Ram Pump

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Abstract

Agua Clara plants use gravity and smart hydraulics to operate, which provides difficulties in providing treated water back to the plants to fill chemical stock tanks for coagulant mixing. The ram pump is going to be implemented in a plant in Las Vegas, Honduras where the outlet of the plant is significantly lower than where the chemical stock tank is located. However, the ram pump can also be applied to other locations, Las Vegas is used only as an example with known parameters. The stock tank is located 5.65 m above the plant outlet with the ram pump will be located 1.5 m below the plant outlet, giving the pump a delivery head of 7.15 m. The ram pump team aims to create a model for a system that could deliver 1100 L of water over the course of 3 hours, or a delivery flow rate of 0.102 L/s. A testing apparatus using 3/4" inlet and 1/2" outlet pipes were built in order to test correlations between various parameters of the pump. It has been found that higher drive heads along with greater weights on the waste valve are two ways to increase the delivery flow rate. Typical drive flow rates from our testing aparatus tend to be about 0.151 L/s, with our best delivery flow rate being 0.0102 L/s (about 7% of drive). The optimal delivery flow, and percentage of drive, have been attained when the drive head was at its highest and the weight on the waste valve was its greatest.

1 Literature review

1.1 Design of hydraulic ram pump systems

Ram pumps have been used for almost 200 years to pump water with only the power of gravity. Recently, they have become more popular as they offer a sustainable and carbon free method of pumping. While they have only two moving parts, their behavior is complex and not well understood. Several approaches have been taken to model their operation, breaking the cycle anywhere from two to seven distinct phases. One of the most pervasive outlines the cycle as 1) acceleration, 2) pumping, and 3) recoil. However, empirical observations and rules-of-thumb still dominate in ram pump analysis. [1]

For example, Young's report contained several significant conclusions for ramp pump designs derived from experimental observation:

1. L/H, the ratio of the drive pipe length to the drive height, has a basically negligible effect on performance.

2. The ratio of steady state velocity in the drive pipe (u_0) to the critical velocity (u_c) that allows the waste valve to close should be less than 0.8 ($u_c/u_0 < 0.8$).

3. Performance deteriorates when$h > 0.6 * h_{max}$ (delivery height/the maximum theoretical delivery height).

1.2 Clemson University

Ram pumps function by converting the momentum from a large amount of falling water into the potential energy required to raise a small amount of water to a height much higher than the source. This is done by utilizing the effect of "water hammer" shock waves. First, water falls from the source into the ram pump via the drive pipe. At the beginning the cycle, the water flows up out of a waste valve. The waste valve starts out as open, but as the water accelerates, the drag force on the valve increases, and slams the valve shut. At this point, the water coming down the drive pipe still has momentum, yet it can no longer flow out of the waste valve. A strong water hammer occurs, causing a pressure spike at the closed waste valve and sending a shock wave through the pump. As a result, water is pushed through a spring check valve into the air pressure chamber as well as back up the drive pipe. After a significant amount of pressure has traveled up the drive pipe, the the spring check valve outside the air pressure chamber will close and retain the pressure inside the chamber. After slightly more pressure is lost, the waste valve reopens, allowing water to flow through it and for the process to begin again. After enough water is built up within the air chamber, the pressure inside the air chamber will push the water through and out the outlet pipe.[2]

Because the water hammer effect has strong forces associated with it, the rigidity and straightness of the drive pipe is very important when it comes to the ram pump's efficiency. A weaker pimp is prone to vibration, and thus energy loss. Therefore, the use of galvanized steel is recommended, but the cost may be an inhibiting factor. The length of the drive pipe is another important factor as it has been observed that a longer drive pipe results in a longer stroke period. Empirical data has determined the following ratios for drive pipe length (L) and drive pipe diameter (D)[**?**]:

$$L = 150 * D \tag{1}$$

$$L = 1000 * D \tag{2}$$

Ram pumps are very inefficient. Usually, 8 gallons will pass through the waste valve for every 1 gallon that makes it up the delivery pipe. [2] Fortunately for AguaClara, this aspect is rather unimportant as the waste from AguaClara ram pumps will be transferred to a distribution tank via a downward pipe.

1.3 Warwick University

The air pressure chamber is used to ensure that the flow through the delivery pipe is a steady and continuous flow rather than a pulsating one. It also provides constant head to pump against and helps to cushion the apparatus against the pressure spikes caused by the water hammer. It is recommended that the air pressure chamber be 20-50 times larger than the volume of water pumped in a cycle. This prevents the pressure of the air chamber from changing too drastically with each pump of water into the chamber.[3] In order to prevent water-logging within the air chamber, there are two main options. One is for the air chamber to come equipped with a snifter valve, which would help replenish air in the chamber after each pump to replace the air taken into solution. The second option is to use "contained" air to cushion the shock caused by the pump. Contained air could be in the form of bubble wrap or partially inflated bicycle inner tubes.[4] Commercial pumps typically use sophisticated diaphragms, but these are unrealistic for DIY projects. Contained air appears to be the best option because of its simplicity. AguaClara's current ram pump design utilizes contained air through the use of partially inflated bicycle tires.

1.4 Somaiya University

A research project completed by Somaiya University attempted to analyze ram pump systems by experimental, theoretical, and numerical methods. Their report contains a rough outline for a software program developed to size systems and includes several significant equations for ram pump operations. For instance, there are two standard ways to define the efficiency of a ram pump: [5]

$$\eta_{Rankine} = q * h/((q + Q_w) * H) \tag{3}$$

$$\eta_{D'Aubuisson} = q * (H + h)/((q + Q_w) * H) \tag{4}$$

Where q is the flow rate of the water through the delivery pipe, $Q_w$is the flow rate through the waste valve, h is the delivery height (relative to the source), and H is the source height (relative to the waste valve). These two efficiencies can serve as examples of the varied approaches taken to characterize ram pumps as noted in "Design of hydraulic ram pump systems." The Somaiya report also lists four different rules of thumb to size the drive pipe, including equations 1 and 2.

2 Introduction

A ram pump has the ability to raise a small amount of water to high elevation using a large amount of water's momentum falling a shorter elevation. This technology uses the water hammer to build up pressure and drive the process, so therefore no electricity or external powers are needed to pump the water.

Essentially, smart hydraulics is used, making the pump a perfect fit for use in AguaClara plants.

In an AguaClara plant in Las Vegas, Honduras the ram pump will be used for cycling water back to the main water treatment plant for the village. The water that is being pumped will then be used for coagulant mixing and dosing. The drive head is approximately 1.5 m with a delivery head of 7.15 m., which is well within reason of a ram pump's capabilities. In Las Vegas the necessary delivery flow is 1100 L/d, however for operational purposes the pump should be designed to provide this volume of water while only functioning for three hours per day. With this limitation in mind that requires a delivery flow of about 0.102 L/s. Using a general guideline of 90% waste of drive flow, the inlet flow rate for Las Vegas should be roughly 1.02 L/s.

Our testing apparatus, which can be seen in Figure 1 below, has just recently been completed after improving the needle valve, making the air chamber air-tight, stabilizing the inlet structure, and creating a waste/recycle valve that can be easily modified. A first, quick test for drive flow rate gave us a value of 0.6 L/s. However, with our pressure sensors not currently functioning flawlessly we do not currently have an estimate on our delivery head. Our goals for the rest of the summer include: optimizing our pressure sensors, running further tests on our apparatus to determine key factors in ram pump operation, find a way to increase drive flow rate, and determining a relationship between desired deliver flow rate and ram pump parameters (diameters and lengths of pipes, air chamber size, delivery head, etc.) for use in a ram pump sizing software program.

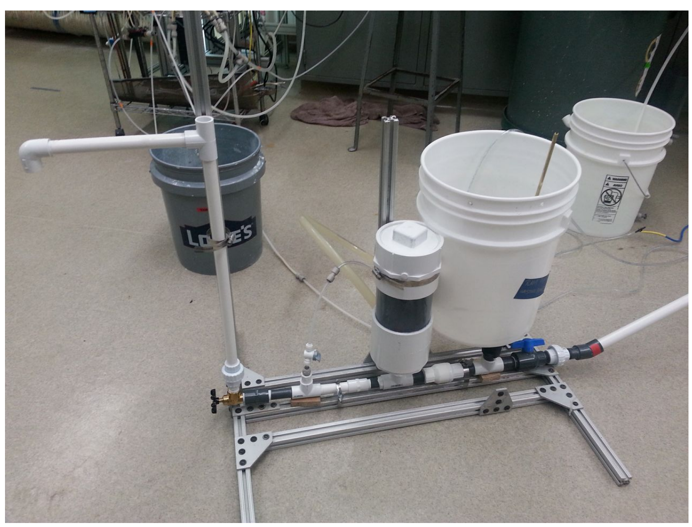

Figure 1: Current ram pump

3 Methods

3.1 Background of methods and materials

The ram pump operates under the conditions of an applied and desired flow rate as well as a supplied drive height and desired minimum delivery height. Therefore we will focus on measuring these variables when testing. Pressure sensors will be primarily used, data from which will be collected using the EasyData program.

A 200kPa pressure sensor will be used to measure pressure after the air chamber and before the needle valve, effectively measuring the potential delivery height before any losses in the delivery pipe. An additional 200kPa sensor is placed directly under the waste valve to observe the pressure waves caused by the water hammer. This may allow us to understand a correlation between the pumps performance and the pressure created at the waste valve. Knowing this pressure will also allow us to judge whether we could exceed the 400 psi rating on the valve, or if we are fatiguing it at a too high pressure.

In order to measure delivery flow rate, a 7kPa pressure sensor was placed near the bottom of the bucket, shown in Figure 2 below, used to collect the water. By recording the growing pressure in the bucket, we can easily derive the flow rate by finding the change in height over time and knowing the cross sectional area of the bucket.

Figure 2: Locations of respective pressure sensors

Currently, measuring the drive flow rate is a rougher method. In the inflow tube connecting the sink to the drive pipe, a tee fitting was inserted with valves on 2 of the exits so that the flow can be directed down the drive pipe or to a bucket, as displayed in Figure 3 below. After a test, the flow is diverted towards the bucket and the flow rate is measured by recording the volume in a certain amount of time.

Figure 3: The tee-fitting

The drive height can be adjusted by raising or lowering the series of fittings, seen in Figure 4 below, on the tower which connect the inflow, overflow, atmospheric vent, and drive pipe.

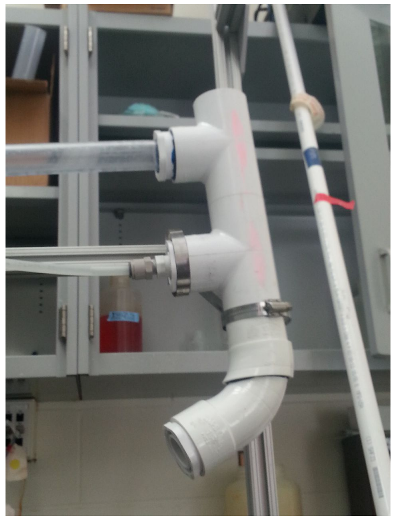

Figure 4: Drive pipe fittings. The top hole is the atmospheric vent; the top tube is the overflow; the bottom tube is the inflow; and the bottom hole connects to the drive pipe.

Due to height limitations, we can only see the theoretical delivery height in the lab, since this could technically reach several meters into the air. This will be monitored by the previously mentioned 200kPa pressure sensor. Another was added after the needle valve, but we have determined that it is only able to measure the amount of water above it and, therefore, is not applicable to delivery head. To ensure that the pressure sensor before the needle valve was an accurate representation of head, we allowed the presure to be equiviliant to the delivery pipe height. When this pressure occured we observed a small trickle coming out of the delivery pipe, confirming that this pressure sensor gave an accurate measurement of delivery head. Additionally, by adjusting the needle valve, Figure 5 below, we can create different delivery flow rates, which will consequently create different delivery heads. Typically, the needle valve should only be opened slightly during operation so that the pressure in the air chamber remains stable.

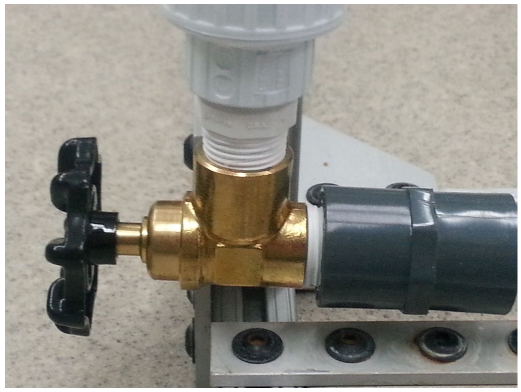

Figure 5: Needle Valve

The waste valve is the most critical feature of the ram pump. The waste valve is a brass disc valve with a Buna-N seal. We removed the springs to allow for it to be open intially and closed when a large amount of water pushes the valve. The pump will most likely have to be “primed” by opening and closing the valve manually. Additionally, we have noticed that the air chamber must be at high pressure before the pump can operate automatically. This can be done by closing the needle valve at the beginning of operation.

The waste valve opens and closes due to the balance of pressure, drag, and gravitational forces acting on the disc which opens and seals the valve. The easiest way for us to measure and adjust these is through changing the weight on the disc, which can be done by adding mass to the plunger resting on the disc. Currently, the method is to add nuts pinned between small rubber stoppers, which is presented in Figure 6.

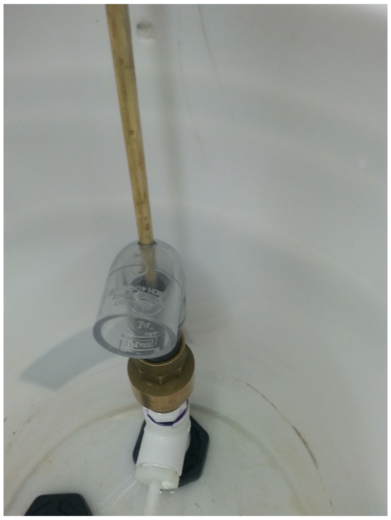

Figure 6: Waste valve

The water hammer in the pump causes the drive pipe to shake violently and leak a large amount of water from where it connects with the ram pump, reducing the pump's efficiency. To stabilize the drive pipe, we added cushioned chairs below it, which can be seen in Figure 7 below. In Honduras, this problem would actually be solved by setting the drive pipe in concrete or the terrain.

Figure 7: Make-shift stabilization system for drive pipe

In order to solve the drive pipe's leaking problem we added a rubber Fernco fitting that could be tightened on both ends that can be seen in Figure 8, which has proven useful.

This overall setup allows us to test and adjust several operating conditions. For example, we can set the drive pipe at a desired height with a desired drive

Figure 8: Rubber fitting

flow rate, and then run the pump with a series of masses on the waste valve to see how it affects performance.

3.2 Testing Procedure

1. Set up ram pump by connecting drive pipe and putting chairs under the drive for stabilization
2. Make sure all necessary valves are opened and closed
    (a) Needle Valve should be closed, waste valve should be open, and the two valve system near the faucet should be oriented so all the flow is guided to the drive pipe
3. Add desired weight to waste valve by adding nuts (6.8 g / nut)
4. Place overflow tube into the delivery tank bucket, so the drive flow can be more accurately tested
5. Check that all pressure sensors are working and line up with their desired function in Easy Data
6. Turn on faucet to a desired flow rate
7. Begin priming the waste valve (opening and closing it manually) until ram pump can begin to operate on its own
    (a) Should only take about 20 or less manual primes to begin.

(b) If not working after 20 priming strokes, change the flow rate based on the waste valves state. If the waste valve stays open, increase the flow. If the waste valve stays closed, decrease the flow. A change in drive head may also be considered, however this takes more time.

8. Allow for pressure behind the check valve and before the needle valve exceed the pressure that the waste valve experiences. This will enable the ram pump to operate freely for long periods of time

9. Open the needle valve in a manner that maintains water level in the air chamber. The needle valve should also ensure that the pressure before it is greater than the waste valve pressure.

10. Begin recording data using Easy Data and allow ram pump to operate for 5-10 minutes

    (a) Open Easy Data

    (b) Make sure all pressure sensors correspond to their proper names in the program (this can be done by pressing fingers against pressure sensors)

    (c) Zero all pressure sensors before allowing any water into the system

    (d) Set the display update frequency to 100 Hz

    (e) Once ram pump is operating on its own begin recording data by pressing the button to the left of the flashing red button

11. Once sufficient data has been collected open the needle valve entirely to allow air chamber to drain (it may not fully drain, but this is unimportant)

    (a) Make sure not to turn off the faucet as it is still needed to test the drive flow rate

12. Change the orientation of the tee valve system by the faucet to test drive flow rate, using a bucket with a pressure sensor

13. Repeat process for different flow rates, waste valve weights, and drive heads

4 Analysis

The previous waste valve was a modified PVC check valve with a steel disc. The problem with this design was that the PVC would likely be too weak to withstand the effects of the water hammer for extended periods of time. Additionally, one of the nuts in the valve was beginning to corrode.

When we first attempted to design a new valve, we experimented with ball check valves. One challenge we faced was making it so the valve would be open initially. Due to gravity, the ball would begin at the bottom of the valve, therefore closing it. We solved this problem by cutting slits in the base where the ball rested so that water could still get through. Another problem with this was difficulty finding a ball with a suitable weight to fit our needs. Despite our efforts to adjust how far the ball would have to travel to change the valve from open to shut, all of the balls we tested seemed to be either too light and stay at the top of the valve, or too heavy and stay at the bottom.

As a result, we tried a new design which has proved to be significantly more successful. We removed the spring from a brass check valve to ensure that it would be open initially and closed when pushed up. Since the valve requires only about 1 psi to open normally[6] (and therefore about 1 psi to close in our modified version of the valve) we had to add weight, which ended up being from a metal rod with a nut soldered to the end. The nut helps center the rod on the disc in the valve. The water then exits out of an elbow joint screwed on top of the valve. This joint has a hole in the top of it which serves as a guide for the rod. Furthermore, additional weight can be added to the valve by placing nuts of a known weight (6.8 grams) to the rod using to rubber stoppers. When the correct amount of weight is added the waste valve can function for a long time with few priming pumps.

We began to investigate the relationship between drive flow and head with the amount of weight we place on the waste valve in an attempt to find the optimal delivery flow (roughly 10% of the drive). We then ran the water as high as needed to get the pump to function and recorded the results, which are listed in Table 1 below.

Table 1: Data from various tests

	Drive Flow (L/s)	Delivery Flow (L/s)	Mass (grams)	Drive Head (inches)	Delivery Head Range (m)	Waste Valve Pressure (m)	Delivery flow/ Drive Flow
2 nuts	0.145	0.004	**68.4**	**55.0**	3.57-4.35	(-1.7)-3.1	0.0265
3 nuts	0.128	0.005	**75.2**	**55.0**	4.51-5.81	(-1.2)-5.0	0.0354
4 nuts	0.153	0.007	**82.0**	**55.0**	4.56-5.54	(-0.8)-4.4	0.0429
2 nuts	0.129	0.008	**68.4**	**68.0**	6.18-7.81	(-0.64)-3.22	0.0582
3 nuts	0.127	0.006	**75.2**	**68.0**	6.21-8.79	(-1.0)-3.5	0.0438
4 nuts	0.144	0.010	**82.0**	**68.0**	4.95-5.51	(-0.8)-4.5	0.0696
2 nuts	0.141	0.009	**68.4**	**75.5**	6.90-7.60	(-0.1)-2.3	0.0614
3 nuts	0.146	0.010	**75.2**	**75.5**	5.19-6.03	(-0.6)-2.9	0.0697
4 nuts	0.142	0.010	**82.0**	**75.5**	5.97-7.17	(-1.0)-3.5	0.0717

Table 1 above and Figure 9 below demonstrate a hypothesis that a higher delivery flow rate can be acheived by either increasing the drive head or the weight on the waste valve. The higher drive head gives a higher delivery flow

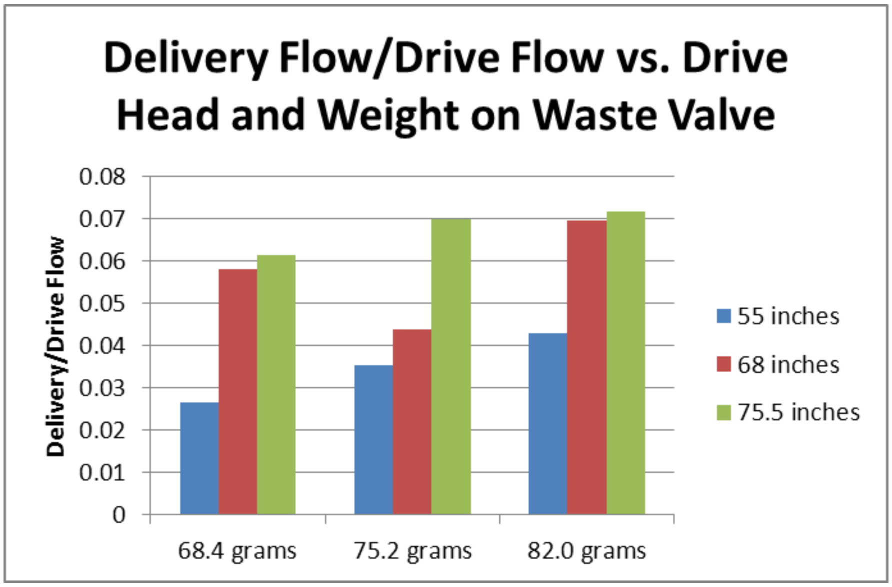

Figure 9: Graph comparing the percentage of delivery flow to drive flow with certain drive heads and weights

rate most likely due to the higher velocity that the water will experience because of gravity. This higher velocity will give the water hammer a greater celerity (wave speed), which in turn will allow the waste valve to close and the check valve to open more frequently. Furthermore, the higher velocity will mean that each time the check valve is open more water will pass before it closes again. The increased frequency of strokes has been observed when the pressure in the waste valve hits its low point in the secondary wave (the gradual pressure changes that can be seen in Figure 10). This phenomenon can be somewhat quantifiably seen in Table 1 as the data for the 1.92 meter drive head also tend to have low pressures in the waste valve. When the waste valve has a greater weight attached to it, it was found that the delivery flow rate is greater. Further observations and research need to be done to determine why this may be. The initial theory is that with a greater weight on the waste valve the time that the valve is open would be less. This would increase the number of strokes per minute, which as afore stated could be a sign of greater delivery flow.

More data is required before definite conclusions can be drawn, but it seems that a greater driving head and a greater mass on the waste valve could lead to a greater delivery flow. Unfortunately, our drive flow is extremely limited. We need to this be higher with greater variability if we are to test greater weights on the waste valve. We would also like a drive flow that is closer to that available in Honduras (1 L/s to 20 L/s). When the sink is at full power and water is flowing through the tubes that lead to the inlet pipe, the drive flow produced is a maximum of 0.151 L/s. Without the tubing, it can reach a maximum of 0.469

L/s. This leads us to believe that the tubing is choking our drive flow.

In an attempt to produce a larger drive flow, we have set up a series of pumps and buckets. The drive and recycle tank will contain water to begin with to get the pump going. Water from the waste bucket will be transferred to the recycle tank via gravity, which will then pump water to the drive tank. The sink will also provide water to the drive tank to compensate for flow lost to the air chamber and delivery pipe. We have hypothesized that the water dropping from the delivery tank will provide a greater drive flow.

We intially attributed low readings from the pressure sensor after the needle valve to a defect in the sensor itself, but after further investigation, we concluded that the sensor could only measure the pressure of the water sitting above it. Therefore, it could only measure the length of the delivery pipe. This was supported by the fact that the sensor measured a pressure of about 40.0 cm, which was also the height of the delivery pipe. Since we intially thought that the pressure sensor before the needle valve would be a more accurate measurement of head, we had to investigate how the measurements taken by the sensor before the needle valve compared to actual head. We allowed the pressure to decrease enough that the pressure sensor before the needle valve measured only about 40.0 cm. We observed that only a trickle came out of our delivery pipe. Therefore, we determined that the head loss in the needle valve was neglible and that the pressure measured before the needle valve was a reasonably accurate estimate of the amount of head we can expect to produce. In the future, it may be useful to calculate the actual head loss, but due to the various orifice sizes that can be produced by turning the needle valve, this would be very complex. A comparison between the pressure at the waste valve and before the needle valve is shown below in Figure 10.

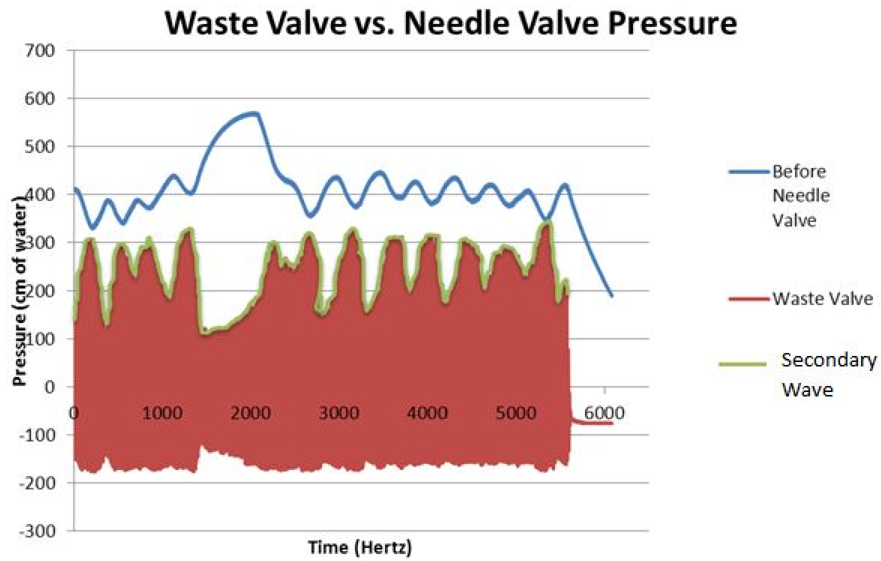

Figure 10: Pressure at the waste valve compared to pressure at the needle valve

The large spike in the graph correlates to a point in which the needle valve was closed. It is interesting to note that as the general pressure in the waste valve decreases, the pressure before the needle valve increases. Therefore, as more water builds up in the air chamber, the pressure in the waste valve generally decreases. We hypothesize that the waste valve pressure rapidly alternates from positive to negative values as a result of the quick and strong effects of the water hammer. It is likely that the area before the needle valve isn't as affected by the water hammer due to the cushioning in the air chamber provided by the air in the chamber itself and in the bike tires, thus giving the before needle valve curve a much smoother response. Another interesting feature of this relationship is that if the pressure before the needle valve falls below the pressure in the waste valve, then the ram pump will stop functioning on its own. This information could be used to determine a method for knowing when the pressure in the air chamber is becoming too low. Currently this is determined by either watching the graph above form on the computer or watching the height of water in the air chamber. Both of these methods will not work in Honduras, so an alternate method should be conceived. A more detailed look into the secondary wave needs to be done to determine why the pressure at these two locations act in this manner.

5 Conclusions

Through our experiments, we have determined that there is a significant relationship between the efficiency of the ram pump and the drive head and weight on the waste valve. As one can see in Figure 9, the greatest efficiency so far was achieved with a greater drive head and a greater weight on the waste valve. However, given a specific drive flow, there is a point at which adding more weight would cause the pump not to function. A mathematical relationship for this should be investigated. We also discovered that once the pressure before the needle valve drops to the pressure of the waste valve, the pump would cease functioning. This could be used in the future to determine a method for an operator in Honduras to monitor the pressure effectively and keep the pump running smoothly. We also discovered that our original set-up limited our variation in drive flow. A new drive apparatus should allow future teams to test multiple drive flows, therefore allowing for more useful data collection and the creation of a mathematical model.

6 Future Works

6.1 New Set Up

We realized that our drive flow rate was extremely limited by the flow coming through the sink via tubing. As a result, we had to construct a new method of creating drive. This involved having a raised tank from which the drive flow dispense, which can be seen in Figure 11 below. Water would be pumped from the waste bucket to a recycle tank at which another pump would pump it up to the drive tank. Water from the sink would replenish water taken into the air tank and lost through the delivery pipe. Unfortunately, these alterations have taken much time away from testing. Future teams will perform various experiments with our altered ram pump.

6.2 Mathematical Model

Through mathematical reasoning and experimentation, they will determine relationships between various factors. This will include: the relationship between the flow rates and heads with the weight on the waste valve; the amount of water in the air chamber and the head delivered from the output; the amount of time required to fill up the air chamber to output a certain head and flow rate given an input head and flow rate; the given flow rate and head and dimensions of the pump; the drive flow and the weight on the waste valve; etc. They will write programs containing relations between various factors. One could enter data or design requirements into these programs and then obtain expected performance parameters. These programs could be used to size future pumps with different desired characteristics than our test model.

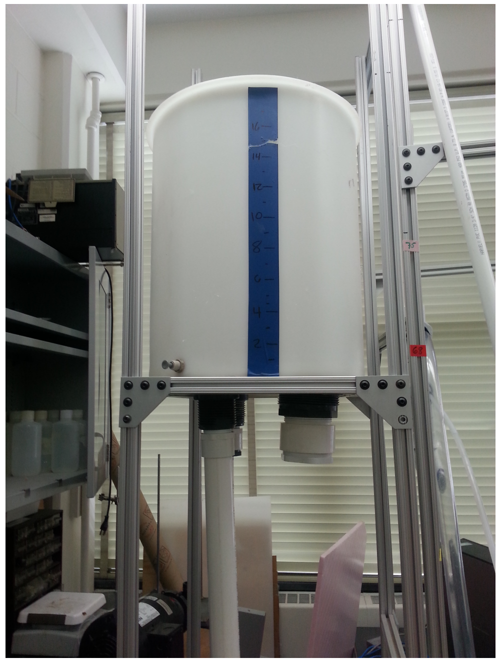

Figure 11: Drive Flow Tank with overflow and pump connection

6.3 Giving the operator eyes into the pump

The future ram pump team also needs to devise a way to allow a ram pump operator in Honduras to determine when the pressure in the air chamber is becoming too low since pressure sensors and looking through clear PVC are not plausible options.

6.4 Differing Air Chambers

Furthermore, it is possible that our air chamber is now too small to produce a suitable flow rate. The next ram pump team will experiment with different sized air chambers in the future to see how the size of the air chamber affects the delivery flow.

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