Review of Manual Pit Emptying Equipment Currently in Use and Available in Freetown and Globally

GOAL

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List of Abbreviations

FGD	Focus Group Discussion
FS	Faecal Sludge
FSM	Faecal Sludge Management
HP	Horse Power
IC	Internal Combustion
LSHTM	London School of Hygiene and Tropical Medicine
MAPET	Manual Pit Emptying Technology
MPE	Manual Pit Emptier
PPE	Personal Protective Equipment
RPM	Revolutions per minute
USD	US Dollars
WRC	Water Research Commission
ZAR	South African Rand

1 Introduction

This is a review of the pit emptying technologies that currently available or are being piloted. A few older technologies have been included in this review to provide context for how the technologies and approaches have been developed throughout the years.

Manual pit emptying is the most common and easiest form of pit emptying in developing countries, allowing access to pits and septic tanks in overcrowded and geographically inaccessible areas that conventional vacuum tankers cannot reach (Mikhael, et al., 2014; Thye, et al., 2011). However, is can be unsafe and unhygienic when done with improper tools and without any form of protection between the manual pit emptier (MPE) and the faecal sludge (FS) they are removing from the pits. MPEs are often stigmatised due to the nature of the work and because of this must do their jobs at night time, adding to the risks involved (Manual Pit Emptiers, 2016; Mikhael, et al., 2014). To improve faecal sludge management (FSM) in an urban context MPEs need to adopt hygienic and clean practices in order to improve their working conditions and this can be facilitated through the use of the correct tools and technologies.

This report first details the methodology used to review and select the most appropriate pit emptying technology for Freetown. The technology review then begins, leading with a summary of all the pit emptying technologies identified and key information about each. They are categorised by technologies that suitable, unsuitable for Freetown, and those that require more information or field testing before they could be used in any context. Following on from this a detailed account is given of each technology listed in the summary. Finally, the conclusions recommend which technologies are potentially most suitable for use in Freetown.

2 Methodology

The aim of this literature review is to gather all information available on currently used and available manual pit emptying technology worldwide, to facilitate the selection of the most appropriate technology to be implemented in Freetown, Sierra Leone. To gather this information searches were made on the Susana (Sustainable Sanitation Alliance) online forum. This forum contains many discussions about the investigation, development, field testing and upscaling of various pit emptying technologies, mainly throughout Africa and Asia. This resource was used as a starting point, from which scientific papers, conference presentation and videos of technologies in action were reviewed. In addition to this, google searches were performed using key phrases such as 'manual pit emptying', 'pit emptying equipment' and 'semi-mechanised pit emptying', along with searching the names of different technologies discovered through the Susana forum to find more papers, reports and articles detailing how different technologies were designed, trialled and the successes and challenges encountered with each. Finally, stakeholders in the sector were contacted for recommendations on any further literature that should be reviewed.

To understand the methods of emptying pit latrines and septic tanks commonly practice in Freetown focus group discussions (FGDs) were held with three groups of MPEs. Each group are based in different locations throughout the city. They shared their experiences with different methods of pit emptying, the challenges they face with these and their thoughts how their methods could be improved upon and what the most appropriate method is for Freetown.

Once all the information was gathered and reviewed, three technologies were preselected and recommended for field trials to investigate how they operate in the context of Freetown pit emptying. According to Still & O'Riordan (2012) factors that need to be consider when selecting appropriate pit emptying equipment include effectiveness, safety, costs and sustainability. The effectiveness should consider if the technology can access the household and the containment system being emptying, if it can cope with the type of FS to be emptied and who the technology interfaces with a transport system to take the sludge from the household site to a treatment and disposal site. Safety considers that of the MPEs, the household members and the surrounding environment. Costs accounts for all costs encountered, including the capital, labour, operation and maintenance, overheads, equipment, transport and disposal costs. Finally, sustainability considers the lifespan of the technology and how resilient it is to the roughness of the job, whether it can be manufactured locally, if spare parts are available locally and if the capital and operational costs are recovered through the income the MPEs receive.

From this, the following key criteria were considered to preselect these technologies:

- Cost (capital and operational)
- Capacity (pumping and storage capacity)
- Can it be locally produced
- Can spare parts be sourced locally
- Durability
- Ease of operation
- Ease of clean up
- Type of sludge it can pump

3 Pit Emptying Technology Review

This section reviews in detail the different pit emptying technologies available to MPEs, first giving an overview of all the technologies identified and key factors about their design and performance in the field. The technologies are categorised into suitable technologies, unsuitable technologies and technologies for which there is not enough information available.

Manual pit emptying can be categorised as 'cartridge containment' and 'direct lift' methods. These methods can be carried out safely and hygienically for both MPEs and the environment, once proper equipment and procedures are followed. The 'cartridge containment' method is built into the toilet system. There is a replaceable and sealable container of reasonable size, for example 20 litre, below the squat hole or toilet seat, which collects the excreta. This system requires an established network of collectors who take away the full container and replace it with an empty one on a regular basis. The full container is taken to a transfer station, which itself is emptied when full and the sludge is transported to a treatment and disposal site. This is a holistic method which requires a particular onsite sanitation technology, for example a urine diverting toilet, which are not used in Freetown. Hence, the 'direct lift' method is the more appropriate practice in Freetown. This involves removing sludge from latrine pits or septic tanks using long handled buckets or shovels to lift the sludge up and out of the pit and is stored in containers for transport (Mikhael, et al., 2014). The reality in Freetown is that often the MPE must enter the pit to remove the FS and it is either buried in a shallow pit dug within the same compound or is dumped nearby in drains or indiscriminately in the community (Manual Pit Emptiers, 2016).

Semi-mechanised technologies, using human power transferred through a mechanism, have been innovatively developed in recent years. The aim of these new technologies is it to allow the MPEs to perform their jobs more safely, quickly and efficiently, while maintaining low capital, operational and maintenance costs. Fully mechanised technologies are powered by electricity or fuel. These are generally more expensive and complex however innovations in recent years are focused and reducing the cost through using locally sourced parts and manufacturers and developing technologies smaller and able to access hard to reach areas due to space restrictions or steep pathways. Furthermore, some of the semi-mechanised technologies can be made fully mechanised, increasing their capacities (Mikhael, et al., 2014).

Fully mechanised pit emptying technologies are usually based on using atmospheric pressure or high airflow rates to suck FS under a vacuum from the pit being emptied (Thye, et al., 2011). In more recent years' work has be done adapting soil augers to pit emptying powered by electric or hydraulic motors. These technologies are relatively successful however have only be trialled in the prototype phase and there is no experience of their use on a commercial level (Still & O'Riordan, 2012; Rogers, 2015).

Key factors when designing a pit emptying technologies including power source, emptying efficiency and safety need to be considered to ensure the final product is affordable. The options for power source are petrol engine, electric motor or human power. Up until the MAPET was developed human power was considered inadequate and electricity supply in slum areas is either non-existent or inconsistently supplied. Small five horse power (HP) engines are available in most African cities and so this became the power source of choice when designing pit emptying equipment, as well for its small size and easy access to fuel. However, the engines and fuel are both at high risk for theft, meaning extra costs are needed to hire a guard, which itself does not ensure it is projected. Furthermore, engines need to be maintained and operated properly to ensure they do not need repairs and replacement prematurely. Petrol engines when included in the emptying equipment design lead to higher capital costs (being a high proportion of the cost), make the equipment heavier and needing a vehicle and mounting for it to be mobile. When there is opportunity to connect to an electricity source an electric motor has an advantage over the petrol engine as it is lighter and repairs can be done locally, they are less vulnerable to poor maintenance and is at a lower risk for theft. Most African cities have a market for new and second hand electric motors (Sugden, 2012).

In terms of emptying efficiency, the most time consuming aspects of pit emptying are as follows:

1. Transporting the waste to a treatment facility
2. Travelling to and from the household
3. Setting up and preparing the equipment
4. Cleaning the latrine after emptying is complete

The discharge rate of the emptying equipment does not have a large impact on the time taken to complete the job from start to finish. To improve emptying efficiency, the time taken to remove, transport and safely dispose of the sludge needs to be considered as a whole, not just the pumping capacity of the pit emptying technology. Emptying efficiency is more closely related to the distance the sludge has to be transported. Hence it needs to be considered whether the emptying equipment is a combined emptying and transport unit or are these elements designed separately. The Vacutug and Dung Buster are examples of combining the emptying and transporting needs into one unit, creating a smaller vacuum tank design using a petrol engine, creating a high capital cost that informal pit emptiers do not have access to (Sugden, 2012).

The main hygiene considerations are those to the pit emptier, the household receiving the service and the community. The main risk for contamination is during the sludge pumping and cleaning up process. Malfunctions or accidents when operating the equipment can cause sludge to be spilled from the tanker or containers or blow from the pipe instead of pumped. Cleaning the equipment is also messy, with sludge remaining inside it after emptying is finished that needs to be removed. Small screw, nuts and bolts make clean difficult and are lost easily if removed and left to dry during the cleaning process. Bayonet fixing or simple locking devices can are appropriate to ensure proper cleaning (Sugden, 2012).

3.1 Overview of Pit Emptying Technologies

Table 1 Overview of pit emptying technologies

Device Name	*Power Source*	*Capital Cost*	*Operational Cost*	*Level of maintenance*	*Removal Rate*	*Hygiene and cleanliness of method*	*Sludge type*	*Success/Failure*	*Years of experience*	*Countries of application*
Suitable Pit Emptying Technologies for Freetown, Sierra Leone										
Hand tools and personal protective equipment	Manual[12, 15]			Low[12, 15]		Can be unsafe and unhygienic if PPE and good practices not used[12, 15]	Wet and dry[12, 15]	Some tools developed were too heavy, otherwise successful[12, 15]		
Sludge Digger	Semi-mechanised[17]			Low[17]			Wet and dry sludge[17]	Prototype stage but looks promising[17]		USA[17]
Rammer/Gulper II	Semi mechanised[2]				Pump rate = 1 L/s[1]		Sludge with shear strength of 100-500 Pa[1]			Uganda[1]
Diaphragm pump	Semi-mechanised[15]	$300 - $850 for manual, $2,000 for mechanical[15]	1 to 2 people to carry it[15]	Airtight seal needs to be maintained, diaphragm prone to cracking[15]	100 L/min, max pumping head of 3.5 m to 3.4 m[15]		Wetter sludge, minimal to no rubbish, septage[15]	Successful if used to empty septic tanks[16]; Spare parts aren't available locally, easily blocked with rubbish[15]	1 to 2 years in Freetown[16]	Bangladesh[15]; Sierra Leone[16]
Pit Screw Auger	Mechanised[12]	$700 for prototype manufacture[15]			25 L/min at RPM>60; 25 L/min (on pig slurry and with cage); 40 L/min on pig slurry with blades and no cage[12];40-50 L/min	Difficult to clean[12]	Thick sludge with some rubbish[12]	Initially manually powered but couldn't reach RPM needed; worked well on pig slurry, issues with blockages when used on pit latrines[12]	Trial phase[12]	South Africa[12]

Device Name	*Power Source*	*Capital Cost*	*Operational Cost*	*Level of maintenance*	*Removal Rate*	*Hygiene and cleanliness of method*	*Sludge type*	*Success/Failure*	*Years of experience*	*Countries of application*
Excrevator	Mechanised[5]	$1000-$3000[6]; $4500, with $4000 being motor[7]	$5-20 per day[6]		50-125 L/min or a 1 m^3 pit in 0.5 to 1.5 hrs[6]		Denser sludge[7]; Low solid content and high solids content[6]	Success in field tests, has not be brought to scale, estimated lifespan of 5-10 years[6]	On version 3[8]	Malawi, India, South Africa[5]
Pressure Vessel	Supplementary equipment[12]				Used to fluidise FS by adding water or pressurised air					South Africa[12]
Unsuitable Pit Emptying Technologies for Freetown, Sierra Leone										
Gulper	Semi mechanised[1]	$160[3]; $100[14]; $40 - $1,400[15]		Low[2]	2hrs[2]; flow rate of 30 L/min[15]	Splashing of sludge between Gulper outlet and transport container[15]	Watery[2]; Wet pit latrines, inceptor drains[3]; low viscosity[15]	Success[3]; Failure – after few months of use extendable pipe is stuck due to sludge build up[4]; PVC pipe prone to cracking[15]		Tanzania, Malawi[2]; Cambodia[3] [3]
The Nibbler	Semi-Mechanised[1]					Very messy[1]	Very thick[1]; not suitable for very dry sludge with high rubbish content[15]	Failure – rejected by entrepreneurs[1]; Not taken past early prototype[12]		Uganda[1]
The Gobbler	Semi-mechanised[12]	$1,200[12]						Heavy and early versions clogged/jammed easily[12]		South Africa[12]
Pedal Power Gulper Pump	Semi-mechanised[9]	$406[9]			0.0006 m^3/s[9]			Success on 5 pit latrines[9]		Malawi[9]

Device Name	*Power Source*	*Capital Cost*	*Operational Cost*	*Level of maintenance*	*Removal Rate*	*Hygiene and cleanliness of method*	*Sludge type*	*Success/Failure*	*Years of experience*	*Countries of application*
Pedal Power Treadle Pump	Semi-mechanised[10]	Prototype $101[10]; Prototype $175[11]						3 prototype developments, first two tested on mud slurry, 3rd tested on sludge simulant and 30 actual pits[10]		
MAPET	Semi Mechanised[14]; Piston pump powered vacuum[12]	$3,000[14]	3 labourers[14]; $175 per annum (maintenance cost only in 1992)[15]		5 to 25 minutes depending on sludge consistency and head[14]; 10 to 40 L/min depending on sludge, max head of 3 m[15]		Liquid sludge[12]	Failure[12]; required strong institutional support to operators, spare parts not available locally, maintenance costs not recovered by emptying price[15]		Tanzania[12]
eVac	Mechanised - Electric engine and vane pump[12]	$2,200 to $2,700[13] (cost of generator and transport of it not included)[12]	3 labourers[12]		45 mins for set up, emptying and clean up; 40 litre tank filled in 10 to 15 seconds[12]	Splashes occurred easily with wetter sludge contaminating the environment[12]		63 kg but can be moved as mounted on trolley[12]		South Africa[12]
Mircavac	Mechanised				9000 L/min[18]			Relatively successful mostly because it can pass narrow pathways and over uneven roads[18]		Zimbabwe, Malawi[18]

Device Name	*Power Source*	*Capital Cost*	*Operational Cost*	*Level of maintenance*	*Removal Rate*	*Hygiene and cleanliness of method*	*Sludge type*	*Success/Failure*	*Years of experience*	*Countries of application*
Vacutug	Mechanised - Petrol engine[2]	$5,100, shipping ranged from $3,000 to $8,000[14]	$29.5/m^3 [12] (excluding cost to empty transfer tank). WATP was $20[12]	Spare parts difficult to find locally; tips over often causing damage[14]	10 minutes[2]; in Tanzania 4 latrines were emptied a day, other countries complain of it taking too long due to longer distances to dispose the sludge[14]		No rubbish, wetter sludge, drier sludge needs to be fluidised with 40 to 80 L[12,14]	According to operators failure – spare parts hard to find and has been out of use over 1 year, tips over easily, in Ghana deemed unsuccessful in the end[14]	One month of field testing, 39 low flush toilets[12]	Ghana, Bangladesh, India, Kenya, South Africa[12,14], Senegal, Tanzania, Mozambique[14]
NanoVac	Mechanised - IC Engine and piston pump[12]		2 labourers[12]			Easy to clean[12]	Liquid sludge[12]	Not robust enough in the field[12]		South Africa[12]
					Pit Emptying Equipment Requiring More Information					
Bangalore Screwer	Semi-mechanised[12]							Didn't pass early prototype phase[12]		India[12]
Beaumont Manual Pump	Semi – mechanised[19]		2 labourers[19]					In early prototype phase[19]	Field testing expected in June 2016[19]	
EMAS Pump	Semi – mechanised[20]							In early prototype phase – first tests results seem promising[20]		
Dung Beetle	Mechanised – diesel engine[12]							Maximum speed 12 km/hr[12]		Ghana[12]

[1] (Malinga, et al., 2016); [2] (Sugden, 2012); [3] (Ideas at Work, 2007); [4] (Sugden, 2016); [5] (Rogers, 2015); [6] (de los Reyes, 2016); [7] (Rogers, 2016);[8] (de los Reyes III, et al., 2014); [9] (Mzuzu University, 2015); [10] (Chipeta, 2015); [11] (Chipeta, 2015); [12] (Still & O'Riordan, 2012); [13] (1 ZAR = 0.118 USD in December 2012 and 1 ZAR = 0.1354 USD (Exhange Rates UK, 2016); [14] (O'Riordan, 2009); [15] (Mikhael, et al., 2014); [16] (Manual Pit Emptiers, 2016); [17] (Andreatta, 2015); [18] (Thye, et al., 2011); [19] (Whitesell, 2016); [20] (Buchner & Moninger, 2016)

3.2 Suitable Pit Emptying Technologies

This section details the pit emptying technologies noted as potentially suitable for implementation in Freetown, Sierra Leone.

3.2.1 Hand tools and Personal Protective Equipment

The most basic method of removing FS from a pit is to do it manually using hand tools (O'Riordan, 2009; Still & O'Riordan, 2012). There are two categories of hand tools; scooping and flushing. Scooping involves opening the squatting slab and the emptiers scoop out the sludge, which is either buried on site or taken away in containers. Flushing (also referred to as sluicing) the sludge is flushed into a pit that is beside the latrine pit and deeper than it. This method requires large quantities of water and appropriate soil conditions. (O'Riordan, 2009). A variety of equipment is used by MPEs to open the pit, remove the FS and for health and safety. For opening the pit shovels, pry bars and screwdrivers are commonly used. To actually remove the FS long handled shovels and buckets are used, as well as hooks to remove rubbish and sometimes hoses to add water to fluidise drier sludge. Ideally, personal protective equipment (PPE) and general safety equipment is used such as overalls, face masks, eye protection, boots, gloves, hardhat, disinfectant and bags for clean-up especially as the emptying device is removed from pit covers in sludge and fresh faeces. PPE is often abandoned in countries with high temperatures in countries that use manual pit emptying, even when the risks are known (Sugden, 2012; Mikhael, et al., 2014).

According to the MPEs in Freetown they use the bucket method, which can be categorised as scooping and involves using a bucket, often attached to a rope, to lift the FS from the pit. However often the MPE must enter the pit to be able to full empty it. Most often this is done without any health and safety equipment and often times naked to prevent ruining their clothes (Manual Pit Emptiers, 2016). This is a major risk to their health.

MPEs often face stigmatisation due to the nature of the work and it either being illegal or misunderstood as illegal in some countries. This stigmatisation forces MPEs to work at night, with minimal light with no PPE and are can be met with violence and abuse from community members (Manual Pit Emptiers, 2016; Thye, et al., 2011).

The eThekwini Metropolitan Municipality in South Africa have a major onsite sanitation emptying program and have developed hand tools for this, including a hay rakes, long handled shovels and shovel/scoop (see Figure 1). The long handle shovel/scoop was unsuccessful when trialled in the field because it was too heavy (Still & O'Riordan, 2012). Heavy duty gloves and gumboots are worn for PPE (Thye, et al., 2011).

Figure 1 Left: Long handled rake and shovel; Right: Hand shovel/scoop (Still & O'Riordan, 2012)

A long handled tool was developed by Still & O'Riordan (2012) as part of a Water Research Commission (WRC) funded project to design and develop pit emptying solutions. It consisted of a pitch fork that closed over a spade, see Figure 2. There was a reversing mechanism on the pitch fork, which was operated by pushing and pulling the handle, causing the fork to be pushed into and out of the FS. The idea was that it would effectively close the mouth of the shovel, holding in the FS, but due to the nature of the FS this was not needed. The fork did not operate was expected and the tool was minimally effective at lifting waste from the pit. It was also very heavy making it unfeasible for manual pit emptying. At this point the development of this tool was halted. The following recommendations were given for future developments:

- The tool should be developed in short and long versions, using the shorter one to remove the top layers of sludge, the longer to be used for sludge closer to the base of the pit.
- Reduce significantly the weight of the tool

Figure 2 Modified hand tool (Still & O'Riordan, 2012)

According to Still & O'Riordan (2012) the main disadvantage to the scooping method is the length of time it takes, the associated health risks and social acceptance of the MPEs. The advantages are however that it relies on local labours which means spending funding in the community, low capital and operational costs and the process is less affected by breakdowns in machinery or running out of fuel.

3.2.2 Sludge Digger

The Sludge Digger is a low cost alternative to technologies like the Gulper, Vacutug (both to be detailed later in this review) and full sized vacuum tankers. It was under development in September 2015, with the objective of emptying FS without the need for fluidising or removing rubbish before pumping (Andreatta, 2016). It is a low cost solution that can empty both wet and dry FS, is simple to maintain and does not struggle against rubbish like most other emptying technologies. The design is an adaptation of a bucket to reduce the contact between the MPE and the FS. A 7 litre bucket is attached to a metal bracket, with pivots to allow the bucket to rotate between upright and upside-down. There are stops to prevent the bucket fully rotating and a rope is attached to the rim of the bucket and held in the operator’s hand to manoeuvre it as needed. The bucket can fit through a hole of 25 cm. To empty pits with wet FS the bucket is lowered into it upright to fill with FS and then lifted from the system. The rope is lowered to pour the FS into a container to be transported from the site. See Figure 3. To empty pits with thicker FS there is a small hole in the base of the bucket to allow air to pass through as it is pushed into the FS. The rope is completely lowered so the bucket is pushed into the FS upside-down. Once the bucket is fully submerged, the rope is pulled to upright the bucket and is lifted from the pit and emptied into a container in the same ways as the wet FS. Development so continue to reduce the diameter of the bucket to fit through smaller squat holes and septic tank access holes and to combine the two buckets, one with the air hole and one without, into one bucket design (Andreatta, 2015).

Figure 3 Left and centre: Sludge Digger being used on wet 'sludge'. Right: Sludge Digger used on thick 'sludge'

3.2.3 Rammer/Gulper II

The Rammer, now known as the Gulper II, was developed as an improvement to the Gulper by Sanihub/Water for People (Sanihub, nd; Malinga, et al., 2016). It is designed such that it can pump thicker sludge, it is extendable so goes deeper into the pit and can be dismantled making it easier to clean. The Gulpers positive qualities are maintained in Gulper II design, such as low capital costs, low running costs, locally manufactured, possibility for local repaired and its light weight. Like the Gulper, the Gulper II is a direct lift pump, an outer PVC casing slides up and down forcing the sludge up the pump without using suction and can reach up to 3 m depth. There is a flexible hose pipe at the outlet to facilitate hygienic operation. A donkey handle level arm allows for easier pumping. Both lined and unlined pits can be emptied with the Gulper II (Sanihub, nd).

The main components of the Gulper II are composed of galvanised iron and steel, hence is durable. The total cost is $191. Tests were conducted by Sanihub to compare the performance of the Gulper and Gulper II using synthetic sludge. The Gulper II was able to pump sludge with a shear strength ranging from 100 kPa to 500 kPa over a head of 3.5 m whereas the Gulper could only pump the sludge with shear strength 100 kPa. The Gulper II has also undergone field testing to empty pit latrines and was undergoing market testing at the time of the publication of the Sanihub Factsheet (Malinga, et al., 2016; Sugden, 2012). It seems like it is a successful design improvement, yet there is no larger scale commercial experience using it.

Figure 4 Gulper II design (Sanihub, nd)

3.2.4 Diaphragm Pump

Diaphragm pumps are a low-cost solution, appropriate for emptying liquid FS (low viscosity) that contains minimal rubbish (O'Riordan, 2009; Mikhael, et al., 2014). It consists of a 'rigid, disc shaped body clamped to a flexible rubber membrane called a diaphragm'. There is an airtight seal between the diaphragm and the disc, so when it is pushed and pulled using a lever, the cavity between the disc and the diaphragm expands and contracts causing the sludge to flow through the pipe. A screen and non-return foot valve are fitted on the end of the pipe; the screen prevents rubbish entering the pipe whereas the non-return foot valve prevents the backflow of sludge through the pipe (Mikhael, et al., 2014).

The diaphragm pump is light enough to be transported by one or two people, however sometimes it is mounted on wheels for easy transport. The capital cost of the diaphragm pump ranges from $300 to $850. The challenges encountered with the diaphragm pump include frequent blockages due to rubbish in the sludge, difficulties maintain the airtight seal between the diaphragm and the disc causing leaks, air entrainment and low efficiency of the pump, the rubber diaphragm cracks easily and difficulties manufacturing the pump locally and sourcing local spare parts (Mikhael, et al., 2014).

Diaphragm pumps are suitable for more liquid sludge. The main disadvantage of these pumps is that the sludge passes through the pump itself making it very vulnerable to blockages. Experiences in South Africa have seen the pump become blocked due to the presence of rubbish in the pit, when using a 3.5 HP diaphragm pump. However, the diaphragm pump can be easily transported by car and is easy to use, only requiring one day of training for the operator (O'Riordan, 2009).

As part of the Emergency Sanitation Project (ESP) and S(P)EEDKITS project, three different emptying technologies were trialled over a nine-month period in Malawi in an attempt to find a solution to emptying 'difficult faecal sludge'. In this case this means pit latrines that are difficult to access due to narrow, unpaved, hilly roads, latrines which have fragile squatting pans or covering slabs and sludge that has a low moisture content and rubbish present. The diaphragm pump was one of the technologies trialled. The diaphragm pump doesn't have a fluidising mechanism included in its design, a separate high pressure washer was manufactured to be used in conjunction with it (Spit, et al., 2015).

Throughout the course of the trial 200 lined and unlined pits were emptied using the three technologies. It was found that fluidising the sludge was necessary for the diaphragm pump to be able to remove a significant amount of FS from the pits. On average the volume of water needed was 15% of the total volume of sludge. The diaphragm pump was the most sensitive to blockages from rubbish of the technologies investigated. 'Fishing' rubbish out of the pits after fluidising but before emptying was essential to prevent blockages in the equipment. This was done with a 2 m metal rod with hooks welded on. This was successful at removing larger items but it was found that smaller items such as stones and medicine bottles could not be fished out using this piece of equipment and could still cause blockages. It was successful at pumping sludge from septic tanks with no rubbish but was not capable of pumping sludge from pit latrines (Spit, et al., 2015).

Figure 5 Diaphragm pump used in Malawi when investigating three pit emptying technologies for 'difficult sludge' (Spit, et al., 2015)

In Freetown, 30 MPEs participated in a FGD to understand their experiences and challenges using a diaphragm pump to empty pit latrines and septic tanks in the city. Currently the standard desludging practice in Freetown is the bucket method, either using a bucket on a rope but often the emptiers enter the pit to more efficiently empty it. There were mixed opinions but in general it was agreed that the main advantage of the diaphragm pump over the bucket method is that it is quicker when emptying septic tanks and its more hygienic and safe because it removes direct contact between them and the sludge. Furthermore, pit emptying is more comfortable and socially accepted when they use the diaphragm pump. The main difficulty encountered with the diaphragm pump is that the hose is too narrow and becomes blocked easily. The MPEs do not have access to any tools such as pliers, screw drivers and spanners and have to resort to using sticks and small pipes to clear the blockage. It was emphasised that the diaphragm pump is only appropriate to empty septic tanks that have minimal rubbish inside. Even when the rubbish is removed from pit latrines, the sludge is always too dry or thick to be pumped out (Manual Pit Emptiers, 2016).

Those that preferred the bucket method said it was quicker and more convenient, particularly in water logged areas. In pits with drier sludge pickaxes and shovels are also used so the pit can be fully emptied. The need to rake out solid waste from the pit or septic tank before using the diaphragm pump consume a lot of time and energy, making the diaphragm pump less attractive to them. Approximately two thirds of the FGD participants agreed that the diaphragm pump is more appropriate for pit emptying compared to the bucket method. The remaining third thought that both the bucket method and diaphragm pump are appropriate pit emptying options (Manual Pit Emptiers, 2016).

Figure 6 Diaphragm pump used in Freetown (Photo Credit: Mirco Keller)

The diaphragm pump can also be powered mechanically, either hydraulically, electrically or by compressed air, however petrol or diesel engines are the most common methods. The pump and engine are mounted on a frame and moved either by hand or trolley. The diaphragm pump power mechanically is also suited to pumping wetter sludge but can handle some smaller solid particles. The flow rate of a 3-inch pump is 300 to 330 L/min with a maximum pumping head of 15 m. The capital cost is approximately $2,000. Spare parts for both the engine and pump are difficult to source locally and it blocks easily with large particles like rubbish (Mikhael, et al., 2014).

3.2.5 Pit Screw Auger (PSA)

A manually operated auger was developed as part of a WRC funded project to design and develop pit emptying solutions. However, the speed needed to pump the sludge from the pit was higher than what can be achieved manually. This led to the development of a pit screw auger that was fully mechanised and was proven to lift drier FS in laboratory tests (Still & O'Riordan, 2012).

The auger and pipe from the manual prototype itself was successful, so a 1.1 kW motor with a 15:1 reduction gearbox was mounted to this, producing a RPM of 90, in comparison to an RPM of 50 to 60 which was achieved manually. The gearbox was used to test a variations of gear rations and it was found that the flowrate remained at 25 L/min once the RPM is over 60 RPM. After initial efforts to manufacture an auger failed, a 700 mm length of post hole drilling auger was selected and fitted inside a 125 m PVC pipe, providing a 15 mm gap between the pipe wall and the screw to reduce friction between the and the pipe. The pipe was hinged so it could be easily opened to remove any blockages, which commonly occurred due to rubbish in the FS. The screw extends 15 cm beyond the bottom of the pipe. A portion of the screw being exposed means the pit cannot be fully emptied, however it is necessary to direct the sludge into the pipe. It is argued that it is necessary to leave some sludge remaining in the pit to seed it with microbes to facilitated sludge breakdown as it begins filling again.

Initially a cage was added to the base to prevent rubbish entering the pipe, however this also prevented denser sludge entering the pipe. Instead, three blades were added to cut through the rubbish and sludge, making it flow more easily up the pipe. At the top of the auger screw a section of reverse screw auger was placed inside a pipe angled downwards at 45 degrees to facilitate the sludge discharging and to prevent the sludge reaching as far as the pump. A 110 m diameter flexible pipe was attached (after both a lay flat hose and heliflex pipe were unsuccessful) to the outlet to allow control over where the sludge is discharged. This is detachable for ease of cleaning.

The auger was originally designed to be modular and extendable, however even though the extension doubled the length of the auger, the lifting distance of the sludge was not greatly increased. Different methods of supporting the auger were investigated. Mechanisms such as hanging it from a bungee cord, mounting on a ball joint to enable it to be lifted up and down on a jack and finally a tripod were all tested but did not prove effective. A collapsible 3 m tripod made from lightweight stainless steel was manufactured and the auger hung from a chain to allow it to be manoeuvred was successful. These mechanisms were for support the auger on a pit that was accessible separated to the superstructure. For pits that were accessible through the pedestal only multiple support mechanisms were tested but none were successful. These mechanisms include an A-frame, a frame that gave a hanging point for the auger at the roof of the latrine and a supporting jack (Still & O'Riordan, 2012).

The auger underwent various tests using simulated sludge consisting mainly of pig slurry, investigating its performance when different materials were present in the sludge, such as newspaper, plastics and rags. The auger performed well under all these conditions and the emptying time was not greatly reduced through the addition of any of these materials. The cage at the bottom of the auger successfully prevent plastics being taken in by the auger, although it was messy to clean up after the job was complete. The auger was then tested on pit latrine sludge, however the presence of rubbish (plastics and clothes) was too high and the auger was blocked immediately (Still & O'Riordan, 2012).

Although the auger can cope with more rubbish than other methods, it is simple to use and understand and reaches relatively high flow rates, it is also very heavy (up to 40 kg when emptying), difficult to clean and has a fixed length. Recommendations to improve on the design include decreasing the weight, innovations to deal with the rubbish in the pit, extendable length, improve the mobility of the auger inside the pit, accessing the pit if only access is through the superstructure, and methods of reducing contact between the operator and the FS, especially during storage, transport and cleaning (Still & O'Riordan, 2012).

Figure 7 Modified mechanically powered auger (Still & O'Riordan, 2012)

3.2.6 Excrevator

The Excrevator was developed by the North Carolina State University with funding from the Bill & Melinda Gates Foundation initially in August 2011. The Excrevator is composed of a 4-inch diameter pipe containing an auger, which is rotated by a hydraulic motor to lift sludge up the pipe and out through a wye connection, under which a storage container can collect the sludge. The 11 HP gasoline engine makes the technology light and the engine can be up to 30 m from the emptying tool. The auger is mounted on a dolly frame to allow easy movement in and out of the pits. In laboratory testing the Excrevator measured a flow rate of 50 L/min at typical gas engine speed of 300 RPM (de los Reyes III, et al., 2014). A 1m^3 pit can be emptied in 30 minutes. However, during field tests a flowrate of 40 L/min was achieved, estimating a pit to be fully emptied in one to two hours (Sisco, et al., 2015). The rotation of the auger can be reversed which is very useful for when rubbish or FS gets blocked inside the pipe. The pressure produced at the outlet is minimal, hence sludge cannot be pumped uphill (de los Reyes, 2016; Sisco, et al., 2015). It is a small device that needs only two people to operate it, one to manage the device and another to collect and contain the sludge at the outlet of the system (de los Reyes, 2016).

It was developed to deal with both liquid sludge, as seen and tested in Malawi, and thick or dry sludge, as seen and tested out in eThekwini, South Africa. However, it is best suited to high solids sludge (Rogers, 2016). By March 2014 the third iteration was developed and being field tested (de los Reyes III, et al., 2014). Phase I of the project involved development of the prototype, laboratory testing and field testing in South Africa. Phase II followed aiming to improve on the challenges encountered during the previous field tests, such as making the design more user friendly, the ability to empty pits and septic tanks containing FS of varying consistencies and how to handle rubbish that is commonly dumped into pits. Currently two approaches to manage the pit trash are being tested. Firstly, two cutting head have been prototyped and are being tested. Secondly, the method of removing trash before emptying the pit is being investigated, with design improvements being applied to what is currently used and are being tested (Sisco, et al., 2015).

It was field tested in Hyderabad, India mostly on septic tanks and leach pits. These showed a high variability of sludge, with minimal sludge solids accumulated at the bottom of the tank or pit. In Durban, South Africa, it was tested on mostly dry VIPs which generally contained a large proportion of rubbish (de los Reyes, 2016). Finally, it was also tested in Mzuzu, Malawi, where pits were difficult to access, again containing large proportion of rubbish, however the Excrevator was fairly successful. The Excrevator has also undergone laboratory testing to develop inlet heads to deal with the rubbish present in the pits. A sludge simulation/synthetic sludge was used in these tests with materials such as papers, magazines, sponges, plastic bags and ropes added to represent rubbish encountered in the field. If rubbish content in FS can be controlled, the Excrevator can be an effective pit emptying tool. However, an assortment of tools are needed to deal with the highly variable nature of FS (Rogers, 2015).

Figure 8 Modified auger - "Excrevator" (Sisco, et al., 2015)

3.2.7 Pressure Vessel

A pressure vessel was developed as part of the WRC funded project mentioned previously in this review to design and develop pit emptying solutions. It can be used to either vacuum up sludge from the pit or pump air or water into the pit to agitate, mix and fluidise the sludge to facilitate pumping (Still & O'Riordan, 2012)

3.3 Unsuitable Pit Emptying Technologies

This section details pit emptying technologies that are not currently suitable for implementation in Freetown, however some were successful in other contexts and hence are important to be aware of for future implementations.

3.3.1 Gulper

The objective of the Gulper design was to create a portable and affordable pit emptying technology (O'Riordan, 2009). It was designed in the UK at the London School of Hygiene and Tropical Medicine (LSHTM), (Sugden, 2016) and the prototype was tested in Dar es Salaam, Tanzania (Ideas at Work, 2007; O'Riordan, 2009). Testing was successful at pumping more liquid sludge, commonly found in Tanzanian pit latrines. It is a semi mechanised pit emptying device based on a simple direct action hand pump (O'Riordan, 2009; Malinga, et al., 2016). It is a simple and low-cost design that can be manufactured locally using locally sourced materials. It consists of a 2 m long, 100 mm diameter PVC riser pipe housing two stainless steel non-return butterfly valves. One valve is fixed at the base of the pipe acting as a stopper, the other is attached to a moveable T-handle and puller rod to act as a plunger. When the handle is moved up and down the valves are opened and closed in series, lifting the sludge up the riser pipe and discharging it through and downward angled outlet pipe, under which a container can be placed to collect the sludge. There is a screen over the inlet to prevent larger rubbish items entering the pipe (Mikhael, et al., 2014; Ideas at Work, 2007).

It is lightweight, robust and requires minimal maintenance. However, it does not allow pits to be emptied as cleanly or quickly as petrol powered emptying devices. As part of the field testing, households in Dar es Salaam whose pits were emptied using the Gulper were interviewed. The positive aspects were noted as it being cleaner and more hygienic compared to manual methods; FS was not piled in the compound as it was removed from the pit because it was discharge into containers; the emptiers wore PPE and were sober; there was no mess left in the compound; the pit slab didn't have to be broken; the job was quicker compared to manual emptying (took approximately 3 hours) and finally the FS removed from the compound to be properly disposed of. The disadvantages included the pit not being emptied fully (only the top meter or so comprising of watery sludge because the Gulper cannot reach deeper than 1.5 m) and using handcarts to transport the containers of FS to the disposal site slowed the process making it last a full day (Sugden, 2012; Malinga, et al., 2016).

Further challenges were encountered, noted by Mikhael, et al. (2014), include difficulties in setting up and operating inside small latrines, blockages caused by rubbish in the pit, the PVC riser pipe cracking after longer-term use and sludge splashing out of the pit and Gulper contaminating the environment and pit emptiers.

Ideas at Work developed on the Gulper design in Cambodia. It was trialled in the workshop, producing a flowrate of 3 L/stroke, depending on the stroke depth, estimating 10 minutes to empty a pit 1 m in diameter and 1.5 m deep. This excludes the time needed to prepare and replace full containers with new ones. The Ideas at Work Gulper was field tested by one MPE team on a drain interceptor in October 2007. The MPEs used cement bags to store the FS pumped from the pit. Flow rates were not measured but the cement bags were filled within a few strokes. The MPEs noted three advantages compared to their usual pit emptying method of entering the pit and using buckets (Ideas at Work, 2007);

1. They didn't have to enter the pits, keeping their clothes clean;
2. Not entering pits reduced their risk of getting sick;

3. The time taken to remove sludge from the pit was much quicker compared to their usual bucket method.

A Gulper costs $160, including labour, materials, workshop overheads and a small profit, but excluding technical drawings and development costs (Ideas at Work, 2007). According to O'Riordan (2009) the Gulper costs approximately $100 to manufacture. It has reached the largest number of service providers in Africa and Asia of the semi-mechanised pit emptying technologies (manually driven mechanical technologies), however use of the Gulper without external intervention (funding, training, technical support) is not recorded (Mikhael, et al., 2014).

Figure 9 The Gulper emptying FS into a container to be transported (Thye, et al., 2011)

3.3.2 The Peddler

A peddle mechanism can be attached to the Rammer to use leg power to driver the external rods, allowing thicker sludge to be pumped for longer because the leg muscles are stronger than the arm muscles. (Sanihub, nd). There is limited information available on this adaption and no field or commercial experience using this was found.

3.3.3 The Nibbler

The Nibbler was developed by Steve Sugden at the LSHTM at approximately the same time as the Gulper, for very thick sludge or pits located up very steep hills. The design consisted of steel disks welded onto a bicycle chain, which acted as scoops to lift the waste up and out of the pit, housed inside a PVC pipe. A crank at the top of the pipe was rotated by hand to move the chain. The sludge is scrapped off the discs at the top of the pipe and directed through a connected Y-shaped pipe, discharging the sludge into a container for transport. A vertical plate inside the PVC pipe divided the metal discs that are moving up lifting the sludge, and the discs moving down after the sludge has be scrapped from them. The pipe was narrow enough to fit through a squat hole or access point of a pit or septic tank without needing to break the cover slab or structure. (Mikhael, et al., 2014).

At the date of a WRC report by O'Riordan (2009) the Nibbler had only been tested on pig slurry and was showing positive results, however it was hypothesised that it would struggle with drier sludge and sludge with a high content of rubbish. It was never taken past early prototype phase (Still & O'Riordan, 2012). Later, it was tested on synthetic sludge by Sanihub however it did not make it past this as entrepreneurs were not willing to adopt the technology. Furthermore, it is messy to use and removed very little sludge from the pit (Malinga, et al., 2016).

Figure 10 The Nibbler 'scoop' attached to a standard bicycle chain (Still & O'Riordan, 2012; O'Riordan, 2009)

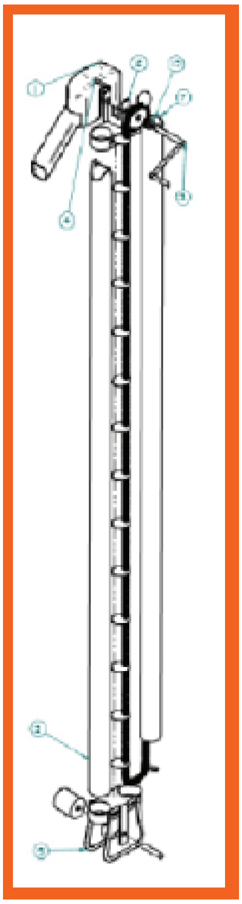

Figure 11 The Nibbler prototype design (Malinga, et al., 2016)

3.3.4 The Gobbler

The Gobbler was developed as an improvement to the Nibbler, as part of a WRC funded project to design and develop pit emptying solutions for developing countries (Still & O'Riordan, 2012). The Nibbler was designed based on parts and materials easily sourced in Tanzania, designers in South Africa developed on the design to create the Gobbler. With a well-developed agriculture industry, they were able to create a more robust version of the Nibbler. Off the shelf chains, links and brackets were machined together to scoop the sludge and lift it up the pipe and discharge it into a container. At the time of the report by O'Riordan (2009) for the same project, the prototype was being developed to test different scoop configurations, which replaced the metal discs used in the Nibbler design. It was noted that the Gobbler was over engineered at this point, but if it was successful in field trials that the design could then be optimised to reduce the weight, number of parts and cost. The prototype cost approximately 10,000 ZAR, approximately $1,200.

The Gobbler uses two chains to guide scoops up a pipe and over a bend to allow gravity to assist the sludge exiting the pipe. Issues were encountered with sludge jamming in the sprockets, preventing the chains to roll and lift the scoops up the pipe. It was thought a small motor might solve this issue, hence a 0.125 kW motor was used to move the chains. This made the chains move very smoothly when tested outside of the pit, but once sludge was introduced into the system it would block up again. Furthermore, the addition of the motor created a risk for catching fingers and clothes on the many moving parts (Still & O'Riordan, 2012).

Due to the challenges encountered above, a second version of the Gobbler was developed, using a single chain and sprung scraper to lift the waste from the pit. This simplified the design. However, although the Gobbler in theory seems like a simple solution to pit emptying, there were multiple issues with it. It consists of many parts, increasing the capital cost, making it difficult to fabricate and introducing many potential failure modes. The device is heavy and supporting it was a challenge, a tripod was developed but it was only useful when the device was stationary, not when it was being transported and moved around. The development of the Gobbler was stopped at an early stage due to the technology being too heavy, too difficult to manoeuver and the high frequency of blockages (Still & O'Riordan, 2012).

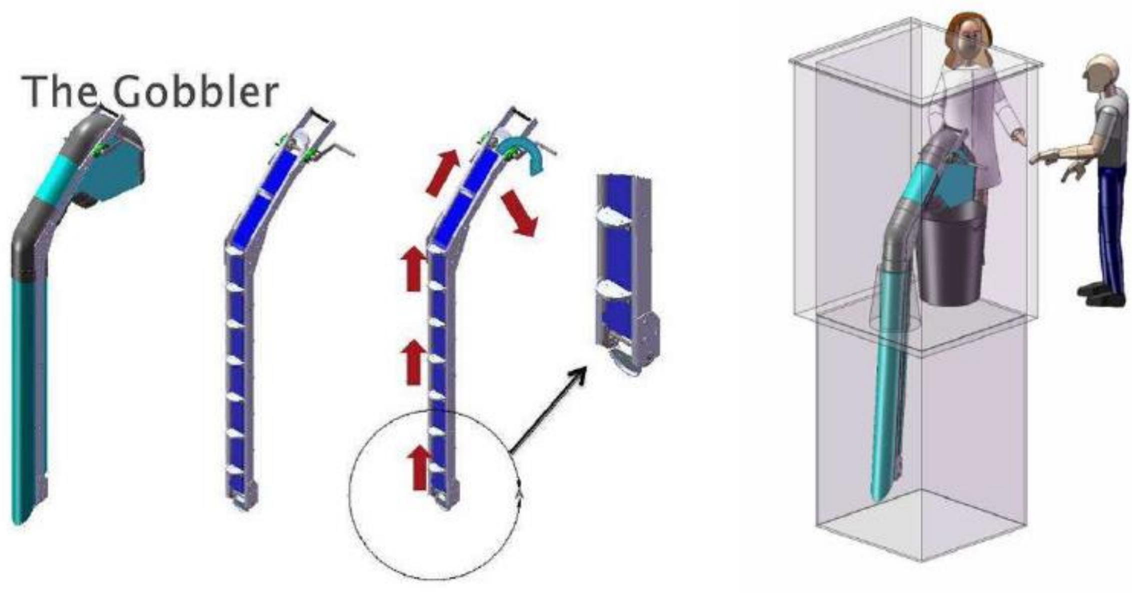

Figure 12 The Gobbler prototype design (O'Riordan, 2009)

3.3.5 Pedal Power Treadle Pump

A modified treadle pump prototype was developed by an MSc student at Mzuzu University in Malawi, funded by the WRC. A chain similar to a bicycle chain replaced the rope to drive the pulley. The expected advantages of this design is that the pump is powered outside of the latrine, reducing exposure of the MPE to contaminated faeces and that it can be built using local materials. A second prototype was developed and referred to as the Pit Pump, changing the half cycle motion to full cycle to increase the ease of operating the pump, as the half cycle made the work 'tedious' and 'awkward'. Furthermore, the bicycle chain kept breaking during operation so it was replaced with a motorbike chain. The suction hose is 50 mm, which is easily blocked. The third prototype looked at using suction power but the pump was not successful lifting weak mud slurry. The designer then moved to investigate modifying the Gulper to be pedal powered rather than hand powered. See the following section for the description of this Gulper modification (Chipeta, 2015).

3.3.6 Pedal Power Gulper Pump

The Gulper was modified by students at Mzuzu University by adding a pedal propelled mechanism using a motorbike chain and crank connected to a flywheel. Pedalling creates up and down strokes of the connector handle, which is attached to the gulper handles inside the pit latrine. The equipment was manufactured at Mainga Engineering, Mzuzu, for $406 and was successfully tested on five pit latrines in peri-urban Mzuzu. These developments took place early 2016 and so there is no further information on the development of this. (Mzuzu University, 2015).

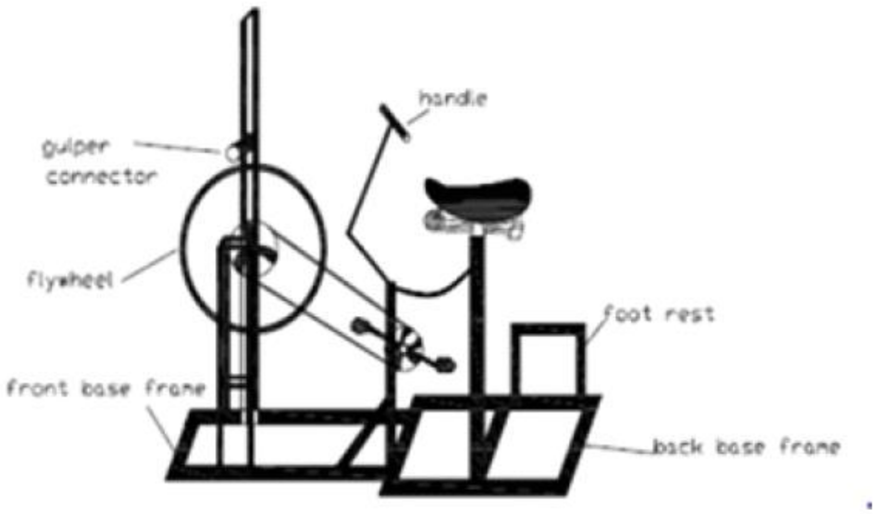

Figure 13 Pedal Power Gulper (Mzuzu University, 2015)

It should be noted that the development of the Gulper II investigated using pedal powered mechanisms, however the efforts were abandoned due to issues such as the chain rusting, difficulty cleaning the equipment and the equipment not being extendable to reach the thicker sludge at the base of the pit (Drummond, 2014).

3.3.7 MAPET

The MAPET was developed and trialled by WASTE in Tanzania in 1992 to empty wet or liquid FS from pits (Mikhael, et al., 2014; Still & O'Riordan, 2012). It is a human-powered vacuum system consisting of two components, a piston pump and a 200 litre vacuum tank, both mounted on push carts. This method used an air vacuum in the sludge holding tank to suck up the sludge through a hose pipe 4 metres long and 10 cm (4 inch) diameter, meaning the squatting slab doesn't need to be broken. The sludge does not pass through the pump, making the device more durable. The pump is manual powered by a hand pump and push carts are used to transport the collected sludge. The width of the device is 800 mm meaning it can fit down narrow pathways. The cost of the MAPET in 1992 was $3,000 (O'Riordan, 2009).

Design challenges included sourcing wheels strong enough to support the load of the devices and hose pipe couplings were expensive. Prior to pumping a mixing rod was used to make the sludge fluid enough to be pumped and a hook was used to remove rubbish such as rags that would block the hose pipe during pumping. Trials have shown that it can pump sludge from a depth of 3 m and with a rate of 10 to 40 L/min, depending on the depth from which the sludge is being pumped and the viscosity of the sludge. Eight years after the trials only one remained working and in use, after thirteen years all were out of use (Mikhael, et al., 2014). The MAPET proved to be durable under the local conditions, the parts that wore and required replacement were cheap and no damage was caused to the device as a whole due to the failure of these parts (O'Riordan, 2009). However once the most fragile parts, for example the leather piston ring and the wearing parts of the vane vacuum pump, failed they were not easily sourced locally. Once these items needed replacement the diaphragm pump would be out of use for a long time, if not completely abandoned (O'Riordan, 2009). Furthermore, the maintenance and transport costs associated with the MAPET weren't being covered by the emptying fees collected and finally the institutional support upon which the MAPET operators were reliant on broke down (Mikhael, et al., 2014). The technology was a failure but however proved that the piston pump can achieve the required suction to lift liquid sludge from pit latrines (Still & O'Riordan, 2012).

Figure 14 Left: MAPET in use (O'Riordan, 2009); Right: MAPET container being emptied (Thye, et al., 2011)

3.3.8 eVac

The eVac was developed as part of the WRC funded project mentioned previously in this report. It was designed based on the same principles as the NanoVac, but the vacuum is powered by a vane pump rather than a piston pump. The vane pump was sourced from a dairy equipment supplier and can achieve an airflow of 300 L/min at vacuum of 0.5 bar. The vane pump is powered by a 1.5 kW electric motor and generator because the motor needs a 230V power source. The pump, motor and generator are mounted on a steel trolley and connected by a belt drive. Above this was mounted the vacuum relief valve, moisture trap and oil supply for the pump. Two float valves were included to prevent the sludge being sucked up into the pump when the tank is full. The moisture trap was included should sludge splash up before the float blocks the vacuum line. The second float was included here in case the moisture trap becomes full of liquid. At the bottom of the moisture trap there is a one-way valve, to allow the liquid to drain by gravity into a container below whenever the pressure is released. A 3 m long, 2.5 cm (1 inch) diameter flexible hose was used for the air pipe and a 5 m long, 7.62 cm (3 inch) diameter flexible 'heliflex' hose was used for the sludge. A plastic bushing was used on the inlet of the sludge pipe to prevent large objects such as rubbish enter the pipe and cause blockages. The total weight of the rig is 63 kg, however because it is mounted on the trolley it can be moved along rough ground and can be loaded onto a vehicle by two people. A petrol engine could have been used but would make the eVac more difficult to manage and easier to damage (Still & O'Riordan, 2012).

Various tank designs were tested as issues were encountered with the vessels buckling under the vacuum pressure. The final vessel design was manufactured from a roto-moulder, producing tanks of 47 litres using Linear Low Density Polyethylene (LLDPE) measuring a height of 770 mm, diameter of 310 mm and wall thickness of 14 mm and weighing 9.6 kg. Handles were put on the containers so they can be moved easily. Two lids were designed to allow for two ways of emptying the sludge from the tank; a "suck only" method where the sludge is sucked into the tank which is then tipped to discharge the sludge and a "suck and blow" method where the sludge is sucked into the tank and discharged through a second hose (Still & O'Riordan, 2012).

The lid for the "suck only" method was interchangeable so multiple tanks could be used – when one is full it can be moved to be emptied while the second tank is filling. The lid did not have attachments, the force of the vacuum kept it on and a foam rubber strip on the underside provided a seal. The lid had an air-line (to create the vacuum) and sludge line (to suck up the sludge). The lid for the "suck and blow" method was bolted onto the tank, hence only one tank was used. It could be removed for maintenance. Bolting the lid to the tank allowed the tank to withstand positive pressures as well as the vacuum pressure. Hence the lid had two air-lines, one for positive pressure and one for the vacuum. The lid had the sludge inlet pipe, whereas the sludge outlet pipe was connected to the base of the tank as an attachment. The sludge inlet and outlet pipes required valves to close them so the sludge doesn't go through the wrong pipe. Ball valves were used for this as they were locally available (Still & O'Riordan, 2012).

The eVac was tested on pig slurry with success, encountering one blockage by a plastic bag. It was tested on a dry VIP but was unable to remove the dense sludge. Wetter sludge in a low flush toilet and wet VIP was emptied without difficulty, filling the 40 litre tank in less than 10 seconds. There was rubbish present in the pit, causing one blockage during the emptying process. It was found that for most pits the tank would fill within 10 to 15 seconds, the time consuming activity was take the container back and forth from the disposal pit. During the emptying of the wetter sludge it was found that spills and slashes occurred easily, contaminating the surroundings. Both the "suck only" and "suck and blow" methods were tested on the pits. The "suck and blow" method emptying quicker than the "suck only" method (Still & O'Riordan, 2012).

Further tests are needed on the eVac and the following recommendations were made. (Still & O'Riordan, 2012). The moisture trap needs to be developed to prevent sludge dripping onto the ground. The electric control box is fragile and needs some form of protection against rough handling. The vane pump requires a lot of oil, furthermore the oil leaks when the container is not kept upright or is knocked. Developments are needed to reduce the amount of oil used/lost or to develop an oil from vane pump. The vacuum and pressure gauges are not necessary as the noise indicates if sufficient pressure is being reached. The lid designs can be improved upon, the “suck only” lid could be made lighter and the “suck and blow” lid could be larger to accommodate better the greater number of pipes attached to it. Finally, there are 4 valves for the “suck and blow” configuration, and although they are not difficult to use it could potentially cause confusion during operation (Still & O'Riordan, 2012).

In this WRC project which reviewed many pit emptying technologies to aid the design of new solutions, it was concluded that the eVac was most successful technology. It was successful at desludging from low flush and pour flush latrines, as well as wetter pit latrines, however it was not successful at emptying drier pit latrines where continuous addition of water and mixing was needed along with a stronger vacuum pump (Still & O'Riordan, 2012).

Figure 15 eVac with two tanks and "suck only" lid fitting (Still & O'Riordan, 2012)

3.3.9 Mircavac

Developed by Manus Coffey, the Mircavac is a fully mechanised vacuum technology developed for use where fully scale vacuum tankers are not suitable (Still & O'Riordan, 2012). It consists of a 2,000 litre tank and a vacuum pump which has a rate of 9,000 L/min. It was designed in the 1980s. Two Mircavacs were used in Blantyre, Malawi, and also trialled in Zimbabwe and was relatively successful, primarily due to its ability to travel through narrow, uneven roads in unplanned urban areas (Thye, et al., 2011).

Figure 16 Micravac – a small scale vacuum technology (Still & O'Riordan, 2012)

3.3.10 Vacutug

The Vacutug was originally developed in 1995 by UN-Habitat with funding from DfID and support from Irish Aid (O'Riordan, 2009) as an improvement to the Brevac, a pit emptying technology design as a result of research carried out in 1983 in Botswana. It consists of a 500 litre steel vacuum tank with a sliding vane pump with a capacity of -0.8 bar. A 3-inch diameter (7.62 cm) is connected to the vacuum tank, through which the sludge is removed from the pit. The vacuum is powered by a 4.1 kW Honda petrol engine, available in most cities and is cheap relative to full scale vacuum tankers. However, it has low power output meaning in can only travel at 5 km/hr. It can empty a pit in ten minutes but will take significantly longer to get the sludge to a disposal site (Sugden, 2012; Still & O'Riordan, 2012).

The Vacutug was tested on low flush pits in South Africa in 2012 (Still & O'Riordan, 2012). It had to be transported on a tipper trailer to the test site. Once on the ground the Vacutug struggled to move over uneven ground with it at risk of tipping over, even though the terrain was relatively flat. It was tested on low flush toilet pits, with the expectation that these pits contain less rubbish and hence would be more suited to pit emptying via vacuum tanker. However, there was rubbish present which caused delays up to 1.5 hours when rubbish entered the pipe causing a blockage. Rubbish was removed manually prior to emptying with the Vacutug but this also was time consuming. These pits very fairly dry, despite the use of flushing water, requiring the addition of 40 to 80 litres of water to the pit to fluidise the sludge sufficiently and increased the pit emptying time by approximately 15 minutes. When the Vacutug was full the sludge was transferred to a 5000 litre transfer tank, which was emptied by a municipal vacuum tanker when full. The municipal vacuum tanker would take approximately 15 minutes to empty the full transfer tank. It was noted that 5 litres of fuel were needed to empty 5 pits. 39 households over 80 trips were emptied over one month in the trial (Still & O'Riordan, 2012).

It was found that the majority of the time taken to do the job with the Vacutug was the travel time, to the site and between the site and the transfer tank, taking 70 minutes of a total time of just about 110 minutes to complete the entire job. The time taken to pump the sludge was the quickest of the pit emptying stages measured (per trip, set up time, evacuation time, prepumping time, pumping time, time between trips), taking less than 5 minutes, if the FS didn't need to be fluidised (Still & O'Riordan, 2012).

The Kenya Water and Health Organisation (KWAHO) trialled the Mark I Vacutug on a commercial basis over a two-year period, making a profit of 36% on its overheads, although it was noted that the operators had a monopoly allowing them to charge more than was necessary. However, after the two-year period the Vacutug suffered from mechanical problems which took approximately ten months to repair. The problems included the bearings and rollers wearing out and the hose pipe wore out and was leaking. It was noted that the Vacutug was vulnerable to theft, parts were stolen and it was vandalised, despite it being stored at the District Officers camp and the hiring of a watchman. The Vacutug couldn't reach latrines during rainy season because roads were impassable (O'Riordan, 2009).

The Mark II Vacutug model, developed in 2002, cost $5,100, excluding shipping. Shipping quotes ranged from $3,000 to $8,000. It was manufactured in Bangladesh with the aim of source all materials and parts locally, however the engine, vacuum pump, axles and wheels had to be imported. Ten Vacutugs were manufactured and air freighted and shipped to twelve different locations throughout Europe, Africa and Asia for field testing (O'Riordan, 2009). The Vacutug users were interviewed by O'Riordan (2009) and their experience showed that four operators were necessary rather than two as advised by the designers, the spare parts could not be source locally and the equipment had been out of use for a year at the time of the interview. Furthermore, it was difficult to move and stir the Vacutug, it had low traction on sandy soils and it tipped over frequently. Positives of the Vacutug included its small height, ability to pump into a larger tanker, the cost is 20% of a full size vacuum tanker (O'Riordan, 2009).

The Vacutug was trialled as part of the Emergency Sanitation Project (ESP) and S(P)EEDKITS project in Malawi with two other emptying equipment (diaphragm pump in Section 3.2.4 and the ROM2 for which minimal information was found). Difficulty was found when crossing uneven terrain and the slow speed at which it moved, making longer distances impractical. It was successful at emptying sludge from pits, once it was fluidised, however several breakdowns occurred during operations (Spit, et al., 2015).

Figure 17 Vacutug (Still & O'Riordan, 2012)

3.3.10.1 The Maqunieta Maputo

The Vacutug trials in Maputo, Mozambique, identified quickly that the high demand and long distance for pit emptying made it unsuitable for using the Vacutug. To solve this issue the Maquineta was designed, effectively a low cost mobile transfer station, consisting on a 1.5 m^3 transfer tank with a small vacuum pump mobilised by a 2 wheeled tractor. This accompanied the Vacutug as a mini transfer tank, or would empty the pits directly if the situation allowed for it. The Vacutug was more powerful and able to suck up heavier FS, however the Maquineta was quicker in transit and so became the technology of choice. The Vacutug had higher labour costs but lower operational costs in comparison to the Maquineta. The combination of the Vacutug and Maquineta made for a successful FSM program in this context, however the need for municipal tankers to empty the Maquineta and transport the sludge to the treatment site became a limiting factor as they are unreliable. The alternative option was to discharge the sludge from the Maquineta into the sewers, however authorisation for this was difficult to obtain (O'Riordan, 2009).

Figure 18 Maqunieta (O'Riordan, 2009)

3.3.11 NanoVac

The NanoVac was developed as part of a WRC funded project to design and develop pit emptying solutions. It is vacuum technology powered by a piston pumps, inspired by the MAPET technology, discussed in Section 3.3.7, using an internal combustion (IC) engine. The aim was to develop a pit emptying device that was "low cost, compact, easily manoeuvrable and easy to repair and maintain" (Still & O'Riordan, 2012). The NanoVac underwent many versions to determine the most efficient design. It consists of two large diameter pistons, allowing for both suction and air blowing so that the sludge can be sucked from the pit to empty it, and the sludge could be discharged from the tank with the blowing action. Many tests were conducted to determine the most efficient stroke length to RPM ratio to achieve the desired suction. The stroke length could be varied between 100 to 300 mm, with

150 mm determined as optimal. At the fixed stroke length of 150 mm it was found that the higher the RPM the faster sludge was pumped from the pit and the optimal RPM of 200 was determined. The final (current) design achieves a suction flow rate of 0.076 m^3/min and a discharge flow rate of 0.112 m^3/min. The original design was power by a 1 kW electric motor, however it was later powered by a 5.5 HP IC engine so it could be used in areas without electricity. The IC engine had excessive power to what was required, so a 1:20 reduction box and a 1.5 reduction pulley drive were used to reduce the power. The NanoVac achieved positive pressure of 6 bar and a negative pressure of -0.8 bar. The rig strained under the power of the engine and hence needed a stronger frame to support it. The design was improved with smaller diameter fittings, improving seals but producing only a slightly higher vacuum pressure (Still & O'Riordan, 2012).

The original design of the tank consisted of a steel drum, however this was bulky. It was replaced with a Hippo Roller. This is an 80 litre water carrier that can be rolled along the ground. Therefore, the sludge can be pumped into a transportable container, from which it can be easily poured out of, removed the need for the NanoVac to blow/pump the sludge out. The Hippo Roller had to be braced, allowing it to achieve a vacuum of -0.3 bar, without which it would buckle at -0.25 bar. The vacuum of -0.3 bar was sufficient as the Hippo roller is on the ground and hence doesn't require a large head to pump. A tipping tanker was designed as an alternate from a cylindrical gas canister. Instead of rotating the tank it can simply be tipped to one position for filling and another for emptying. A bleed valve was required to allow emptying via gravity (Still & O'Riordan, 2012).

It was successful at pumping wet FS from low flush and pour flush latrines however field tests showed that the design was not robust enough. Recommendations for improving the NanoVac include using more robust materials for the pistons, strengthening the frame to reduce movement during use, addition of handles to the frame to facilitate transport, include ways of cutting up rubbish in the pit so it doesn't cause blockages.

Figure 19 Left: NanoVac prototype; Centre and right: different tanks attachments for the NanoVac (Still & O'Riordan, 2012)

3.4 Further Information Required

The following technologies are either currently in early prototype phase or limited information was available on the design and success in the field. It is important to be aware of the technologies currently being developed for future implementations as this field is continuously growing.

3.4.1 Bangalore Screwer

The design of the Bangalore Screwer was based on using an auger screw to lift sludge from the pit but it was not taken past early prototype phase (Still & O'Riordan, 2012).

Figure 20 Bangalore Screwer (Still & O'Riordan, 2012)

3.4.2 Beaumont Manual Pump

The Beaumont Manual Pump is currently under development. Testing of the prototype is to begin in June 2016 and the designers are in the process of selecting partners to conduct field testing to facilitate the design development. The technology will need two operators, one to pump it and another to direct the inlet pipe (Whitesell, 2016).

Figure 21 Design sketch of Beaumont Manual Pump

3.4.3 EMAS Pump

A latrine pump with manually operated valves, using a handle at the top that is pulled up and pushed down to pump up the sludge combined with a foot pedal. It is still undergoing testing, with initial results seeming promising (Buchner & Moninger, 2016).

3.4.4 Dung Beetle

The Dung Beetle is a small version of a vacuum tanker developed by a Dutch company and used in Ghana (Sugden, 2012; O'Riordan, 2009). It is a fully mechanised vacuum technology, developed for use where fully scale vacuum tankers are not suitable. It uses a two-wheel tractor based drive. The driver sits on the tanker and uses long handles to steer (Still & O'Riordan, 2012). It is powered by a 4 stroke 16 HP diesel engine with an electric starter with a tank capacity of 800 litres. The positive pressure reached is 0.5 bar and the suction capacity is -0.8 bar. Its width is 1.1 m meaning it can manoeuvre through narrow streets, its maximum speed is 12km/hr (O'Riordan, 2009).

Figure 22 Dung Beetle (O'Riordan, 2009)

4 Conclusion and Recommendations

A variety of manual, semi-mechanised and fully mechanised pit emptying technologies were reviewed in this report to gain an understanding of the currently available technologies throughout the world. The objective of this being to select the three most appropriate technologies for manual pit emptying to be trialled in Freetown, Sierra Leone, following which the best technology will be selected. The sludge properties need to be understand to facilitate emptying and transport of it. The primary properties that influence these activities are water content, sludge age, quantity of rubbish and presence of organic material (Mikhael, et al., 2014). The variation of FS from one sanitation unit to the next is large, ranging to very liquid to dry and soil like. For these reasons it is important to trial various pit emptying technologies before implementing them on a wide scale. Multiple tools and technologies will most likely be necessary for city wide scale implementation to match the variation of FS encountered.

The manual pit emptying business in Freetown is completely informal, many of the MPEs are uneducated and do not own bank accounts. Hence access to finance is a major barrier to elevate the status of their work (Manual Pit Emptiers, 2016). For this reason, of the criteria listed in *Section 2: Methodology*, capital and operational cost were given priority. This leads to the recommendation of the modified long handled tools and the Gulper II to be trialled in Freetown. These are the cheapest options available. The modified hand tools are the simplest technology in terms of design as it includes tools such as hay rakes, long handled shovels and buckets on rope, which can be used to emptying both wet and dry FS. These combined with proper PPE and safe hygienic practices could be effective at emptying pits and septic tanks with minimal exposure of FS to the MPEs, the household and the environment. The Gulper II has been field tested with success on a range of wet FS, however it has not been implemented anywhere on a commercial basis. Conducting field testing of the Gulper II in Freetown will help determine if it is suitable for pit emptying in this context. Third technology recommended is the Excrevator which is fully mechanised and has been trialled successfully on drier FS. Due to the informal nature of MPEs, fully mechanised emptying technologies are not appropriate because they are too expensive and their operation may be too complex. For this reason, it is proposed the fully mechanised Excrevator is trialled along with the two other pit emptying technologies, however the business owners operating the vacuum tankers will be approached to trial the Excrevator.

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[Accessed 21 03 2016].

6 Online Resources

Technology	*Online Resource*
Hand tools	http://www.wrc.org.za/Knowledge%20Hub%20Documents/Research%20Reports/1745%20Volume%203.pdf
Sludge Digger	http://forum.susana.org/forum/categories/99-faecal-sludge-transport-including-emptying-of-pits-and-septic-tanks/14842-lively-discussion-on-fishing-of-rubbish-from-pit-latrines-at-wedct-including-emptying-of-pits-and-septic-tanks/15617-the-sludge-digger-a-device-ive-developed-for-emptying-pit-latrines-septic-tanks-and-similar-tanks-new-video http://forum.susana.org/media/kunena/attachments/5333/FourSanitationSolutionsApril2015.pdf
Gulper II	http://forum.susana.org/media/kunena/attachments/1472/rammer.pdf http://forum.susana.org/forum/categories/99-faecal-sludge-transport-including-emptying-of-pits-and-septic-tanks/7066-looking-for-a-gulper-in-west-africa-and-the-rammer-being-the-new-and-better-gulper-for-pit-emptying https://sanihubwaterforpeople.wordpress.com/2015/10/02/the-rammer-gulper-2/ http://www.waterfund.go.ke/safisan/Downloads/Business%20Model%20for%20Pit%20Emptiers(1).pdf
Diaphragm Pump	http://wedc.lboro.ac.uk/resources/conference/38/Spit-2164.pdf
Pit Screw Auger	http://www.wrc.org.za/Knowledge%20Hub%20Documents/Research%20Reports/1745%20Volume%203.pdf
Excrevator	http://www.susana.org/images/documents/07-cap-dev/b-conferences/15-FSM3/Day-2/Rm-1/2-1-3-6-Rogers.pdf http://forum.susana.org/media/kunena/attachments/52/Excrevatorwebinar2.pdf http://forum.susana.org/forum/categories/99-faecal-sludge-transport-including-emptying-of-pits-and-septic-tanks/4252-the-excrevator-power-auger-to-empty-pits-north-carolina-state-university-usa-now-field-testing
Pressure Vessel	http://www.wrc.org.za/Knowledge%20Hub%20Documents/Research%20Reports/1745%20Volume%203.pdf
Gulper	http://ideas-at-work.org/images/pdf/Gulper_pit_emptying_device.pdf www.sswm.info/sites/default/files/reference_attachments/O%20RIORDAN%202009%20Investigation%20into%20Methods%20of%20Pit%20Latrine%20Emptying.pdf http://www.waterfund.go.ke/safisan/Downloads/Business%20Model%20for%20Pit%20Emptiers(1).pdf
The Peddler	http://forum.susana.org/media/kunena/attachments/1472/rammer.pdf
The Nibbler	www.sswm.info/sites/default/files/reference_attachments/O%20RIORDAN%202009%20Investigation%20into%20Methods%20of%20Pit%20Latrine%20Emptying.pdf
The Gobbler	www.sswm.info/sites/default/files/reference_attachments/O%20RIORDAN%202009%20Investigation%20into%20Methods%20of%20Pit%20Latrine%20Emptying.pdf
Pedal Power Treadle Pump	http://forum.susana.org/forum/categories/99-faecal-sludge-transport-including-emptying-of-pits-and-septic-tanks/10663-modified-treadle-pump-pit-pump-prototype-peddle-powered-gulper-modification-malawi
Pedal Power Gulper	http://forum.susana.org/forum/categories/99-faecal-sludge-transport-including-emptying-of-pits-and-septic-tanks/10663-modified-treadle-pump-pit-pump-prototype-peddle-powered-gulper-modification-malawi?limit=12&start=12 http://forum.susana.org/media/kunena/attachments/3750/WRCMUSUMMARYOFFAECALSLUDGE2016.pdf
MAPET	http://www.sswm.info/sites/default/files/reference_attachments/Muller%20and%20Rijnsburger%201992%20Mapet.pdf http://www.bvsde.paho.org/texcom/cd050999/muller.pdf
eVac	http://www.wrc.org.za/Knowledge%20Hub%20Documents/Research%20Reports/1745%20Volume%203.pdf
Mircavac	http://www.tandfonline.com/doi/abs/10.1080/10643389.2010.481593#.VweLyeKLTIU
Vacutug	www.sswm.info/sites/default/files/reference_attachments/O%20RIORDAN%202009%20Investigation%20into%20Methods%20of%20Pit%20Latrine%20Emptying.pdf

	http://www.wrc.org.za/Knowledge%20Hub%20Documents/Research%20Reports/1745%20Volume%203.pdf http://wedc.lboro.ac.uk/resources/conference/38/Spit-2164.pdf http://www.waterfund.go.ke/safisan/Downloads/Business%20Model%20for%20Pit%20Emptiers(1).pdf
NanoVac	http://www.wrc.org.za/Knowledge%20Hub%20Documents/Research%20Reports/1745%20Volume%203.pdf
Bangalore Screwer	
Beaumont Manual Pump	http://forum.susana.org/forum/categories/99-faecal-sludge-transport-including-emptying-of-pits-and-septic-tanks/16618-solicitation-for-manual-pump-testing-partners
Dung Beetle	www.sswm.info/sites/default/files/reference_attachments/O%20RIORDAN%202009%20Investigation%20into%20Methods%20of%20Pit%20Latrine%20Emptying.pdf
EMAS Pump	https://www.globalinnovationexchange.org/innovations/manual-sludge-pump

ANNEX I: Manual Pit Emptiers Focus Group Discussion

Introduction

The focus group discussion (FGD) was designed to understand the experiences of manual pit emptiers (MPEs) to facilitate the selection of appropriate pit emptying technologies for Freetown. In addition, the FGD aimed to capture information on the use of the diaphragm pump in regard to the emptying of sludge from both pit latrines and septic tanks. A total of thirty (30) MPEs from Kingtom, Willington and Thunder Hill participated actively in the discussion.

Objectives of the Focus Group Discussion

1. To assess the opinions of MPE on the appropriateness of emptying techniques
2. To assess the opinions of MPE on the effectiveness of the diaphragm pump
3. To assess opinions of MPE on what their customers want

Focus Group Discussion Methodology

The FGD featured thirty (30) MPEs and were divided in groups of ten each. The MPEs are themselves informally organized into groups by the location of their work, hence they were kept in these groupings for the FGDs. Questions were developed to understand what pit emptying methods the MPEs are familiar with and have used and to capture the key elements that determined the effectiveness of the diaphragm pumps based on their past experience using it. The exercise was facilitated by the faecal sludge management (FSM) team using a moderator to administer the questionnaires. A note taker was assigned to record responses and time keeper to ensure the discussion concluded within the required time frame. The discussions were held at the Calaba Town Office.

Findings from Focus Group Discussion

Current methods used

When MPEs where asked about the methods or equipment they have used to empty latrines and septic tanks in the past, almost all of them mentioned the "Bucket emptying" method and the use of the diaphragm pump, for both the latrine and septic tanks. Particular emphasis was placed on the bucket method. Reasons being:

- "It is fast to desludge"
- It is more convenient in water logged areas. Here rope is tied to the bucket in order to press down into the pit with the use of stick to take the sludge away. In circumstances where the sludge is dry, one of them enters the pit with the bucket tied with rope, pick axe, and shovel to dig the sludge out completely.

According to the MPEs they prefer to use the diaphragm pump to that of the bucket method. Giving reasons for their preference the MPEs said the diaphragm pump has so many advantages including:

- Quicker work when emptying septic tanks.
- Safe and hygienic conditions.

A few of the MPEs prefer to use the bucket method mainly for pit latrines with a thicker sludge content. “We need the diaphragm pump where the sludge is watery but where the sludge is thicker and dry we use the bucket”. The use of the diaphragm pump according to the MPEs is only applicable in water logged areas where mostly the sludge is watery. In certain pit latrines the diaphragm pump can work well, but this can only be done if the sludge is properly raked to remove solid waste and this consumes time and energy.

When MPEs were asked about what they think should be the most appropriate method for manual pit emptying interestingly, about one-third of them thought both bucket and diaphragm pump methods are appropriate considering the diaphragm pump appropriate for septic tanks with a watery content and the bucket for pit latrines. The remaining two-thirds thought the use of the diaphragm pump is most appropriate.

Experiences with the diaphragm pump

The majority of the MPEs said they are very comfortable using the diaphragm pump for desludging. Some of the reasons they provided were:

- Less energy is utilized.
- Prevents contact with the sludge.
- The work is more comfortable.
- The work is somehow encouraging and socially acceptable

According to the MPEs, socially no difficulty was encountered when using the diaphragm pump. They claimed that in all their desludging operations with the diaphragm pump clients admire the work as it prevents direct contact with the faeces. For technical difficulties, the MPEs made it clear that the hose of the diaphragm pump is too narrow for thicker sludge to flow through at a fast rate. This most times results in blockage of the hose. Lack of tools to amend faults such as pliers, screw driver, spanner etc. pose a challenge to their work. Minor maintenance to solve problems encountered with the diaphragm pump is usually done by manually inserting objects like sticks and pipes to clear blockage in the hose. There seems to be some reasonable knowledge and skills in maintenance of the diaphragm pump amongst the MPEs. Financially no difficulty was highlighted in relation to the use of the diaphragm pump.

MPEs made it known that the use of the diaphragm pump has added value to their operation. The majority of the MPEs said using the diaphragm pump to desludge is more hygienic compared to the bucket method. It reduces stigmatization and allows them to operate in a safe and decent manner. One of the participants explained how the use of diaphragm pump has even changed their behaviour towards smoking during work: “Whenever we are using the bucket method there is a temptation to smoke because we get direct contact with the shit but since we started using the diaphragm pump this temptation has minimized”.

MPEs noted that the diaphragm pump it is only effective to desludge septic tanks. The diaphragm pump is not effective for desludging pit latrines, the sludge is too dry and the hose is too narrow to deal with rubbish like plastics and other solid waste. According, to them “this can pose lot of challenges for us even if we stir the sludge and rake out solid waste particles, yet the sludge is thick to pump from pit latrines”.

The time it takes to empty a septic tank with a diaphragm pump depends on the depth of the pit and in some cases it takes time to rake out solid waste particle and sometimes barrels are not enough to hold the sludge. No exact time was agreed upon. Rough estimates were given by the MPEs, to empty a latrine said it takes roughly about 6hrs to empty 18ft pit latrine, and a small pit latrine about 1.5hr if the sludge is watery or in a water logged area. If the pit is small and sludge is dry it takes about 3hrs to empty.

When MPEs were asked again about the durability of the diaphragm pump a good number of MPEs said it can last for long if properly taken care of and few were of the view that it duration is highly dependent on the type of pit normally used to desludge, while a vast majority of the MPEs said comparatively the imported diaphragms are more durable than locally made diaphragm pumps.

To determine the obstacles to the MPEs using the diaphragm, they were asked about ownership options. Almost all participants agreed they would prefer to own rather than rent one. The willingness to pay was somehow conflicting, but some are willing to pay for it depending on the number of jobs they would have and if they could raise the funds. They did not state how much they would pay for a diaphragm pump few of them are not willing to pay for it at all. For the purpose of rent, none of them agreed. Other reasons they put forward that would encourage them to use the diaphragm pump on a regular basis were safety (main reason for using the diaphragm pump), time flexibility, hygiene and less energy utilization on septic tanks emptying. So specified that they would only use the diaphragm pump regularly for jobs emptying septic tanks.

Experience with customers

When participants were asked about how they feel about desludging during the day, the majority said they feel very good about it. Emphasis was made on desludging in a compound that is fenced, which most of them often called the "*Martini show*" in Krio, which means broad daylight event. Also, they feel more comfortable desludging during the day using the diaphragm pump compared to the bucket method. A few of the MPEs completely rejected the idea of desludging during the day, as this could result in derogatory name calling and stigmatisation.

Requisition from customers about the use of a particular method to empty their pit or septic tanks has never occurred. Reasons for this according to the MPEs was that customers are not even aware that there is a more than one option for pit emptying. According to the MPEs customers already know that if they are contacting MPEs they should have secured a space within their compound or nearby to bury the sludge. According to the MPEs, sludge is mostly buried in compound; but in seldom cases especially during the rains, they desludge in drainages/culverts if available in the community. If they don't want it to be buried in their compound they will call the mechanical pit emptiers.

The majority of the MPEs stated that the payment terms/pattern vary according to the arrangement for both the pit latrine and septic tanks. At large scale the payment pattern is normally done on an instalment basis. Here, instalment payments are only allowed after they dug the hole of the same depth to desludge. And immediately after desludging, balance payment would be made. On the other hand, where the job does not require digging full payment is required. "shit work does not require debt so we normally ask for full payment before we carry out the job".

Recommendations and Conclusions

The only manual emptying technology the MPEs are aware of aside from the bucket method is the diaphragm pump. They highlighted positive and negative aspects associated with both methods. It was agreed that the bucket method is quick and convenient and suitable for sludge from both latrines and septic tanks, however it is unhygienic and has stigmatisation. The diaphragm pump is quick to use for emptying septic tanks and is hygienic as it provides a barrier between the emptier and the sludge. However, it clogs easily when pumping drier sludge or if there is rubbish in the pits. It is recommended to test other manual and semi-mechanised technologies that will be effective to empty the different types of pits and the MPEs were open and willing to try out new pit emptying options. MPEs need more training on safety, hygiene and best practices for manual pit emptying.

Customers should be educated on the existence of different kinds of emptying methods, so they are aware of the options available to them. They should also be educated about the negative effects of burying the sludge in their compounds, that there are options for transport and disposal of the sludge away from their compounds and the benefits associated with this. It was noted by the MPEs that if a customer wants the sludge taken away from their compound they are more likely to call a mechanical pit emptier, because when a pit emptier is called it is assumed that the sludge will be buried on site or nearby.

NO	QUESTION	Responses – Group 1	Responses – Group 2	Responses – Group 3	Cumulative summary
1	What methods or equipment have you used to empty pit latrines and septic tanks in the past?	✓ Bucket. We enter the pit with buckets to take away faeces from the pit. ✓ Pick axe, shovels and bucket, rain boot & coat, Dettol, hand shovel. We first dig the place where the sludge will deposited. Sometimes we use rope to go in the pit.	✓ Bucket emptying ✓ Diaphragm pump	✓ Bucket tied with rope is used to empty the pit. This (bucket) is sometimes forced in to the pit with a stick if the sludge is wet. If it is dry, we manually go in the pit ✓ Diaphragm pump which more convenient on septic tanks	All three MPE groups reported to have used both the bucket and Diaphragm pump methods. Some of the tools identified as part of the bucket method were pick axe, shovels, rope and sticks.
2	What method do you prefer to use for pit emptying and why do you prefer this method of emptying?	✓ Some MPE prefer both the bucket and diaphragm pump in every operations ✓ Majority of group members supported the use of the Diaphragm pump only.	✓ Diaphragm pump because it makes the work fast, simple, and hygienically preferable	✓ The diaphragm pump (almost all of them prefer it)	According the MPEs they prefer to use the diaphragm pump to the bucket method. Giving reasons for their choice the MPEs said the diaphragm has so many advantages which include: • Makes work quicker when emptying septic tanks • And also allow them to do the work under a safe and hygienic condition. Few of the MPEs prefer to use the traditional bucket method mainly for pit latrines with a thicker sludge content.
3	What do you think should be the most appropriate method for manual pit emptying?	✓ Majority of the MPEs prefer the Bucket method particularly for pit latrines and the Diaphragm pump mainly for septic tanks.	✓ The diaphragm pump	✓ The diaphragm pump	Participants considered the diaphragm pump appropriate for septic tanks with a watery content and the bucket for pit latrines.
4	How comfortable are you with using the diaphragm pump for pit emptying?	✓ Very comfortable	✓ Very comfortable, less energy is exerted on the diaphragm pump	✓ Very comfortable. After raking all the solid waste, it makes the work more comfortable and easy to pump the sludge into the barrels	Majority of MPEs said they are comfortable with the use of diaphragm pump because less energy is utilized on it. It also prevents them from being in direct contact with the sludge.
5	What difficulties (socially, technically, financially or otherwise) do you encounter when using the diaphragm pump?	✓ Socially no problem ✓ Easily get blocked due to plastics and other hard particles found in the pit	✓ Socially no difficulty ✓ Technical - Blockage ✓ Financial difficulty was not answered at all.	✓ Technically – hose is very small for the sludge to flow easily through it. This can lead to blockages of solid waste particles.	No social difficulty was identified with the use of diaphragm pump. Technical difficulties: the hose is too small for thicker sludge to flow through at a fast rate.

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		✓ Lack of tools to solve the problem			This often results in blockage of the hose. Lack of tools like pliers, screw driver, spanner etc. Financial difficulties: None
6	How do you solve these difficulties? Does the solution need to come from an external source? If yes, where does it come from?	✓ Lack of tools (e.g. pliers, spanners etc.) has been one of the common challenges faced by MPEs using the diaphragm pump to desludge. Many of them pinpointed on this.	✓ Thoroughly clean with water to remove the blocking particles. ✓ No external support is required	✓ Thorough cleaning, and sometime a PVC pipe is inserted to clear the blockage(s) in the hose ✓ No external support is required	The MPEs undertake minor maintenance to solve problems encountered with the diaphragm pump by manually inserting objects like sticks and pipes to clear blockage in the hose. The MPEs have a reasonable knowledge and skills in up keeping the diaphragm pump.
7	Do you think the diaphragm pump has any additional value as compared to the bucket method?	✓ Yes, the diaphragm it prevents us from diseases, but the bucket is more advantageous (fast) in terms of emptying	✓ Yes, yes, with the diaphragm pump our health is safer ✓ It reduces stigmatisation and makes our work more decent ✓ The bucket method exposes team to smoking and drinking but with the diaphragm pump it is less necessary to smoke and drink	✓ Decent work is being done with diaphragm pump as compared with the bucket system ✓ Work is done at ease ✓ Less exposure to illness ✓ It reduces stigmatisation and makes the work more decent	Using the diaphragm pump to desludge is more hygienic compared to the bucket method. It reduces stigmatization and allows them to the operation in a safe and decent manner.
8	How efficient/effective is the diaphragm pump in relation to the different types of pits you encounter? How does it handle rubbish (plastics etc.) as compared to the bucket method?	✓ Not too effective/efficient - when continuously used on pit latrines	✓ Good in terms of effectiveness and efficient in it usage	✓ More effective/efficient in septic tank only ✓ Bucket method is more effective for pit latrines	The diaphragm pump is not effective dealing with rubbish like plastics because the hose is too small for solid materials.
9	Can you roughly estimate the time it takes to empty (a) a septic tank and (b) a latrine, using (a) the bucket method and (b) the diaphragm pump, from	✓ Diaphragm pump – it depends on the depth of the pit. It takes too much time to empty the sludge	✓ In terms of latrine it is time consuming, because we usually rake out plastics ✓ Sometimes because of the high presence of solid	✓ Septic tank – diaphragm pump depending ✓ The bucket is faster. It takes roughly about 6hrs to empty 18ft latrine	For bucket it takes roughly 1.5hrs to desludge a small pit and 6hrs and above for a bigger pit to latrines.

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	start to finish. What part of the process takes the longest?	✓ Bucket is very fast to complete emptying in pit latrines	waste in the pit, the bucket is preferable ✓ Diaphragm is quicker in septic tanks	✓ Small pit about 1.5hr if watery (water logged areas). ✓ If the pit is small about 5ft and dry it takes about 3hrs to empty	
10	What can you say about the durability of the diaphragm pump? How long do you think it would last if you used it as your main method for pit emptying?	✓ Duration – if properly taken care of, it can last long.	✓ Guarantee -diaphragm pump can last long (imported). But the locally made diaphragm pump sometimes poses problems in operation	✓ Last long depending on the pit	The diaphragm pump will last long if used exclusively for septic tank desludging. But due to frequent blockage when using it for latrine operation it might not last long.
11	What would make you want to use the diaphragm pump on a regular basis?	✓ Only on septic tanks regularly	✓ Make us safe and healthy	✓ Safety (injury) – this could be the main reason for using the diaphragm pump. ✓ Time ✓ Hygiene ✓ Less energy	MPEs prefer using the diaphragm pump for safety reasons. Hygiene, time and helps to fight stigma associated with the job.
12	Would you prefer to rent the diaphragm pump or own it yourself? What would you be willing to pay in both these scenarios? (For rental would you prefer to rent on a monthly basis or per job?)	✓ To own it ✓ We are only willing to pay depending on the cost i.e. (per job)- almost all of them ✓ Unable to pay for it (few)	✓ To own the diaphragm pump ✓ Willing to pay provided we have work and account to be able to raise money to pay for the pump.	✓ To be owned by us ✓ Willing to pay for it ✓ They cannot estimate the cost at their level	100% of the MPEs prefer to own the diaphragm pump. They also expressed willingness to pay a minimum sum for the diaphragm pump.
13	Where do you normally dump the sludge? Why do you dump the sludge there?	✓ Compound buried ✓ Some areas where culverts are available, the sludge is empty directly in it (mostly in the rains) ✓ Septic tanks – the sludge is taken to Bumeh mostly	✓ Buried in compound ✓ If no place is available in the compound of operation, we put the sludge in barrels for it to be taken to the deposit site.	✓ Mostly we buried in the compound ✓ Sometimes we put the sludge in a plastic bags and convey it on vehicle to the dumping site	Most of the sludge is buried in compounds. Some will take it to the dump site and during heavy rains some will deposit the sludge in drainages.
14	How do you feel about desludging during the day?	✓ Very good especially in a compound (most). Out of compound, no way at all.	✓ Good with the diaphragm pump	✓ Good in a compound (aka martini show)	Majority of MPEs feel good to desludge during the day only if the site is in a compound and in some cases they are comfortable working

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					during the day when using the diaphragm pump. They describe their work during the day as 'Martine' (Afternoon show)
15	Do customers ever request that you use a particular method to empty their pit or septic tank? Do they care about what method is used or do they know that there is a choice?	✓ No	✓ No	✓ No customer has ever demanded the methods use in empting the pit ✓ The customer has no knowledge in the use of the diaphragm pump.	It was discovered from the MPEs that customers do not request the type of method the MPEs should use to desludge. The reason being customers are not aware of the different types of methods available when dealing with MPEs. There is an information gap between what is available with the service provider and what is known by the customer.
16	Do customers ever specify whether they want the sludge to be buried in the compound or taken away? What is the reason for their choice?	✓ No	✓ No	✓ No, because clients/customers that call on the manual pit emptier have already designated a place where the sludge is bury	Customers already know that if they are contacting MPEs they should have secured a space within their compound or nearby to bury the sludge. If they don't want it to be buried in their compound they will call the mechanical pit emptiers.
17	How do customers pay for the services? (If instalment is mentioned how are they divided up)	✓ Instalment ✓ Full payment	✓ Instalment ✓ Full Payment	✓ Instalment ✓ Full payment	Most customers pay by instalment and the first part is usually paid after the MPEs have dug the pit where the sludge will be transferred and the final payment is done after the work is completed.