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**LOCAL ACTION WITH INTERNATIONAL COOPERATION TO IMPROVE AND
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**Designing pit emptying technologies:
combining lessons from the field with systems thinking**

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The ideal pit emptying machine has been envisioned to be safe, hygienic, and economical, while being mobile and lightweight, allowing access to pits located away from main roads. The machine should be robust, should be amenable to easy operation by a few personnel, and can be maintained using local expertise and supplies. Using the insights from a recent workshop and our own field experience, we discuss the challenges of designing such a machine, and broaden the discussion to include the entire system of pit emptying, collection, and transport. We classify pit emptying technologies according to the type of pit (e.g., wet pits with little trash, wet pits with lots of trash, and dry pits with lots of trash), and argue that designing technologies accordingly should be the focus in the future. A systems approach that includes transport optimisation, sustainability of small businesses, and operator safety and training is advocated.

Background

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 every day (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. Previous workers have focused on devising the ‘best’ machine that can effectively and reliably empty any pit. The ideal machine is envisioned to be safe, hygienic, and economic, while being mobile and lightweight, allowing access to pits located away from main roads. The machine should be robust, should be amenable to easy operation by a few personnel, and can be maintained using local expertise and supplies.

In April and June 2016, the Omni Ingestor (OI) programme of The Bill & Melinda Gates Foundation convened two workshops and a series of site visits 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 organisations. The goal of the workshops was to use a facilitated brainstorming approach to devising the ‘best’ pit emptying technology.

A unique aspect of the workshops was that field visits were incorporated to ensure that all participants understood the real-world challenges of pit emptying. 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. This paper summarises the workshop results, discusses the challenges of designing the ideal pit emptying machine, and, using the insights from the workshop and our field experience, broadens the discussion to include the entire system of pit emptying, collection, and transport.

A pit is like a box of chocolates

One of the first outcomes of the workshop site visits was the understanding that a comparative analysis of pits in different countries quickly dispels the belief that a single technology will work for all types of pits. Many different factors account for huge differences in pits and pit contents:

- Whether the population is predominantly composed of washers or wipers
- Offset pits (e.g., pour flush) vs. pit latrines underneath the pedestal or squat pan

- Access to pits and differences in pit designs (e.g., VIPs with side cover access or keyhole access)
- Availability of solid waste services, affecting the use of pit latrines as trash receptacles
- Rural vs urban setting
- Depth of water table.

While pit contents and faecal sludge characteristics in a country or region can be described, these descriptions should be considered generalisations. Even within the same community, pit contents can vary greatly in trash content, water content, strength, viscosity, and other characteristics that will significantly impact pit emptying procedures and choice of technologies. It is difficult to determine the nature of the pit contents before arriving at the site and opening the pit. Like a box of chocolates, with pits, you never know what you're going to get. Based on the site visits, the workshop devised a generalised pit classification that will impact emptying as shown below.

Wet pits with little trash

Indian septic tanks and pits can be described as wet pits with little trash that are off-set from the user interface. In many cases, 200-800 L of water, provided in advance by the householder (Photograph 1) is needed to reduce the viscosity sufficiently that it can be removed by a vacuum tanker or a centrifugal pump (Photograph 2). Electricity is expected to be supplied by the householder. There is little trash, which can be handled with a simple screen at end of the hose. The sludge is discharged into a tank mounted on a small truck or tractor-trailer set. The pits are also generally accessible by vacuum tankers with a 40 to 50 m hose.



Photograph 1. The addition of water to a pit by the householder in India



Photograph 2. Centrifugal pump external to a pit

Wet pits with a lot of trash

In Dar es Salaam, Tanzania, workshop participants observed wet pits that contained significant amounts of trash. The “Sludge Go” (Photograph 3) is a vacuum technology consisting of a small storage tank with a vacuum pump powered by an engine, mounted to a trailer, and transported by a small motorised vehicle (in this case, a small tractor). Even after addition of approximately 100 L of water and trash removal using manual poles and hooks, the “Sludge Go” experienced clogging due to trash blocking the vacuum hose.

In Lusaka, Zambia, the pits were emptied manually by creating an opening through the outside of the superstructure base. Buckets and dippers were used to empty liquid faecal sludge with trash. However, it is known that pit contents are not homogeneous, and layers of different sludge strengths are possible. Our observations in Mzuzu and Blantyre, Malawi also highlighted the special approaches needed to deal with trash. In Blantyre, an approach called “fluidisation and fishing” was developed, in which a power washer is used to introduce water and mix the pit contents, followed by using long poles with hooks to remove the floating trash. This is a messy and unsafe operation (Photograph 4), but is the only way to avoid blockages in the subsequent vacuum pump removal.



Photograph 3. Small vacuum system used in Dar es Salaam, Tanzania



Photograph 4. “Fishing” out the trash in Blantyre, Malawi

Dry pits with a lot of trash

The VIP (Ventilated Improved Pit) latrines in eThekweni municipality in Durban, South Africa represent the third type of pits found. These are pits that have been designed with a partially off-set pit with removable slabs outside the superstructure. The FS is quite thick and full of trash. In Durban, these pits are emptied manually using shovels and rakes with long handles (Photograph 5).



Photograph 5. Manual emptying of dry pits with trash in Durban, South Africa

Implications for designing the ideal pit emptying machine

Workshop results

The workshop participants went through five stages:

1. Problem Definition: This involved making clear the technical, economic, environmental, and cultural problems that the workshop needed to consider and was summarised as “We don’t have sustainable

technical solutions that protect public health and economically empty wet and dry urban pit latrines of various designs”.

2. Current Status: This was informed by field visits to observe pit emptying practices as outlined. In addition, other participants were invited to describe current issues and practices in Malawi, Uganda, Tanzania, South Africa, Madagascar, and Bangladesh. This resulted in the generalised pit classification illustrated above.
3. Objectives and Deliverables: This focused on evaluating the 168 design requirements defined by the OI programme. The main requirements of pit emptying technologies included: a minimum emptying rate of 3 L/s, all pit-side equipment to be transportable by an average person, sludge containers that weigh no more than 15 kg, road-side units to be less than 1.5 m wide and 6 m long, equipment to be self-cleaning, all common and expected sanitation items normally encountered in pits to be pumpable, design life of 20 years in developing country conditions and all-in capital and operating costs (excluding personnel) of USD20/cubic metre.
4. Idea Generation: Here, several approaches were employed, including *intuitive* and *formal* methods. The emphasis was on generating all kinds of ideas and solutions and using other ideas as springboards. Small groups were formed based on specific focus areas, and the groups further worked on their solutions, including some initial prototyping and cost analysis. A total of 440 ideas were generated across 17 categories. A further 150 ideas were generated after the workshop in India. The ideas were combined to generate potential solutions and documented for further consideration.
5. Evaluation: The entire team 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. There were few outcomes from this activity due to the limited time available for the task.

The workshop showed that designing a single machine that can empty all types of pits is challenging, if not insurmountable. The solutions generated thus focused on designing for wet and dry pits. Several solutions were highly ranked and presented potential for future funding and development. Additionally, a few participants noted that key factors such as trash were not clearly addressed.

Further analysis of “the trash problem”

Numerous types of trash have been reported in latrines including plastic bags, broken glass, cloth (Brouckaert et al., 2013), needles, sanitary towels, clothes (Chowdry et al., 2012), newspaper, and anal cleansing materials (Still, 2002). Designing a mechanical approach to dealing with trash is difficult given this wide variety of shapes, sizes, and other characteristics. Manual and mechanical emptying systems suffer from blockages because of trash. Based on the workshop and our field experience, there are limited options for dealing with trash in pits:

1. Screening: This may work in low trash situations (e.g., septic tanks in India), but screens become blocked and need to be periodically cleaned of trapped debris. In theory, screens need a high surface area to avoid frequent cleaning, but designing a screen that can fit through a 100 to 200 mm hole is challenging.
2. Macerating: Given the various types of trash found in pits (e.g., jeans, shirts, etc.), a macerator would need high-energy inputs, and again would need to fit through a small hole.
3. Fluidisation and Manual Fishing: While this approach is currently used, fishing is messy, unhygienic, and potentially dangerous to workers and the public. Fishing can take hours, while the actual pumping of FS may take minutes. Improvements, such as more efficient fishing tools have been developed (Sisco et al., 2017), but in general, fishing for trash is a suboptimal approach.
4. Trash exclusion: A new approach for handling trash is to prevent it from being pumped out during emptying of FS. This approach relies on a mechanical screw auger turning in the “opposite” direction while a vacuum is applied to remove FS (Rogers et al., 2017). This technology is the basis of the Flexrevator and the Flex-X, an add-on to any vacuum system, and has been shown to work in Blantyre, Malawi and Hyderabad, India (Rogers et al., 2017). Trash exclusion has several potential benefits, including: (1) changing household behaviour by leaving the trash in the pit since this reduces effective pit volume and increases frequency of emptying; (2) providing a new business opportunity for pit emptiers, if trash collection after the FS has been removed is desired by the customer; (3) benefiting downstream processing since trash is usually a nuisance in processes such as composting, anaerobic digestion or the use of Black Soldier Fly larvae. Continued field experience with this new approach is needed to see if these benefits emerge.

The need for a systems view

The workshop was focused on designing a machine with the goal of removing FS from an existing pit to above ground, and then to a road-side unit (e.g., a truck). Wider solutions, including redesigning pits and considering transport to collection stations or treatment facilities were not considered. In other words, the workshop focused on the current situation and did not consider more general system improvements.

It is the opinion of the authors that a more comprehensive analysis of FS collection and transport is needed. The overall goal is to make the entire process safe for the environment and for people (workers and community), efficient, and economical, while increasing services to pits that are difficult to access. Several issues that support this view and that emerged during the workshop and from our own field experience and analysis include:

1. Upstream effects on pit emptying: Considering the design of pits

Minor improvements in pit latrine design can make emptying more efficient. For example, constructing side access ports will eliminate punching holes in the superstructure every time a pit needs to be emptied. Designing a different squat pan or pedestal may prevent or minimise users from throwing trash down the pit. For example, the SaTo pan or the South African pour-flush pedestals (Still and Louton, 2012) appear to provide a psychological and physical barrier to trash disposal in pits. This, and other issues, can be considered as part of improving pit emptying beyond designing an optimal emptying device.

2. Downstream effects of pit emptying: Differentiating between pit-side units and road-side units

This involves potentially considering the design tasks for a pit-emptying machine to be two-fold: removing the FS from inside the pit to above ground, and moving the material to a transport unit on a major road. The differentiation would allow thinking of unique solutions optimised for each task. A pump that lifts out FS and deals with trash might be different from a mechanical method for moving the FS from pit to the road. Combinations of mechanical and manual approaches can be explored. Innovations in local transport devices, containers, and methods of conveyance can be a focus of future efforts. This would also mean differentiating between “batch” and “continuous” processes of FS removal and conveyance, taking into account overall rates of removal, and not just the operating pump flow rates.

3. Downstream effects of pit emptying: Considering transport costs and available treatment facilities

Field experience has shown that what often limits the total number of pits emptied per day is not the time required for pumping FS, but the time it takes for transporting the material to a treatment facility. Transport between pits and between pits and treatment facilities accounts for the majority of costs in fuel, labour and vehicle resources (e.g. inefficient trips and transport, trucks and drivers sitting in traffic). The impact of travel time and cost is directly evident to pit emptiers - when treatment facilities are distant, pit emptiers either refuse to service certain areas or illegally dump FS into the environment, negating the benefits of FS collection from pit latrines. What is needed is a more general analysis that takes into account the collection, transport and treatment steps for any defined area (such as parts of a city or town) as an integrated sanitation system from pit emptying through to proper disposal. The analysis can be an optimisation model that considers a variety of input data: GPS coordinates of pits, road and traffic conditions, current and potential locations of FS collection stations (i.e., easily accessible FS aggregation points that cover multiple pits), availability and use of road-side/onsite dewatering technologies, and location and operation of treatment facilities. The goal is to minimise transportation, fuel, and energy costs, and the costs of new facilities (dewatering, transfer stations, and treatment) for a system-wide management of FS from pit latrines.

4. Additional principles that require consideration:

The workshop did cover public health and worker safety, and ideas for improved PPE (personal protective equipment) were generated. Safe and hygienic emptying operations should always be part of pit emptying and transport optimisation. Training of operators is crucial to successful operations. Business models that will lead to sustainable pit emptying operation should also be explicitly considered. These analyses will put upper bounds on the cost of a machine and its operation, consider the market for pit emptying in any given area, and include analysis of financing options for small business owners. Machine production and supply chain issues should also be considered. Eventually, designers of new pit emptying technologies will have to incorporate commercialisation needs into their thinking as well.

Conclusions

To date, there is not a single machine that can be used to effectively remove FS from pit latrines of all types and with varying contents. Classifying pit emptying technologies according to the type of pit (e.g., wet pits with little trash, wet pits with lots of trash, and dry pits with lots of trash), and designing technologies accordingly appears to be the direction for machine design. Ideally, any pit emptying device deployed in a region needs to be robust enough to handle trash, different strengths of sludge within pits, and a range of water content encountered in the same region. Optimising pit emptying needs to include considerations of FS collection from the pit, to the road, transport to a treatment facility, and the operations of the treatment process, and not just pit emptying itself. A systems approach to pit emptying should include analysis of other issues such as supporting small business owners and providing for proper safety and training.

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