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***CREATE*16**

Latrine Pit
Pumping
System
Mzuzu, Malawi

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TEAM 40: TEAM LATRINE

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ABSTRACT

In underdeveloped countries, diseases resulting from lack of sanitation are prevalent. Pit latrines have been installed to improve sanitation, but the lack of a good mechanism to empty the pit latrines means the latrines fill up. When the latrines are full, people are forced to use other less sanitary ways to dispose of their waste. In addition, the current methods for emptying latrines are very unsanitary and dangerous to the individuals completing this task. This situation has been especially common in developing communities such as Mzuzu, Malawi. To assist in solving these problems, this team focused on improving the pit latrine-emptying process in Mzuzu through the development of a product that can empty pit latrines using energy efficient and cost effective methods. The client, Mr. Willy Chipeta, provided the team with a list of the type of materials that are commonly available in Mzuzu; PVC pipes, automotive or bicycle parts, wood, some metal stock, and hand tools are readily obtainable in local stores and scrap yards. The team established the target specifications, requirements, and generated concepts based on the information about the problem provided by the client. The basic design requirements were that the device will be made of locally available materials, easy to maintain, and safe to operate. After a preliminary concept generation and selection process, the team decided to modify and improve the "gulper" piston pump design currently being used in Mzuzu.

The team improved the performance and safety of the gulper by making the product more ergonomic, with a lower input power requirement and protection for the operator from direct exposure to human waste. The proposed design uses the

same valve technology as the gulper, using a check valve on a moving piston and a check valve at the base, but offers several improvements. First, the design uses an adjustable lever design, constructed of lumber and water pipes, as the method of power transmission instead of a hand pump. The pump itself is made mostly from PVC and has a modular design, meaning it can pump at various depths and can be easily adjusted. The improved design is also fitted with a 2 inch hose which connects directly to a storage drum, minimizing sludge contact. The entire design is completely collapsible from the lever to the pump and can easily be transported. The product in total cost approximately $350 to manufacture. This device performed well in simulated latrine testing. We were able to achieve a flow rate of 4.56 cubic meters per hour which corresponds to pumping a 3 m^3 latrine in approximately 40 minutes.

INTRODUCTION

Mzuzu is a city in Malawi, a developing country in southeastern Africa that struggles with waste containment and sanitation. While this project's primary goal is to improve sanitation in Mzuzu, it is important to both the client and the team that this product can be utilized by developing countries around the world. Currently, approximately 8,800 people in Malawi die annually as a result of diarrheal diseases. Of these deaths, 4,500 (51 percent) are children under the age of five.

Pit latrines have been used to improve sanitation but still do not solve the problem as these latrines often are filled to capacity and not routinely cleaned. Emptying the latrines with vacuum trucks is prohibitively expensive and the alternative manual methods are unsanitary. The goal of this project was to develop an affordable, easy-to-use device that is capable of emptying pit latrines while protecting the operator from contact with waste from materials that are readily available in Malawi.

NOMENCLATURE

a = Length of input side of lever

b = Length of pump side of lever

F_A= Lever input force

F_B= Lever output force

BACKGROUND

In 2015, the United Nations agreed upon a new set of Sustainable Development Goals. Goal 6 is to "Ensure access to water and sanitation for all". It's difficult to overstate the importance of this goal. Over 2.3 billion people worldwide still do not have access to adequate sanitation, and roughly 1 billion still practice open defecation [1]. Sanitation access is extremely important, not only to health, but also to education, nutrition, and gender equity. Some experts at UNICEF believe that the other sustainable development goals will be impossible to meet without first addressing water and sanitation access [2]. Pit latrines can be considered adequate sanitation if a slab floor is present to adequately separate humans and waste. However, if a village only has access to a few pit latrines that are all so full that they cannot be used, then sanitation is once again grossly inadequate. Many pit latrines were constructed in Malawi during the last push for sanitation access without a concrete plan for what would happen when they fill up. The amount of trash and debris that end up in latrines has presented another unexpected challenge to pit emptying. Our client asked us to design a device that could be used by two people to safely empty the contents of a latrine pit into a container that would then be taken away to a proper sanitation facility, like a sludge pond.

In developing our solution, we first benchmarked existing technology. Our client suggested we look first at the gulper, a simple manual pump that he had previously used and modified to be powered by a bicycle. A gulper is basically a piece of pipe that contains a piston and a system of valves. By pulling the piston up, sludge is lifted out of the latrine pit and dumped out of a discharge into a bucket [3]. The drawbacks to the gulper are that it's difficult to operate on thick sludge and the operator must stand directly over the latrine unless it has an outside access hole. The bicycle powered gulper was large and difficult to fit into latrines. In both cases, the sludge discharged freely into a bucket and exposed the operator to sludge. Despite these limitations, the gulper definitely served as the inspiration for this design. Our first prototype was a gulper, which we tested to identify other areas for improvement.

To get an idea of the type of fluid we would be pumping, we reviewed papers by Radford [4, 5] about the characteristics of latrine sludge. The main takeaway from these papers was that latrine sludge is generally hard to characterize, properties vary depending on climate and culture, and latrine sludge is a thixotropic material (shear-thinning). The best way to simulate latrine sludge was with a mixture of clay and compost, but ultimately there was no substitute for animal waste in testing these devices.

REQUIREMENTS AND SPECIFICATIONS

Before the team could begin developing any concepts, we first needed to identify the customer's needs for the design. After contacting our client, Willy, and understanding his wishes, the team generated a list of customer needs. Willy specified that the pump be able to efficiently empty a 2 or 3 m^3 latrine in 2 hours. Additionally, the operator should not come in contact with any sludge or dangerous moving parts of the device throughout the pumping process. Once the specifications were established, the team formalized the specifications as engineering requirements.

We chose three requirements that encompassed all of the design specifications and customer needs. They are as follows: the pump shall remove sludge regardless of latrine size or composition, the pump shall cause no harm to the operator, and the pump shall cost no more than $1,500 to make. These requirements can also be seen in the Requirements and Specifications table below accompanied with their corresponding customer needs.

TABLE 1: ENGINEERING REQUIREMENTS AND SPECIFICATIONS

Requirement	Category	Specification	Threshold	Target
The pump shall work regardless of latrine size or sludge composition	Sludge Properties	Maximum Size of Debris	0.05 m	0.075 m
		Flow Rate	1.33m^3/hr	2 m^3/hr
	Modularity	Availability of Resources	75%	90%
		Characteristic Length of Pump	2 m	0.6 m
		Weight	75 kg	50 kg
The pump shall not cause harm to the operator	Safety	Number of Contact Incidents	1	0
		Ergonomic	180 W	160 W
		Number of Exposed Moving Parts	3	2
The pump shall cost no more than $1,500	Durability	Pumping Time for 1 Latrine	1.5 hours	1 hours
		Life Expectancy	5 years	15 years
		Cost	$1,500	$1,000
		Drop Height for Shipment	0.5 m	1 m

ANALYTICAL RESULTS

In order to move forward with a design that improved upon the previously discussed gulper design, significant improvements would have to be done to the power transmission aspect of the design. Difficulties with the original design usually stemmed from a bicep curl-type motion required to move the piston. This method has proven to be very difficult within the confines of a latrine and usually requires two operators. As such, the team needed to be able to develop a power transmission that would reduce the required force input. This became the key component of analysis before design of the final pump could begin. While several designs were considered for this, the operation of a lever has been determined as the best method of reducing that power input. For this lever to be a viable option, the height, pump length, and resulting stroke length had to provide the appropriate, ergonomic motion for an operator. Early experimental iterations of a lever design resulted in poor kinematics and an inoperable pump. So, it was determined that the lever design needed to be properly designed in order to optimize the user input. The first step in designing this lever would be to determine the height of the pivot location on the lever. Based upon the height of an average adult male user, placing the pivot height at the 42" mark brings the fulcrum to chest level. From there, the team needed to determine how the input stroke and output stroke would be related in terms of mechanical advantage. With a desired pumping stroke of 30" inches, from about shoulder to hip level, the lever stroke could be determined based upon the mechanical advantage desired.

A reduced stroke length from the gulper design allowed for a piston stroke smaller than 30". In order to obtain any real mechanical advantage from the lever, there needed to be a significant difference in the lengths from each end to the pivot point. Placing the longer end on the user input end allows the user to use this mechanical advantage and their own weight to reduce the effort needed to operate the pump significantly. A mechanical advantage of 3:2 was determined provide a significant reduction in input without sacrificing too much in terms of pump stroke. This mean that a 30" user input would result in a 20" stroke received by the pump. The stroke was originally limited by the stopper in the why on the upstroke and the cage at the bottom on the down stroke to prevent linkage crossover at the top and the piston leaving the intake tube at the bottom. This was true until the third iteration of the pump, at which point the addition of a check valve in the bottom of the intake tube shortened the possible stroke length to about 17". Figure 1 shows the determined kinematic relations at the top of the stroke, with the user on the left end and pump on the right.

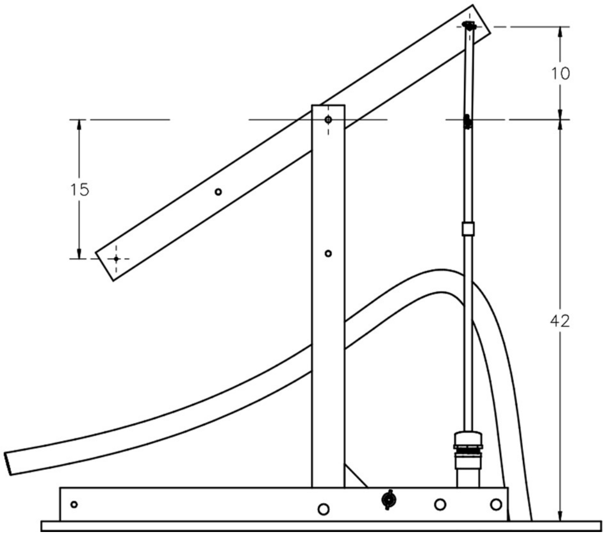


FIGURE 1: DIMENSIONS OF LEVER AT TOP OF INPUT STROKE.

The laws of mechanical advantage in Equation 1 state the following relation between side lengths, a and b, and the two input forces.

$$\frac{F_B}{F_A} = \frac{a}{b} \tag{1}$$

This reveals that using this mechanical advantage, the user input force would be multiplied by 3/2 when it is transferred to the pump. Early calculations revealed that a required input force to lift the sludge filling a gulper pump would be roughly 250 Newtons. This means that this lever configuration would reduce to input from the user to 167 Newtons. It was determined that this mechanical advantage would provide a great improvement to the gulper design and make the use much more reasonable for a single operator. The team was able to prove that this force input was accurate in testing with an input load of 186.4 Newtons, outputting approximately 280 Newtons of lifting force.

PRODUCT REALIZATION

Designing a device to empty pit latrines proved to be a challenging endeavor. The team overcame many obstacles with this design, including restrictions on available materials and manufacturing processes, a confined operating space, small latrine access holes, difficult to characterize and difficult to pump fluids, debris in the latrine, requirements for portability, as well as a lack of detailed information about the variety of latrine designs in Malawi. This design includes many simple features that are able to address these issues.

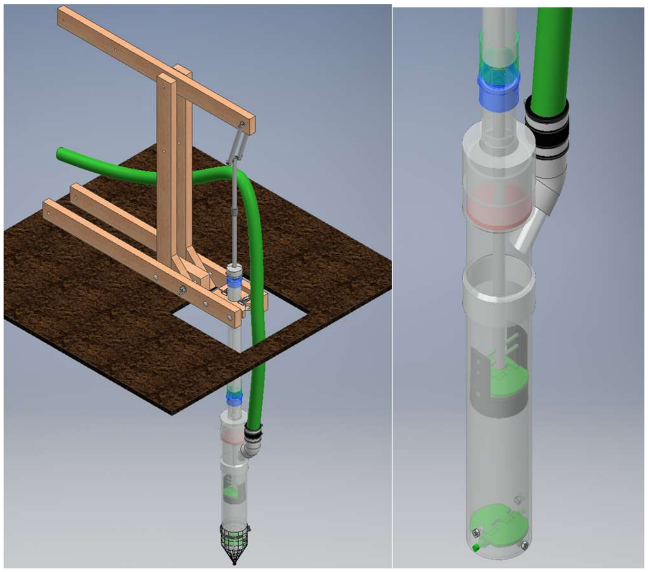


FIGURE 2: ON THE LEFT, AN OVERALL RENDERING OF THE DEVICE. ON THE RIGHT, THE SYSTEM OF FLAPPER VALVES CAN BE SEEN THROUGH THE TRANSPARENT PUMP INTAKE PIPE.

This design includes only materials that are locally available in Malawi, and thus represents a more sustainable solution to the issue of sanitation. By excluding rare and inaccessible materials, citizens of Malawi will be able to build their own low-cost latrine pumps without depending on any foreign aid or donations. Materials specified in this design are either standard size hardware, like ¼” bolts or ½” pipe with standard fittings, standard size PVC, or simple raw materials like 2” x 4” lumber. The notion of local availability extends beyond the materials comprising the product in that all of the tools required for manufacture are readily available, and most manufacturing processes have the option to be performed manually or with power tools. The entire design could be built in one day with a hacksaw, a drill, an angle grinder, and a stick welder.

The problem of operating in the confined space of a latrine room was addressed by designing a lever for power transmission with a maximum width of 9”, length of 4’ and an overall maximum height of less than 6’. The small footprint allows it to be used in just about any latrine that is big enough for a person. The floorboards of the lever extend back to the operator for stability and also allow bracing to be easily attached to compensate for uneven floors. The lever also allows operators to stand back from the access hole, rather than right over top of it as they must when operating the gulper. The lever itself is designed to be ergonomic and comfortable to use. It is basically a simple hand pump, with a pumping stroke ranging from hip height to shoulder height. The lever offers the user a 3:2 mechanical advantage, maintaining balance while amplifying the user’s input force.

The small latrine access holes dictated that the combined diameter of the pump and hose must be less than 8". The wye where the discharge hose is connected to the pump intake tube is the widest part of the pump with a diameter of just about 8" after trimming down the 2" section of a standard 4" x 4" x 2" wye. The cross-sectional area of this component matches the keyhole shape that is common in many latrines. The pump uses 4" PVC for the intake hose because it is the largest readily available size that fits in most access holes.

Latrine sludge is not a well understood material, with only three papers on the topic available as of 2014. The major decision when it comes to characterizing sludge is whether to treat it as a strong fluid or a weak solid. We treated it as a strong fluid, which informed the decision to use high-flow one-way valves made from door hinges. The valve system provided for the sludge to be lifted out of the latrine in case suction was not possible with dry sludge. A cage made from 1" wire mesh, formed into a point, protects the valves from damage and jamming by debris in the latrine and helps the pump penetrate into sludge.

Some of the novel features of the pump include its portability and modularity. The pump was designed to be transported by two or fewer people. The lever collapses and locks into one long bundle with the removal and replacement of one bolt. It could easily be strapped to a dolly with the pump and wheeled around behind a person, bike, or motorcycle. The pump breaks down into segments, which allows for easy transport as well as easy cleaning. Completely disassembled, the longest component of the pump is the lever, at 4' long. The modular design allows the pump to be easily and cheaply repaired, and it also means that it is capable of pumping pits of varying depth. By unscrewing the linkage from the piston rod and the cap from the guide tube, additional 2' sections of piston rod and guide tube can be screwed in. The cap and linkage then screw back on to these extensions, then after unbuckling the pump clamps, which are a pair of draw latches, the pump can be pushed 2' deeper into the latrine. Re-buckle the pump clamps and the pump is set up to pump an additional 2' of sludge.

Potential improvements to this design could include a better system for pipe clamps. We recommend using bicycle quick releases to pull the clamps together evenly, unlike the top-mounted draw latches, which tend to cause the clamps to bind on the guide bolts. The draw latch clasps can also interfere with the PVC fittings on the end of the guide tubes. It could also use a better method for cleaning. Right now, the policy is to rinse it as it is being removed from the latrine, pack it up, and take it off-site for more cleaning. Designing a valve that would allow flow to be reversed could clean the inside of the pump more thoroughly and would also help liquidize the sludge. The piston to cap interface could be improved with the addition of a nylon bushing.

The device meets our client's need to empty about two latrines of just about any configuration each day. It can be transported and operated by two people, protects the operator from sludge contact more than the current method does, and can be made in one day, affordably and from local materials.

TEST AND EVALUATION RESULTS

TESTING MATERIAL AND ENVIRONMENT

To test our design, the team wanted to begin by testing on water, then on a simulated sludge, and finally on actual pig waste. The goal of this testing was to determine the capability of the device using fluids with increasingly difficult pumping characteristics. Additionally, we wanted to measure flow rates and the required pumping power for each fluid. We began by testing our pump on water and on various platforms such as picnic tables, loading ramps, and truck beds to simulate depth while using a 32 gallon trashcan to hold the fluid. After successfully testing on water, we began testing a clay-water mixture from a simulated latrine environment that we constructed at the Virginia Tech Swine Center. Finally, we tested on pig waste that was collected from the Swine Center also using the simulated latrine environment. We also wanted to test the extensibility feature of our design in order to see how easy it is to extend the pump in use. To do this, the team tested at Pandapas Pond, where we were able take advantage of the depth to adjust our pump to its longest length.

To start off, we tested on water which had the best pumping characteristics of the three fluids tested. This was to ensure that the device was capable of pumping a fluid with a relatively low density and viscosity before moving on to a more difficult fluid mixture. When we were going through the first iterations of the pump, we used picnic tables and loading ramps outside the APPLIED laboratory as platforms to test off of. This gave us the height we needed to pump fluid out of a 32 gallon trash can. This initial testing on water was to test the pumping ability of the device due to the design being in the early stages of development and testing. In the later iterations of the pump, we measured pump flow rates and the required force to operate the pump. Water testing was done every time we modified the pump or made a change that could have affected its pumping capabilities.

After many successful tests on water, we looked for a way to create a simulated sludge and planned to develop a better environment to simulate the actual conditions in Malawi. To improve our testing environment, the team built an outhouse and dug a 3.5 foot deep hole at the Virginia Tech Swine Center. The outhouse was built according to plans provided by our advisor, Dr. Kochersberger. Our solution to creating a simulated sludge material was to use well a mixed combination of clay and water. If stirred well enough, the clay particles become mostly suspended in water, leaving some settling on the bottom, much like how sludge would stratify in a latrine. Upon doing this, we achieved a clay-water mixture with a density between 1,113 kg/m^3 and 1,183 kg/m^3, approximately 19% more dense than water, which was measured at 962 kg/m^3. The density of the clay mixture was determined by using the principle behind a hydrometer. Using some buoyancy calculations, we were able to calculate the density of the fluid mixture by how far a dowel rod penetrated the fluid. Like the water, the clay was initially used to test the pump's capability before moving on to a denser, more viscous fluid mixture with greater solid to liquid content.

Once testing on clay was complete, we moved on testing on actual pig waste. To do this, we obtained 1 week's worth of pig feces from the Swine Center and filled our hole with the waste. We first attempted to determine the density of the pig waste by filling a 5 gallon bucket and weighing it using a load cell. The density of the sludge was calculated by dividing the measured mass by the known volume of the bucket. It was determined to be 1105 kg/m^3 which was slightly less dense then the tested clay mixture. From a visual inspection of the pig waste, we concluded that it had a higher solid to liquid content than the clay mixture but still contained a good amount of liquid due to the urine that was mixed with the feces. During testing we found that it was necessary to liquefy the sludge by adding water and mixing it. This was necessary in order to reduce the size of the solid contents and the amount of stratification. Mixing helped to prevent the pump from clogging.

CONFIGURATIONS TESTED AND RESULTS

Throughout the semester, we tested several different configurations of the pump. The first of these was the original Gulper attached to a simple lever using a mechanical linkage. This design did not prove to be very effective after initial water testing due to the long stroke length required and valve crossover at the top of the stroke. After discovering these issues, we designed the second iteration of the pump which featured a modified piston, a swing door check valve, and a submersible housing that redirected flow through the check valve using a stopper. This design proved to work well with both water and the clay mixture but was not able to pump sludge due to a clogging issue. A final configuration of the pump which featured an additional flapper valve and no swing door check valve proved to be the most effective configuration that was capable of pumping water, the clay mixture, and pig waste.

The first iteration of the pump which used the original Gulper with a lever power transmission system had several design issues that prevented it from being an effective pumping device. One of the main reasons was the long stroke length that was required to lift the sludge the entire length of the tube. This generated the issue of linkage crossover which would occur at the top of the stroke. The lever operates on an arced path with the most lateral movement at the top and bottom of the stroke relative to the pump. This lateral movement generated a torque on the piston rod at the top and bottom of the stroke. This torque would cause the valve to tilt inside the tube which in turn would break the fluid seal and allow the fluid to flow around the piston valve. Since there was such a large stroke length required, a large lever was required. The latrines in Malawi are generally confined areas so a large lever design would have required a wall to be knocked down in order to pump the latrine. Additionally, the Gulper was not extensible for different depths. This means that the pump would be unable to operate in stratified sludge.

In order to fix the problems that the first iteration of the pump presented, it was necessary for the team to go back the drawing board. From this, a second design of the pump was created which featured a swing door check valve, modified piston, and submersible pump housing with a stopper similar to the final configuration. The modified piston was made from a 3.5" metal pipe which reduced the possibility for a breakage of the fluid seal by keeping the piston centered. The submersible housing was made using a 4" to 2" PVC Wye fitting with a stopper at the 4" outlet to redirect flow through a 2" swing door check valve. The housing significantly reduced the stroke length to only 2 ft. This is turn allowed us to create a smaller, simplified lever that could operate in confined spaces.

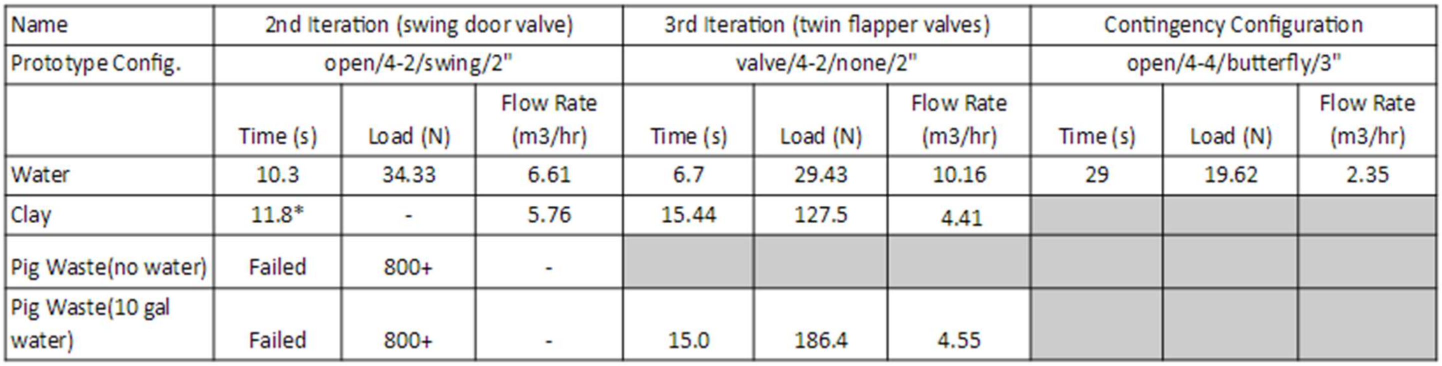
The second iteration design proved to be effective on water and the clay mixture but experienced a clogging issue when tested on pig waste. This is the first pump we attempted to pump pig waste with and we learned that it was necessary to liquefy the sludge. Even with the sludge liquefied, the pump continued to experience clogging issues at the swing door check valve. We concluded that this was due to the constriction point at the swing door check valve which transitioned abruptly from 2" to 1.5". One thing that we learned when testing on the clay mixture was that we were getting suction from our piston. Even though the tolerances were not extremely tight between the piston and the tube, we concluded that the clay mixture was helping to create a seal similar to how oil helps to create a seal between the piston and the cylinder in an internal combustion engine. This discovery was significant in contributing to the design of the third iteration of the pump.

To fix the constriction issue in the second iteration of the pump, we created a third iteration which is the current configuration of the pump. The third iteration eliminated the swing door check valve at the outlet of the pump and added a second flapper valve at the bottom of the intake tube. The final configuration also consisted of small modifications like the addition of draw latches to clamp the pump and clevis pins in attachment areas for easy disassembly. Since we learned the pump was creating suction, we decided to put an additional high-flow flapper valve at the bottom of the intake tube. This additional valve allows the pump to draw in fluid on the up stroke and prevent the fluid from escaping on the down stroke. The third and final iteration proved to be effective at pumping all three fluids.

An additional configuration was created in the event that the third configuration didn't work. This configuration consisted of a 4" to 4" PVC Wye fitting as the main housing, a flapper valve at the outlet, and a reduction to 3" instead of 2". A 3" corrugated hose was used instead of the 2" reinforced rubber hose. The idea behind this design was an attempt to reduce the amount of constriction that we were experiencing and increase the pumps capability to pump fluid mixtures with high solid to liquid content without clogging.

The team tested three different configurations of the pump for flow rates and the operational force required. The configurations included the second iteration and third iteration of the pump as well as the contingency configuration which utilized the 4" to 4" PVC wye housing. In order to measure the flow rates for each material, we timed how long it took to fill a 5 gallon bucket. We then converted this to a flow rate of cubic meters per hour. For each material, we measured the force required to operate the lever using a load cell that we borrowed from the Unmanned Systems Lab. We tested all three configurations on water, but only two configurations on clay and pig waste. We chose to not test the contingency configuration on clay and pig waste because of its low flow rate on water. Table 2 shows the measured times to fill a 5 gallon bucket, the required force, and the calculated flow rates for each fluid mixture.

TABLE 2: TEST RESULTS



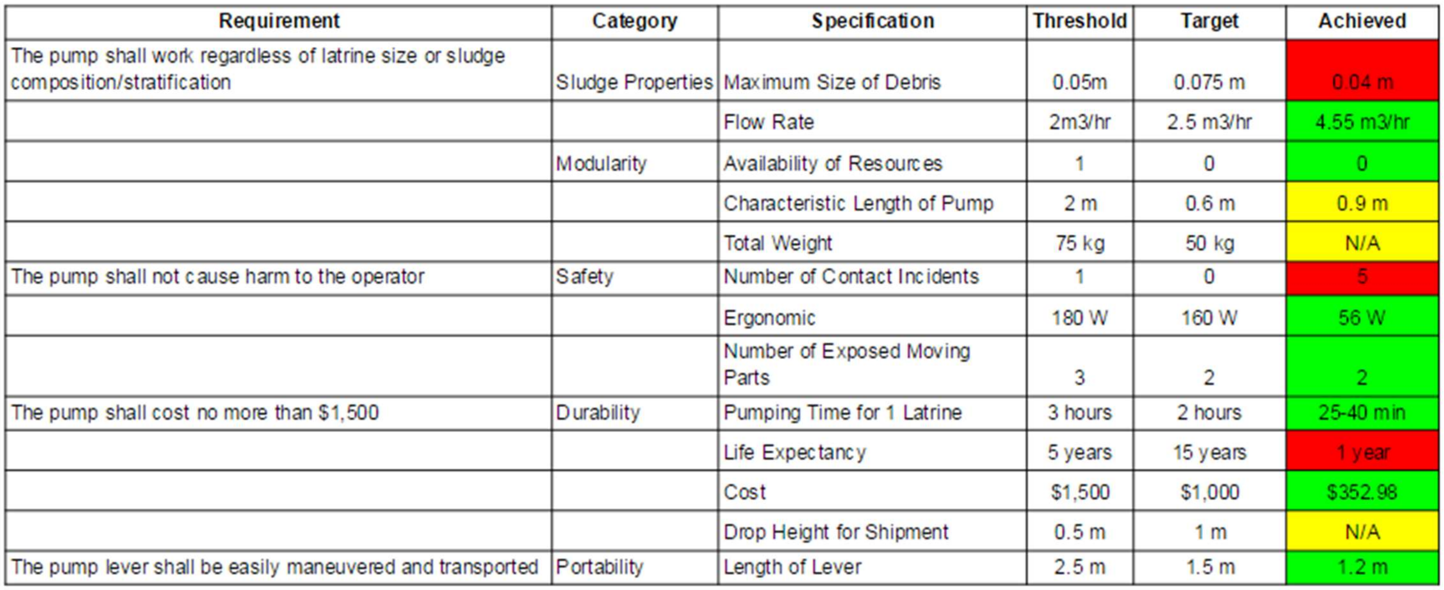
Name	2nd Iteration (swing door valve)			3rd Iteration (twin flapper valves)			Contingency Configuration		
Prototype Config.	open/4-2/swing/2"			valve/4-2/none/2"			open/4-4/butterfly/3"		
	Time (s)	Load (N)	Flow Rate (m3/hr)	Time (s)	Load (N)	Flow Rate (m3/hr)	Time (s)	Load (N)	Flow Rate (m3/hr)
Water	10.3	34.33	6.61	6.7	29.43	10.16	29	19.62	2.35
Clay	11.8*	-	5.76	15.44	127.5	4.41			
Pig Waste(no water)	Failed	800+	-						
Pig Waste(10 gal water)	Failed	800+	-	15.0	186.4	4.55			

*Estimated

From the results we determined that the third iteration of the pump was the most effective at pumping a variety of fluid mixtures. For the second iteration of the pump, we were able to achieve decently high flow rates for water and the clay mixture. The pump was capable of flow rates of 6.61 m^3/hr for water and 5.76 m^3/hr for the clay mixture. The second iteration pump was not capable of pumping pig waste even with a very high operating force. The third iteration was capable of flow rates of 10.16 m^3/hr for water, 4.41 m^3/hr for the clay mixture, and 4.55 m^3/hr for pig waste. Surprisingly, the third iteration performed worse than the second iteration pump on the clay mixture despite having a much higher flow rate for water and actually being able to pump pig waste. We believe this to have been because of different testing conditions when performing the clay testing. The clay testing was performed on separate days and the clay was not as well mixed when testing the third iteration of the pump. We can also see from the results that there is an increasing force requirement to operate the pump as we move from water to clay to pig waste. This is mostly likely due to the increase of solid content within each fluid mixture as well as an increase in viscosity.

Comparing the capabilities and characteristics of our pump against our target specifications, we can conclude that the design was successful at achieving most of our target goals and only failed in a few areas. A comparison of the pump capabilities and characteristics versus the target specifications can be seen in Table 3.

TABLE 3: EVALUATION OF ENGINEERING REQUIREMENTS



Requirement	Category	Specification	Threshold	Target	Achieved
The pump shall work regardless of latrine size or sludge composition/stratification	Sludge Properties	Maximum Size of Debris	0.05m	0.075 m	0.04 m
		Flow Rate	2m3/hr	2.5 m3/hr	4.55 m3/hr
	Modularity	Availability of Resources	1	0	0
		Characteristic Length of Pump	2 m	0.6 m	0.9 m
		Total Weight	75 kg	50 kg	N/A
The pump shall not cause harm to the operator	Safety	Number of Contact Incidents	1	0	5
		Ergonomic	180 W	160 W	56 W
		Number of Exposed Moving Parts	3	2	2
The pump shall cost no more than $1,500	Durability	Pumping Time for 1 Latrine	3 hours	2 hours	25-40 min
		Life Expectancy	5 years	15 years	1 year
		Cost	$1,500	$1,000	$352.98
		Drop Height for Shipment	0.5 m	1 m	N/A
The pump lever shall be easily maneuvered and transported	Portability	Length of Lever	2.5 m	1.5 m	1.2 m

We were able to achieve a flow rate of 4.55 m^3/hr which was 2 m^3/hr over our target goal of 2.5 m^3/hr. A flow rate of 4.55 m^3/hr enables the operators to pump a latrine in a mere 25-40 min depending on the size of the latrine. This was way under our target goal of 2 hours. To add to that, the pump only requires 56 Watts to operate. This was determined by multiplying the required force by the stroke length and dividing it by the time to perform one stroke. This characteristic is almost one-third of our target goal for the power required.

The design features no special components that would need to be imported from out of country and can be entirely made from locally available materials. Additionally, no special tools are required to manufacture the pump except for a welder which we were told was locally available. The overall dimensions of the pump and lever were compact enough that we were able achieved our target value for the length of the lever and the threshold value for the characteristic length of the pump. Also, the pump only features two potential pinch points which the team considered to be exposed moving parts. These two areas are the mechanical linkage that attaches the lever to the piston rod and the actual lever itself. This still meets our target goal of only two exposed moving parts. Finally, the entire design can be made for $352.96 which was significantly lower than the target value of $1,000. This price is also an overestimate due to some components having to be bought in bulk such as washers, bolts, nuts, etc. Each part is relatively inexpensive with the most expensive part being the 10 ft long rigid hose which costs $47. This is important because the device could be repaired inexpensively if a component of the device breaks.

There were only three target specifications that the pump failed to meet. The pump is unable to pump debris larger than 0.04 meters because of the constrictions of the flapper valves and the maximum size of the pipe. Our client wanted us to design for a pit latrine size hole of 16-20 cm which constricted us to a maximum tube size of 4”. To ensure that no debris larger than 0.04 meters enters the pipe, the design features a 1” by 1” wire cable mesh cage around the intake tube. This significantly reduces the probability our debris larger than 0.04 meters entering the device.

Another target specification that our pump failed to meet was the number of contact incidents with fecal matter. When we created this particular target specification, we did not specifically define how it would be evaluated. As a result of this, we considered any contact with the fecal matter to be a contact incident. We concluded that majority of the contact incidents were during the cleaning process and not during the actual operation of the device. The contact incident that occurred during the operation of the device were due to the team trying to get video footage of the pump flow. If the operators wore proper Personal Protective Equipment and had a closed container to pump the sludge into, the contact incidents could be significantly reduced if not eliminated.

The last target specification that our pump failed to meet was the life expectancy specification. The threshold value for this was 5 years, however the team predicted the device to last 1 year without any maintenance. With maintenance and some servicing parts, the team predicted the device could last up to 2 years, however it is difficult to predict life expectancy without testing in an operational environment. During our pump testing, no parts broke on the device but the team did recognize some potential wear on the device such as rust on the piston valve and enlarging of holes on the wood components. Some of the potential wear points could be minimized by small modifications such as rust protective paint. Additionally, if something on the device did need to be replaced, it would be inexpensive and easy to do. The entire device could be manufactured in less than one day by two people.

SUMMARY AND ASSESSMENT

This design should be considered a success because it was able to successfully remove sludge from a simulated latrine. We would assign a Technology Readiness Level of 6 (TRL 6) to this product because our prototype was tested in a simulated operational environment. This summer, it will have the chance to achieve a TRL 7 when an actual locally constructed prototype is tested on an actual latrine in Malawi.

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REFERENCES

[1] Batty, M., 2015, "Beyond the SDGs: How to deliver water and sanitation to everyone, everywhere," DevEx Global Views on Water and Sanitation, https://www.devex.com/news/beyond-the-sdgs-how-to-deliver-water-and-sanitation-to-everyone-everywhere-86975

[2] Gupta, G. R., 2015, "Opinion: Sanitation, Water & Hygiene For All Cannot Wait for 2030", Inter Press Service, http://www.ipsnews.net/2015/10/opinion-sanitation-water-hygiene-for-all-cannot-wait-for-2030/

[3] Tilley, E., Ulrich, L., Luthi, C. Reymond, Ph., and Zurbrugg, C., 2014, "Compendium of Sanitation Systems and Technologies. 2nd Revised Edition", Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dubendorf, Switzerland, pp. 86-87.

[4] Radford, J.T., and Fenner, R.A., 2013, "Characterization and fluidization of synthetic pit latrine sludge", Journal of Water, Sanitation, and Hygiene for Development, **3**(3), pp. 375-382

[5] Radford, J.T. and Sugden, S., 2014, "Short communication: Measurement of fecal sludge in-situ shear strength and density", Water SA, **40** (1), pp. 183-188