systems despite the assumption that anaerobic digestion takes place in the pits. Furthermore, some systems are reported to fill up much faster than expected; indicating that the anaerobic breakdown of faeces was not proceeding as would be expected in an anaerobic digester (Bhagwan et al. 2008).

In this study, it is hypothesised that the high concentrations of ammonia from urine (3-17 g/L) may inhibit anaerobic biodegradation of the faecal sludge in pits, leading to faster sludge accumulation rates. Previous studies (Sung and Liu 2003) (Park and al., 2016) have shown that such type of inhibition can be adequately characterised and modelled by adapted specific methanogenic activity (SMA) tests (i.e. batch inhibition assays). This could serve as a useful tool to characterise ammonia inhibition in latrines. However, such an approach was done using sludge from conventional digesters and needs to be validated with sludge samples that are more representative of pit latrines. The objective of this study is to evaluate the potential of SMA method coupled with mathematical modelling to characterise the inhibitory effect of ammonia on fresh and aged faecal sludge samples.

Material and methods

SMA-based anaerobic toxicity assay

The SMA protocol consisted of placing the samples in 250ml serum bottles together with a specific substrate (acetate), nutrients, pH buffer, mineral solution and different concentrations of the inhibitor (NH_4Cl). Oxygen was removed from the bottles using 60-s nitrogen purge. During the assays, samples were mixed and the temperature was controlled at 35 °C. An Oxytop© system was used to measure biogas volumes, as a proxy for methanogenic activity.

Gompertz model

From the cumulative methane curves, data-fitting method using modified Gompertz model (Eqn.1) can be used providing useful information about substrate degradation kinetic under inhibition conditions (Park et al. 2016).

$$M = P \cdot \exp\left[-\exp\left(\frac{B \cdot R'e}{P}(\lambda - t) + 1\right)\right] \qquad (1)$$

From Eqn 1, M : (ml) Cumulative CH_4 production; P : (ml) maximum CH_4 production; R' : (ml CH_4/gVS) SMA; B : (g VS) volatile solid concentration, λ : (h) lag-phase.

Results and discussion

Model parameters in Eqn.1 was estimated using least-square estimation from typical SMA curves (Figure 1a – SMA from control sludge). However, as we can see on Figure 1b, adequately fitting data can't be done from performing SMA assay with FS or FF. Indeed, Figure 1b show that the addition of a specific substrate (acetate) doesn't lead to the typical SMA curve (Figure 1a) and therefore does not present a good fit with the Gompertz model.

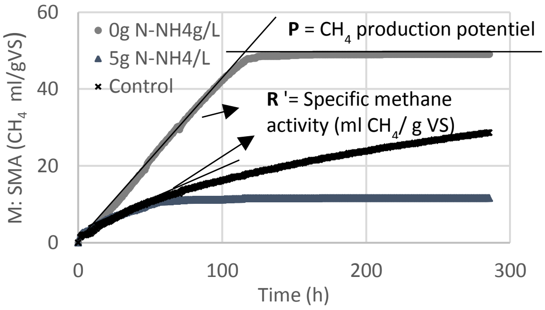

Figure 1a Demonstration of modified Gompertz for modelling kinetics of anaerobic degradation from standard anaerobic sludge (CSTR).

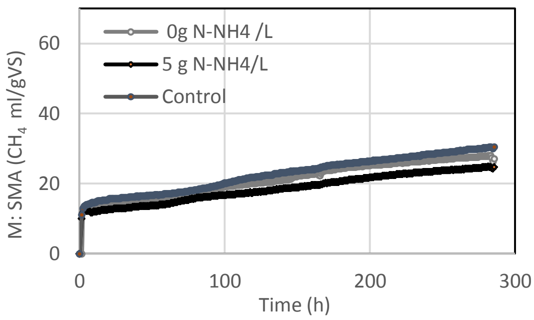

Figure 1b Results from SMA tests with faecal sludge. Inoculum to substrate ratio (ISR)= 4

The SMA protocol using Gompertz model assumes that metabolic biogas production follows bacterial growth kinetic of bacterial culture affected by growth-limiting nutrient. Therefore, standard SMA test are based on the principle that the anaerobic sludge (inoculum) is well mineralized and has a low concentration of readily biodegradable organic matter. Hence, theoretically CH_4 production can be estimated by adding known substrate concentrations (i.e. 1g COD acetate). However, it seems that FS and FF can't be considered as an exhausted anaerobic inoculum, as the concentration of easily biodegradable material (i.e. carbohydrates, protein, VFA) results in characteristics in-between those of an inoculum and a substrate (VS/TS > 95 %). Also, methanogens population from the human gut are hydrogenotrophic, as compare to mainly acetoclastic microorganism found in the majority of anaerobic reactors (Vanderhaeghen et al. 2015). Suggesting that acetate doesn't seem to be an appropriate substrate when performing SMA with FF or FS. Further tests are required. Among possible solutions, an adaptation of SMA tests using first order kinetic model from batch biomethane potential assays will be investigate to measure the easily biodegradable concentration (S) of FS and FF samples prior to the inhibitory assays.

Conclusion

SMA tests using Gompertz model and specific substrate has not lead to characterize the ammonia toxicity in anaerobic digestion of FF and FS. Further tests will involve the testing of a modified SMA methodology with no addition of specific substrate.

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Ammonia sanitisation for a safe use of sewage fractions – from theory to practice

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Keywords: ammonia, faecal sludge, pathogen

Conference Track: (1) Research Track
Track Topic: *Health, safety and hygiene*
Personal Preference: *Oral presentation*

Background

Safe reuse of plant nutrients from human excreta can increase agricultural production and societal sustainability. The acceptance, and thus its successful implementation, may however depend on the safety of the reuse. Ammonia sanitation has proven to provide controlled pathogen inactivation in different fractions of sewage, as well as in other materials, and this across a variety of organism groups with very different characteristics as bacteria, parasites and viruses. Currently the method is brought to scale and this paper aim to outline ammonia sanitisation as a treatment method to produce a hygienically safe fertiliser from source-separated urine and faeces or from faecal sludge diluted to various degrees by flush water. The paper will include review of literature as well as experiences from the laboratory and implementation focusing on practical implications for safe reuse, as well as highlighting issues for further research.

Principles for ammonia sanitisation

Ammonia in gasform, NH_3 (aq), is microbiocidal. Materials naturally high in ammonia as e.g. source-separated urine is therefore self sanitising[1]. Other materials can be supplemented with ammonia by the addition of e.g. urea or aqueous ammonia[2,3]. Both substances also give an alkaline pH necessary to push the NH_4^+/NH_3 equilibrium towards NH_3. Using urea, also carbonates (CO_3^{-2}) contributes to viral and bacterial[4].

Treatment implications

Ammonia sanitisation works within the ambient, sub-lethal, temperature range. Treatment, as well as storage before use as fertiliser, should take place in closed containers which retains the volatile ammonia and prevents contamination and/or regrowth. Since biological processes are hampered by ammonia, methane and nitrous oxide production are negligible. Material aspects that needs to be considered when implementing the technology are e.g. the pH reached from additions and its stability, the distribution of ammonia etc. Faecal sludge contains some ammonia mainly due to the ammonia in urine, but the concentrations can be low due to dilution from flush water and losses to air. Mixing source-separated urine and faeces from urine-diverting dry toilets will give a high enough NH_3 concentration for pathogen inactivation. Estimations of NH_3 concentrations in faecal sludge from vacuum, pour-flush and low-flush toilets indicated that the ammonia concentrations required for stable pH may not be reached without the addition of ammonia[5]. The final value and stability of the pH achieved from urea depended, apart from rate of additive, mainly on initial pH and dry matter content. Urea and ammonia solution give a pH above 9 and 10 respectively, and ammonia solution a pH above 10, provided the breakpoint is reached.

With low TS faecal sludge (1%), a stable and high pH (9.2) can be reached with 0.5% urea; whereas with high TS (≥20%), 1.5% urea may be needed for a stable pH ~9 during the sanitisation process. When ash or lime is used as cover material, the resulting alkaline pH can enhance the effect of intrinsic and added ammonia, but at pH >10 enzymatic degradation of urea will be inhibited, hence potentially limiting the system. In such cases aqueous ammonia can serve as ammonia additive. Ammonia concentration is critical for inactivation of e.g. Ascaris eggs and high dilution of source separated urine (1:3) and 20 mM NH_3 was identified as the critical minimum even if the temperature was 24 ºC. Sun exposure can increase urine temperature and shorten treatment time, and is feasible when urine containers are small.

Safe reuse

The WHO Guidelines for the safe use of wastewater, excreta and greywater in agriculture (2006) give sanitisation recommendations based on the health-based goal that the additional burden of disease from excreta reuse should not exceed a loss of 10^{-6} disability adjusted life years (DALYs), which is the level of protection already set for drinking water. For ammonia sanitisation inactivation of Ascaris eggs will determine the treatment time, especially at lower temperatures where it is much slower than for other pathogens. An assessment of health risk associated with consumption of crops eaten raw indicated that a 4.5 $\log_{10}$ reduction of Ascaris eggs were required for unrestricted use of ammonia-treated faecal sludge as a fertiliser[6]. In the full paper, a 4.5 $\log_{10}$ reduction of ascaris eggs will be used as the target to illustrate the required treatment time at different temperatures and ammonia concentration.

Also for ammonia sanitisation ascaris eggs have proven more persistent than other parasites as whipworm egg and Entamoeba's (unpublished results) and can be considered a conservative indicator organism. For virus inactivation naturally present f-RNA bacterio-phages seem to be useful as indicators since their inactivation is in the range of several human viruses[7,8]. *Salmonella* spp. and *E. coli* O157:H7 are inactivated to a high degree even at low NH_3 concentrations and temperatures and thermo tolerant faecal coliform bacteria can serve as indicators for Salmonella spp.

WHO (2006) mainly consider storage and alkali for faecal treatments and the product quality recommendation of less than 1 helminth ovum g^{-1} TS is based on application of 10 tonnes treated faeces (25% TS) ha^{-1} $year^{-1}$. Such application would for source separated faeces treated with 1 and 2% urea (w/w) result in 150 and 200 N ha^{-1} yr^{-1}whereas with sewage fractions of lower TS than 25% the nitrogen in relation to the TS will result in lower risk to apply helminth eggs to the agricultural land.

Conclusions

Sanitation systems that collect human excreta separate with a low dilution with flush water allows for a more economic ammonia sanitisation. Thermo tolerant coliform bacteria as E.coli, f-RNA bacteriophages and Ascaris eggs are suggested as indicator organisms to assess treatment efficiency to ensure the safe reuse.

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Stabilization of Faecal Sludge through Anaerobic digester at Devanahalli

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Keywords: Faecal Sludge, Stabilization, Biogas digester
Conference Track: (1) Research Track
Track Topic: *Technologies for the collection, transport, treatment, disposal and use of faecal sludge*
Personal Preference: Poster presentation

Abstract:

With the recent developments in Swacch Bharath Mission (SBM) in India, there is a rapid increase in provision of sanitation infrastructure in terms of toilet construction. Although centralized underground piped sewerage systems are preferred by most Indian cities, the coverage is so limited that over 95% of the towns have to depend mainly on onsite sanitation systems (Bhat, N. et al 2011)[1]. The scientific way of treatment and safe disposal of the collected FS in developing countries is a growing concern. Based on the studies conducted by different researchers on FS characteristics, it is found that sludge contains high organic content and solids and in order to remove these, biological treatment is feasible; especially the anaerobic process (Bachman, N. 2015)[2]. In developing countries with a tropical climate (mesophilic range), operation of an anaerobic digester is more stable, as the microbial communities can tolerate greater changes in environmental parameters and consume less energy (Vögeli, Y. et al 2014)[3]. Stabilization through anaerobic digestion is beneficial in scenarios where low operating costs, higher loading rates and effective removal of organic solids is required. With this background CDD Society and BORDA have implemented a town level pilot Faecal Sludge Treatment Plant (FSTP) at Devanahalli, which primarily treats FS anaerobically. The main criterion for selecting anaerobic digester was to enhance digestion of volatile solids/bio degradable solids thereby reducing odour when applied in sludge drying beds. Further this digestion process also enhances the dewatering capability of FS. The digester uses turbulence created within due to gas pressure to increase the process of digestion. In this paper, the focus is on the data collected during the stabilization process in terms of Volatile Solids reduction, Biogas production and dewatering capability.

Description of treatment module:

The FS from pits and septic tanks present in Devanahalli is conveyed to the FSTP of capacity 6 cum/day through cesspool vehicles. The treatment modules include: Feeding Tank (FT) with screen chamber for solid liquid separation. The separated solid portion is treated in two Biogas Digesters (BGD) with Stabilization Tank (ST), followed by Sludge Drying Bed (SDB) and Percolation pit for the leachate from SDB. The liquid portion is treated in DEWATS modules. The process flow diagram can be seen in the figure 1.1

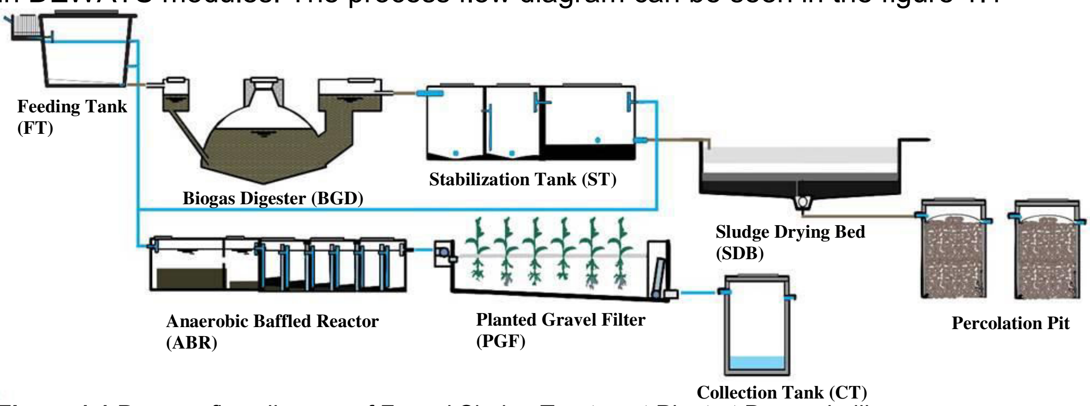

Figure 1.1 Process flow diagram of Faecal Sludge Treatment Plant at Devanahalli

The biogas digester installed is a fixed dome digester of capacity 5 m^3 each (with expansion chamber) with a gas storage volume of 1.5 m^3. The partially digested sludge from biogas system is taken into 3 chambered stabilization tank with capacity of 10 m^3 for further digestion and sedimentation of digested sludge. The biogas collected in the digester is used as fuel for cooking or water heating. The total sludge retention time allowed for digestion is around 12-14 days and then the digested sludge from stabilization tank is disposed into SDB by gravity.

Methodology

The methodology followed in this study is to

i. Analyse inlet quality of faecal sludge and outlet of anaerobic digestion process. The collected FS sample is tested for pH, COD, BOD, Total solids (TS), Volatile Solids (VS) in the laboratory as per APHA standards.
ii. Biogas production readings are also recorded using biogas meter at hourly intervals after disconnecting gas connection for reuse.
iii. Comparison of drying period of stabilized sludge versus raw faecal sludge

This analysis provides information about quality of incoming sludge, the stabilization/digestion that the sludge undergoes as well as the dewatering capability of sludge.

Observation and Results:

The feed to FSTP varies between 1200-4000 liters/day and with an average feed of 2000 liters/day; the solid and liquid separation in the feeding tank is approximately 56% and 44 % respectively. Average feed to Biogas digester is 1400 liters/day and varies between 200-3000 liters/day. The incoming organic load as VS ranges between 40- 26 g/l (an average112 samples) respectively and the digestion process in the anaerobic modules results in 50-70% of organic load reduction. The digester effluent organic load in terms of VS content varied between 8g/l to 16g/l. The maximum gas stored was recorded to be 1.306 m^3 per day under regular feeding. The dewatering ability of stabilized sludge in terms of rate of percolation is faster in first two days compared to the fresh FS and the stabilized sludge was odour free compared to fresh FS.

Conclusion:

This study shows that adoption of anaerobic digestion process for faecal sludge stabilization is suitable for countries like India. This study also shows that the anaerobic digestion process is suitable for VS reduction which in turn resulted in better dewatering capability and odour less sludge compared to fresh faecal sludge. As the data points that are studied here are less, more data points needed to be further monitored under different climatic conditions, at different treatment plants. Further research has to be conducted in order to establish statistical significance of the findings.

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Inactivation Of Ascaris In Urine By Drying In Calcium Hydroxide For Application In The Autarky Toilet

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Keywords: Ascaris, Source separation, Lime, pH, Urine, Drying,

Conference Track: (1) Research Track
Track Topic: Health, safety and hygiene
Personal Preference: oral presentation

With over 4.8 billion people's excreta not being treated before entering the environment (Baum et al., 2013), better sanitation systems are being developed to remediate this. This study assessed the hygienization of a newly proposed sanitation system: the Autarky Toilet from the Reinvent the Toilet Challenge. The urine is treated using calcium hydroxide ($Ca(OH)_2$) powder to enable evaporation of water still keeping the nitrogen in the concentrated fraction (Randall et al., 2016). Ascaris and viruses (bacteriophages MS2 and phiX174 not presented) were selected as indicator organisms. Bacteria were not assessed as indicators since it is already known that they do not survive at elevated pH levels (Nyberg et al., 2011). Ascaris is a parasitic intestinal worm that still infects 1.22 billion people annually. The eggs are persistent (known to remain viable >17 yrs in soil) and resilient (can withstand elevated pH). The US-EPA recommends lime treatment for 3 months at pH above 12 for inactivation of Ascaris in biosolids.

Methodology

Fresh human urine was mixed with $Ca(OH)_2$ (10 g/L) for 10 minutes and left to stabilize for three hours. Human feces were inoculated with Ascaris suum eggs (100 000 eggs g^{-1} feces) that were retrieved by sieving swine faeces (Excelsior Sentinel, Inc., USA). The stabilized urine was aliquoted (150 ml per sample) and inoculated with the feces (0.1 g per sample). The samples were dried at room temperature to achieve target total solids content (85%). Reaching the targeted total solids, the treatments were sealed and stored at two temperatures (20 and 35°C). Destructive sampling was conducted as independent singlets (n=10) during 128 days of treatment.

Results

With the current sampling frequency, no two phase inactivation pattern could be observed at 20°C; whereas at 35°C a model for two phase inactivation (Pecson et al., 2007) was fitted and used for estimation of time for 3 $\log_{10}$ reduction of egg viability. At 20°C (Fig 1a), the inactivation took longer time (59 days for 3$\log_{10}$ reduction) than at 35°C (18 days for 3$\log_{10}$ reduction). The high pH (12.5) or TS (85%) alone had no effect on the inactivation rate of Ascaris at 20°C during the 90 days studied. At 35°C, an effect was observed for the treatment factors alone (pH, TS and temperature) but the combined factors by the treatment had a compounding effect (Fig 1b) which to a large part could be attributed to the high pH.

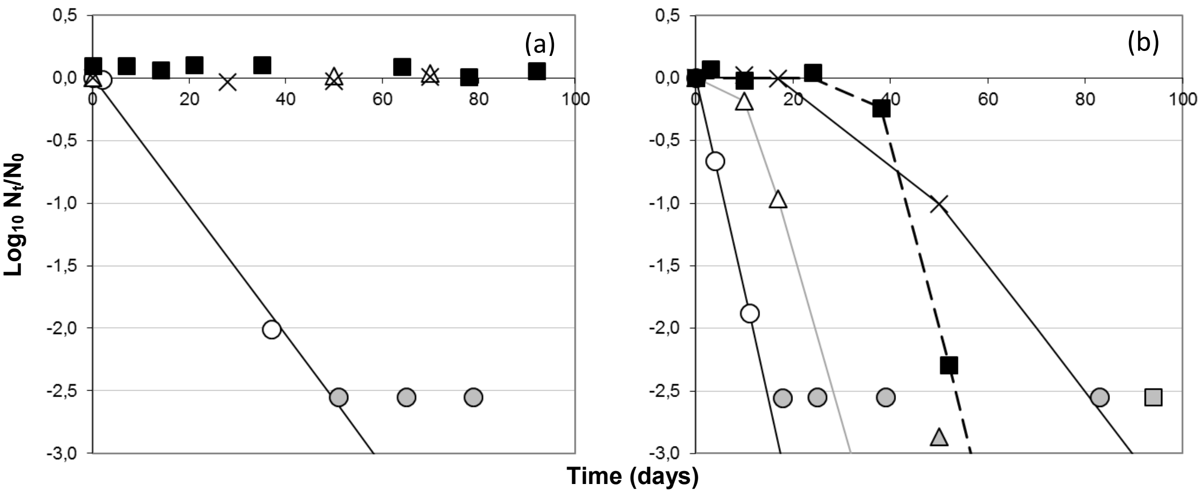

Figure 1 Log_{10} inactivation of ascaris egg viability over time at 20°C (a) and 35°C (b) in urine-$Ca(OH)_2$ suspension dried to a TS of 85% (○) and controls for pH 12.5 (∆) and TS 90% (■) and temperature (X). Grey filled symbols indicates when no viable eggs were found.

Conclusions

High pH, with some effect from drying, promotes Ascaris die-off at the higher temperature (35°C). Raising the urine temperature alone from 20 to 35°C shortened the time for a 3 log_{10} reduction from 60 to 20 days. At 35°C a 3 log inactivation in treated urine was reached within three weeks and at 20°C a two months of storage was needed, which is faster than the US-EPA recommendation for biosolids. The results indicate that high pH in combination with drying can concentrate the nitrogen in the urine while at the same time outputting a sanitized final product – however the storage time required depends on temperature.

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