

## Research Paper

# Trash removal methods for improved mechanical emptying of pit latrines using a screw auger

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### ABSTRACT

Trash in pit latrines is one of the largest challenges facing pit emptying technologies, including the powered auger (the *Excrevator*), developed for improved emptying in lower- and lower-middle income countries. This study focused on two trash removal methods in conjunction with pit emptying by the *Excrevator*: (1) simultaneous removal of trash with sludge and (2) manual trash removal prior to sludge removal. Simultaneous removal was tested by adding to the inlet of the *Excrevator* system two cutting heads designed to reduce the size of trash particles before entering the pipe and auger. Laboratory testing indicated that the auger will not provide the rotational speeds necessary for proper maceration of fibrous materials such as clothing, indicating that a separate maceration unit with higher rotational methods may be more appropriate. Four manual trash removal mechanisms were designed to improve on existing manual trash 'fishing' tools such as iron rods with fixed hooks. Two of these tools (the 'claw' and the 'hook') showed promising laboratory results and were subsequently field tested in Mzuzu, Malawi. Both tools proved more efficient than the current tools used in the field and have potential for use in Malawi.

**Key words** | auger, developing countries, *Excrevator*, pit emptying, trash removal

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### INTRODUCTION

An estimated 1.77 billion people worldwide use pit latrines that collect and store fecal sludge onsite (Graham & Polizzotto 2013). Pit latrines were designed to be covered over when full and allow the waste to decompose (Hawkins 1982). However, in many areas, there is no room to dig another pit, or it is cheaper for the owner to empty the pit than to build a new one. As a result, emptying fecal sludge from pits is necessary (O'Riordan 2009).

The simplest form of pit emptying is manual emptying with buckets and shovels. Pit contents and their

characteristics can vary widely, but manual emptying can clear any pit regardless of waste composition, water content, and/or location (Chowdhry & Kone 2012). Manual emptying is relatively inexpensive, and does not rely on machinery that will need maintenance and repairs. However, manual emptying is often unhygienic, creates a greater potential risk of polluting the environment, is undignified for workers, and deemed illegal in some countries (Thye *et al.* 2011). Additionally, personal protective equipment (PPE) is often not used, and workers can still be exposed to pathogens even when PPE is used (Van Vuuren 2008).

Existing mechanical pit emptying tools are often not able to access pits, not able to empty the dense sludge that accumulates in the pits, or are too expensive for households. There is a need for portable, hygienic, low-cost technologies to empty

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pit latrines. This study focuses on the continued development of one such technology, the ‘*Excrevator*’ (Rogers et al. 2014). The *Excrevator* consists of an auger housed inside a 100 mm PVC pipe, with a small clearance between the auger and pipe. As the auger turns, it conveys waste from the pit, up the pipe, and out of a 45° wye connector into a container for transport to treatment facilities. In a previous prototype, a hydraulic motor powered by a 7.5 kW (10 hp) gasoline engine turns the auger. The power source and the ability to assemble the full length of the auger at the pit make the *Excrevator* highly portable (Rogers et al. 2014).

The *Excrevator* has undergone testing on simulant waste (bentonite clay) and cattle waste, and on actual pit latrines in South Africa, Malawi, and India. Field testing in these countries revealed that the presence of large amounts of trash in the pits was the largest obstacle to effective emptying.

In cities in low income countries, the financial resources, skills, and political will to implement solid waste management is often lacking (Aremu et al. 2012). When there is nowhere to put refuse, pit latrines become a convenient receptacle. Numerous types of trash have been reported in latrines including plastic bags, broken glass, cloth (Brouckaert et al. 2013), needles, sanitary towels, clothes (Chowdhry & Kone 2012), newspaper, and anal cleansing materials (Still 2002). All mechanical emptying technologies are negatively affected by the presence of trash. In field testing in South Africa and Malawi, the *Excrevator* was able to pass some trash such as small pieces of newspaper, but often became clogged. This hindered the flow of sludge, and occasionally stopped the auger’s rotation completely. In Malawi, plastic bags and cloth were the most problematic types of trash encountered.

Pit emptiers have developed some strategies for managing trash in pits. It is reported that vacuum truck operators in Uganda will charge more for pits that require trash removal, although the removal method was not specified (Murungi & van Dijk 2014). In Malawi, pit emptiers were observed removing trash before vacuuming. The pit was first ‘fluidized’ with high-pressure water, and then trash was removed using a fixed hook at the end of a long pole and discharged into a corner of the superstructure. The process of manual trash removal is referred to as ‘fishing’ and could take up to an entire workday for a single pit. After fishing, the sludge was vacuumed out, although this often requires several iterations, as not all of the trash

is removed in the first ‘fishing’ and the vacuum could still become clogged. The removed trash, which is highly contaminated with fecal material, should ideally be handled and disposed of properly, whether buried in a separate pit onsite, or in a community trash pit.

The goal of this study is to examine several methods for managing trash and sludge removal from pit latrines using the *Excrevator*.

## METHODS AND MATERIALS

The methods of removing the trash in the pit latrines as well as the sludge were divided into two categories: simultaneous removal of sludge and trash, or pre-removal of trash before sludge. Two simultaneous removal methods were tested: (1) cutting heads that attach to the end of the auger; and (2) a shaftless auger with and without a vacuum. Four mechanisms for pre-removal of trash from pits were developed and tested to improve on the current ‘fishing’ technique.

### Simultaneous removal

Two different cutting heads were designed to attach to the auger described above. The first cutting head, called Double Blades (Figure 1(a)) consisted of two steel mixing blades. The top blade was stationary and attached to the pipe outside the auger. A hole in the middle was designed to allow material to pass through. Approximately 25 mm

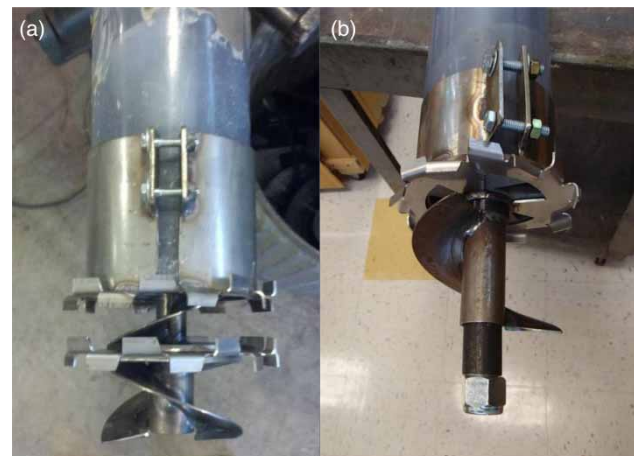


Figure 1 | (a) Double blades and (b) slicer.

from this blade was a second blade attached to the auger that would rotate with it. The auger flights extended to the second blade so waste would still be conveyed. Reverse flights were also added below this blade to allow the cutting head to dig into the solid sludge. The other cutting head, called the Slicer (Figure 1(b)) was designed to shear material. A steel plate with several openings was attached to the pipe outside the auger. Located adjacent to the plate was a mixing blade with similar openings. Forward flights were included below the blade to convey material up to the cutting head.

A shaftless auger was also tested to explore the possibility of trash flowing through more readily than in an auger with a center shaft, due to the opening through the middle of the flights. Additionally, the shaftless auger was combined with a vacuum to test if trash removal can be improved and jamming reduced.

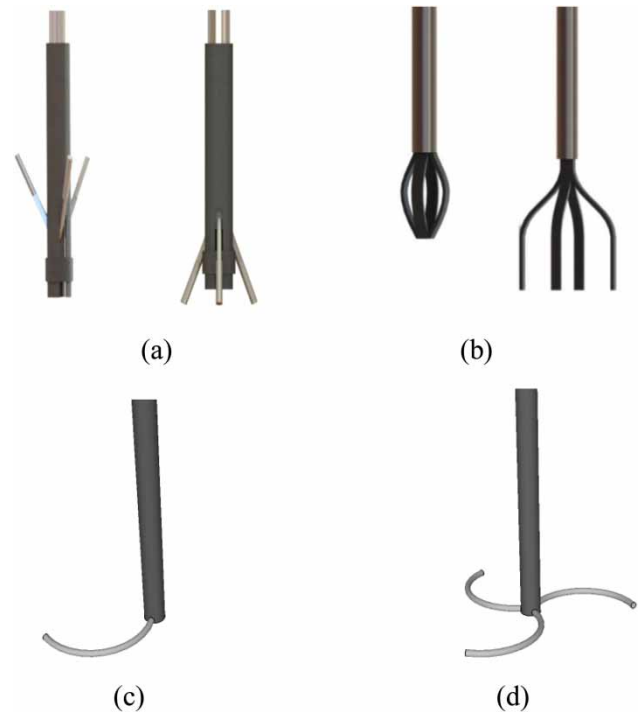
### Manual trash removal

Four devices (Figure 2) for grabbing trash were developed based on several design criteria (Table S1, available in the online version of this paper).

Two of the trash removers, the ‘Hook’ and the ‘Claw’, used moving components operated at the top of the handle by the operator to either grab or release trash. The Hook has three steel tines that point up at a 30° angle to grab trash, and change to a 30° downward angle to release trash (Figure 2(a)). This was based on the current ‘fishing’ tool used by private sector operators in Malawi, which consists of a rod with three rigid hooks. The Claw had four flexible arms made of thin steel that open when pushed out of the shaft and close when brought back in (Figure 2(b)). The other two trash removers were designed to be rotated by an external power device. They rotate clockwise to pick up trash and counterclockwise to release it. Spinner 1 had one 100 mm tine that curved in the direction of rotation to pick up trash (Figure 2(c)). Spinner 3 was similar, but with three 50 mm tines (Figure 2(d)).

### Experimental setup

For laboratory testing, a 1.5 m vertical *Excrevator* prototype with an electric motor was used and a 1 m<sup>3</sup> plastic container simulated the pit. A transparent pipe was used to allow



**Figure 2** | Illustrations depicting Trash Removers (not to scale): (a) hook, (b) claw, (c) spinner 1, and (d) spinner 3.

observation of the trash as it moved through the system. Fecal material was simulated with a mixture that contained 6–8% by weight of dry bentonite and water. This mixture has similar properties to human waste, including being thixotropic and having comparable viscosities and densities. However, it does not contain pathogens and is biologically stable, allowing for extended testing times (Rogers et al. 2014). A pipe connected to the wye at the top directed the waste into a bucket, and a ball valve connected to the bottom of the bucket allowed for emptying back into the pit. The bucket had a removable screen that caught particles of trash.

The rotational speed of the auger was measured with a digital tachometer, and flow rates were calculated for each condition. Solids tests were performed on the clay in triplicate according to ASTM D2216-10 during each testing period, to ensure it stayed between 6 and 8% bentonite by weight.

### Testing the cutting heads

A trash testing matrix (Table S2) was developed based on the University of KwaZulu-Natal report of pit contents

(Zuma et al. 2015) and on prior fieldwork experience with the *Excrevator*. The auger with no cutting head and with 100 mm of auger beyond the pipe was used as control to provide a baseline.

The cutting head tests were performed with the auger rotating at 400 rpm ( $\pm 5$  rpm). For the baseline tests, trash was placed one piece at a time in the simulant waste 25–50 mm from the exposed flights, and the *Excrevator* was run for 3 min and then turned off. During the cutting head tests, five pieces of the same test piece were placed 25–50 mm from the exposed flights, and then the *Excrevator* was run for 3 min. The trash was then sorted into four categories. Particles that traveled all the way through the auger and caught on the screen in the bucket were collected and comprised the ‘Pass’ category. Trash still in the container of bentonite and not touching the auger or cutting heads was considered ‘No Entry.’ Particles caught on the cutting heads or caught between the auger flights and the inside wall of the pipe were categorized as ‘Caught.’ Trash causing the auger to cease rotation was classified as ‘Jammed.’ All tests as shown in the trash matrix above were performed in triplicate. For each test-specific trash type, an estimation of volume was made for each category, since weighing would not be accurate due to differences in moisture content and amounts of mud coating the pieces.

### Testing the shaftless auger

The shaftless auger was tested with and without a vacuum using the same trash matrix described above. The setup with the vacuum utilized a pipe with cam-lock couplings to connect the wye to a vacuum container. A repurposed smog pump (rotary vane pump) was used to pull a vacuum of approximately 0.27 bar (200 mm Hg), which allowed the simulated waste to reach the wye when the auger was not turning. The auger rotated at 250 rpm ( $\pm 5$  rpm), the lowest rotational speed that still allows material to flow up to the wye. The same rotational speed was used without the vacuum so that the effect of the vacuum could be quantified. The shaftless auger was also tested without the vacuum, using the same rotational speed of 250 rpm ( $\pm 5$  rpm). Due to the large difference in flow rates (51.2 LPM with the vacuum and 13.3 LPM without the vacuum), the same volume of simulated waste was passed through the *Excrevator* for the tests, rather than using

the same run time. The run time for each test without the vacuum was therefore adjusted to 2 min per test. The same categories as before (No Entry, Caught, Pass, and Jammed) were used to sort the trash after each test, and volume estimations were made for each category.

### Testing the trash removal tools

A testing setup at the North Carolina State University Lake Wheeler Farms with a 1 m<sup>3</sup> container of bentonite clay to simulate an actual pit was used to test the four trash removers. It was positioned next to a platform such that the top of the container was level with the platform to simulate trash removal from an actual belowground pit. A board with a 100 mm diameter cutout was placed over the container, through which the trash removers had to enter and maneuver. Into this container were placed and mixed 20 each of t-shirts, plastic bags, folded newspaper, and crumpled newspaper. Each trash remover was tested on this pit 3–5 times, for both trapping and releasing trash.

## RESULTS AND DISCUSSION

### Simultaneous removal

### Cutting heads

The baseline *Excrevator* passed substantially more material than either of the cutting heads, for all trash types (Figure 3, Figure S1 and Figure S2, available in the online version of this paper).

This is most likely due to a larger, uninhibited, entrance and continuous auger in the baseline compared to the

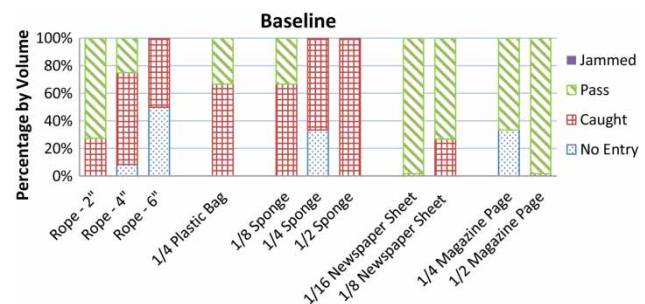


Figure 3 | Performance of the baseline auger.



smaller openings with the cutting heads. The baseline *Excrevator* was able to pass the majority of the trash with dimensions smaller than 51 mm. Trash of this size fits between the auger shaft and pipe wall, and thus is easily carried up the auger with the simulant waste. A large percentage of the sections of newspaper and magazine also passed, due to the loss of strength after saturation in the simulant waste, which caused it to break up and flow easily. The baseline results validated previous field testing results where smaller pieces of trash passed easily, but longer, fibrous material often caught or jammed the auger (Rogers et al. 2015).

Both cutting heads showed similar results (Figure S1 and Figure S2, available in the online version of this paper). Most trash pieces were caught on the blades or did not enter the system at all. As mentioned above, the trash was not able to enter the pipe because of the reduction in the opening size, and the auger creates a very small draw of material on its own. The exclusion of trash provides two possibilities for the future: (1) a design that purposefully excludes trash and only accepts fecal sludge, or (2) a vacuum system to pull the trash to the cutting heads and through the system.

For the trash pieces that were not excluded, most were caught in the cutting heads. For both the baseline and auger with cutting heads, 'caught' trash will cause blockages in the system, decreasing the flow of waste. The sharp edges on the cutting heads caused fibrous material, such as plastic bags and rope, to get caught and wrap around the head. Higher rotational speeds may yield better shearing results. In these experiments, the rotational speed (driven by the maximum speed in the field version) is only about 12% of typical macerator pumps. Future work on simultaneous trash removal should focus on the use of a slicer unit separate from the *Excrevator* system capable of higher rotational speeds and better shearing.

A very small amount of trash jammed the system during laboratory testing. The Slicer design experienced some jamming, particularly with the 9.5 and 16 mm diameter ropes, again most likely due to the low rotational speeds making it difficult to shear the thicker rope. The Double Blades did not jam at all, but very little trash made it through the blades and into the system. It is also worth noting that running the auger in reverse would often unclog 'caught' trash but not with the reliability needed for field use.

### Shaftless auger

For a shaftless auger with the vacuum, 14% more trash entered the auger, and 11% more passed through, compared to without a vacuum (Figure 4).

This is expected as the vacuum draws more of the material surrounding the pipe inlet, and subsequently, more of the trash. The increase in passing was observed in all categories, except for plastic bags and newspaper. The plastic bags continued to get caught on the auger, even with the addition of the vacuum. The 16 mm diameter rope was the only trash for which jamming occurred, and with the addition of the vacuum it occurred 66% less often.

### Manual trash removal

Trash removers were qualitatively evaluated in the simulated pit latrine based on the criteria in Table S1 and the results are shown in Table 1.

The Claw was the only trash remover that met all 14 criteria. However, the Claw works better if the trash being removed is visible, unless operated by a very skilled user. This could be problematic when working only through the squat hole in a dark pit latrine. The Hook also performed well and does not require visibility of trash being removed. However, it had numerous moving parts that contributed to weight, difficulty in cleaning, and a perceived lack of durability. All provided trash removal without operator contact with the waste and were made with materials and techniques that are expected to be available locally (e.g. in Mzuzu, Malawi). The spinning trash removers worked well on newspaper, but plastic bags and clothing were able to

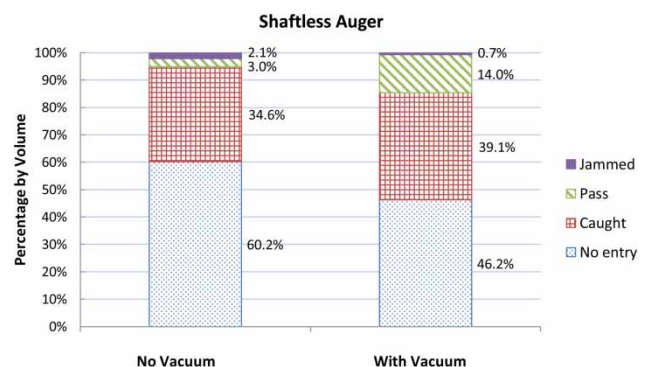


Figure 4 | Shaftless auger with and without a vacuum.

**Table 1** | Evaluation of trash removers. Check marks indicate that the trash remover qualitatively met the criteria

Criteria (in order of importance)	Hook	Claw	Spinner 1	Spinner 3
Operator has no contact with waste	✓	✓	✓	✓
Easy to clean		✓	✓	✓
Grabs and releases plastic bags	✓	✓		
Grabs and releases clothing	✓	✓		
Grabs and releases rigid objects		✓		
Fits through 10 cm diameter hole	✓	✓	✓	✓
Can maneuver within the pit	✓	✓	✓	✓
Requires no external power unit	✓	✓		
Penetrates dense sludge	✓	✓	✓	✓
Made of low-cost materials	✓	✓	✓	✓
Locally available materials	✓	✓	✓	✓
Locally available manufacturing	✓	✓	✓	✓
Durable		✓	✓	✓
Lightweight		✓	✓	✓

wrap all the way around the removers due to the small size, making removal by rotation in the reverse direction difficult. The necessity of an external power source for the spinning trash removers was also a disadvantage.

### Field testing in Mzuzu, Malawi

Based on the initial laboratory results, the Hook and Claw were chosen for field testing prior to emptying activities on four pit latrines in Mzuzu, Malawi, where trash has been a challenge. The Hook was able to pick up cloth items such as washcloths and plastic bags. However, these items were still easily entangled with the hooks at the bottom, requiring additional effort to release the trash. The Claw was able to pick up trash including cloth items such as washcloths, plastic bags, sanitary pads and plastic Anti-Retroviral (ARV) bottles.

Both the Hook and Claw were easily maneuvered and operated by one field technician during field testing. Overall, the Claw proved to be more versatile in the variety of trash items it was able to remove. However, the retraction and release motion of the Claw failed after testing on three pit latrines. Lubrication (brake fluid) was required at the

bottom of the Claw, and it had to be manually loosened with a tap of a hammer. The lubrication restored the release-retraction function. Although the trash removal tools were manufactured in the USA, the simple design could easily be fabricated locally in Malawi.

### CONCLUSIONS

For the *Excrevator* to be effective in emptying any pit, it must be able to handle both fecal sludge and the wide variety of trash found in pit latrines. Cutting heads for simultaneous removal of fecal sludge and trash and tools for pre-removal of trash were developed and tested.

Cutting heads did not perform as anticipated, and excluded trash more than they cut trash into smaller pieces. Several areas for improvements to the designs were identified during laboratory testing. Modifications could be made to encourage the shreds to circulate rather than to stick on the blades. It may be beneficial to add a vacuum to the shredding mechanisms to pull the trash through. Higher rotational speeds may be required to achieve the shearing action needed for the more difficult materials, such as plastic bags or clothing. A unit separate from the *Excrevator* would need to be developed for trash removal as higher speeds would not be viable for the auger. It is also worth noting that removing trash by shredding could pose a potential problem for some treatment techniques, such as biogas production and composting, where ideally non-degradable trash is separated. Therefore, it may be necessary to screen the waste depending on the downstream processing.

The shaftless auger also had problems in bringing trash into the inlet and passing it through without getting caught. The addition of a vacuum slightly improved trash removal, but not to a sufficient level to warrant the use of this technique in the field.

Field testing showed the 'Claw' proved to be the most effective manual trash removal technique. Although manual trash removal is not ideal, it is effective and separating the trash from the fecal sludge makes downstream treatment easier. Additionally, the Claw can provide immediate benefits to pit emptying teams who are already using manual trash removal. Its ability to easily grab and

release trash will greatly reduce the trash removal time and make it a cleaner process compared to tools currently used. Extensive field testing with the Claw is needed to prove its robustness in a field setting.

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