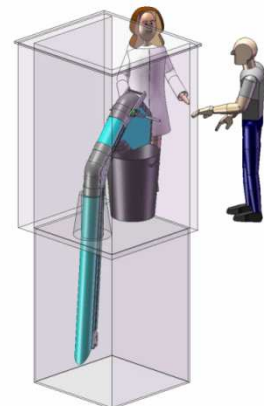


WRC PROJECT 1745

Management of sludge accumulation in VIP latrines

Investigation into Methods of Pit Latrine Emptying



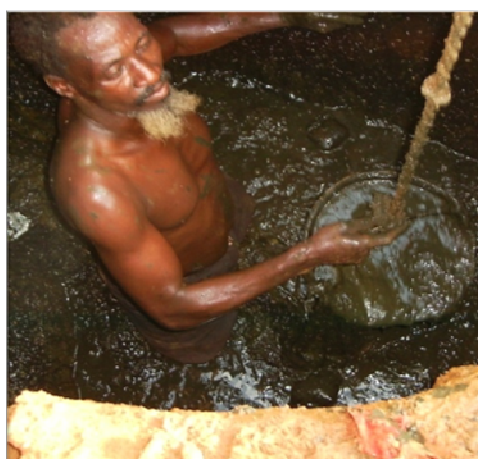
Executive Summary

Improving sanitation is now increasingly being recognized as a key factor in ending poverty; providing basic sanitation has been included in the Millennium Development Goals (MDGs) under target 10 of halving the proportion of people without access to adequate basic sanitation by 2015. In an attempt to reach this MDG target many developing countries have embarked on the construction of pit latrines and improved sanitation in people's homes. An emerging challenge that is resulting from this work is what to do when the latrines are full. If they are to be emptied how should the waste be extracted, where should the waste go and what should be done to it and with it?

The approaches to meeting this question are the focus of this report. The report aims to summarise all information currently available to PID resulting from;

- General research
- Durban's pit latrine emptying programme
- Work with the Vacutug on loan from UN Habitat
- A visit to UN Habitat in Nairobi
- Site visit to Vacutug facilitating charity Maji na Ufanisi working in Kibera, Nairobi
- Design and development work on the 'Gobbler'

The main part this report is a fairly high level introduction to the issue of faecal sludge management. Where details and information have been readily available the report goes into further depth. A large section of this report focuses on assessment of the United Nations Vacutug project in an attempt to build guidance for the development of a successful latrine exhausting system. PiD's trail work with the UN Vacutug is detailed and an update on progress made in the development of the Gobbler is given. Other established latrine exhaustion systems are also discussed, and there is a discussion of how the waste can be transported once it is extracted. Some of the options for waste disposal are considered. The report concludes with recommendations for the research work going forward.



A pit latrine emptier, or “frogman”, at work in Dar es Salaam

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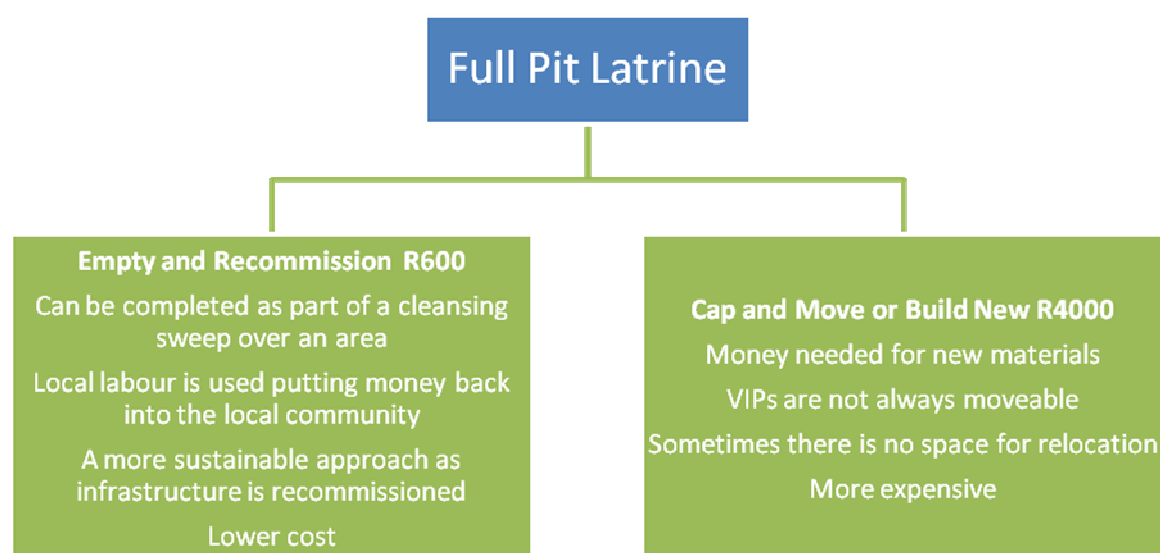
Glossary of Acronyms

MDG	Millennium Development Goal
VIP	Ventilated Improved Pit Latrine
MNU	Maji na Ufanisi
UN	United Nations
KWAHO	Kenya Water and Health Organization
MCA	Manus Coffey Associates
MAWTS	Mirpur Agricultural Workshop and Training School
DFID	The British Development Fund for International Development
FSM	Faecal Sludge Management
FS	Faecal Sludge
MSF	Medecins Sans Frontieres
ASASBU	Associacao de Desentralisamento de Aua & Saneesmento d Bairro de Urbanisacao
SLS	Solid Liquid Seperator
UHT	Underground Holding Tanks
AHT	Aboveground Holding Tanks
MAHT	Moveable Aboveground Holding Tanks

Introduction

The aim of abolishing open defaecation has lead many developing nations to embark on large scale pit latrine projects seeing households in developing regions equipped with Ventilated Improved Pit-Latrines (VIP's) that substantially enhance the households levels of sanitation.

The success of these schemes over past decades has inevitably resulted in the new problem of what to do when the latrines are full. The super structure of the VIP latrine represents an appreciable investment in development and the ideal option would be to disassemble the structure and reassemble it over a new pit burying the old waste forever and continuing the provision of improved sanitation to the household. This however has been seen to be in some cases too expensive and in many cases impractical in urban settlements where there is sometimes not enough space for new pits. In some cases the only solution is to empty the pits and re-commission the original VIP. The diagram below shows the two main options available for a full pit latrine.



The option “Cap and Move or Build New” has the advantage that no waste has to be carted off site and the excreta can be buried permanently on site, but it has two major limitations. The first is the possible contamination that burying the waste could have on the local ground water, and the second is associated with the problems that can be expected if the redevelopment of this contaminated area of land should be considered.

The challenge of how to deal with contaminated land was discussed at both the UN and Maji na Ufanisi (MNU) meetings in Kibera (please see section 7.1 for the meeting minutes). With recent infrastructure developments in Kibera no matter where they tried to locate new pit latrines or buildings old latrines would be exposed. The contents of the exposed old pits have to be removed and carted off site before the development work can start. This causes many problems, and escalations in project costs as costly carting away of material is required along with extensive back filling. The following is an extract from the visit to Kibera;

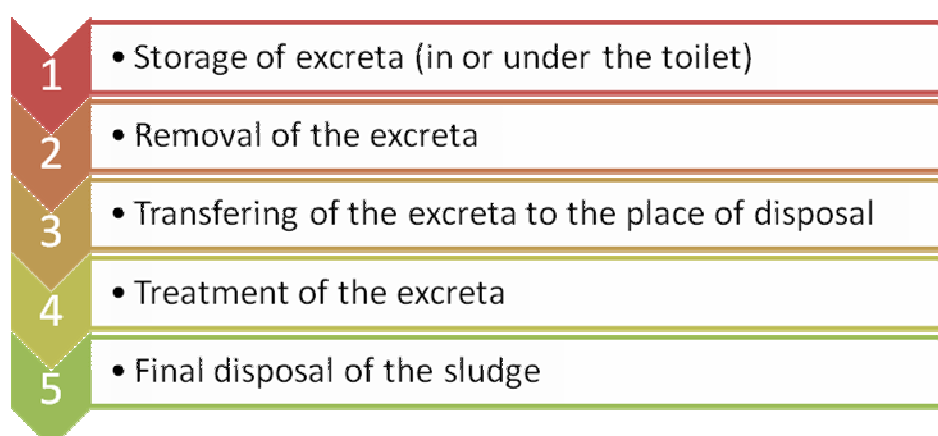
A visit to a new construction site was made. The site was for a new library, computer centre and toilet block. The first task faced by the developers was clearing the site and removing a number of old pit latrines. The waste from the unlined pit latrine

(most common latrine found in the area) pits had to be excavated leaving 10 to 15 holes ranging from 2 - 3m in depth.

Manual excavation had been used to complete this work. Locals who were used to the smell and the local environment completed this work. They are also adapted to the local hazards and less susceptible to the health risks. In spite of the stated resilience they still seemed to get ill, problems with rashes on arms had been seen in the last batch of worker. The recommended approach for emptying the pits is to dig out and cart the waste to the local sewer point where the waste is screened and domestic waste is separated and the remainder dumped into the sewer. This is hard work and often if there is not adequate supervision the waste may just be carted off and dumped in a nearby open field.

Workers wear many protective items of clothing. Often during the day the smell is overpowering so people work at night, this also mitigates complaints from the community who are very against waste being carted through their streets.

The challenges of contaminated sites could have been avoided if original latrines were re-commissioned rather than relocated. This however leads to other challenges of how to get the waste out and what to do with it once removed. The collection of human excreta from private latrines in urban low-income neighborhoods is an infrastructure service that consists of several activities;



These divisions of excreta collection are used as the basis for discussion of this topic in this report. Each activity is taken in turn and discussed, and current approaches are detailed. The information detailed has been collected during three months of research work on this issue, including a visit to the UN-HABITAT headquarters in Nairobi, Kenya and a site visit to Kibera, the largest slum in East Africa. Minutes of meetings attended during this visit are attached in the Appendices (Section 7.1) and are quoted throughout this report. Details of design and development work on novel machines to aid latrine emptying are also discussed towards the end of the report. Each chapter finishes with conclusions and suggestions for effective approaches. Then report concludes with ideas for development and recommendations for further work.

1 Storing of Excreta

This section of the report gives a brief overview of typical sanitation provisions seen in developing areas, highlights some of the choices available to a household when the latrine is full and outlines the nature of the waste that has to be extracted from the latrine.

1.1 Provision of Improved Sanitation

1.1.1 Pit Latrines

The Ventilated Improved Pit latrine, or VIP, is the most common basic sanitation technology in Southern Africa. It is the extraction of waste from pit latrines that this research project focuses on. Therefore it is important to briefly evaluate the main varieties of latrines. These are shown graphically below.

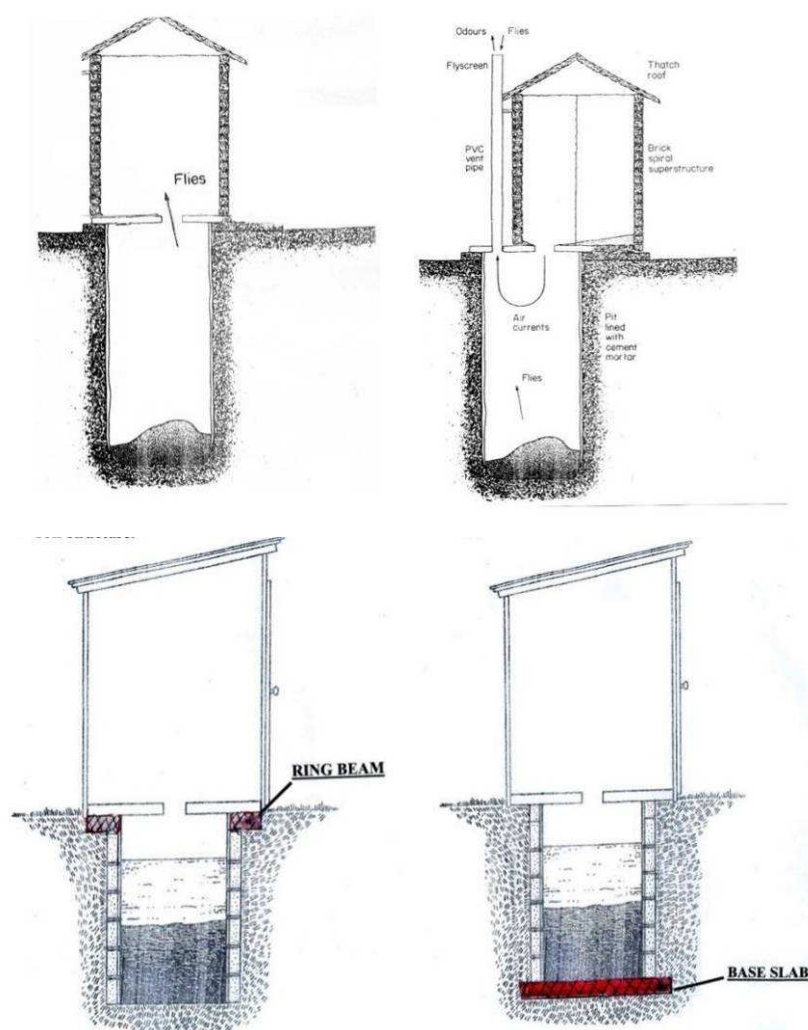


Figure 1 a) The basic dry Pit Latrine b) Ventilated Improved Pit Latrine (VIP) c) Ring beam system; for stable soils, weight of super structure carried by ring beam on top soil. d) Base slab system for unstable soils, weight of superstructure carried by walls onto sub-soil or base rock. (3)

The use of appropriate and adequate structural reinforcement is very important if collapse of the superstructure, as illustrated in Figure 2 below, is to be prevented. The lining of the pits must, however, not be sealed, in order to allow the liquid content

to percolate into the surrounding soil. If the walls of the pit are fully sealed a conservancy or septic tank is produced that will fill within a matter of months.



Figure 2 An unlined or unreinforced pit cannot support a heavy top structure

Where water or grey water is readily available a pit latrine can be further improved through the addition of a water trap which holds odors from the waste in the pit chamber. This is the pour flush latrine, concept, which is common in South East Asia.

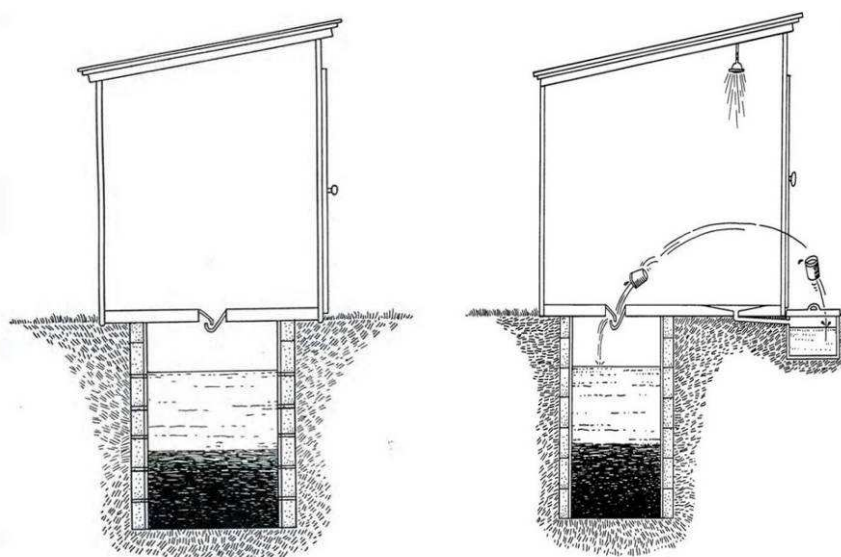


Figure 3 a) Pour flush latrine b) Using grey water for flushing (1)

1.1.2 The full range

The full range of sanitation technologies for providing adequate basic sanitation covers the spectrum between dry on-site systems and full bore waterborne sewage systems. Typically improved sanitation in South Africa takes the form of Ventilated Improved Pit-latrines (VIPs) which are individually owned, but in other areas of the developing world where funding may be more limited communal systems are more common. The World Health Organisation and Unicef do not recognize communal sanitation as meeting the minimum standards for basic sanitation (WHO, Unicef 2008), although such systems, if properly implemented and maintained, are considerably better than nothing at all (Borda, etc).



The figures below show two examples of these types of toilets. These systems contrast in their method of sanitation provision. The VIP stores the waste in a dryish pit under the floor slab of the latrine, while the communal block latrines typically have low volume pour flush toilets with the waste stored in a septic tank. Both solutions will eventually encounter the challenge of what to do when their storage tanks are full and effectively represent the extremes of the challenge. VIPs full of dryish human excreta with a low water content, and septic tanks with a thick and dense scum layer, a liquid layer and a wet sludge layer (with a range of density encountered in practice, depending mainly on emptying frequency).



Figure 4 A typical South African VIP being emptied manually (1)

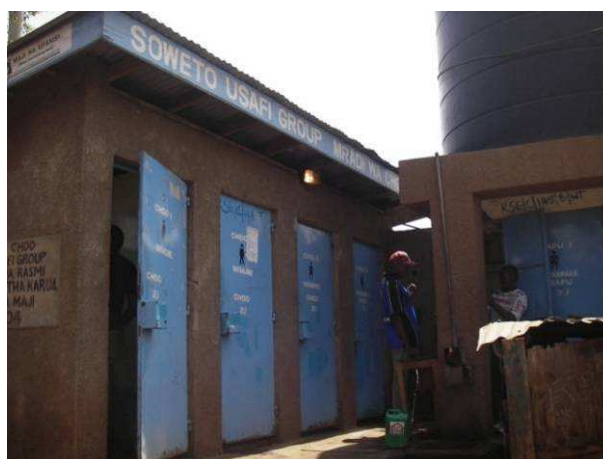
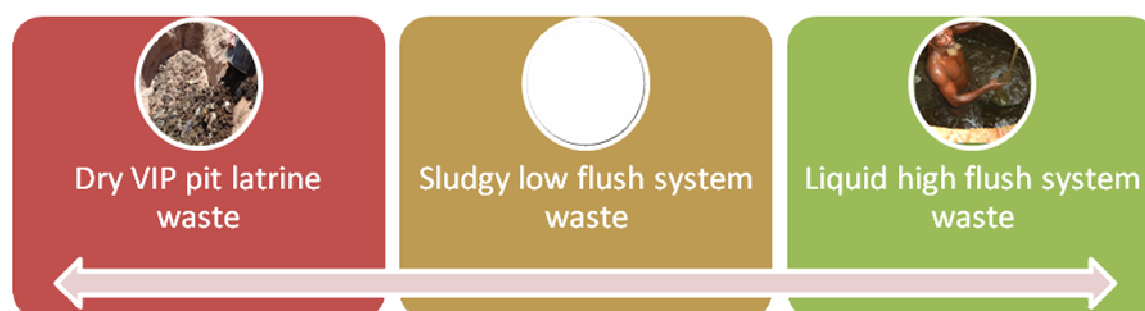


Figure 5 A typical communal block seen during a site visit to the Kibera Settlement in Nairobi, Kenya (2)



They also contrast in the distribution of the waste, as communal systems will hold a lot more waste but have it concentrated into a single site aiding collection. VIPs will often be distributed across a wide area with one installed at each household. Finally in some countries (not South Africa, which has a free basic sanitation policy) a communal system will be a pay per use facility. This money is used to pay staff to

supervise and clean the toilets and cover the costs of emptying any associated storage tanks. There is no associated revenue stream for a VIP.

1.2 The full excreta storage dilemma

Wet or dry, on site sanitation systems do eventually become full. The user could (4);

- Build another latrine. This has to be achieved within constraints of money and space
- Empty the pit
- Sluice the contents of the pit into a purpose dug adjoining pit
- Use a neighbour's toilet
- Revert to open defecation

The options for disposing of latrine waste are many:

- Transport directly to a sewage treatment facility
- Discharge into a main sewer which will bring the wastes to the sewage treatment facility
- Bury at a landfill site or dedicated sludge disposal site
- Discharge into specially constructed sludge drying ponds.

1.3 VIP waste

The main focus of this project is removal of waste from the typical VIPs seen in South Africa. The picture below shows waste manually removed from VIP latrines in Umlazi, Durban.



Figure 6 - The waste from a typical South African Latrine (1), which is a mixture of human waste and domestic refuse.

It is clear from the image above that the waste extracted is not just excreta, but contains a certain amount of domestic refuse such as nappies, rags, bottles and newsprint.

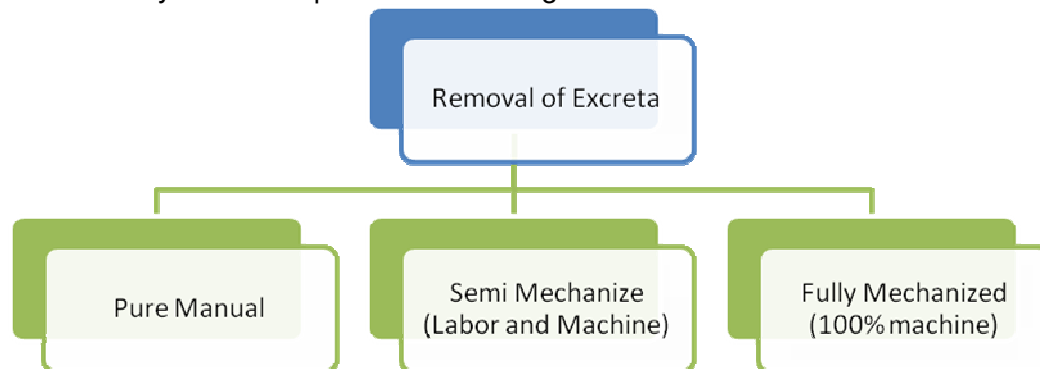
1.4 Septic tank waste

In some areas with on-site sanitation low flush or full flush systems may be in use and these make use of septic tanks. For these wetter mixes of waste vacuum machines are used in preference to manual emptying but complete evacuation of these tanks is not easy to accomplish. Over time the sludge thickens, with the result that the solid at the bottom becomes harder to suck. For this reason vacuum tanker operators try to encourage their clients to empty their septic tanks frequently, and not to wait until they are completely full of solids. For both septic tanks and pit latrines median sludge accumulation rates are around 30 litres per person per year, but there

is great variability so for planning purposes it is safer to use a figure of 50 litres per person per year.

2 Removal of Excreta

This section of the report discusses current methods used to empty pit latrines, which are divided into Manual, Semi Mechanized and Fully Mechanized approaches. Whereas Manual systems use only manual power with hand tools, Semi Mechanised systems use manual power transferred through some mechanism, and Fully Mechanised systems use power from an engine or motor.



Regardless of which system is used it will be managed and supervised by a team of 'emptiers'. These workers expose themselves to a number of hazards and challenges;

- Health risks from possible direct contact with human excreta
- A low status in society with the work often viewed as 'disgusting' which results in;
 - A pressure to complete work quickly to minimize disruption
 - A pressure to complete work at low cost (in spite of equipment being capital intensive)
 - In some cases the requirement to do the work during the night hours
- Customer demand being fragmented in time and space
- Distance between exhaustion and emptying sites vary overall costs

These points lead to critical issues which are important to consider when comparing exhaustion methods:

- The possible level of contact with waste by the latrine emptiers
- The speed of latrine exhaustion
- The cost of exhaustion equipment
- The durability and reliability of approach
- The ease of linking into a waste carting method

2.1 Pure Manual Exhaustion

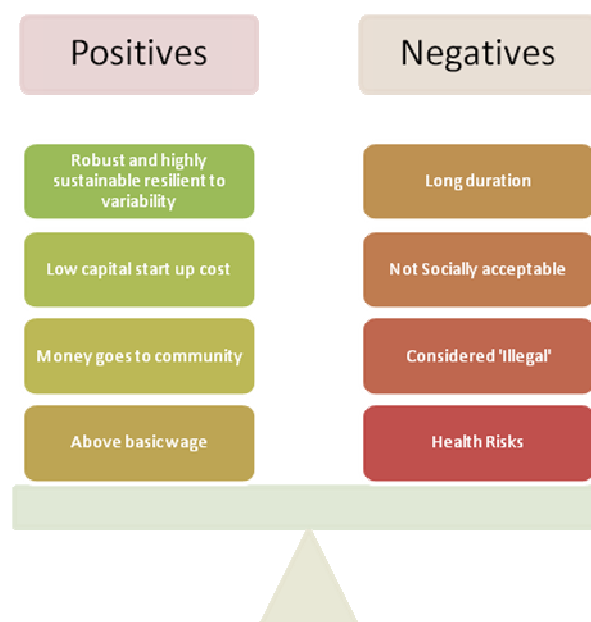
The most basic approach to excreta removal is manual pit emptying for which there are two main techniques, scooping and flushing. With scooping the emptiers open the squatting slab and scoop out the pit or storage tank. The waste is then either carried away in containers or buried on site if there is space for a hole to be dug. With flushing or sluicing the sludge is flushed into an adjacent hole that is deeper than the pit latrine, which requires access to a large volume of water and suitable site conditions.

In East Africa the traditional emptiers, who are in full contact with the sludge, consider the work to be unhygienic and often dangerous. They therefore want to be paid well. For these reasons and because of the low social status of the work, the traditional emptiers typically do this work only on a part-time basis (not more than once or twice per month), in spite of no shortage of available work.

Manual latrine emptying has many disadvantages, with the length of time for pit emptying being the major one. The time taken to empty a latrine varies with pit size but is nominally longer than one day which results in an uncovered latrine and disposal hole (if one is being used) which is inconvenient and even dangerous to latrine owners.

The eThekweni latrine emptying programme uses local labor to manually empty the latrine pits. Despite the nature of the work it has been possible to source labor as they get paid relatively well. This however has contrasted with the results from the site visit to Kibera, Nairobi, where manual emptying is very unpopular. In Kibera Work often has to be completed under the cover of darkness as locals do not wish to see their waste being extracted from latrines and then carted through their streets.

There are some major advantages to manual latrine emptying. Firstly it is very resilient to change, many workers will be employed, and if one should be ill, tired etc the work will still continue, this contrasts with a machine where if it runs out of fuel or breaks work would stop. Secondly if local labor is used funding for a latrine emptying project moves from the funders to the community and is not tied up in expensive machinery and maintenance costs. This is good for the community and will have benefits beyond simply emptying their latrines. The benefits however must be balanced against the health risks and social acceptance. The image below summarizes the positives and negatives already discussed.



2.1.1 Aids to Manual Emptying

For fully manual pit exhaustion appropriate selection of tools and equipment can greatly ease work for the laborers. The images below show a corer tool developed by Steve Sugden of the London School of Tropical Health for the digging of waste out of a latrine.



Figure 7 Image showing the Corer (4)

2.2 *Semi Mechanized Emptying*

This section of the report details some tools and mechanisms that have been developed to assist laborers with latrine emptying in a semi mechanized way where the power for the work is manually applied but a mechanism moves the waste.

2.2.1 The MAPET System

The MAPET (Manual Pit-latrine Emptying Technology) system was developed by the Dutch NGO WASTE and was piloted in Dar es Salaam, where 80% of the homes are served by pit latrines and where most emptying is done by hand.

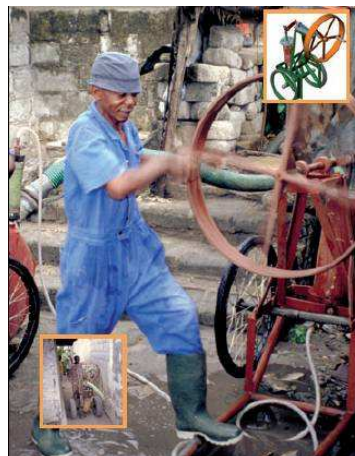


Figure 8 showing the manual pit emptying technology (or MAPET) (5)

2.2.1.1 Design development

The chosen approach to design development was to utilize aspects of existing pumping technologies and parts which were more widely available than vacuum or pneumatic technologies in Tanzania. Prototype hand pumps were constructed in the Netherlands where several tests were made on two types of pumps: a piston pump and a diaphragm-pump. A prototype diaphragm pump was shipped to Tanzania where the first MAPET pump unit was locally completed. The diaphragm pump proved to be unsuitable to the local situation as the most vulnerable part in the pump

was the diaphragm which proved extremely hard to source locally and would rapidly perish. Even heavy duty diaphragms started to crack and leak after a few months due to operational circumstances and the tension in the rubber related to the large strokes.

An alternative was therefore investigated which made use of an air vacuum indirectly in a pressure vessel. By pumping air rather than sludge a vacuum can be created in the sludge holding tank, but the sludge does not pass through the pump, making it far less vulnerable to wear and tear. The challenge was to find a vacuum pump appropriate to this task. Eventually a piston pump with a leather piston in a 6-inch PVC cylinder became the standard MAPET pump. The most challenging parts to source for the pump were the leather for the piston and the flexible hose pipe and associated couplings which were eventually sourced locally but at high cost.

The final design criteria used to develop the MAPET system are detailed in Table 1 below.

Criterion	Design decision and MAPET feature
1. Reduce dependence on expensive fossil fuels	Human powered equipment: <ul style="list-style-type: none"> • Handpump emptying • Pushcarts transport with an operating base close to customers
2. No demolition of squatting slab and super structure	Excavating the sludge through the squatting hole by means of a hose pipe
3. No sludge to enter the pump to prevent risk of blockages and heavy wear	<ul style="list-style-type: none"> • Indirect pumping by creating a vacuum in a tank which draws the sludge out of the latrine • A sight glass to view sludge level
4. Optimal use of human power for a pump head of a maximum 3m	Approximate resulting dimensions <ul style="list-style-type: none"> • Flywheel diameter 80cm • Rotational speed: 40-60rpm • Pump volume per stroke: 2 liters • Mass of fly wheel: 25kg
5. Accessibility through small paths and gates to inner courts	Maximum width: 800mm (relates to the wheelbase of the carts and flywheel diameter)
6. Local construction and maintenance in Tanzania	Applying locally available technologies and skills; <ul style="list-style-type: none"> • Drinking water handpumps and piped water supply parts • Motor vehicle maintenance • Bicycle maintenance
7. No expensive, vulnerable gate valves	Tipping of the tank; <ul style="list-style-type: none"> • Coupling position 'up' for pumping and maneuvering • Coupling position 'down' for discharging

Table 1 showing the design criteria used to develop the MAPET system (6)

The final costs (in 1990) for the construction of a complete MAPET unit proved to be equivalent to 3000 USD based on local manufacture, which included:

- Manufactured components
- Readily bought parts

- Consumables (gas, welding rods, paint etc)
- Transport: to obtain materials and quotations, to follow up orders, collect components etc.
- Incentives to fabricators.

The first MAPET units used 200 litre oil drums for the vacuum tanks, but these proved prone to corrosion and would tend to implode under the nominal operating pressure of -0.4 bar which could be achieved with the piston pump. Eventually it was decided to use a purpose made tank using 3mm steel sheet.

Other design challenges were the following:

- Low cost wheels for transportation of the rig, which needed to be strong and compact. Car wheels proved expensive, hard to find and heavy. Wheel chair wheels were used but these were prone to failure and required maintenance for bearings and spare tyres. Consideration was given to reducing the tank volume to reduce payload. Scooter and wheel barrow wheels were considered as an alternative.
- The hose pipes and couplings were expensive. To reduce costs only a single inlet to the vacuum tank was required, and standard hose sizes (the same as on the commercial vacuum tankers) were used to reduce cost.

The final system has two main components: a hand pump and a 200 litre vacuum tank, both mounted on push carts. A $\frac{3}{4}$ inch hose joins the pump and the tank, and a 4 meter long 4 inch pipe is used to carry the sludge from the pit. Additionally there are some other items which augment the system:

1. A mixing rod for stirring the waste to an appropriate viscosity
2. A hook for picking out rags and other waste that would block the suction hose
3. A spade and hoe for digging the hole for sludge disposal
4. A chisel and hammer for widening the squatting hole or making a hole in the latrine wall for the suction hose.

2.2.1.2 The emptying routine

A crew of three are used for the MAPET system. Typically a hole is dug for the sludge disposal on site and the latrine sludge is prepared for pumping. This preparation entails mixing of water with the sludge (to make it more fluid) and paraffin (to reduce the smell). Latrine exhaustion then starts. Depending on the sludge's viscosity and pumping head it can take five to twenty minutes to fill one 200 litre tank with sludge.

When the tank is full the hose pipes are disconnected and the tank is maneuvered next to the disposal pit and rotated to allow the waste to drain into the pit. In this way only one (expensive) 4 inch pipe connection to the vacuum tank is required and critically no expensive ball valves are needed. After righting the tank pumping can start again. This routine is repeated until the required amount of sludge has been removed from the storage chamber.

The MAPET project proved that it could survive under the prevailing local maintenance conditions and the wearing parts were fairly low cost items which if they did fail did not damage the rest of the machine. This contrasts with a vane vacuum pump where the wearing items (vanes and the vacuum casing) are expensive to replace and often extremely hard or in some countries impossible to source resulting in either a broken machine or the purchase of a new pump.

[add section on the fate of the MAPET system here – it was hoped that the city of Dar es Salaam would ultimately back the project and invest in it, but this never happened and so after the initial set of machines wore out the situation reverted to the status quo ante]

2.2.2 The Gulper

The Gulper is a sewage sludge pump based on an existing simple hand pump design. It was developed by Steve Sugden of the London School of Hygiene and Tropical Health, who was looking for technology that was very inexpensive and highly portable. The Gulper has been tested in Dar es Salaam and has proved successful on the fairly liquid sludge which is characteristic of latrines in Tanzania. The foot valve on the pump is based on a valve type commonly seen in low cost water pumps. Two men operate the sludge pump by moving a handle on the top of the machine up and down. This handle is connected by a long rod to the foot valve at the bottom of the pump, which is submerged in the sewage sludge. The up and down motion of the foot valve draws waste up the rising pipe and out of the outlet at the top of the pump. The pump is extremely inexpensive, costing in the region of \$100. Trials and testing continue in Dar es Salaam.



Figure 9 The gulper developed by Steve Sugden (4)

2.2.3 The Nibbler

A second device developed by Steve Sugden is the Nibbler which uses a chain and “scoops” to draw waste up and out of the pit. A prototype design which uses steel disks welded onto a bicycle chain is shown below. Testing to date has only been completed on farm slurry but first results seem positive. Sugden was, however, of the view that the fairly dry pit sludge encountered in South Africa would be difficult to move using the Gulper or the Nibbler, particularly given the high domestic refuse content.



Figure 10 - The nibbler (4)

2.2.4 The Gobbler

The design of the Nibbler was based on the kind of parts and technology that are cheap and easy to source in Tanzania. However, in South Africa there is a well developed market for a wide range of agricultural machinery, so it was decided to try to develop an extra robust 'Nibbler' which was given the name 'Gobbler'. As a starting point for the design off the shelf chains and links were researched with a focus on a link that could be easily connected to a scoop or claw. It was found that agricultural machines often use chains with links and brackets integrated into the chains and they were found to be locally available at low cost.

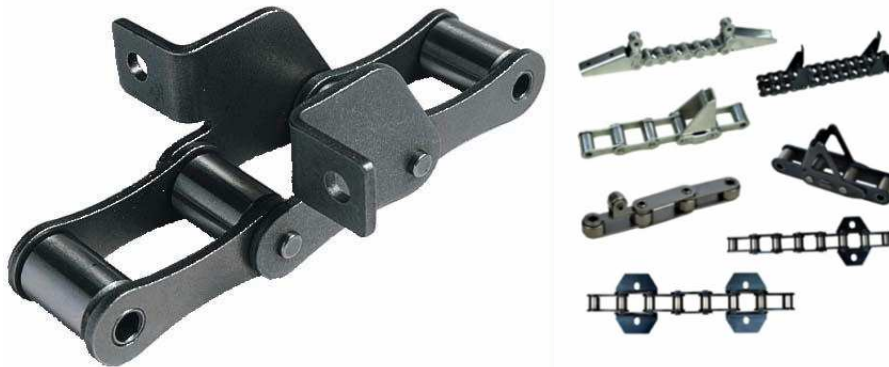


Figure 11 showing examples of off the shelf robust links

With the chain as the starting point for the design development an initial prototype was designed which would use a double chain arrangement guided in a channeled structure. The concept is illustrated in Figure 12 below.

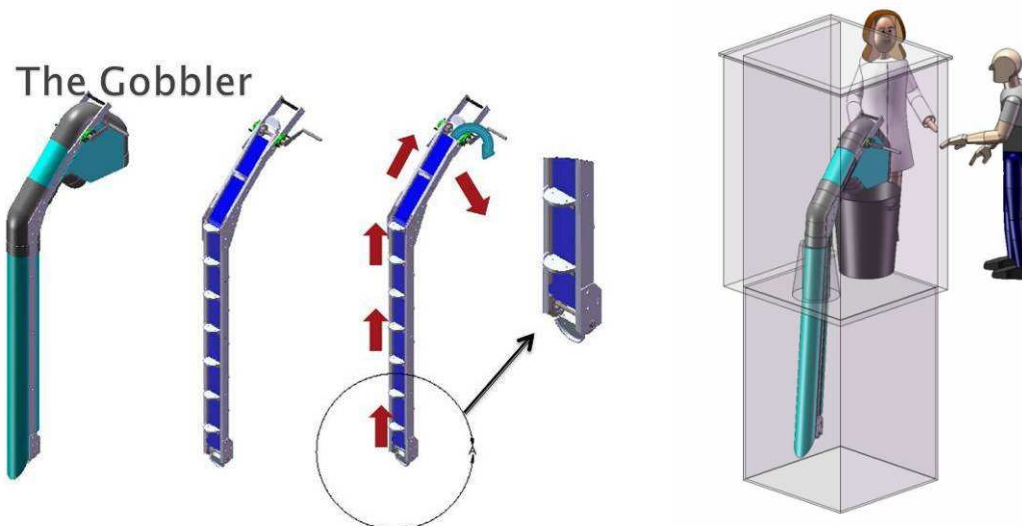


Figure 12 showing the Gobbler conceptual design (2)

The basic concept which is similar in principle to the Nibbler would produce a system that would draw the waste up out of a latrine pit discharging into a container. Construction of the prototype started in March 2009. The approach was to produce a rig that could be used to test different scoop designs, and be as strong, robust and reliable as possible. This has resulted in a slight over engineering of the Gobbler and use of machining processes that would not be necessary in a final optimized production design.



Figure 13 showing machining of the top handle bracket, the main plastic structure, and bending of the plastic to form the 45 degree bend on the gobbler.

The prototype construction is progressing well and if it proves successful, which will only be seen after the testing of the prototype, there will be an opportunity for further design work and production of a more optimized solution. Initial suggestions for optimization on the design are;

- **Cost reduction** through selection of lower cost materials, plastics replaced with plywood or bent metal sections, elimination of expensive fixtures and fittings, and cheaper chain and brackets
- **Part count reduction** to aid cost reduction, complexity of manufacture and failure modes

- **Weight reduction** through the use of thinner sheet steels and a lighter weight chain.

The exercise of producing the prototype has provided many opportunities for learning and research on machining processes available in South Africa. It has become clear that accurate CNC plasma cutting and the bending of sheet is a readily available process here, which can be used to rapidly fabricate accurate sheet metal parts at low cost.

The materials, manufacturing and labour costs for the prototype Gobbler are in the region of R10 000 (see table below). It is anticipated that a redesign could reduce this cost through better material selection and simpler manufacture. This redesign however can only happen after testing of the current design which should commence in May 2009. Off setting this possible reduction in cost, would be cost increases that would result from added design sophistication (e.g. it would be preferable if the 45 degree bend was not fixed but adjustable or even flexible).

Item	Cost
Chains	1 759.28
Sprockets and bearings	149.62
Steel Structure	876.7
Plastic Parts	841.28
Shrouding	300
Buckets	300
Tripod	500
Tripod Winch	75
Fixtures and fittings	630.14
Sub Total material costs	5 432.02
Fabrication and machining cost	1541.8
Tooling and setup costs	1 061.32
Contingency and overheads	1 964.86
Total	10 000.00

2.3 Fully Mechanized Emptying

Fully mechanized waste exhaustion systems use an engine to supply the required power. The most common method for this are systems using a vacuum based approach to draw the waste out of the pit. There is a wide variety of machines that use a vacuum based approach, and the main ones are discussed in this section.

2.3.1 Vacuum tanker

Commonly sewage exhaustion from pit latrines and septic tanks in large developments is divided between municipal sanitation departments and local entrepreneurs who wish to capitalize on a business opportunity. The most common machine of choice for this task is the vacuum tanker, and often 'fleets' of these machines will service large areas, extracting waste and carting it to treatment sites. Vacuum tankers are characterized by high capital and maintenance costs. In less industrialized countries long delays in repairs are very common and the cannibalizing of broken down vehicles to obtain usable spares is a regular practice. The typical result is a chronic shortage of tankers.

Vacuum tankers are mostly used for services in planned settlements where the septic tanks and pit latrines are easily accessible and waste is fairly liquid and not mixed with solid waste. Many of the residents living in unplanned areas cannot be serviced as roads are poor and paths too narrow to be accessed by the tanker trucks. Moreover the domestic refuse often found in pits in informal settlements blocks the vacuum hoses making the job time consuming and messy. The owners of these expensive machines prefer to limit their services to the planned areas of town with more advanced sanitation systems. The images below show a variety of vacuum tankers.



Figure 14 A variety of vacuum tankers (7) including a tractor trailed vacuum tanker (1)

2.3.2 The Microvac

The Microvac is a micro vacuum tanker developed for use on uneven roads and areas with poor access.

[used where, how successful?]



Figure 15 Micravac latrine emptying vehicle (a micro vacuum tanker) (1)

2.3.3 The Dung Beetle

The Dung Beetle is a machine developed by a Dutch company J.Hvidtved Larsen and deployed in Ghana. This machine uses a two wheel tractor based drive, with the driver sitting on the tank and steering using the long handles on the machine. These machines have been successfully used for many years in Ghana. The table below shows the main specifications (8) for the machine.



Figure 16 The Dung Beetle, which is used in Ghana (8)

Type: 2-wheeled universal “walking” tractor.

Engine: 2-cyl. 4 stroke 16 hp diesel engine with electric starter.

Transmission: 4-speeds forward plus 1 reverse. Engageable differential lock.

Power Take Off: Independently operating. Vacuum pump powered through V-belt.

Max. speed: 12 km per hour.

Brakes: Handle operated drum brakes on front wheels with separate parking brake. Pedal operated drum brakes on rear wheels.

Turning radius: 3.05 metres within kerbs, 3.3 metres within walls

Body: Self-supporting tank, twisting angle through pivot point limited to + 20 degrees
Overall length: 3.5 metres.
Overall width: 1.1 metres.
Total weight empty: ~675 kg, fully loaded including driver ~1550 kg.
Vacuum pump capacity 4300 litres per minute.
Maximum vacuum in tank: - 0.8 bar.
Positive pressure: 0.5 bar.
Sludge tank: Net operating volume approx. 800 litres.
Valves: Suction valve 3" ball valve, top mounted, discharge valve 3" ball valve, bottom mounted.

2.3.4 The Vacutug

The UN-HABITAT Vacutug project was funded by the British Development Fund for International Development (DFID) as part of the Engineering Knowledge and Research Programme along with support from Irish Aid. The project evolved out of the need for a low cost and fully sustainable system for emptying pit latrines in unplanned, peri-urban areas and refugee camps in the developing world. The UN-HABITAT Vacutug's development goes back to nearly twenty years of research which was started by IRCWD in Botswana in 1983. The work of IRCWD resulted in the development of the Brevac (a low cost vacuum tanker) and consequent developments of the Micravac and MAPET systems.

The Vacutug's main specifications are shown below:

Weight: 950 kg
Size: L 3900mm X W 1350-mm X H 2000 mm
Speed: 5 km/hr
Engine: Four stroke 8 HP Honda models GX240 petrol engine with electronic ignition.
Vacuum pump: Battioni & Pavesi Type 2000P. Manufacturer's rated vacuum 0.9 bar, rated pressure 2.0 bar.
Vacuum Tank: 500 liters capacity sludge tank with two sight glasses, and pressure relief valves. Rated at 0.9 bar vacuum and 1.0 bar pressure.



Figure 17 the UN-HABITAT Vacutug (8)

The capital cost of the Mark II model is USD\$ 5,100 (excluding freight). The machines are manufactured in Bangladesh and shipped from there.

In February 2009 a visit was made to the UN-Habitat centre in Nairobi to learn more about this technology. Not only did this provide an opportunity to learn a lot about the development of the Vacutug, but it also provided an insight into methods of latrine emptying in general and wider issues. Minutes from the meeting are attached in appendices (see section 7.1). The initial design criteria used to develop the Vacutug were;

1. The system should have access to high-density settlements and be maneuverable
2. The capital cost of the technology should be affordable to small-scale entrepreneurs
3. The machine should be designed for local manufacture, operation and maintenance
4. Operating costs of the service should be covered by revenue generated
5. The system should be capable of transporting the waste to an appropriate disposal point
6. The system should be able to evacuate compacted sludge from latrines.

A visit to the Vacutug pilot project in Nairobi's Kibera informal settlement was made. It was found that there were some differences of opinion between the UN Habitat Vacutug project managers and the Vacutug operators in the field, which are set out as follows:

Opinion of Project Managers	Opinion of Vacutug users
<ul style="list-style-type: none"> • Spare parts are easily available and machine is locally manufacturable • Only two operators are required to operate the machine • The Vacutug is highly maneuverable and optimized for movement on settlement roads. 	<ul style="list-style-type: none"> • Spare parts are NOT locally available the machine has stood out of action for almost a year • 4 operators and not 2 are required to operate a Vacutug • Handling is poor and machine often falls over.

These points provoked interest in the Vacutug's development and further background research was completed. The following is abridged information taken from the technical reports of field trials conducted during the period 2003-2006 (9).

2.3.4.1 Phase one first trials in Kibera 1995-2000

The trials of the UN-HABITAT Mark I Vacutug began in 1995 in partnership with the Kenya Water and Health Organization (KWAHO) in Kenya and Manus Coffey Associates (MCA), the chosen designers for the Vacutug. The Mark I Vacutug comprised a 0.5m³ steel vacuum tank connected to a sliding vane vacuum pump capable of -0.8 bar vacuum. A 4.1kw petrol engine connected either to the vacuum pump or a friction roller to drive the front wheels through an adjustable belt drive. The vacuum tank was fitted with 3 inch diameter valves at the top and bottom of the tank and the waste is evacuated from the latrine via a 3-inch diameter PVC vacuum hose. The waste sludge can be discharged under gravity or by slight pressurization of the vacuum tank by the pump. The machine is equipped with a throttle, a clutch (in the form of an adjustable belt drive) and two brakes.

In 1997 the Mark I Vacutug was given on loan to KWAHO to be tested in the Soweto village, Kibera, Nairobi. The sanitation technology used by the residents in Kibera is either a simple pit latrine or VIP latrine [although for those without access to any facility they use the “flying toilet” method whereby excreta is collected in a plastic bag and thrown out of the dwelling into the street or onto the roofs of adjacent buildings]. The machine was operated on a commercial basis and during the two year trial period earned a total profit of 36% on its overheads. KWAHO estimates that over 400,000 people benefited directly from the use of the Mark I Vacutug in Kibera (one pit latrine can serve between 80-100 people) and that in the absence of the Vacutug residents would have no other option but to resort to manual pit exhaustion. Five people were employed and paid by the revenues generated from the project: a supervisor; two operators; a mechanic and a watchman.

After two years of operation the Mark I Vacutug developed mechanical problems which took almost 10 months to repair. The problems were:

- The two rollers/bearings were worn out, and the spring roller was worn out and could no longer provide the pressure to drive the machine.
- The hose pipe was worn and had major leaks
- There was a problem with the chain.

Phase one highlighted a number of issues:

1. **Good financial management and planning.** The management of the Vacutug is as important as the technology itself. In low income settlements security from theft and vandalism is important (hence the watchman). Even though the Vacutug was kept at the District Officer's camp it was still vandalized and parts were stolen. Due to misappropriation of some funds there was not enough money to cover some of the repairs and UN-HABITAT had to subsidize the repairs.
2. **Routine operation and maintenance:** Neglect of routine maintenance, increases the frequency of break downs. The operators who were not qualified mechanics, typically made quick fixes to keep the machine in operation, but these were not lasting.
3. **Minimum number of loads:** The demand of the Vacutug was high, exceeding supply, and it was calculated that if the machine could empty at least 8 loads a day it would cover its O&M costs.
4. **Terrain:** The Vacutug was not operating to its full capacity due to the inaccessibility of the latrines. The poor quality roads proved impassable during the rainy season.
5. **Need for competition:** The lack of competition, with the only alternative being manual latrine emptying, caused the operator to charge more for the service than was necessary to cover overheads.
6. **Water scarcity:** The latrines were difficult to empty as the sludge was very thick. Water was needed to dilute the sludge but as there were water shortages and high water prices, it was not always possible for owners of the latrine to afford the volume of water required.

2.3.4.2 Design and production of the Mark II Vacutug

In April 2002 UN-HABITAT received further funding from DFID and Irish Aid, to produce a second batch of 9 Vacutugs and to test the technology further in different socio-economic and geographical conditions. Manus Coffey Associates (MCA) were re-appointed as the Technical Consultant. The first requirement for MCA was to revise the drawings and the Vacutug design. The following design modifications were made on the Mark I design:

- Drive rollers are now all hard faced
- Spring pressure was increased to reduce slippage on the drive system
- The steel brushes on the engine mounting are now welded into place
- Appropriate documentation for operation and maintenance was produced

In June 2002 the manufacturing contract was awarded to the Mirpur Agricultural Workshop and Training School (MAWTS) in Bangladesh for the production of 9 Vacutug Mark II machines. The MAWTS contract stipulated that they would source as many parts as possible locally and with the help of the MCA would import all other parts. In the end it was necessary to import the engine, vacuum pump, axles and wheels. Shipment of these items was a protracted process and caused delays in production.

In order to speed up the manufacturing process and avoid any further delays, it was agreed that the first machine would be produced entirely from locally available parts, even if the quality wasn't as good as hoped. MAWTS used a Chinese engine and locally procured wheels to produce a tenth machine on the understanding that this machine could be used by MAWTS in the trials or as a demonstration model in the workshop.

2.3.4.3 Shipment of the machines and field trials

The map below shows the sites where the Vacutugs were tested by project partners (NGOs implementing faecal sludge management programs). This illustrates in part the global network involved in tackling the issue of Faecal Sludge Management (FSM). It was decided that the machines would be air freighted to the various partner countries. Quotations were between USD\$3000 – USD \$8000 per machine for shipment. However the cargo planes operating out of Dhaka airport were not large enough to receive the 1 x 2 x 3m wooden container for the machine. The only option remaining was to ship them to Dubai or Singapore and airfreight the machines from there. However countries such as Tanzania and Mozambique did not have airports with the capacity to receive the cargo planes, and in the end MAWTS completed the shipment on behalf of UN-HABITAT at considerably lower cost.

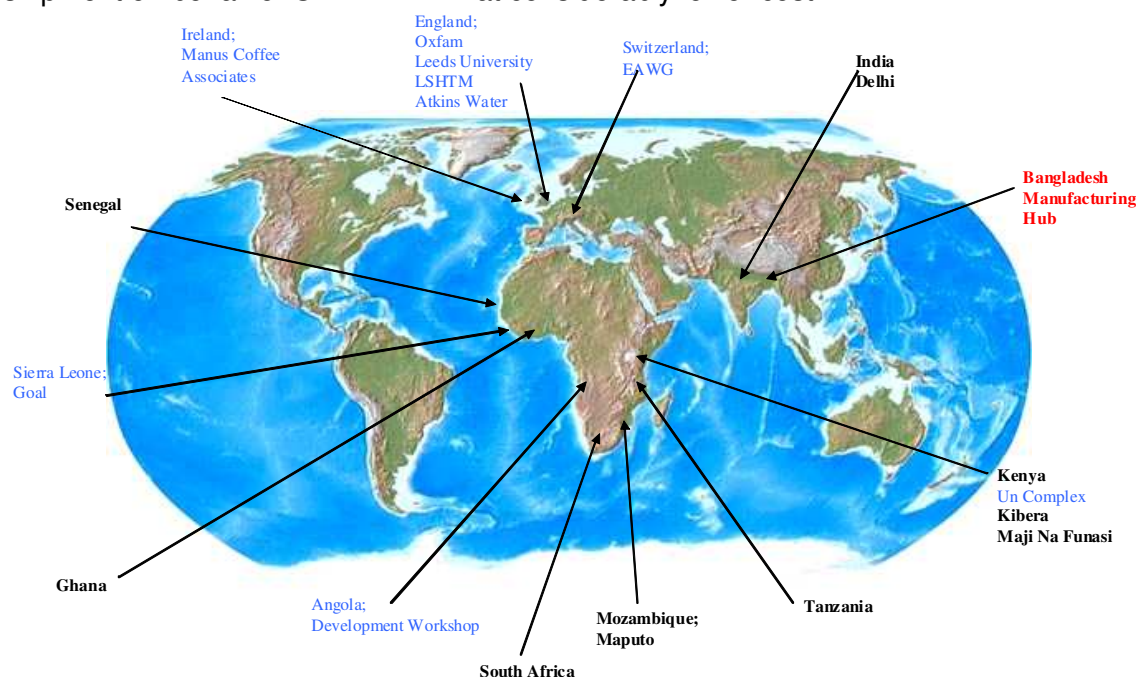


Figure 18 showing the sites of activity for the Vacutug field trials (2)

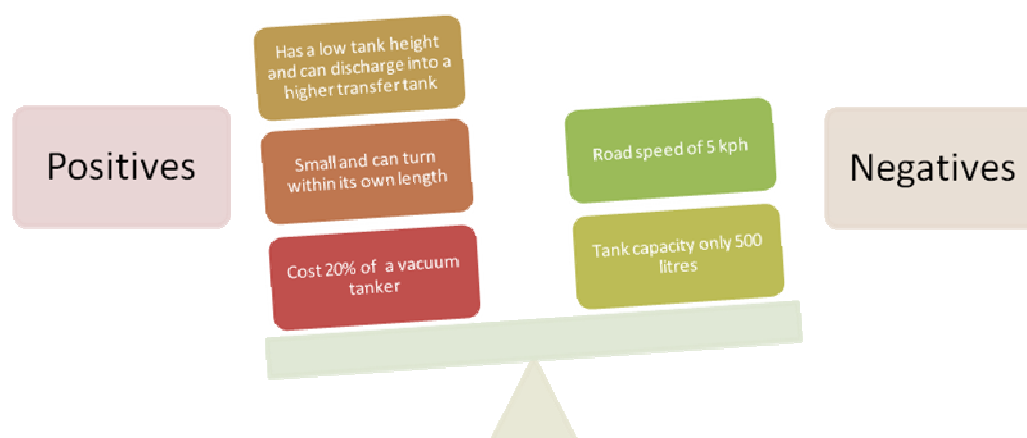
Based on the experiences at MAWTS UN-HABITAT were able to establish a minimum checklist for evaluating potential manufacturing outlets when up-scaling the project in the future. This list is shown below.

Minimum Machinery Requirements	Components required (can be procured or imported)
<ul style="list-style-type: none"> • Sheet metal shearing machine • Bending machine • Punch and notching machine • Rolling machine • Pipe Bender • Arc Welder • Lathe Machine • Milling Machine • Drill Machine • Plasma Cutter • Grinding machine • Painting and electro plating • General workshop tools 	<ul style="list-style-type: none"> • Vacuum pumps • Engine • Wheels, tyres and axles • Quick couplers • Ball valves • Safety valves (pressure and vacuum) • Float ball, sight glass and gauges • Hoses, cables, controls and rubber dumpers • Fasteners and other elements

The issue of up-scaling and distributed manufacturing sites for the Vacutug was discussed at the February visit to Nairobi (see section 7.1 for minutes of the meeting) and it seems clear that UN-HABITAT will probably move forward with production in countries other than Bangladesh when funding becomes available.

2.3.4.4 UN-HABITAT conclusions from their field trials

An overview of the feedback that was given by the charities and organizations that received a Mark II Vacutug is included in the appendices (see section 7.2) and is drawn on at several points in this report. The figure below shows the positives and negatives of the Vacutug outlined by UN-HABITAT.



The Vacutug by itself is therefore a short haul vehicle but can operate with a larger 'mother' vehicle for longer distances. Based on the feedback received by UN-HABITAT suggestions were made for continuing work on the project.

- **A transfer system.** There are a number of options available for sludge transport, including combinations of tractors and trailers, trucks and fixed transfer points. For most situations a tractor with two transfer trailers would be the most cost effective system, as one trailer can be hauled and emptied while the Vacutug is filling the other. A 4000 liter tank would carry eight Vacutug loads and can be pulled by a 40 – 50 hp tractor. The tractor could be hired in for a daily or twice daily collection or a single tractor can service two or more Vacutugs. A very simple improvement to this system is proposed where the trailer tank is fitted with a trap system and connection for the Vacutug's vacuum pipe. In this way the Vacutug can create a vacuum in the trailer tanks meaning they can be filled directly. The trailer tank could also have an additional trailer with which it can move the Vacutug at the start and end of the day.
- **Transfer stations.** In terms of the daily operation of the machine the feedback indicated that the actual time spend sucking the wastes from the pit is short, typically not more than 5 minutes. Where there is a short haulage distance it is quite possible to achieve 20 or so loads per day. However where there are long and difficult haulage distances the slow speed of the Vacutug limits collection rates down to only two or three loads per day. It is therefore critical to establish a low cost transfer station so that the Vacutug can reduce time spent hauling.
- **Local manufacturing and servicing of Vacutugs.** Partners in Kenya, Mozambique, Tanzania and Senegal were quick to make design modifications to the machines straight from the engineering drawings. This demonstrated potential for local manufacturing of the machines.

As a result of the field trials and suggestions from partners, the following design modifications will be made on new models:

1. Sight glasses – a single sight glass made of 5mm thick plastic locally available will be used and moved to the front of the machine so that it is less liable to damage if the machine tips over.
2. Throttle – a more robust and durable throttle will be specified
3. Cut-off on engine – replace with a tougher one in future
4. Machine dimensions
 - Increase the tank diameter from 960 mm to 1100 mm
 - Reduce the tank height from 925mm to 750mm
 - Reduce the wheel diameter and tyre size from 155-15 to 155-14

The effect of the above changes will reduce the height of the centre of gravity for the machine by 15%. This combined with a slight increase of wheel base will make the machine more stable. Some further possible modifications are:

1. To increase the capacity of the tank to 3000 litres or more
2. To include a provision to increase the speed of the system for motoring on main roads
3. To include a seat for the operator

A further report was produced in 2008 (9) as an update on activities with the Vacutug. The conclusions were similar to the 2006 report, with additional points summarized as:

- The technical design needs some improvement in areas such as sight glass (a flat glass to avoid damage), size and height of tank for proper balancing, tyre size etc.
- Design of latrine pit to promote mechanized exhaustion and
- Hygiene promotion for the operators and public.

- Design a transfer system for areas that are far from sewerage line as in the case of South Africa, Tanzania and Senegal
- UN-HABITAT to include a start up fund as a package with the donation to help the local communities involved to meet initial but necessary costs like insurance etc.
- Establish regional production centers to enhance machine production, ensure spares are available locally and to reduce shipment costs.

The main result from this report was a change of focus for the UN-HABITAT team from machine design to latrine design. Courtesy of Manus Coffey and Associates, trials of various vacuum based machines showed that:

- Latrine wastes of up to one year old are generally easy to evacuate
- Between one year and two years thickening takes place and the waste become progressively more and more difficult to exhaust as it dries and binds together
- After two years latrine wastes are very difficult to suck by conventional methods.
- The density of waste in pits extends through the depth of the pit. Attempts to add water and stir the wastes do not prove successful as the water simply floats on top of the denser sludge at the bottom
- There is a tendency when emptying pits for operators of vacuum tankers to take only the low density wastes which are easy to suck from the top of the pits, leaving the denser wastes at the bottom. This results in a progressive build up of unsuckable dense sludge at the bottom of the pits. Thus large deep pits become small shallow ones over a period of time.
- When constructing pits there is a tendency for the household to construct deep pits which will last for many years without emptying. However when paying for emptying service they will tend to minimise their costs by only paying for a small amount of waste to be removed. Inevitably this results in the low density wastes (which are easy to suck) being removed leaving the rest.
- Deep unlined or poorly lined pits in unstable soils are liable to collapsing if they are emptied by more than 1m.
- In older pits it is very difficult to get the suction hose to penetrate the bottom of the pit. Thus a regular two year latrine emptying regime using a built in suction pipe in the latrine will be much more effective.

These points identified very clearly that in situations where mechanized pit emptying was to be used for single household pits:

- There was a need for smaller capacity pits typically holding two years waste from that particular household.
- There was a need for an effective method of fluidizing the wastes at the bottom of the pits
- There was a need for a method of ensuring that the dense sludge from the bottom of the pits was removed first rather than the water from the top.

This has led to a focus on re-design of pit latrines, which are built with a suction hose pre-installed (see Figures 19, 20 and 21 below). The Vacutug can then hitch in to suck waste out from the base of the latrine. Water can also be pumped in to loosen the waste. Contact details for the team currently working with UN-HABITAT on this second phase of the project are included in the appendices (see section 7.1).



Figure 19 Even when water is added to the sludge it does not mix well with the dense sludge at the bottom, the waste remains too thick to suck. (1)

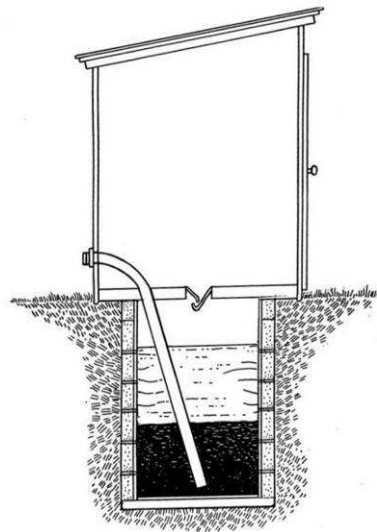


Figure 20 showing the integrated suction hose proposed by UN-HABITAT. (1)

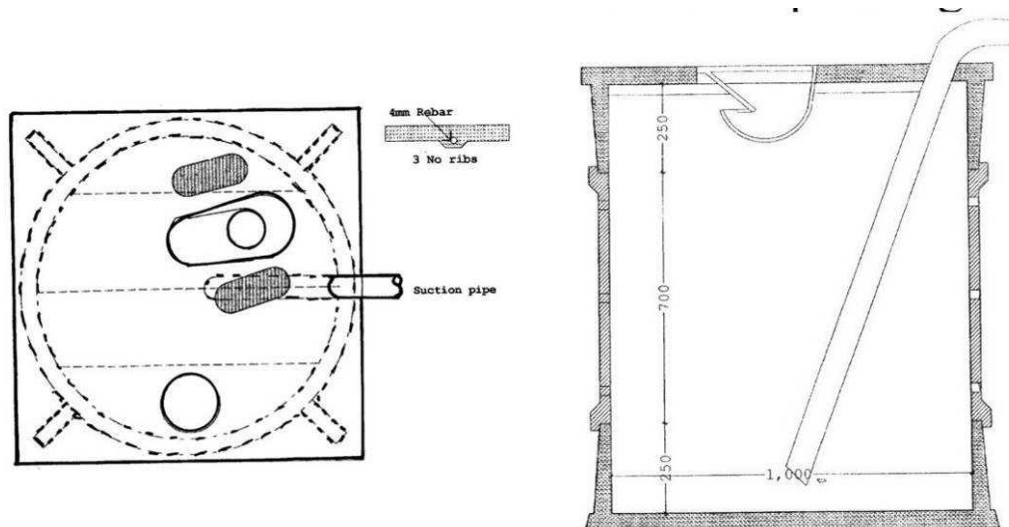


Figure 21 Top view, side view UN-HABITAT proposed pre-cast concrete pit design (1)

The expected benefits of the UN-HABITAT's proposed latrine system are:

- More hygienic for both householders and operators compared to placing the suction hose through the pit seat
- Pits won't silt up progressively over emptying cycles as they will be consistently emptied to a fixed level (the base of the integrated hose)
- Toilet areas are not fouled during emptying
- Lengthy clean-up times for hoses and toilets are reduced to a minimum
- Pits are designed for mechanized emptying
- Simple system for fluidizing dense waste through pump in air and water through suction hose
- Suitable for shallow soil areas and unstable soils
- Suitable for high water table and flood areas
- Low manufacturing costs
- Low installation costs

The largest emptying contractor in Accra (Larsen Ghana) initiated a pilot trial of replacing their pan latrines with fibre glass boxes (2). These boxes were fitted with a connection that allows dung beetles (or other vacuum tankers) to directly couple in and empty the storage boxes. This proved to be a successful and low cost method of retrofitting the UN-HABITAT modification to pit latrines. A field visit to Ghana is planned for June 2009, and this system will be inspected while there.

2.3.4.5 Conclusions from UN-HABITAT field trials of the Vacutug

There are points of interest and importance that were highlighted through the Partner feedback reports (summarized in the appendices, see section 7.2). These are:

- Payment of pit latrine exhausters seems most effective when completed on a task based pay system.
- Vacutug test areas in Mozambique and Tanzania have both experienced Cholera outbreaks making the effective management of sludge in these areas essential to mitigate further risks of outbreaks.
- Wherever possible discharging waste into a local sewer line saves time and money as carting costs are significantly reduced. However discharging of concentrated pit latrine sludge is not always permitted or is at least difficult to negotiate with local authorities. An option is to discharge only the liquid portion of the latrine waste into the main sewer, after which the solid and sludge wastes can be carted to disposal sites, which reduces the carting burden. This could be effectively facilitated through transfer stations with small bore solids-free sewers.

The original design criteria used for development of the Vacutug have not yet been fully achieved, as is detailed below:

1. The system should have access to high-density settlements and be maneuverable ***Achieved in part. With the back axle adjusted to its widest setting and with an experienced operator the machine can access most areas. However the lack of a reverse setting and the high total weight once full does limit the Vacutug's ability to get back out of these places. It is not uncommon for the operator's to roll the machine when attempting to negotiate uneven terrain, and the tug cannot power itself up steep slopes.***
2. The capital cost of the technology should be affordable to small-scale entrepreneurs. **Although the Vacutug is cheaper than a larger tanker, at**

approximately 8000 USD including shipping it is still not particularly affordable.

3. The machine should be designed for local manufacture, operation and maintenance. ***Complaints have been seen about problems with spare parts. All machines were air freighted to partners except one machine which was produced using locally available parts.***
4. Operating costs of the service should be covered by revenue generated. ***This is possible.***
5. The system should be capable of transporting the waste to an appropriate disposal point ***Achieved but at slow speed (max 5 kph) and it cannot travel on open roads without obstructing traffic.***
6. The system should be able to evacuate compacted sludge from latrines. ***Not achieved. The Vacutug struggles as does any vacuum based system with the suction of compacted or dried sludge.***

The table below gives a matrix of the issues and the frequency of mentioning. Ghana is not included as the Vacutug deployment was unsuccessful in that country.

	Time to Empty	Speed of Machine (5 km/hr)	500 ltr volume of tank	Maneuverability	Competition	Sewage quality	Discharge	Individual notes
England			Tank is too small	Machine lacks reverse				A modified 1.9m ³ machine has been made
India	People like to get their latrines emptied in the minimum of time, the multiple Vacutug trips slowed exhaustion	Transport distances of between 8-10km were not uncommon	Taking up to 10 trips to empty typical septic tanks	Very hard to move on uneven alley ways especially when full.	Competition with larger 6000 liter exhausters was detrimental to the Vacutug as they were much faster		Discharge into local sewage treatment plant, then change to Biomass reactors.	Vacutug often cause traffic disruptions on the main road.
Kenya		The slow speed meant local man hole access to the sewer main had to be used but this upset the community.		Major problems machine unable to adapt to conditions in Kibera. Vacutug often tipped over.	Manual exhaustion is cheaper, as the Vacutug needs more trips	Waste often broke or damaged suction hoses	Main sewer line; conflict sometimes seen as blockage and overflowing was common	Marketing of the Vacutug service was required to stimulate demand, spare parts very expensive
Mozambique	The Vacutug was fast to fill but slow at transporting	An alternative system, the Maquineta, had to be developed that was faster at carting				Quality of waste often blocked suction hoses	A 15000 liter transfer station was used which was then emptied by municipality tankers.	A credit scheme was implemented for customers. Since the Vacutug has emptied pits its demand has gone down
South Africa		The machine had to be transported on a trailer with a large vehicle between villages at considerable extra cost				The waste is often too hard to suck		A 3.5hp trash pump was successfully used as an alternative to the Vacutug
Tanzania	4 latrines could be emptied per day			Machine was tipped over causing Tsh 35000 of damage			Tough to get consent to discharge into the local sewer line	Challenges in getting a road license for the vehicle
Senegal				Maneuverability in the settlements and sand is hard as the traction on the machine is poor				O&M manual was in English this lead to MAJOR issues with operating this complex machine. More machines have however been ordered.

Table 2 Showing the issues encountered in the various Vacutug trials

This gives an indication that the issues in order of greatest significance for a latrine exhaustion method are:

1. Maneuverability
2. Simple discharge and fast transfer (carting) method
3. Fast emptying time and able to deal with variations in sewage characteristics
4. Large volume and resilience to competition (i.e. low capital and running costs)

The Senegal partner highlighted that in future Vacutug projects it will be important to translate the manual into French and Portuguese and Spanish. The partner spent a lot of time testing the machine and trying to understand it. Some mechanical and operational misunderstandings could have been avoided had the manual been translated. These included but were not limited to:

- Use of the spare drive belt supplied with the machine being used to drive the drive wheel while the pump is engaged.
- Operation of the vacuum pump for long periods whilst not sucking will lead to vane and oil seal failure (which occurred as it was run whilst driving the machine – see point above) which ultimately destroys the pump.
- The importance of daily and monthly maintenance was lacking and yet is clearly indicated in the manual
- A difficulty reported in the operation of the machine is that its maneuverability in the settlements and on sand is difficult as the drive traction is not very good.

Finally in May 2006 there was a joint field visit by MCA and MAWTS and UN-HABITAT, which sorted out some of the technical and operational issues. Indirectly this highlights that the Vacutug is more complex to use than was perhaps initially thought and it was not until after a visit and practical training that most partner could effectively operate the machine. It is thought that the frequent reports of the Vacutug tipping over could be due to partners operating the Vacutug with the back axles retracted. This important feature of the Vacutug is certainly not obvious. A similar issue has been highlighted with the belt tensioner which is designed to be used as a clutch.

It is therefore suggested that a fifth point is added to the list above that an effective pit exhaustion system should be as intuitive to use as it is practical. Apart from an effective O&M manual being important, it would be particularly helpful if the critical controls, of which the Vacutug has 17, were all labelled.

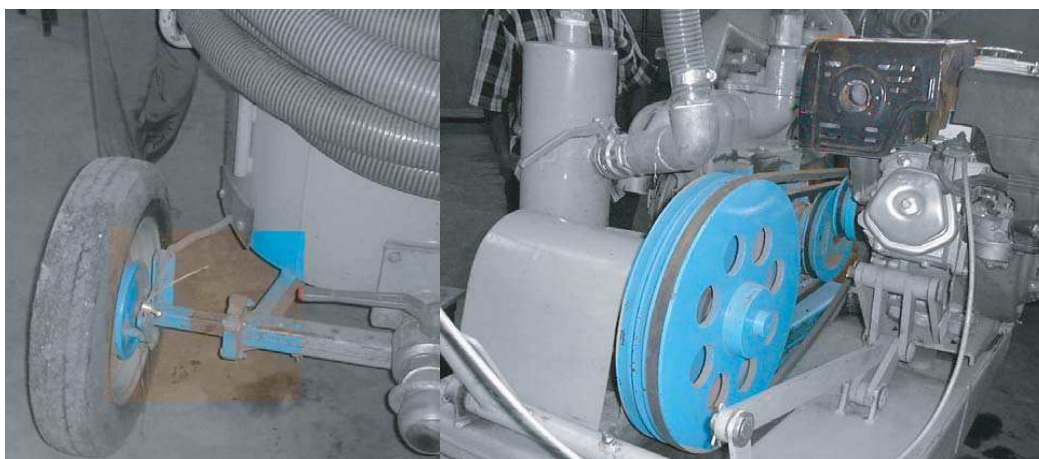


Figure 22 Showing features of the Vacutug which need to be explained to a new operator: the extendable back axles that improve the stability of the machine and the belt drive arrangement that can be used as a rudimentary clutch (8)

2.3.4.6 Ideas for modifications to Vacutug

The following suggestions are made as possible modifications that could be made to a Vacutug to enhance its performance, or tested to see how they affect its performance:

1. Test a reducing nozzle fitted to the end of the 3" suction hose to reduce the inlet from 3" to 1". This will significantly increase the suction velocity and may enable the Vacutug to suck drier waste.
2. Test the use of an electric powered macerator/flicker fitted at the end of suction hose to encourage dry waste to move into and up the suction hose.
3. Fit a cage over the end of the suction hose to permit suction of sewage waste while keeping out domestic solid waste.
4. Fit an aerating hose to the end of the suction hose so that it can be driven into dry waste fluidizing it for easier extraction.
5. Establish a comparison between the Vacutug's ability to suck over certain distances and pump over others. How does the machine perform in swift suck-pump cycles?
6. Try decoupling the Vacutug from its chassis and drive system and mount the engine and tank on an ordinary trailer which can be hauled by any suitable available vehicle (e.g. a 4x4 pick up truck, see section 3.3.3). This will drastically improve carting speed and accessibility. However it does require access to a relatively expensive vehicle and a competent driver.
7. Try adapting the Vacutug to take a 2 wheel tractor for the drive replacing the current inefficient and ineffective drive mechanism.

2.3.4.7 Testing the Vacutug in South Africa

In 2004 UN-HABITAT supplied a Vacutug to the Mvula Trust as part of its international field test exercise. This was used by the Trust to empty pits in Vanwyksvlei in the Northern Cape and then in Nedell and Bakerville in the North West province. The Trust reported that while the Vacutug worked well, moving the machine from site to site was difficult and they resorted to pulling it around on a

trailer. Once these trials were completed the machine remained in Bakerville and was no longer used.

The Mvula Trust has now transferred the Vacutug to PiD for further testing. At the time of collection it had been standing unused for several years. The first task was getting the machine running. Small items like a new belt drive and suction hoses had to be purchased. Thereafter PiD had to work out how the Vacutug functioned without the benefit of the O&M manual, as none was supplied when the Vacutug was collected from its resting place in Bakerville. After some work and with the help of an experienced vacuum tanker operator (Lindsay Sharp of Aquatec) the basic functions were mastered, but PiD was still lacking in understanding of all aspects of the machine.

It was only when visiting the UN-HABITAT headquarters in Nairobi that PiD acquired the O&M manual for the machine. The manual highlighted some important features of the machine which were of assistance with operating it but which were not immediately obvious, including the following:

1. The manner in which belt drive could be used as a rudimentary clutch
2. The adjustment to the back axle which improves the stability of the machine
3. The system for the locking of the roller drive wheel onto the driving tyres. When this is combined with the use of the belt drive as a clutch, then driving and maneuvering the Vacutug became a lot easier and the slopes that the machine had been struggling with previously could now be climbed. The machine still struggles on very steep or loose ground.

Once running the machine was moved to Slangspruit, which is in Edendale, Pietermaritzburg. Originally it was hoped that the Vacutug could be loaded onto the bed of a pick-up truck for this move. This however proved impractical (the machine weighs a ton empty so loading is no simple matter) and a tipper trailer had to be hired for the purpose. The images below show the transportation of the machine.



Figure 23 a) A comparison between the size of the Vacutug and a 1 ton bakkie b) The Vacutug being loaded onto a trailer c) The Vacutug on the trailer and d) The Vacutug could not power itself over this small earth ridge.

Now that the machine is on site it is being tested on the 1 m³ septic tanks which are standard in that area. The roads in the area are mostly tarred and though hilly in parts the Vacutug should be able to access most areas.

From PID's still limited experience with the Vacutug the following recommendations are made:

- **Addition of deadman's handle:** A deadman's handle is a handle that has to be held for the machine to work. If it is released the machine stops automatically. This would make the Vacutug much safer to operate.
- **Modify the drive system** so that it is capable of reverse.
- **Label.** Some design features are a little cryptic on the machine, perhaps these could be labeled, for example:
 - The locking of the drive arm to give 'non slipping' drive
 - The extendable back/rear axle feature which is not immediately obvious (if highlighted this might possibly reduce the number of operators who manage to tip over their Vacutugs).
 - Labeling of the belt tensioner as a clutch so operators know to use it as a clutch.
- **Engine Mounting.** The use of belt tensioned as a low cost clutch is effective, but hinging the whole engine seems a little unnecessary - perhaps just a

tensioning idler wheel could be as effective and mean the engine mounting is more stable.

These suggestions were communicated to the Vacutug designer, Manus Coffey, and the following responses were obtained:

- **Addition of deadmans handle.** *"The "twistgrip" throttle should revert to tickover if it is released, however the twistgrips supplied by the Bangladeshi manufacturer were not very good. I would like to have included a centrifugal clutch instead of the "slipping belt" clutch arrangement and this, together with a spring loaded twistgrip, would give the dead mans handle effect."*
- **Modify the drive system** *This would add quite a lot to the cost and the complexity of the machine. As the tug unit can be rotated to face almost backwards we did not consider a reverse gear essential, however it would be a useful additional feature. Do you have any bright idea as to how to accomplish this whilst maintaining the concept of only using low cost parts which are readily available in the less developed countries. It would also be nice to have two forward speeds but again this would add to the cost.*
- **Labelling.** *Yes this should be improved. It needs to be graphic rather than in words as many of the operators will not be able to read and may speak different languages.*
- **Engine Mounting.** *This would be quite feasible, however it would require more space between the engine and the countershaft pulley to allow for the tensioner pulley. Again this could be overcome by using a centrifugal clutch.*

A final point made by Manus Coffey: *I have considered using the whole transmission system (perhaps including the diesel engine) from one of the very low cost, and extremely robust, Chinese two wheeled tractors. The problem here is that it introduces a more complex supply problem for local manufacturers in developing countries and the need to ensure spare parts availability. However as they already have to import the vacuum pumps this may be an acceptable solution.*

A possible solution to enable the Vacutug to drive both forward and backward is illustrated below. This would drastically improve the Vacutug's maneuverability. PiD and the Vacutug designer are now in an active dialogue about this design modification. The solution is briefly outlined schematically below.

The current drive system uses a drive roller to drive the front wheels in a friction based system. The drive roller is brought to engage with the tyres by pushing the engagement arm into its locked position. This forces the drive roller to rub on the front wheels driving them forward.

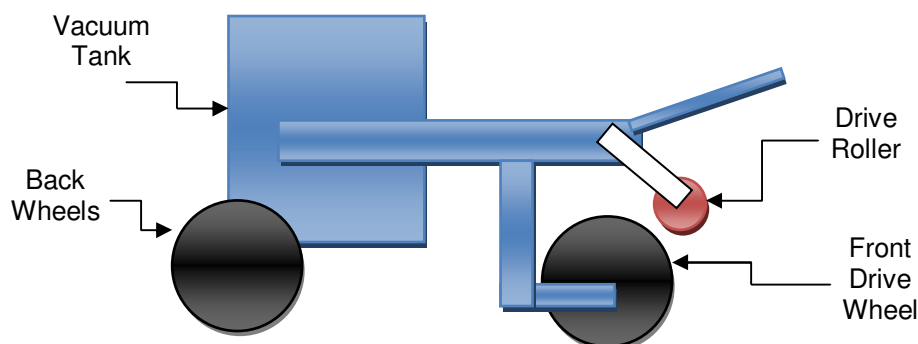


Figure 24 showing some parts of the Vacutug

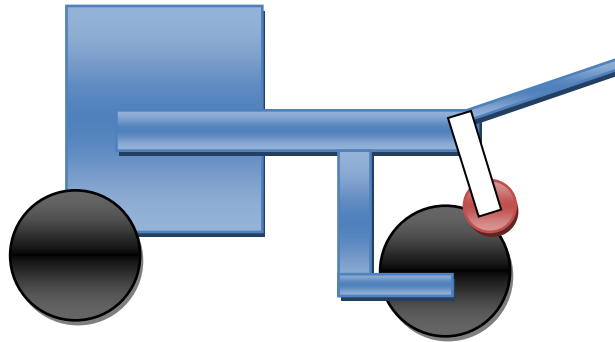


Figure 25 showing the Vacutug with the drive wheel engaged

As a modification to the current system it is proposed that a second drive roller that is geared so it rotates in the opposite direction to the first roller be added. This could simply and reliably be achieved using only a few spur gears, some additional steel and another drive roller. The machine would be driven forward as per the original system. To reverse the second roller would be brought to engage with the drive wheels, turning them in the opposite direction.

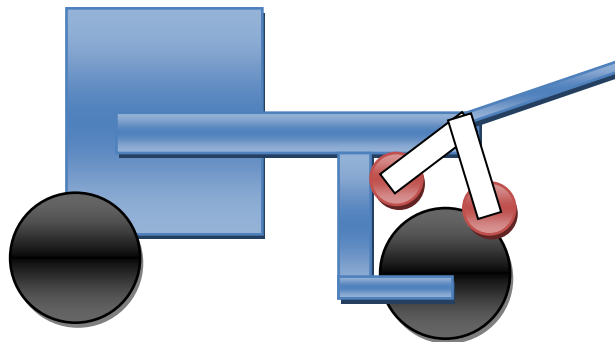


Figure 26 showing the modified system driving forward

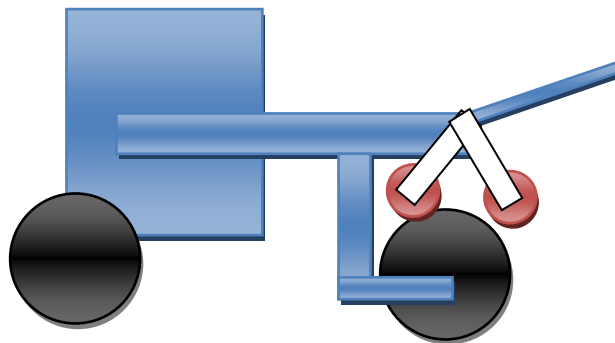


Figure 27 the modified system in reverse with the reverse roller engaged.

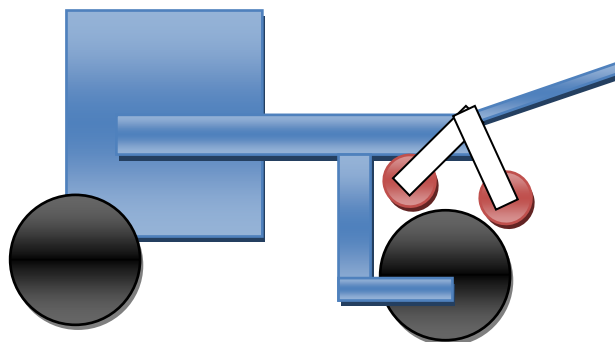


Figure 28 the modified system in the neutral position with no drive roller engaged. The Vacutug can be simply pushed around.

2.3.5 Conclusions drawn on vacuum based approaches

Four variants of vacuum based exhausters have been discussed above: the Vacuum tanker, the Micravac, the Dung Beetle and the Vacutug. Highlighting the challenges with vacuum based exhaustion is important as it is the most widely used mechanized system of exhaustion. The performance of any latrine evacuator using vacuum is affected by the height of the water in the tank above the ground, the length and inside surface of the suction hoses, the depth of the waste in the pit and the density and viscosity of the waste. A suction system has advantages compared to other systems (such as archimedian spirals, bucket systems and piston pumps) when the following constraints on pit latrine emptying are considered:

- a. With the mixed and variable object size, moisture content and abrasiveness of pit contents a vacuum system works better than a system which requires sludge to pass through the pump mechanism.
- b. With difficult access, both to the housing plot and to pit contents, a vacuum system can have an advantage in that the main tank and power source can be up to 50 metres away.
- c. A vacuum system (as long as the pipes remain unblocked) means that the operating crew and the general public are not exposed to contact with raw sewage.
- d. A vacuum system (as long as the pipes remain unblocked) overcomes social nuisances associated with pit emptying such as odor and fly nuisance.

Common problems and challenges with vacuum tankers are the following:

1. There must be vehicle access to at least 50 metres (preferably 30 metres) from the site
2. The vacuum tanker must be able to park not more than two metres above the site to be emptied (see Figure 24 below).
3. Commonly these machines have poor access capabilities, and are often unable to reach slum settlements. In some instances holes have to be made in house walls to pass suction hoses the shortest distance to storage tanks (11).
4. High capital costs.
5. High operation and maintenance costs.
6. Lack of spare parts especially for the vacuum pump which is nominally an imported part.
7. Difficulty manoeuvring requiring a large strong base vehicle.
8. Variability of faecal sludge (FS) viscosity which influences performance and makes pricing difficult

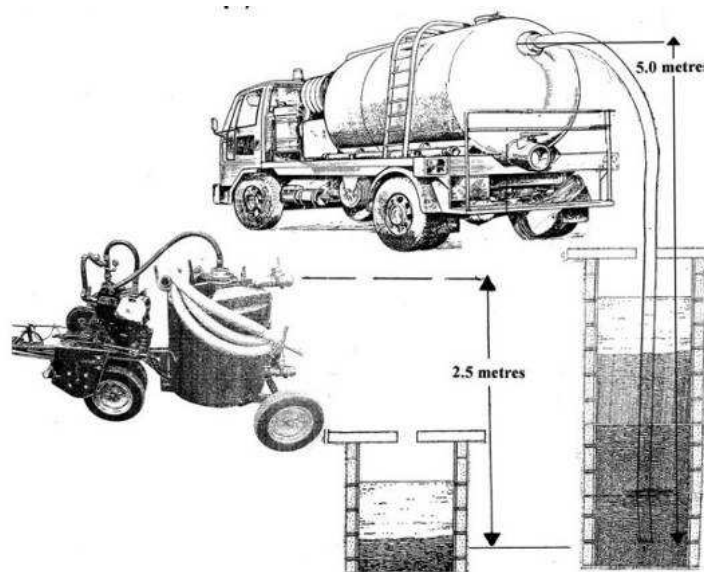


Figure 29 Showing the operating suction head of a vacuum tanker and the Vacutug machine. (1)

2.3.6 The Maqunieta Maputo

At the beginning of the field trials of the Vacutug in Maputo it became clear that due to the high demand for emptying and the long haul distances between latrines and disposal sites a superior transfer option would be needed. In response to this need, Medecins Sans Frontieres (MSF, the Vacutug Project Partner in Mozambique) designed the Maquineta; a 1.5m³ transfer tank pulled by a 2-wheeled tractor, which accompanied the Vacutug and would either service latrines directly (using a small suction pump) or be used as a mini transfer point.



Figure 30 the Maquineta in use in Maputo (4)

The exhausted sludge would then be transported to the 15000 liter transfer tank in the Associacao de Desentralisamento de Agua & Saneamento d Bairro de Urbanizacao (ASASBU) yard. From there the sludge is hauled another 5 km to the treatment works by one of the municipality's vacuum tankers. If there is a bulk sewer close to the work site then the transfer tank is skipped and the waste is emptied straight into the sewer line instead of carting to the ASASBU yard. The images below show the various transfer options that were available in the staged system developed by MSF which proved quite resilient to variation.



Or



Or



In December 2003 through to January 2004 work stopped as ASASBU/MSF were unable to get authorization to discharge into the sewer and were relying on municipal trucks to empty their storage tank. These trucks are not reliable and could take up to 2 weeks to service the main 15000 liter transfer tank. This delayed work.

The introduction of these varied options made it difficult for the operators to choose in which situation to operate the Vacutug or Maquineta tractor. The Vacutug was much more powerful and capable of sucking heavier contents but the Maquineta was faster in transit and it seems that for this reason the Maquineta became the preferred exhausting machine.

Observations from the field were as follows:

1. The transfer tank cannot always be emptied by the municipal trucks. This has been a major obstacle since the service provided by the latter was not reliable and the Vacutug could not operate whilst the temporary storage tank was full.
2. Compared to the Maquineta the Vacutug had higher labour costs but lower operational costs.
3. The Vacutug is better at emptying latrines but the Maquineta is faster over land, therefore the Maquineta is more frequently used (where access is possible).

This trial highlighted two successful FSM systems:

1. The use of a low cost carting machine (the Maquineta) when combined with the Vacutug can produce a successful FSM program.
2. When this is further integrated with a transfer station a FSM program with good flexibility is produced. However reliance on the municipal tankers was still a limiting factor. Discharging into the sewer main was also used as a disposal option.

2.3.7 Solid Liquid separators

Solid Liquid Separators (SLS) are a high tech solution to FSM. Suction is still used to extract waste from the storage tank, however it then undergoes solid liquid separation. This then gives a very useful tool in FSM as concentrated sludge cannot be discharged straight into a main sewer line, and carting of large volumes of liquid is a lot of work, slow and puts a burden on carting methods. A compromise can be found (where appropriate infrastructure is available) to discharge all liquid content into a sewer and then cart only the remaining solid content. This significantly reduces carting costs as less trips have to be made and the mass of the transported loads is lower. If a SLS could be integrated into a transfer station with a small bore solid-free sewer connection then a highly optimized FSM program could be produced.

There is some potential here for development of a low cost technology which can achieve this solid liquid separation. However this would require considerable research and development.



Figure 31 A fluid separation machine (FSM) for more efficient service and cost savings.
(7)

2.3.8 Diaphragm pumps

Diaphragm pumps can be used to extract the more liquid sludge from storage tanks. The limiting factor for this method is that the waste passes through the pump and

inevitably blocks the pump, making frequent maintenance necessary. The South African Vacutug project partner tested the use of diaphragm pumps and reported as follows:

In 1996 VIP toilets were built at Nedell and Bakerville, and by 2003 these latrines were full. Emptying the pits became the responsibility of the Mvula Trust and was attempted using a 3.5hp diaphragm pump but this failed because domestic waste was present in the pits and this would then block the pump, as the wastes have to pass through the pump.

The objective of the project was to empty 500 VIPs and to educate the community about the proper maintenance of the latrines. 25 VIPs would be emptied using the Vacutug. One operator, one assistant and one laborer for the backfilling of pits were hired, along with three educators to raise awareness and to ensure that the households prepared their VIPs. The logistics of moving the Vacutug between villages and latrines were far too complicated; often a trailer and a heavy vehicle had to be used which required another operator. This did not compare favorably with the diaphragm pump which only required a car and one day of training an operator. The main conclusions of the project in regard to the Vacutug were:

- The waste is often too hard to suck
- The logistics of moving the Vacutug between villages are complicated where as the alternative diaphragm pump can transported more easily.

With regard to the diaphragm pump it was seen that:

- The pump could effectively exhaust the pits
- It compared favorably with the Vacutug as only a small vehicle was required and one day of training for the operator
- It was limited by the fact that the pump often blocked and broke.

2.4 Conclusions drawn from this chapter

This section highlights the main conclusions that can be drawn from the analysis of available excreta exhaustions methods.

Firstly it is highlighted that Manual Exhaustion is far from ideal and should be used only where partially or fully mechanised systems are either not available or unaffordable. However, in terms of costs and simplicity, it is a system that works. The development of a semi manual system that reduces direct contact of waste with labourers would have considerable benefits. The development of appropriate aids to manual emptying (e.g. the Nibbler and the Gobbler) is therefore well worth pursuing.

For situations where new latrines are being built and vacuum based exhaustion is to be used, the integration of a suction hose seems to have significant benefits for exhaustion and can be achieved at a minimal additional cost. For existing latrines a FSM system needs to be developed. Research on the Vacutug programme gave an indication that the issues in order of greatest significance for a latrine exhaustion method are:

1. Maneuverability
2. Simple Discharge and fast transfer (carting) method
3. Fast emptying time and ability to handle variations in sewage moisture and density
4. Large volume

5. Cost effectiveness (i.e. low capital and running costs)
6. Simple and robust in operation

A compact, light weight, easily transportable and low cost system therefore seems to have the most potential. The MAPET and diaphragm systems discussed earlier (in sections 2.2.1 and 2.3.8) do have these qualities. However they are not appropriate to all situations. The MAPET system has the advantage over the diaphragm pump in that the waste does not pass through the pump.

Effective management of the waste and its carting is critical. Solids-Liquids Separators have been seen to be an effective but high tech solution that has potential for development, and if integrated with a small bore solid-free sewer line, or transfer station could result in a highly appropriate solution. This principle is discussed in more depth later in this report.

3 Transferring of Excreta to a place of disposal

This section of the report focuses on the challenge of how to move the waste once it is out of the latrine. Some exhaustion systems are integrated with a carting system as they are mounted on a vehicle (vacuum tanker) or have their own integrated drive (Vacutug or Dung Beetle). But this is not always an effective solution and there are more appropriate solutions for carting the extracted waste.

3.1 Integrated carting

Often a mechanized exhaustion system is integrated with a transportation system, for example it is mounted onto a transporting vehicle i.e. a vacuum tanker, or uses a specially developed drive system as with the Vacutug and Dung Beetle machines.

This seems like an obvious solution to carting needs, but it limits extraction efficiency in that the extraction and carting cannot happen simultaneously. Separating extraction and carting into distinct systems has its benefits in that exhaustion into one tank can take place whilst another tank is being transported to the disposal site. Additionally for the Dung Beetle and the Vacutug the integration of the drive system has sacrificed speed as though they are self propelled they are slow compared to trucks and tankers.

As countries develop road laws will become more stringent. The Senegal partner on the Vacutug project experienced problems with getting consent to use the Vacutug on the roads. Other partners did not mention this problem but it is likely that in time vehicles like the Vacutug and Dung Beetle may have to pass road worthy tests and assessments, which would add to their costs quite significantly.

Finally the existence of an effective servicing and spare parts chain needs to be available for the carting system being used. Spare parts for the Dung Beetle and Vacutug drive mechanisms would be hard to source in most countries. For these reasons it is felt that use of either distinct carting systems or a locally available pick up truck would be most suitable as it will tie into existing spare parts systems, be legal on the road and can be used to drop the exhauster at the site and then transport the waste away. Options for distinct carting systems are now discussed.

3.2 Manual Carting

At its simplest a cartage system would use people carrying containers of waste filled directly at the latrines. Acceptance of manual carrying of waste varies from country to country. In South Africa it seems labor is happy to carry drums of sewage waste so long as they receive adequate remuneration for their work. In Kenya, however, there is a major stigma associated with the movement and handling of this waste and so often it is necessary to work under the cover of darkness as people do not want to witness this work being completed (this is described further in section 7.2.3).

The next stage could be the push or animal drawn cart (an illustration of a push cart is shown below), and beyond these systems motorized cartage would have to be used to transport waste over longer distances.



Figure 32 In poorer countries large loads are commonly moved using manual carts.

3.3 Mechanised Carting

Where long haul is required mechanized carting has to be used. Some examples of mechanized carting are discussed in this section.

3.3.1 The UN-HABITAT 2 wheel tractor

UN-HABITAT are running an SWM project in conjunction with their Vacutug program. This project has researched ways of transporting solid waste out of urban settlements. The aim was to produce an inexpensive machine able to access these areas. The picture below shows the prototype. The drive is achieved using a low cost Chinese Tiller (2 wheeled tractor) which is attached to a back axle supporting a load bed (see section 7.1.1). This is a low cost product manufactured and marketed by Ndume Limited in Gilgil, Kenya.



Figure 33 The UN-Habitat 2 wheel tractor solid waste transporter (10)

3.3.2 The trike

Steve Sugden (4) has been developing a low cost manual option for pit exhaustion for Dar es Salaam settlements. An effective transport vehicle that has been constructed for use in trials of this low cost pump is shown below. It shows a locally procured motor-trike which has been modified to carry the latrine exhaustor (a Gulper) and the bins for carting the waste. The vehicle was sized to carry the waste from one typical latrine pit. This FWM system represents a Manual extraction, Manual carting and finally Mechanized haulage combination.

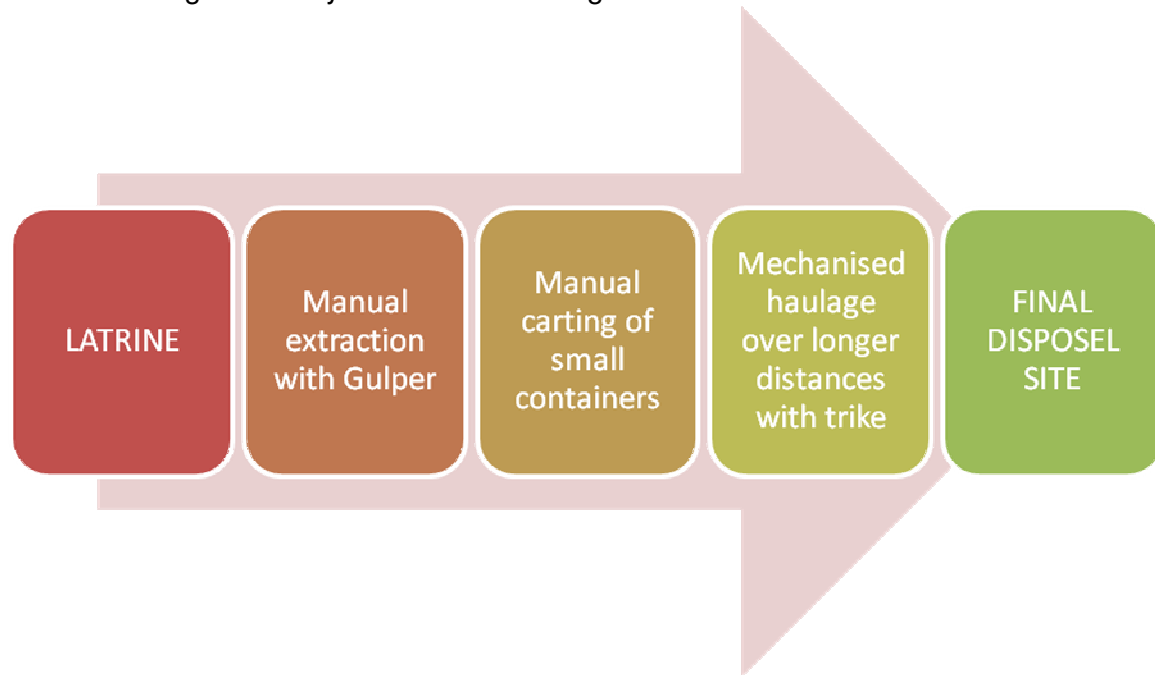


Figure 34 the trike in use in Dar Es Salem (4)

3.3.3 The modular machine

The image below shows a system developed for a multi-utility service provider of water, solid waste, and faecal sludge management.



Figure 35 showing one truck which is used for refuse collection, water delivery, and vacuuming (7)

This approach was developed out of the similarities in solid waste and faecal sludge management services:

- SW: collection, transport, treatment, disposal/recycling
- FS: emptying, transport, treatment, disposal/reuse
- Similarities in equipment and institutional accountability
- Possibility of co-treatment (co-composting)

As the demand for these services is not continual (latrines only need to be emptied when they are full) a single vehicle can be used to provide a range of services. In this case the three services of FS emptying, transportation of SW and carting of water were coupled into a single multi-utility service provider using three system elements:

1. Flat bed truck
2. Vacuum pump and vacuum tank
3. Water tank

All of the above can be mounted onto the main vehicle (see Figure 35 above). This seems like an effective approach and could be achieved in a similar way with a variety of vehicles, for example a smaller four wheel drive pick up. Pick up trucks are common and can access the majority of areas in a typical settlement. Tractors are another option. If the system elements are designed appropriately then there would be no need for the purchase of a dedicated vehicle, but instead one can be rented from the local community, which will reduce overheads. This approach could also allow for one vehicle to be used to transport a number of trailer mounted exhausters between work sites and disposal points.

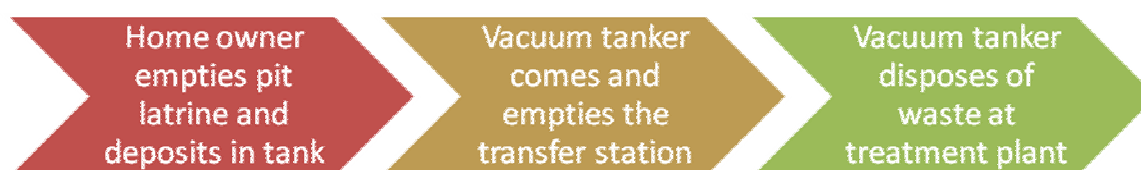
3.3.4 Storage Tanks

Some Vacutug project partners used transfer stations to reduce carting costs. These took various forms, from large plastic containers to more expensive concrete chambers. The image below shows a successful solution tested in Ghana and called an Underground Holding Tank (UHT).



Figure 30 showing a transfer station Faecal Sludge Management and the Use of Transfer Stations in Accra, Ghana, (11)

The tanks (totaling around 30) were installed as part of a bigger project in Ghana. To stop indiscriminate dumping of sludge by unregistered contractors only registered emptying contractors can use them. The focus with this project was the minimization of haulage distances. Originally pit latrine emptying contractors had emptied directly into local sewer networks. However due to a number of problems transfer stations were built which would temporarily store waste until larger vacuum tankers could come and empty the tanks and cart the waste to the disposal site.



These stations have proved have potential, but were challenging to operate for a number of reasons. Siltation of the sludge within the tanks is the main problem, exacerbated by the dry nature of the waste they receive. Periodic removal of consolidated faecal sludge requires the above-ground section of a UHT to be removed by a crane, allowing access into the tank for it to be de-silted. This is a costly process. The dry nature of the waste also makes it hard for the vacuum tankers to empty the waste on a day to day basis.

3.4 Conclusions on carting issues

This section highlights the main conclusions that can be drawn from the analysis of available excreta transfer methods.

Manual carting is appropriate and can be used where haulage distances are short, either to a transfer station or to a mechanised carting system. The Gulper - motor-trike combination tested in Dar es Salaam illustrates an effective manual-mechanised combination carting process.

It also seems that carting systems that are integrated with the exhaustion system are actually less useful than carting systems that are separate to the exhaustor as:

- Speed is always sacrificed with integrated systems
- The transmission systems do not often tie into existing spares or servicing chains in developing countries.
- In time road legalities may become complex and costly to adhere to

It is therefore suggested that a carting solution that uses existing vehicles (pick up trucks, trailers etc) already present are most suitable, and should be used to facilitate a "mother daughter" system as recommended by Manus Coffey. Additionally if the vehicle can use modular attachments that can be deployed then a multi-utility service can be produced which is resilient to the time and space variance of FS and SW management whilst continuing to be a viable business.

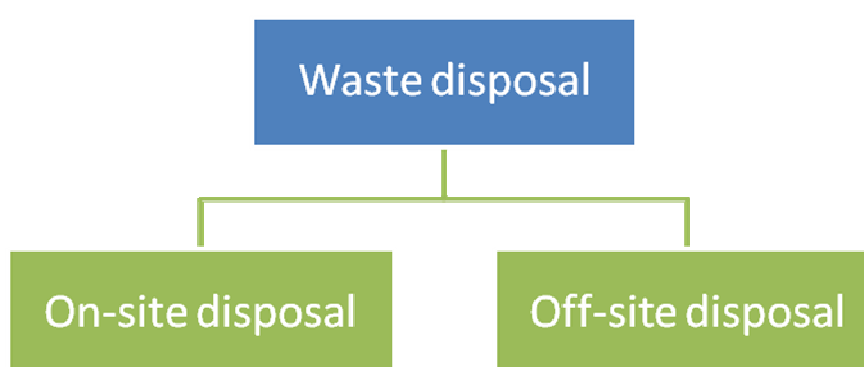
If a transfer station can be further integrated into this with some sort of solid liquid separation then the system can be fully optimized. This solid liquid separation could occur in a stand alone structure which is then exhausted, or more ideally could be achieved using deployed storage vessels which couple into the small bore sewer for solid liquid separation, and when full of solid waste are then towed to and from the transfer point.

4 Treatment and Disposal

There are many methods for the treatment of waste and all are not discussed here. Only an overview of the methods seen in the research completed for this report are briefly discussed.

4.1 What to do with the waste

There are essentially two initial options for sludge disposal, on or off site. The main drivers for the decision between the two are space and the water table levels. If there is space available for a pit then on-site disposal is highly appropriate as it is the lowest cost option as transportation costs are abolished.



On-site disposal implies burying the sludge on the residential plot itself and covering over the pit.

Where there is insufficient space, or a high water table which causes contamination problems with the local water, or where there is simply a desire to properly screen, treat and dispose of the waste, then off-site disposal is necessary. The sludge has to be transported by some means to a permanent or temporary disposal site hopefully in the local area. To make off-site disposal a sustainable practice a system of sludge transfer and treatment is necessary, which screens out domestic waste and then neutralizes the sludge. In most cases screening can effectively be done manually as all that is necessary is to remove solid waste like plastic bags, packaging etc.

4.2 Treatment and disposal methods

After transportation of the waste from the emptying site some form of treatment or screening is required before the waste can finally be disposed of. Acceptable methods applied in urban areas often combine both treatment and disposal:

- Trenching; the waste is buried in fenced areas outside of towns, covered with earth and left for at least two years to decompose and dry.
- Aerobic or anaerobic treatment in waste stabilization ponds.
- Co-composting with organic household garbage
- Incineration of pit waste together with other types of refuse.

- Treatment at a waste water treatment plant

Less appropriate methods of disposal are also employed:

- Disposal of waste directly into streams, rivers and lakes
- Disposal directly into sewers. This can cause trouble in the sewer system as the high solids load may cause blockages
- Direct application on the land as an agricultural fertilizer
- Disposal at the landfill site used for general waste disposal



Figure 31 Discharging of a vacuum tanker and a waste water treatment plant (10)

There is growing interest in treating excreta as a resource. Excreta is a rich source of nitrogen and other nutrients and as long as the solid waste content is removed it can be of use. One of the Vacutug project partners based in India used biogas reactors for disposal. This is briefly described below.

After some unsuccessful experiences with the Vacutug, SIIRT decided to use the Vacutug to improve their Biogas project. Based on the 'Sulabh Model' design, 54 biogas plants had been constructed with a capacity of 35 to 60 m³ by Sulabh to address the problem of disposal of sludge. In the Sulabh model the digester is constructed underground into which excreta from public toilets flows under gravity. Inside the digester, biogas from the anaerobic fermentation (from the methanogenic bacteria) is produced. The biogas can then be used for cooking, lighting, electricity and heat generation.

In the outer peripheral part of Delhi Sulabbh has two large size biogas plants attached with public toilets. The idea of utilizing faecal matter from the Vacutug for biogas appeared to solve the disposal problems associated with distance to disposal points and the small Vacutug tank. Faecal matter was therefore discharged from the Vacutug into the biodigesters.

5 Conclusions and Recommendations for Further work

The five stages in FSM have been discussed from storage through to disposal. Focus has been given to exhaustion and transport methods. Conclusions have been drawn on each method. This chapter pulls together these conclusions into recommendations for areas of further research and development.

First it is interesting to establish where there is capacity for improvement in the process. The diagram below was produced by Steve Sugden and illustrates the perceived space for improvement.

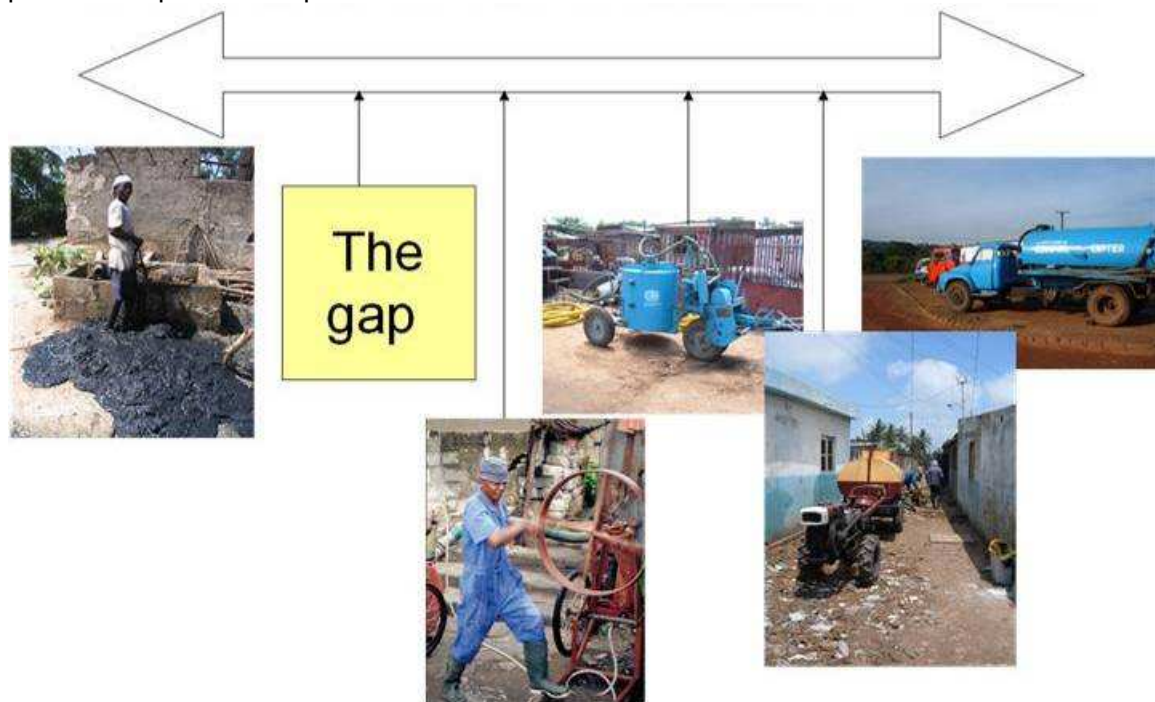


Figure 32 showing 'the gap' in latrine emptying technologies (4)

The jump from manual to fully mechanized machines for pit latrine exhaustion brings with it many additional complexities. As mentioned there are some major advantages to manual latrine emptying:

- It is very resilient to change, many workers will be employed, and if one should be ill, tired etc the work will still continue. This contrasts with a machine where if it runs out of fuel or breaks work stops.
- If local labor is used funding for a latrine emptying project moves from the funders to the community and is not tied up in expensive machinery and maintenance costs. This is good for the community and will have benefits beyond simply emptying their latrines.
- It is low cost and robust.

Semi Mechanized machines then have the added advantage of reducing the contact between latrine waste and the laborers. The six key criteria for an effective exhausting technology are:

1. Maneuverability

2. Simple Discharge and fast transfer (carting) method
3. Fast emptying time and able to handle variations in sewage quality
4. Large volume and resilience to competition (i.e. low capital and running costs)
5. Obvious and simple in its function
6. Cost effective

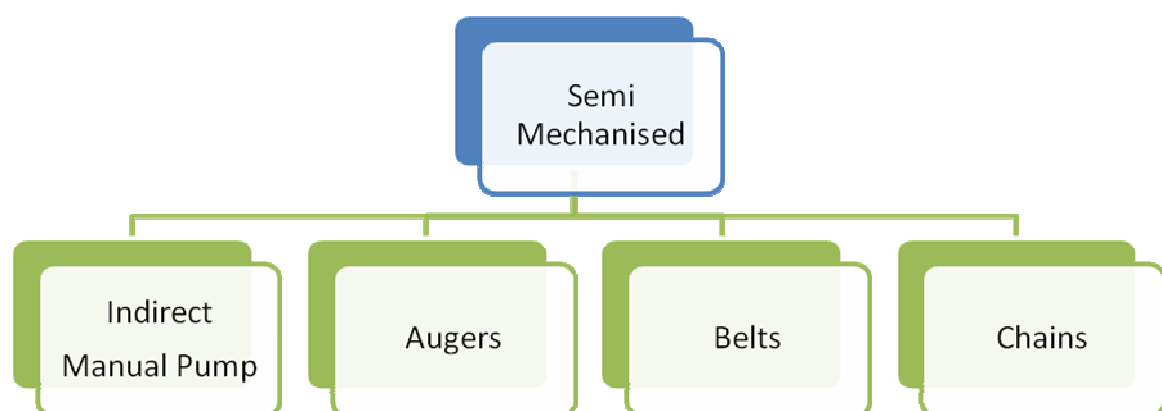
These points have been established into a full Product Design Specification which is shown in section 0. This specification lists all the attributes that a successful exhausting system needs and should help to guide further research and development work. For clarity the motivation for the development of this new technology is repeated here:-

- On-site sanitation will continue to be the most widely utilized and low-cost option in low-income urban areas. Demand for FSM services will continue.
- In densely populated urban areas relocating pits when they are full is not an option.
 - There is a need to find an alternative for manual emptying

Therefore there is a need for a low cost, hygienic and fully sustainable system for emptying latrine pits in the unplanned or peri-urban areas of the cities of developing countries. (4)

Semi mechanized and fully manual exhausting services should then be implemented as part of a stage transfer system which uses a varied approach to transporting the waste so that it is resilient to change. If appropriate, manual carting can form the first stage in the process where waste moves from the pit to a transfer station or into a large transporting vehicle. Locally available vehicles like pick-up trucks or tractors with tanker trailers should then be used to move waste from extraction sites or transfer stations to the disposal sites.

Semi-mechanized options for waste exhaustion are limited and currently the MAPET represents the only proven realization of a semi mechanized system. The figure below shows the four options for semi mechanization.



Each option should be developed and assessed for its potential. Adding the other recommendations made in this report the following list of areas for further work can be made:

1. Design and testing of a light weight indirect manual pump
2. Design and testing of an auger based latrine exhauster
3. Design of a belt driven latrine exhaustion system
4. Design of a chain driven latrine exhaustion system
5. Continued work with the UN-Vacutug
6. Research and development of hand tools to assist manual exhaustion
7. Investigation of solid liquid waste separators
8. Design and testing of sludge transfer stations
9. Deployment of VIPs with integrated suction hoses

These activities split into design and development tasks. Design tasks are for ideas that may have potential but need further research or design work to assess whether they are worth carrying through to prototype stage. Development tasks are ideas that are already in the prototype phase and need to be tested in the field. Each point is now discussed in detail.

5.1 Design

The following are design activities which include suggested concepts from this report and ways they could be developed, given enough resources.

5.1.1 Archimedean spirals

As mentioned archimedean spirals or augers may have potential as a mechanisms for the realization of a semi mechanized machine for assisting with Manual Exhaustion of pit latrines and other sewage storage chambers. Traditionally used for post hole boring and other ground drilling tasks the auger is a proven method for the lifting of solid material. However for the purpose of moving waste out of a latrine the auger would have to be ducted in some way. The images below show two post hole boring machines. The counter balancing of the engine and the auger on the first machine gives a good guide of the structure to follow. An assessment of whether the auger could be manually driven and move waste up a duct needs to be made. Initially there seems to be potential for development.



Figure 33 showing two auger based drilling machines (15) (16)

The counter balance of the engine on the wheels makes light work of maneuvering the auger. The main design problem would be how to get access to the latrine waste with a machine like this.

5.1.2 Belt drive

As an alternative to the use of chains would be the use of flexible belts fitted with claws or grips. This is still an idea in the concept stage and would need considerable development. Initial questions are: can belts in long enough lengths be sourced at a reasonable price? Can the system be manually driven? The figure below shows an early stage CAD model of one concept.

Double belts

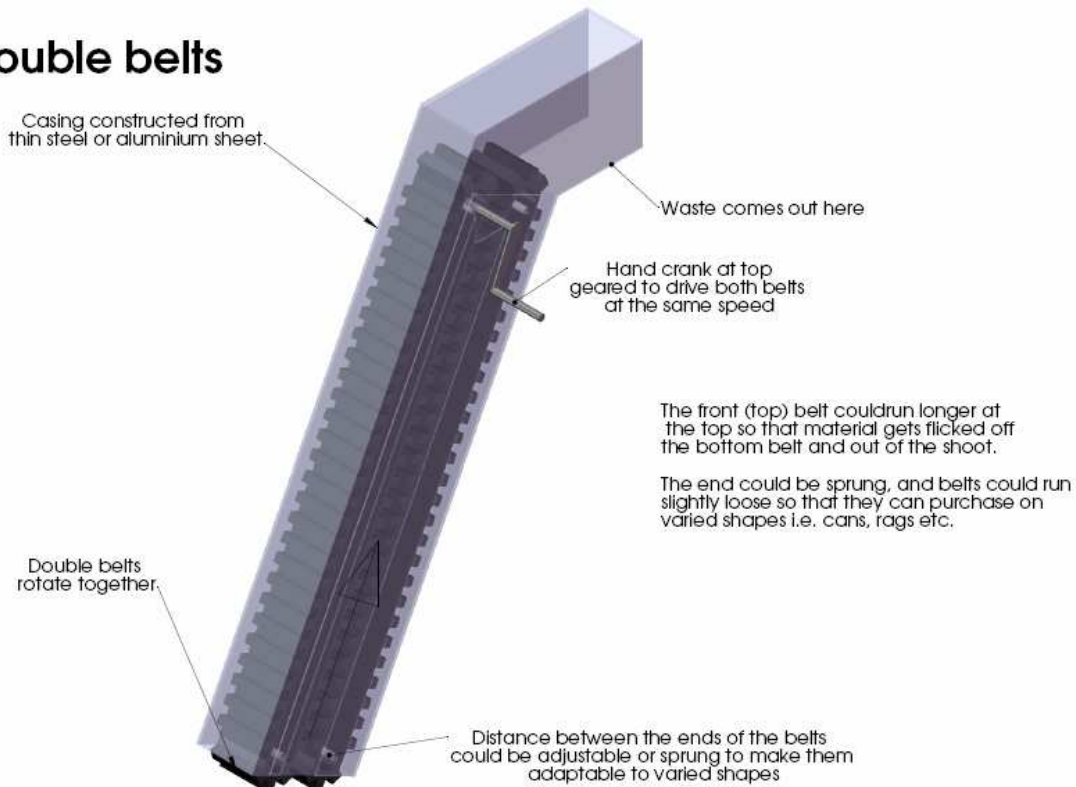


Figure 40 showing an early stage design idea for a double belt design (3)

5.1.3 Solid liquid separator

Effective management of the waste and its carting is critical. Removal of only the solid waste content of latrines is appropriate, as the liquid content can be easily discharged into small bore sewer lines, soakaways or evaporating ponds. The current machines used for solids liquid separation are extremely complex and expensive. There is clearly an opportunity for developing a low cost tank that can facilitate solid liquid separation (SLS). This could possibly be integrated into the light weight vacuum pump discussed in the development section below and considered for integration into a transfer station.

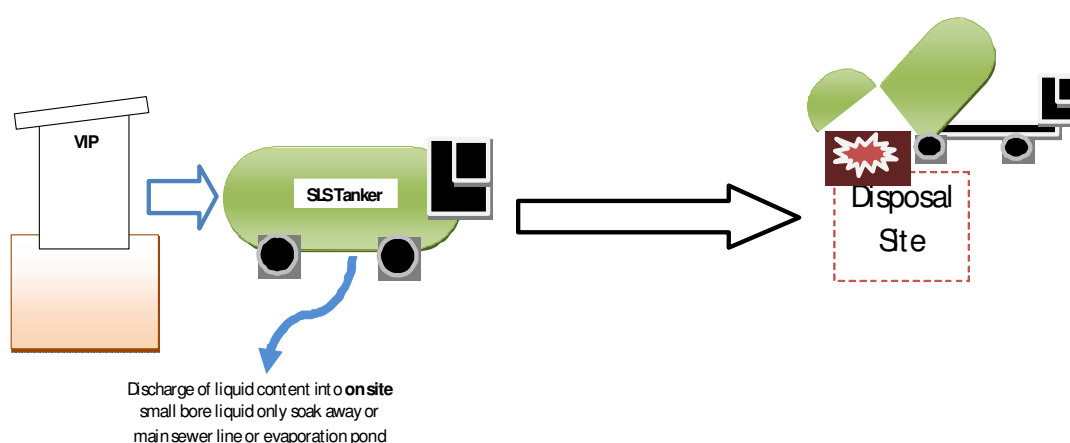


Figure 41 showing the principle of a SLS machine. Only the solid wastes are transported to the disposal sites.

Another option would be for separated liquid to drain back into the chamber being emptied this water could then be used to liquidize the sludge being removed in an effectively closed loop system. All these ideas would benefit from further research and development.

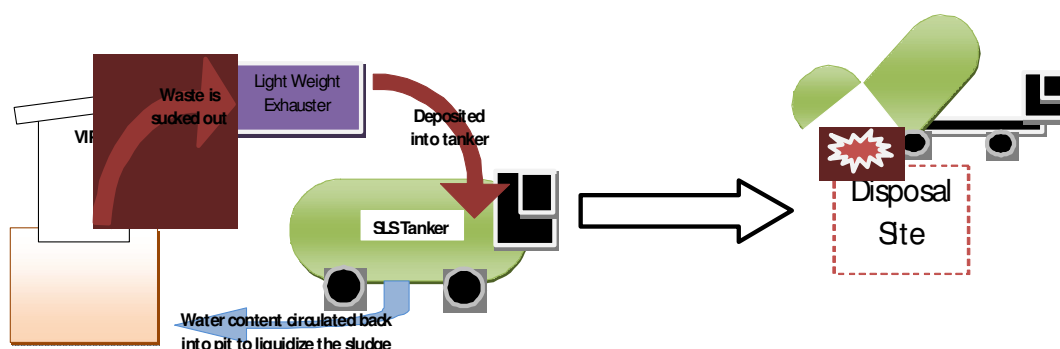


Figure 42 showing the principle of a closed loop SLS latrine exhaustion.

5.1.4 Transfer stations

The efficient use of transfer stations as part of the waste transportation can have a big impact on the costs of waste transport. Transfer stations can facilitate a coupling of manual carting to a deposit site with long distance carting with mechanized carting. Plastic or concrete containers can be used as transfer stations or more complex structures like that seen in Ghana can be made.

If a small bore liquid only connection to a soakaway or main sewer line is added to the transfer station then the volume and weight of waste to be transported would be significantly reduced. This would have the benefit of allowing large volumes of water to be used (to liquefy compacted sludge to help exhaustion) without significantly impacting the quantities of waste to be removed, as the added water would only go as far as the transfer station.

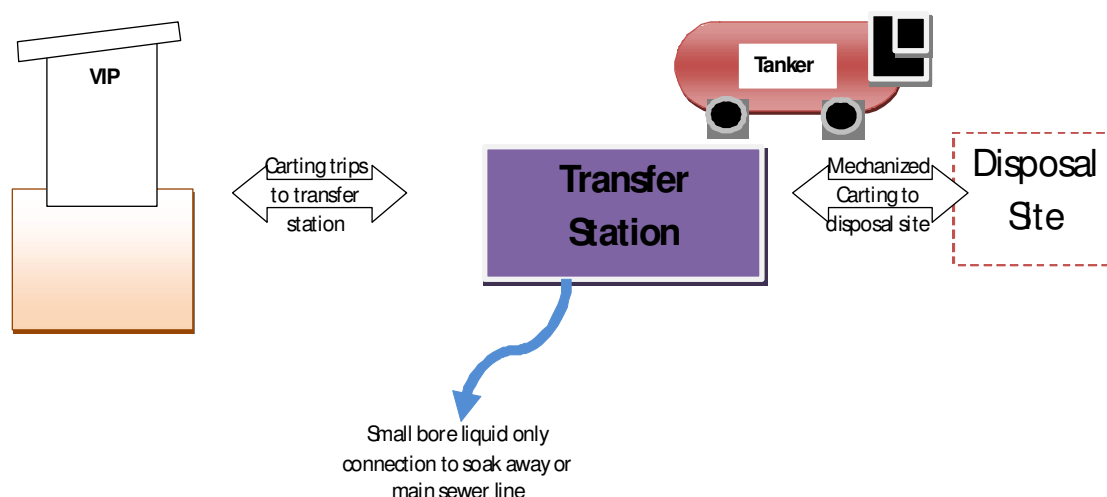


Figure 43 showing the principle of the transfer station. Waste can be carted, perhaps manually to the transfer station until there is enough waste to warrant a large tanker to come and collect the waste.

Furthermore if the transfer tank was modular and used tanks which could be towed to and from stations and coupled into the small bore sewer then the concept could be fully optimized. This concept needs further development.

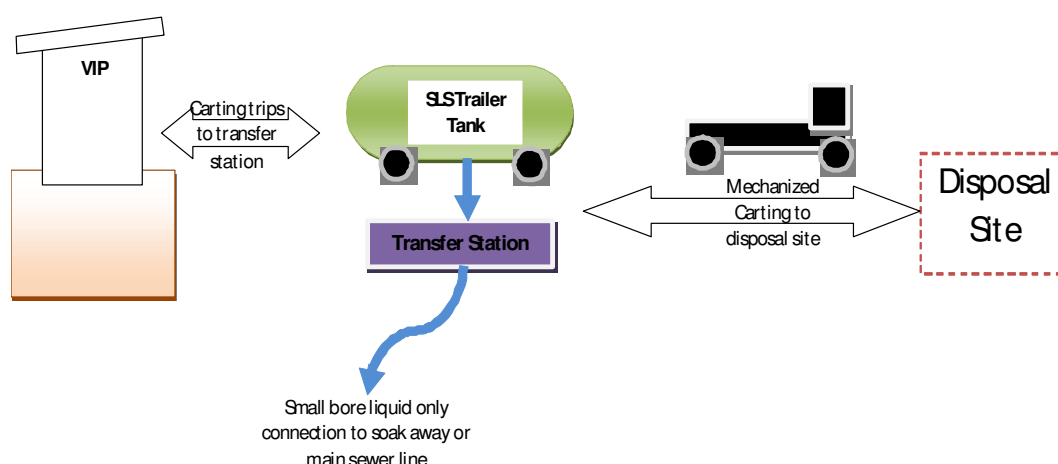


Figure 44 showing the principle of a SLS tank which can be deployed at the transfer station for filling. As it is filled the water content drains to the transfer station and on to a soak away or main sewer line. The full SLS tank is then replaced with an empty one and towed to the disposal site.

Preliminary research on the cost of trailers and parts for a moveable transfer station has lead to contact with Multi-Axle, a trailer manufacturer based in Empangeni. The issue of waste transport and the principle of mobile transfer stations was discussed at length. The main limiting factor on carting of waste are the regulations on towing. A standard road vehicle is only permitted to tow 75% of its unladen weight. A high clearance two wheel drive pickup truck weighs approximately 1600kgs, which means it can legally tow 1200kgs. This is the total weight of the trailer including its load. Additionally any trailer weighing over 750kg (including its load) must have override brakes which adds another level of complexity. For purchasing vs building a trailer it was suggested that the best approach would be to purchase a basic off the shelf trailer, then use this as a base for a tank and other additions. The cost of a trailer of

suitable size is R11 000. This would then need to have a hitch upgrade and override brakes fitted for a further R4 000. Modification of the trailer so that it could be tipped (to aid emptying of waste from the tank) would cost a further R1 000. For the tank itself fiberglass would be a good option, as it is strong, light, easily repaired and easily cleaned. The tank would need to be able to be easily opened and sealed for filling and storage, and then opened at the end to enable full emptying. A reasonable budget price would be R5 000, but further work must be done to firm this up. Allowing for overheads and contingencies, an estimate for a single moveable transfer tank which would be able to carry 750kg of waste (leaving 450kg for the trailer and tank weight) would be R25 000. An efficient faecal waste management service would need several such mobile transfer tanks to serve each fixed evacuating machine.

5.2 Development

The following are priorities for further development.

5.2.1 A light weight vacuum approach

The use of vacuum based approaches for sewage chamber exhaustion has been discussed at length throughout this report, with its associated benefits and problems. Vacuum systems will probably remain the most widely used method of sewage exhaustion in the developed world, where access to pits and septic tanks is generally not an obstacle. However to make the approach more generally applicable in poorer countries and in particular in informal settlements with restricted access, costs and machine dimensions need to be reduced. Effectively there is a need for a low cost alternative to the vaned vacuum pumps. Fortunately much of the development work on this issue was completed for the MAPET system which has successfully proven that piston pumps can achieve the required vacuum pressures. This concept can be taken further.

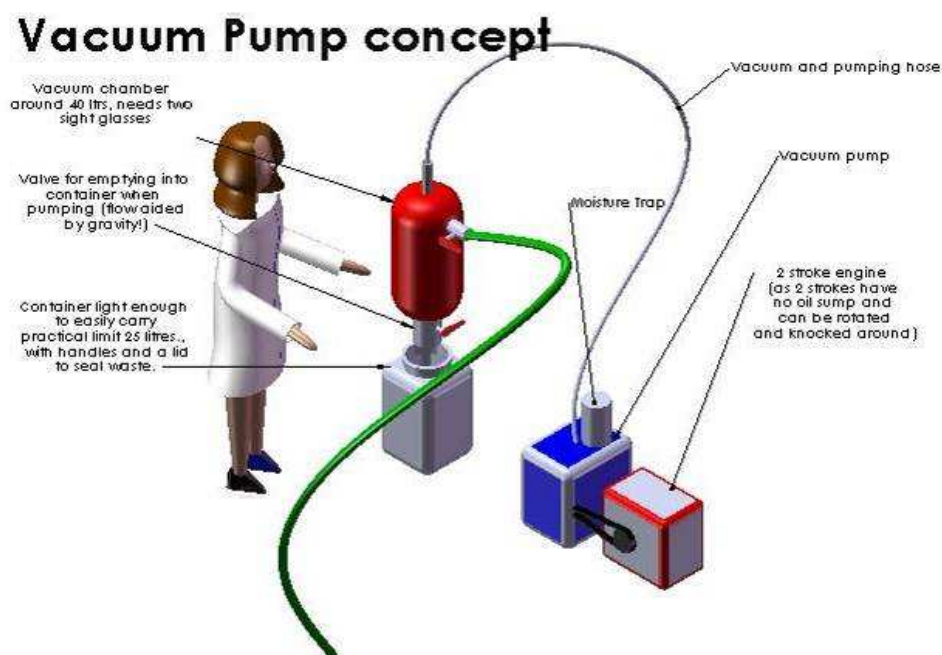


Figure 34 showing the vacuum pump concept. The red container would be alternately filled and emptied removing waste from the latrine and placing it into the container for manual carting off site.

It was concluded in section 3.4 that integrated carting and exhaustions systems are actually less successful than separate ones (unless implemented on very large scales as with a Vacuum tanker). Therefore consideration should be given to how this pump integrates with the carting method. It may be possible to evacuate waste straight into containers that can be manually carted off site, for transport on an appropriate locally available vehicle, or waste could be sucked into a vacuum chamber and then blown back into the transporting container. Opportunities for coupling the processes so two chambers are simultaneously used could speed things up so one chamber is filled whilst the other is emptied into the carting container. Finally perhaps in conjunction with the further work on solid liquid separation a way of coupling the pump into a chamber that separates the solid and liquid parts of the waste could be made.

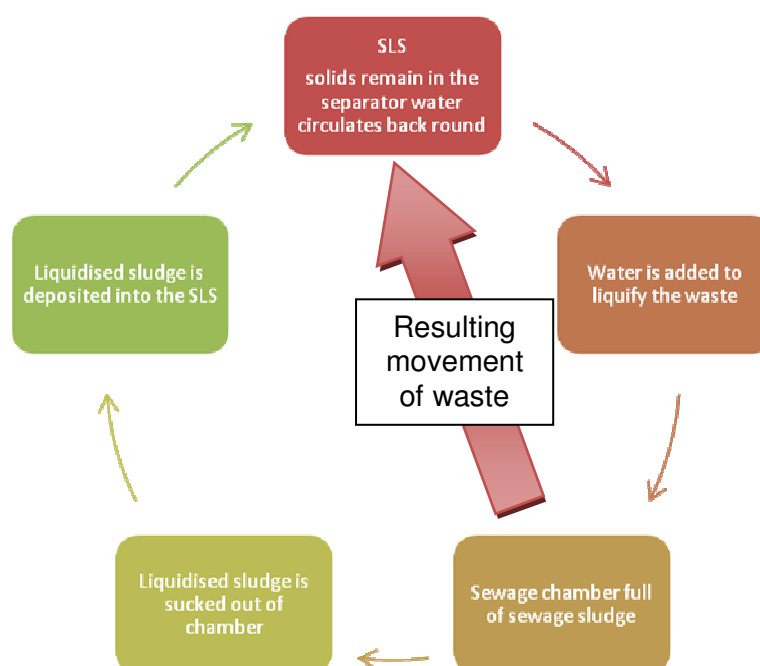


Figure 35 showing the concept of a closed loop SLS where sludge is liquefied, removed from the sewage chamber and deposited into the transfer tank. The water content then re-circulates back into the pit. The net movement of the solid waste content is then from the sewage chamber to the SLS.

Some development work has already started on this pump. It will use two pistons which will rotate 180 degrees out of phase to reduce cyclic loading on parts. The pump will be powered by pedaling (the treadle pump principle). Initial indications are positive. It is hoped that expensive ball valves on the vacuum chamber will be eliminated by emulating the design feature on the MAPET system, which is detailed in point 7 in table 1, and effectively means rather than having a suction and a pumping hose one hose is used and the vacuum chamber is instead positioned vertically for filling and then flipped over for emptying.

5.2.2 Gobbler

The Gobbler design work is now complete and a prototype is under construction. If the concept works in testing then the design can be optimized for:

- **Cost reduction** through selection of lower cost materials, plastics replaced with wood or bent metal sections, elimination of expensive fixtures and fittings, and cheaper chain and brackets

- **Part count reduction** to aid cost reduction, complexity of manufacture and failure modes
- **Weight reduction** through the use of thinner sheet steels and a lighter weight chain.

5.2.3 Complete testing of Vacutug

The Vacutug has been moved to a site in Slangspruit where there are a large number of low flush latrines with associated small septic tanks. If there is available time and resources some or all of the following ideas will be tested:

1. Test a reduction nozzle fitted to the end of the 3" suction hose to reduce the inlet from 3" to 1". What effect does this have, can the Vacutug now suck drier waste?
2. Could an electric powered macerator/flicker be fitted to the end of suction hose to encourage dry waste to move into and up the suction hose.
3. Does fitting a cage over the end of the suction hose still permit suction of sewage waste, but stop blockage of the suction hose?
4. Could an aerating hose be fitted to the end of the suction hose so it can be driven into dry waste fluidizing it for extraction using pressure from the pump.
5. Establish a comparison between the Vacutug's ability to suck over certain distances and pump over others. How does the machine perform in swift suck-pumping cycles?

5.2.4 Research on available tools to assist Manual Exhaustion

As discussed at length in this report manual exhaustion of pit latrines is a common and cost-effective approach to latrine emptying. However the tools nominally used to do this work are simply long handled rakes or spades, and workers are typically exposed to unacceptable levels of risk of infection. There are many tools already available for assisting with digging below the working surface, examples of which are shown in Figure 47 below. Some of these tools may be suitable for use for pit emptying either as they are or with minor adaptation.



Figure 36 images of tools that could assist manual exhaustion of latrines (15) (16) (17)

5.2.5 VIPs with integrated Suction hoses

The idea of constructing VIPs with Integrated suction hoses should be tested. The benefits of this system have been discussed at length earlier in this report. These VIPs could then be used for a period of time and then emptied of waste with a

vacuum tanker. Ideally some reference toilets could be used for a basis of comparison.

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7 Appendices

7.1 Notes on Visit to UN Habitat in Nairobi



7.1.1 Minutes from meeting at UN-HABITAT

Minutes taken by Mark O'Riordan at a meeting with staff at UN-HABITAT responsible for management of the UN Vacutug project.

Date: Thursday 19th February 2009

Location: Water and Sanitation Department UN Headquarters Nairobi Room U118

Attendance: *Mark O'Riordan*; EWB- UK volunteer, Partners In Development

Daniel Adom, Chief Technical Adviser, Water for African Cities Programme, WSIB, Human Settlements & Finance +254 20 7623333

Harrison Kwach, National Programmes Officer, Water Sanitation and Infrastructure Branch, UN-HABITAT,
P.O. Box 30030
Nairobi
Tel: +254 20 7625083
Fax: +254 20 7623588
Email: Harrison.kwach@UN-HABITAT.org

The following notes were taken by Mark whilst attending the meeting;

- The Vacutug is made in Bangladesh
- Currently marketed at approximately \$7500 dollars
- 1 yr ago Dakar in Senegal ordered a few more of the Vacutugs

- Daniel and Harrison state that some problems have been experienced with the machines
- The machine was made for areas with poor access and no planning, specifically Kibera in Nairobi was the target site and used during product design and development.
- The aim was short traveling distances and emptying from up to 30m (using a long length of suction hose) this is the method for getting into the hard to reach places
- The short distances for transport of the waste are available in Kibera as there is a main sewer line that runs under the settlement with a number of manholes that can be used to dump the waste into.
- The target size of the product was between a wheel barrow and a push cart. Mark suggested that the Vacutug still seemed a little large, but Harrison was surprised by this, thinking the Vacutug was very small.
- The only other option other than the current self propelled design would have been more of a car or truck.
- The design and development resulted in a semi mechanized machine.
- Having had trials over the years things become complicated by the household waste, so UN-HABITAT now encourage people to clean and liquefy pits and stir before the Vacutug comes to suck out the waste. This is messy but sometimes done.
- In some areas where the Vacutug has been tested a transfer point or station is used with the Vacutug going into alleys and then emptying into transportation tanks.
- There is currently planning to move forward with de-centralizing manufacture from Bangladesh and perhaps achieving three manufacturing sites across Africa. This seemed very sensible, as the current cost incurred with air freighting the Vacutugs is prohibitive.

Mark made a prepared presentation. Harrison said he had seen some of the items (the light weight vacuum concept and the Gobbler concept) previously as Steve Sugden had presented some items in Zurich in January 2009. The presentation was received well. Discussion moved back to UN-HABITAT's current work.

- They have currently considered/researched and tested the use of two wheeled Chinese tillers (two wheel tractor) an example of one produced is shown below.



- The two wheeled Chinese tractor is being used for solid waste management and has been successfully able to cart 0.6 tonnes of waste. It has a top speed of 25kph.

Discussion moves back to the Vacutug:

- It was intended as a community based relief tool which could be donated and give them the opportunity to manage their own pit latrine issues. It was not intended really for the entrepreneur looking to get rich on the machines. There is however an interest to now move towards an enterprise scheme with more of a business structure.
- There are 2 Vacutugs in Kibera. Many issues have been encountered with the Kibera trials. The current issue is spare parts, among other things the suction hose specifically has been a spare part that has been expensive to source. 40m costs 300 ksh (divide by 8 to get SA rands). This part needs to be considered a consumable as it does wear out. A small machine that can get close to the pit has the added advantage of having a short suction hose (reducing cost of this expensive item) and reducing the work required to draw the waste out of the pit.

Mark enquired about whether any modifications are being considered for the Vacutug as it seems manufacture is continuing;

- Currently the main aim is to decentralize manufacture and give further thought to increasing capacity of the tank beyond the current 500 ltrs.

6 new Vacutugs were recently sent to Dakar. Mozambique have recently ordered 4 more. The work in Mozambique is based near Maputu and evidently they are pleased with the machines they have received.

The current focus of the team working on the UN pit latrine project is latrine redesign. The meeting in January 2009 was attended by Steve Sugden, who is working along side Daniel and Harrison focused on pit latrine design and improvement of hygiene standards.

Discussion moved back to pit latrines and the waste, Daniel explained:

- Over time the sludge thickens and layers, resulting in a stratified mix of liquid on top of solid. The liquid is easy to suck off the top, but the solid at the bottom is extremely hard to suck. Therefore it is very hard to completely empty the pit latrine through suction. Therefore over time the frequency of emptying the pit will have to steadily rise (as it steadily fills up with solids). It is interesting to note that the latrines in the Durban settlement do not seem to layer like this as the water drains out of the latrines.
- Daniel also emphasized that even the vacuum based approach does not completely remove contact between the waste and the labor as they still have to handle the hose. There are still many hygiene issues.
- Attaining 100% clearance is challenging.
- Some variance is seen with the quality of pit latrine construction. Sometimes they can have very weak walls, and unlined pits are especially hazardous. Unlined pits often cave in.
- Steve Sugden and Manus Coffey (the developer of the Vacutug) are looking into latrine design ensuring hygiene standards for users. They propose to bury a pipe in the bottom of pit and then 'latch' the Vacutug onto it to extract the waste and pull everything out. The Vacutug can also be used to slightly pressurize and loosen the waste, and also inject some water into the bottom of the pit.
- VIP technology was developed in the 1980s and since there has not been much improvement.

The international group working on this project for the UN meet every 6 months. The next meeting will be in September/October in Ireland.

The head of the UN-Habitat Faecal Waste Management R&D effort is Dr Graham Alabaster. He has assigned 500 000 USD for the continuation of this project and to push it in the direction of latrine re design. There is also a focus on the documentation of existing designs and methods for handling sludge and producing a compendium of notes.

UN-Habitat co ordinates a number of different organizations working on this project, including:

- London School of Hygiene and Tropical Health
- Leeds University
- Loughborough University
- Manas Coffey Associates
- Practical Action and Solid Waste Management
- Atkins – Water UK
- Goal – Ireland

The discussion moved back to manual handling of the waste and manual carting:

- Acceptance of manual carrying of waste varies from country to country. In South Africa for example it seems ok (ish) but in Kenya there is a major

stigma associated with the movement and handling of this waste, and often it is necessary to work at night.

- With recent developments (addition of infrastructure) no matter where they tried to locate new pit latrines in Kibera they kept exposing old latrines! This causes many problems, and escalations in project costs as often special backfilling is required.

At the end of the meeting I asked Harrison if he would be able to arrange a site visit to their Vacutug project in Nairobi. He said that currently the project was encountering problems. I said this was fine and anything I could learn and see would be of use. He instructed me to return the next morning and he would contact the local charity managing the program.

Overview and feedback from meeting

Overall this was an excellent meeting, and certainly exposed some interesting information on the Vacutug project.

- The developers are obviously quite proud of their machine and seem a little reluctant to acknowledge that it may be inadequate in any respect.
- The machine looks good and has the promotional material to match. They even seem to have a bit of sales pitch. Further reading after meeting confirmed this, even on the brochure there are conflicting statements. For example it states: 'The Vacutug is a latrine pit exhauster – will fill tank in 2 mins' but then has to qualify this statement with 'depending on thickness of sludge', but its not only sludge in a pit latrine
- These people are somewhat detached from the actual problem.
- A discussion about manual vs mechanized approaches lead to an interesting but slightly confrontational discussion (we didn't agree). A machine is a much better result from the project than a manual pit latrine emptying system.

7.1.2 Minutes and notes from meeting with Maji na Ufanisi

Minutes taken by Mark O'Riordan from a meeting with a Maji na Ufanisi, a charity who manage the Vacutug in Nairobi.

Date: Friday 20th February 2008

Location: Water and Sanitation Department UN Headquarters Nairobi Room U118

Attendants: *Mark O'Riordan*; EWB- UK volunteer, Partners In Development

Esther Waikuru; Community Organiser, Maji na Ufanisi, Water and Development

Theta Lane (off Lenana Road)

Hurriingham

PO Box 58684 – 00020

Nairobi

Kenya

Tel +254 20 272 7107/8

Mobile +254 726 939309

Email esther.waikuru@majinaufanisi.org

Web <http://majinaufanisi.org>

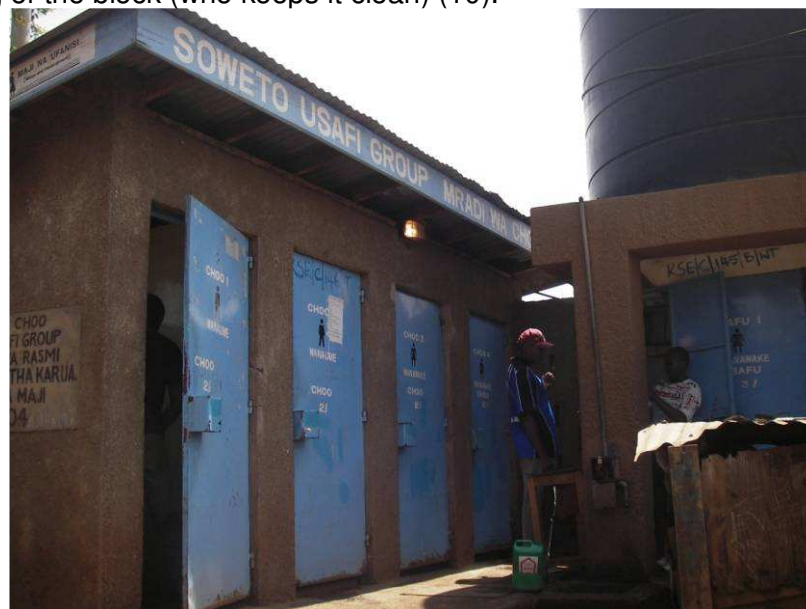
This was a long meeting, and the following are general notes.

At 9:00am I returned to the UN Headquarters and meet with Harrison Kwach, who introduced me to Nancy Githaiga, Programme manager – Environment for Maji Na Ufanisi (MNU - the facilitating charity in Nairobi for the UN Vacutug project). She instructed me to travel to her charity's head office and met with one of her colleagues, Esther Waikuru, a community organizer.

The meeting went very well, and Esther was extremely helpful giving me a guided tour of the project, and the area of Kibera (the slum where they work) which took a few hours.

We visited the Soweto Usafi Community Based Organisation (CBO), who manage a number of sanitation related projects in a little area of Kibera.

First the guided tour visited a sanitation block installed in 2004 (installed by MNU). The block provided 2 male, 2 female toilets and washing facilities. The toilets were pourflush system that empty into a septic tank. This tank is then periodically emptied. People pay 2 Ksh (25 SA cents) to use the toilet, which covers the costs of water and the staffing of the block (who keeps it clean) (10).



Interestingly the new structure had been built around the old original pit latrine.

Next the tour moved on to view the Vacutug that had been used in the area. Currently the Vacutug is broken. It was very dusty having stood unused for a long time. A swift assessment showed that a number of hoses were missing, along with drive wheels and the actual vacuum pump. Details on the locations of these items could not be gained. It was interesting to see that a roll cage had been added to protect the delicate working parts (engine and pump etc). It was mentioned that the machine often tipped over on the local roads and righting it when the machine is full is certainly a challenge. It was also mentioned that the drive on the machine is poor and the normal approach is to help by pulling the machine with ropes. Sourcing the hoses is currently delaying the re-commissioning of the machine, as is fixing the other parts.



A 2nd sanitation block was visited which is plumbed into the local sewer line. This had flushing toilets and was completed in 2008 by MNU. This was a lot cleaner than the first site. There were 3 toilets, and 3 showers per male/female side. Charges for use were, 2 ksh for toilets, 3 ksh for filling and use of a wash basin brought to the ablutions block by the customer and 5 ksh (62 SA cents) to use the shower. She commented “flush toilets are best, better than pit latrines”. The building apparently gets a lot of use. For this toilet block a CBO of 80 members manage the toilet block and staff the 5 water points in the area. Come the end of the year any profit is split between the members.

It was mentioned that before this toilet block was installed there were lots of pit latrines on the site which made excavating the site and preparing the ground for this concrete structure extremely hard. It was mentioned that an example of a site currently having earth works done on it would be visited later.

Having visited two toilet blocks we were able to meet with some of the managers from the local CBO who had run the Vacutug over the past for years. The Vacutug is successful when the community really take on the management and then they will make it work because they need to empty these latrines (that is up until the point when the machine has broken beyond a point that they can fix it). After brief introductions the focus of the meeting moved onto problems with the Vacutug:

- The machine doesn't work well with the rough roads and environment in the local area, but would probably be fine on smoothly tarmac roads, perhaps they will get tarmac some times soon?
- The machine has been flipped over several times.
- The Vacutug cannot exhaust a 6ft deep pit latrine in one go, often as many as 7 trips have to be made to completely evacuate the local pit latrines.
- The normal procedure for emptying the latrines is to take the waste to the main sewer line which luckily passes under this area of Kibera, this is owned and managed by a government body. Currently they permit this dumping of waste. The distance from the access point on the sewer line

to the pit latrine is critical and dictates the time that will be taken to empty the latrine.

- The Vacutug has a lot of work if only the machine didn't always break
- Spears for the machine are very very hard to get! Some parts are apparently made in Sweden? It is so hard to find spares locally.

The Vacutug used to get rented out to landlords who own properties in the area and need their latrines emptied. 600ksh (R75) is the nominal charge per full Vacutug trip. To operate the machine 4 members of staff were used (not 2 as stated on UN promotional material): a driver (300 ksh per day), 2 pullers/pushers (combined 200 ksh per day, these are locals), then there is the supervisor (200ksh per day) who comes from the CBO.

As the machine is broken what do they do to empty the latrines instead? There are two options:

1. For those who are lucky; hire a large vacuum tanker lorry (these are lucky people on the edge of main tarmac arteries of Kibera)
2. Manual excavation with buckets. Charges are: 500 ksh (R52) per 100 liter drum, lots of trips with these drums are made.

Finally a visit to a new construction site was made. The site would be home to a new library, computer centre and toilet block. The first task faced by the developers was clearing the site and removing a number of old pit latrines. The waste from the unlined pit latrines (most common latrine type found in the area) pits had to be excavated leaving 10-15 deep holes on the site ranging from 2-3m in depth.

Manual excavation had been used to complete this work, using locals who were used to the smell and the local environment. They are also adapted to the local hazards and less susceptible to the health risks (though they still seemed to get ill, problems with rashes on arms had been seen in the last batch of workers). The recommended approach for emptying the pits (which were originally unlined) is to dig out and cart off the waste to the local sewer point where the waste is screened and domestic waste is separated and the remainder dumped into the sewer. This is hard work and if there is inadequate supervision the waste may just be carted off and dumped at a local landfill.

Workers wear many protective items of clothing. Often during the day the smell is overpowering so people work at night. This also mitigates complaints from the community who are very against waste being carted through their streets.

This marked the end of a very productive and interesting site visit.

7.2 Partner conclusions on Vacutug trials

7.2.1 Bangladesh (manufacturer) and user

Project area; Kushtia Municipality is a medium sized city with a population of 1.75 million. There are major challenges associated with regular cleaning of latrines and septic tanks resulting in overflow of sewage and clogging of septic tanks especially in narrow and densely populated areas.

Field Results: The Vacutug was received in August 2003 but was not operational until March 2004. Initial observations were;

- The machine has no reverse gear and is therefore not operating smoothly in narrow lanes
- The volume of the tank is too small (the Vacutug needs to undertake several trips to empty an average sized latrine).

A Vacutug has also been procured by WaterAid and managed by DSK in Dhaka. Slight modifications have been made to the size of the tank. It has been increased to 1.9m³ and it is not self propelled but mounted on wheels and towed by a vehicle. The financial results for this modified machine is that it is able to cover its O&M, salaries and garage costs with the revenue earned and it is more efficient in emptying latrines because of its increased capacity.

7.2.2 India

Project area: Delhi is the main metro city of India having a population of more than 13 million. It is partially covered by a sewer system. About 3 million people live in slums and resettlement colonies in this metro city. In slums people use either public toilets (wherever available) or open defaecation. People do not have their own toilets due to space constraints and poverty. In peripheral areas where the sewer line is not available people have septic tanks or two pit systems for disposal of human excreta. The Vacutug was tested in various project sites where the partner was already working in which the main sanitation facilities are either

1. Open defaecation
2. Pour flush two pit toilet
3. Or public toilets wherever available

Field Results; The machine was not operated as an income generating activity, but it was used as an additional service to SIIRT's community toilet schemes. There were difficulties due to transport and discharge of effluent from the Vacutug. The sludge had to be transported 8-10km to the sewage treatment plant or a manhole leading to the nearest sewage treatment plant. A summary of problems encountered by SIIRT were:

1. Capacity of the tank is only 500ltrs. Therefore it was taking 10 trips to clean a septic tank of 5-6m³ (normal size of household). This was cumbersome and labor intensive.
2. Since disposal points were normally 8-10kms away and the maximum speed of the machine is 5km/hr the time required to clean the standard tank is too long. The machine also often caused traffic disruptions on the main road when transporting sludge.

3. People like to get the pits cleaned in the minimum time. They don't like to keep the pit uncovered for a day for cleaning its sludge. In the case of the Vacutug system, it can take an entire day to clean the pits due to the number of trips the machine has to make.
4. Although it is suitable for use in small lanes and congested areas due to its smaller size these lanes are normally not smooth. There are often small ditches and obstacles on the path which cause problems with transporting the Vacutug, especially when it is full.

Furthermore in Delhi there are entrepreneurs who are operating a competing system. They use 6000 liter tanks fitted on wheels and attached to a tractor. These take much less time (one or two trips only) to clean pits.

After some unsuccessful experiences with the Vacutug, SIIRT decided to use the Vacutug to improve their Biogas project. Based on the 'Sulabh Model' design, 54 biogas plants had been constructed with a capacity of 35 to 60 m³ by Sulabh to address the problem of disposal of sludge. In the Sulabh model the digester is constructed underground into which excreta from public toilets flows under gravity. Inside the digester, biogas from the anaerobic fermentation (from the methanogenic bacteria) is produced. The biogas can then be used for cooking, lighting, electricity and heat generation.

In the outer peripheral part of Delhi Sulabh has two large size biogas plants attached to public toilets. The idea of utilizing faecal matter from the Vacutug for biogas appeared to solve the disposal problems associated with haul distance to disposal points and the size of the Vacutug tank. Faecal matter was therefore discharged from the Vacutug into the biodigester.

7.2.3 Kenya

Project Area: Kibera, Nairobi is the second largest slum in Africa with a population close to 1 million. The settlement covers an area of 225ha and is strategically placed to provide labor to Nairobi's industrial area and city centre. The characteristics of the settlement, high density, unplanned and crowded houses, together with lack of infrastructure has lead to acute problems of drainage, sanitation and solid waste management. This scheme is managed by Maji na Ufanisi and was visited in February 2009.

Field Results: The machine was delivered in October 2003. Two machines were given to MNU. In Kibera, a trunk sewer runs across the settlement although none of the houses are connected to it. A request was made to Nairobi City Council to discharge the latrine sludge into the sewer. This was granted, significantly reducing carting distances.

A number of management issues were encountered between the supervising teams for the Vacutugs and MNU. The initial intention was to supply two Vacutugs to Kibera to produce an element of competition between two teams. Instead what happened was the parts from one machine were used to repair the other. At the end of 2004 operations were stopped. In January 2005, UN-HABITAT refurbished the machines and provided some basic training on O&M to newly formed management groups. In the refurbishments the most costly part to replace were the suction hoses which were often damaged by sharp items and solid waste that ends up in the Kibera latrines. It was suggested the best way to address this was by investing in an awareness campaign on the proper use and maintenance of latrines.

In the operation of the Vacutug under MNU collaboration there were a number of important observations made:

1. Competition with other services: a manual exhaustor charges between Kshs 1500 -2000 per exhaustion of a whole pit latrine. The Vacutug costs 700 ksh per trip but is restricted to a tank of 500 litres which results in 5-6 trips to fully empty an average latrine (which totals Kshs 3500 – 4200)
2. Conflict between the partner and the community on discharging of sludge. The manholes on the trunk sewer through Kibera are sometimes blocked and over flowing and the community wants the Vacutug to discharge into manholes further away. This however would mean long haul distances. A new transfer point for sludge could be helpful for this.
3. Technological shortcomings; the Vacutug seems to be unable to adapt to the situation in Kibera. Major breakdowns such as tipping over, puncturing of tires and frequent leakages of the hose pipes hinder proper operation of the machine. In addition the location and purchase of spare parts has required the assistance of UN-HABITAT.
4. Marketing; the joint committee made efforts to market the Vacutug in churches, schools and the provincial administration. This proved successful however it is not a one off activity and needed to be repeated regularly.

7.2.4 Mozambique

Project area; Medecins Sans Frontieres (MSF) was interested in integrating the Vacutug technology into its Cholera Prevention Project in the low-income neighborhood of Urbanizacao in Maputo. In Maputo there exist 3 conventional exhaustors which serve the entire city, because of their size these exhaustors are restricted to servicing a portion of the household latrines. The Vacutug services the remaining areas. The settlement has a population of 20 000 or 2200 families. The environmental conditions are such that make cholera prevalent: high water table, waste dumps frequent flooding and poor drainage.

At the onset of the project the demand for the Vacutug was very high: approximately 25% of latrines were full and 50% half full and coupled with the cholera epidemic at the beginning of the year the management of excreta was critical.

Field Results; The machine was delivered in October 2003. The Vacutug was operated by ADASBU (Associacao de Desentralisamento de Aua & Saneamento d Bairro de Urbanizacao) who provides latrine and pit emptying services to the residents of Bairro de Urbanizacao. MSF provide management and legal support. Disposal of latrine waste was negotiated with the Ministry of Water and granted. Having seen the success of the project the Ministry has expressed an interest in replicating the project in other peri-urban settlements in Maputo.

The observation from the field;

4. The quantity and quality of the waste lead to blockages of the Vacutug and to various breakdowns.
5. The transfer tank cannot always be emptied by the municipal trucks. This has been a major obstacle since the service provided by the latter was not reliable and the Vacutug could not operate whilst the temporary storage tank was full.
6. Most of the clients are unable to pay cash for the services of the Vacutug. ASASBU often had to enter into credit agreements. Fees were eventually recovered but often after protracted periods.

7. High labor costs compared to Maquineta were seen with the Vacutug but lower operational costs.
8. Since the Vacutug has emptied many pits the demand for its service has gone down, therefore there is a need to potentially expand the service area.
9. The Vacutug should aim to make at least 8 trips per day, this will increase income by 40%, and staff should be paid on a output (task based) salary scale.
10. The Vacutug is better at emptying latrines but the Maquineta is faster over land, therefore the Maquineta is more frequently used (where access is possible).

7.2.5 South Africa

Project area; the areas being served namely Nedell and Bakerville are rural peri-urban areas. This is the only project country where the Vacutug was being tested in peri-urban areas. The machine was managed by Mvula Trust.

Field Results; The machine was delivered in March 2003. Tests were carried out in Bakerville between 29 March – 1st April 2004 and in Nedell on 13th May 2004. In both cases the demonstration was extremely successful; 60 seconds to empty 0.5 m³ and 20 seconds to discharge.

After testing in Nedell the following suggestions were made;

- Two people are required to operate the machine
- The pump can be transported on a donkey cart
- Water will have to be available on site, carting of this water took a lot of time. No more than 50 liters of water is necessary, this is mixed into the last bit of content in the pit and to clean the pipes after use.
- A trough/pit will have to be already dug to dispose of the sludge. A long shallower trough worked best as it is not so dangerous to dig and easy to cover over again. This can be the responsibility of the latrine owner if costs need to be saved.
- A stick to stir the pit contents and also to measure the depth of the pit is necessary. A flashlight is handy to look into the pit. Masks and gloves are needed for the workers
- Two toilets per hour can be achieved but getting the Vacutug from one house to the next is the main challenge

7.2.6 Tanzania

Project area; about 85% of Dar es Salaam city population relies on on-site sanitation systems. Therefore there is a huge demand for an emptying service which the Dar es Salaam City Council and City Water cannot meet. Currently there are approx. 30 vacuum trucks serving the city most of which are privately owned.

The Vacutug was operated in Vingunguti and tested in Kipawa, Mogo and Mwananyamala- Kisiwini. Vingunguti is one of the 22 wards in Ilala district. According to the 2002 census there was a population of 68923 living in an area of 48 ha (equivalent to 0.7 m² per person). Information for EEPCO states that 33% of the Vinguti area has a high ground water table and during the rainy season the pits overflow contaminating nearby shallow wells and outbreaks of cholera are not uncommon.

Field Results; There were numerous issues with getting a road license for the machine and permission to dispose waste into the main sewer line. From the monthly O&M forms the Vacutug had no major problems in its operation. The results showed that in the first 12 months of operation the Vacutug emptied 877 pits. On average 4 pits were emptied a day each week. The only major incidents were when the Vacutug was once tipped over causing Tsh 35 000 worth of damage.

7.2.7 Ghana

GOFA is a multi sectional non-government organization with a special focus on the protection of the environment, especially of water bodies. The machine was delivered in February 2004. GOFA has not been able to find a suitable operator of the machine. UN-HABITAT transferred the machine to Water Aid Ghana to operate as part of the ongoing Water for African Cities Phase II projects.

7.2.8 Senegal

Project Area; The Vacutug has been tested in the Peri-urban areas of Dajah, Youf, Baraka, Arafat I and II, Castors and Diokoul which in total have a population of 400 000. In Castors and Diokoul the ground water table is high and therefore removing wastewater is critical. ENDA through their PAD project constructed a simplified sewerage system with a small wastewater treatment pond and have integrated the Vacutug to assist in exhausting the waste at each manhole.

Field Results; The machine was slightly damaged during shipment which had to be repaired before operating in December 2003. Finally in May 2006 there was a field visit by MCA and MAWTS and UN-HABITAT, which sorted out some of the technical and operational issues. The Senegal partner highlighted that in future Vacutug project it is important to translate the manual into French, Portuguese and Spanish. ENDA spent a lot of time testing the machine and trying to understand it and some mechanical and operational misunderstanding could have been avoided had the manual been translated. These included but were not limited to;

- Use of the spare drive belt supplied with the machine being used to drive the drive wheel at the same time as the drive wheel.
- Operation of the Vacuum pump for long periods whilst not sucking will lead to vane and oil seal failure (which occurred as it was run whilst driving the machine) which will ultimately destroy the pump.
- The importance of daily and monthly maintenance was lacking and yet is clearly indicated in the manual.
- A difficulty reported in the operation of the machine is that its maneuverability in the settlements and sand is hard as the traction on the machine is not very good.

ENDA have been satisfied with this technology and as it has projects in many settlements it has found that one machine is not enough more have since been order (based on February visit to UN-HABITAT).

7.3 Members of UN-HABITAT's pit latrine team

No.	Name of participant	Organisation	Country
1.	Manus Coffey manuscoffey@eircom.net	Manus Coffey and Associates	Ireland
2.	Graham Alabaster graham.alabaster@UN-HABITAT.org	UN-HABITAT	UN Complex Nairobi, Kenya
3.	Harrison Kwach harrison.kwach@UN-HABITAT.org	UN-HABITAT	UN Complex Nairobi, Kenya
4.	Jonathan Parkinson parkinsonj@gmail.com	Atkins Water	United Kingdom
5.	Aureli Paoli Aurelie.Paoli@atkinsglobal.com	Atkins Water	United Kingdom
6.	Steven Sugden Steven.Sugden@lshtm.ac.uk	LSHTM	United Kingdom
7.	Daudi Bikaba dbikaba@oxfam.org.uk	Oxfam	United Kingdom
8.	Duncan Mara D.D.Mara@leeds.ac.uk	Leeds University	United Kingdom
9.	Allan Cain Allan.dwang@angonet.org	Development Workshop	Angola
10.	Doulaye Kone doulaye.Kone@eawag.ch	EAWAG	Switzerland
11.	Bob Reeds R.A.Reed@lboro.ac.uk	WEDEC	United Kingdom
12.	Niall Boot niallboot@gmail.com	Goal	Sierra Leone
13.	Viv Abbott	Water Aid	Tanzania

7.4 Specification

As a first step in the design process some general points are considered as desirable features or outcomes.

1. Performance

- 1.1. The solution needs to empty a latrine in the minimum period of time.
- 1.2. The solution should be easy, simple and obvious to use.
- 1.3. The solution should be able to remove waste through the hole in the floor slab (diameter 300mm).
- 1.4. Extract to 2m depth emptying 2m in 1.5 hrs by two operators
- 1.5. Maneuverable through a doorway by two people
- 1.6. The waste needs to be moved into a sealed container which is easily transported away from site.
- 1.7. No direct contact between operators and the waste should be possible.
- 1.8. The solution should require only two people to operate it.

2. Environment

- 2.1. The solution must be able to function normally in heats ranging from 4°-44°C
- 2.2. The solution should be protected from heavy rain and dusty winds, and be easy to clean
- 2.3. Materials should be durable and not rust or degrade over time.

3. Life Span

- 3.1. Demand for a cheap solution to this challenge will not reduce in the foreseeable future. Any solution will be used regularly over a long period of time. The design must therefore be flexible such that if a certain 'scavenged' part goes out of production, a replacement can be found.

4. Life In Service

- 4.1. Product should run for approximately 15 years, with only occasional repairs/replacement of parts e.g. Bearings

5. Target Costs

- 5.1. The main priority for the solution should be to keep costs to a minimum
- 5.2. A range of solutions with a range of prices but at the lower end of the market should be investigated. With a manual and powered variant if applicable.

6. Maintenance

- 6.1. Tools required for maintenance should be readily available in the local area.
- 6.2. The solution should require minimal maintenance and be easily cleaned and sanitized/disinfected. Maximum of weekly light lubrication and bimonthly service.
- 6.3. Where necessary sacrificial elements should be integrated into the design so expensive parts are protected from damage. i.e. belt based drives to protect expensive motors as an alternative to direct chain drives.

7. Marketing

- 7.1. The solution should be aimed at use by municipalities for emptying of pit latrines.

8. Size & Weight restrictions

- 8.1. Size and weight of components must not restrict the ability of two operators to complete the tasks.

9. Manufacturing Processes

- 9.1. Batch or one off production would be most suitable for a solution to this brief. Considerations for mass production are not necessary.
- 9.2. The solution must be as simple to manufacture as possible and avoid complex and costly processes such as CNCing.
- 9.3. Parts must be manufactured using tools and materials available to the region. These consist of:
- Processes
 - Standard workshop hand tools
 - Arc welding
 - Basic powered hand tools (e.g. drill, grinder etc)
 - Limited access to fixed specialist workshop tools (e.g. pillar drill, lathe, ban saw) but will low tolerance capability
 - Materials
 - Reinforcement and smooth steel bar
 - Angle, square and flat iron lengths
 - Corrugated and flat galvanized steel Sheeting
 - GI Pipe and fittings
 - Steel Wire
 - Variety of nails, screws and bolts
 - Assorted Steel Meshes
 - Common car, motorbike, bicycle and milling machine spare parts
 - Oil drums
 - Simply finished (e.g. no dowels) and untreated timber of all sorts
 - Basic electrical components (switches connectors etc)
 - Cement, gravel, river sand and burnt bricks
 - Plastic bags and sacking
 - Rubber tyres
 - PVC and PE Pipe and Fittings
 - Polyethylene and sisal rope

10. Aesthetics

- 10.1. Product does not have to be aesthetically pleasing. Cost and ease of manufacture are the dominant factors.

11. Ergonomics

- 11.1. If used, manual drive input should be at an accessible position relative to the operator which can be used by most adults.
- 11.2. Two people should be able to operate the product alone.

12. Quality & Reliability

- 12.1. Assuming general maintenance is carried out the solution should not generally fail within a period of 2 years and be repairable at least up to the products full life span.

13. Competition

- 13.1. The cost of pit emptying using the solution should favourably compare to manual pit latrine emptying.

14. Standards & Specifications

- 14.1. Excepting the specifications listed herein no further external standards are applicable

15. Safety

- 15.1. The device will only be used by trained individuals.
- 15.2. If the solution is powered by an engine or motor and used a belt or chain based drive automatic safety features should be included.
- 15.3. If the solution is electrically powered it should be made electrically safe by an isolation switch, good earthing, and other necessary safety components.

16. Testing

- 16.1. Testing should be carried out on the whole solution before being fully commissioned.