Ram Pump, Fall 2015

Priya Aggarwal, Juan Guzman, Joshua Levi Ringquist

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Abstract

The ram pump used at AguaClara plants uses gravity and hydraulic principles to operate. The surge in pressure of the water due to the closing of the waste valve is used in the ram pump to lift water to a higher elevation. The ram pump is placed below the water treatment plant and it is used to drive the water to the chemical stock tanks and the restrooms located above the plant. Ram pump design parameters, specifically spring components, check valve type, and air chamber size, were tested to determine their effects on ram pump efficiency. Additionally, the pump needed to be reassembled this semester. The team has changed the design to make it more portable to avoid needing to rebuild the pump if it must be moved again. It is much easier to test different parts of the pump when leaks occur or if a part does not work as it is supposed to with the new setup. The team also tested air chambers and different spring lengths this semester.

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Task List:

1. Assemble pump [all; September]
    - Order parts [early September; Juan]
    - Determine location where we can assemble: account for any height restrictions in that location [early September; Levi]
    - Put the parts together to form the ram pump [late September/early October; Levi]
2. Experiment
    - Determine how changing the spring affects flow rate and cycle time [Priya; late October]
    - Determine where the water leaks from [Sarah; early to middle of October]
    - Determine effects of varying air chamber dimensions [early November; Juan]
    - Determine how our pump will fit into the Honduras plant blueprint [Levi]
3. Design
    - Find the optimal spring length [Sarah; mid November]
    - Implement procedures to seal leaks [Sarah; end of October]
    - Find the optimal air chamber dimensions [Juan; mid-end November]
    - Modify design to mesh with the Honduras plant [Levi; end]
4. Synthesize
    - Bring all research together to make final modifications to the pump and write the final report

Introduction

The goal of AguaClara is to provide clean drinking water to communities where access to clean water is limited. The goal of the Ram Pump subteam is to find a method to pump a portion of the treated water against gravity back into the plant. The ram pump is used to refill chemical stock tanks and provide water for the restrooms in the plant. An electric pump could accomplish this task, but the plant is designed to operate without electricity. Ram pumps operate by taking advantage of fluid mechanics and gravitational potential energy: energy stored via elevated water is converted to kinetic energy against gravity via a system of interlocking valves. The ram pump team worked to make improvements to the existing ram pump that previous teams had developed.

This semester's team expanded upon previous teams' vertical pump design by testing and adjusting the length and rigidity of the check valve's spring and the dimensions of the air chamber. Building on the work and research of previous teams, the team hopes to produce a predictable, consistent, and large enough flow rate.

Literature Review

The first ram pump design was developed in the 18th century, and the first fully functional ram pump was developed just before the turn of the 19th century. In the time between 1796 and 2015, ram pumps have developed and become commercial products that reach efficiencies of 60% or more. The AguaClara ram pump team is not trying to surpass these efficiencies and become a ram pump vender. Instead, the team wants to understand which variables influence efficiency and how they influence it. Using this knowledge, the team will manipulate these variables to create greater efficiency.

Current discussions of efficiency include the following manipulatable variables: pipe diameter, spring constant, and dimensions of pump components. Previous AguaClara work has emphasized the spring and dimensions aspect. This team will continue this research as well as the effects of changing the dimensions of the air chamber. AguaClara research and external research confirm that the air chamber greatly affects the efficiency.

The longevity and value of ramp pumps are also important topics. Most ram pumps exist in places where conventional pumps powered by external sources are unavailable. Money is also an issue in these situations. As a result, people are interested in the value and longevity the pump can produce. The value of a ram pump is threefold: it is relatively cheap to build or buy; it requires little maintenance; and it requires no external power source, so it has a low operating cost. In addition, ram pumps typically have long product lives. They operate with few moving parts, so there are not few parts that can break. They are, however, subject to high pressures, and this is a potential cause for failure.

The AguaClara pump varies from other pumps in its vertical design. The research from previous teams on this development revealed that the conventional horizontal design loses energy due to the bend in the pipe. As a result, the team changed the design of the AguaClara pump to a vertical design.

One final note about literature that the team believes essential knowledge:
AguaClara develops plants mainly in Honduras where the elevation constantly changes, so there is plenty of head.

Previous Work

The previous Ram Pump team designed a new ram pump system which inverted and condensed the previous system. The new system includes a spring manipulation apparatus which makes testing how different springs affect the system easier. The apparatus allows the team to change the length of the spring and change the spring itself without having to take apart the system. After completing the design for the new system the team went on to continue to test and improve the system in order to try to reach the end goal of obtaining the desired flow rate for the plant.

Previously the team thought that flexible tubing could be used in place of an air chamber but after testing with both, it was clear that an air chamber is necessary to provide a constant flow rate. When testing the air chambers it was found that air chambers with greater lengths provided a higher flow rate than those with shorter lengths and the same radius. The previous team was also not able to find an optimal spring for the system because many of the springs tested gave similar results. The team also noticed that there were slight dips in the pressure-time graphs for the system. This is unusual because theoretically the graph should be more or less smooth.

The team was able to show that the new system worked just as well as the old system and that it has the potential to have an even better flow rate than the old system.

Methods

The previous ram pump set up was very difficult to disassemble, and pipes had to be cut in order to move the setup to a different location. Therefore, this time when the team built the setup they made sure that the system could be taken apart without having to cut pipes. The team accomplished this by adding a union to the drive pipe. The ram pump also had to be set up without a kiddie pool in the new lab space. Consequently the team decided to use two buckets connected by a pipe instead. One bucket will hold the auxiliary pump, and the other bucket will contain water that isn't pumped by the ram pump. The buckets are connected by a two inch diameter PVC pipe. The pipe connecting the two buckets also contains a union so that the buckets can be separated when the system needs to be disassembled. The diameter needed for the pipe was calculated using MathCAD and the process outlined below.

For pipe between the floor-bound buckets:
Using Minor Loss Eq:

$$\Delta h = (8KQ^2)/(\pi^2 g D^4)$$

Q = 1 L/s
K = 2 (overestimate, but that's the point)
for D = 2.07 in (2 inch pipe schedule 40), h_{diff} = 2.2cm
for D = 1.61 in (1.5 inch), h_{diff} = 5.9 cm
for D = 1.05 in (1 inch), h_{diff} = 32.7 cm

The flow rate, Q, is the flow rate through the drive pipe. The K value, which is the loss due to bends, assumes that there is no velocity component going through the beginning of the pipe, and that all the kinetic energy is lost immediately upon exiting the other end of the pipe. While a 1.5" pipe could have been used and gotten a small difference in water level of 5.9 cm, there was no reason not to have a lower difference, so a 2" pipe was chosen. The pipe connecting the two buckets also contains a union so that the buckets can be separated when the system needs to be disassembled.

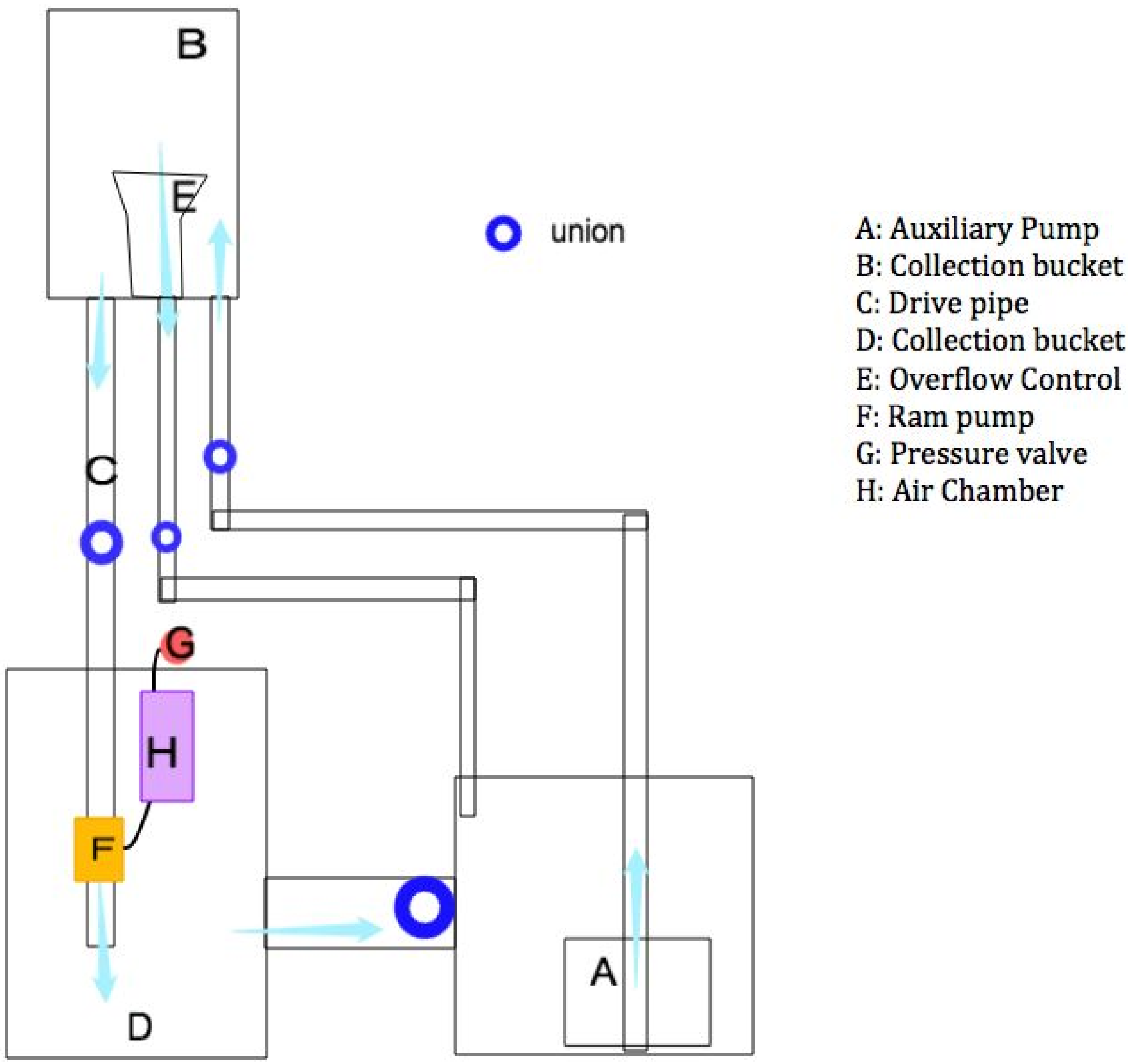


Figure 1: Representations of the changes made to the setup. These changes allow the pump to be disassembled without cutting any of the pipes.

How Water Flows Through the System

Water starts in the two buckets collection buckets at the base of the system. Water is pumped by an external pump (A) to the bucket (B) which is at the top of the system. The purpose of having water in the elevated bucket (B) is to provide the flowing water that the ram pump needs in order to work. Inside the tank there is a weir (E) in order to have a constant head for performing the experiments. There is a manual valve in the drive pipe in order to stop and start the cycle. Water then travels through the drive pipe (C) to the ram pump (F) that pumps water to the air chamber (H). The water then flows to the pressure valve (G) which simulates the head loss and then flows back into the system (D).

Results

It took all of September to reassemble the pump because the team had to order parts, wait for them to arrive, and then use them in the assembly. Furthermore, the team spent time determining how to ensure that the pump was easily portable. The pump was sliced into several pieces at the end of last semester which caused the delay in this semester's data collection. The team decided to take the extra time to ensure that this would not happen in the future.

The team has assembled a functional and mostly leak-free ram pump. While the pump was running, the team noticed that the period of the check valve varied wildly (the changing period seemed to have an oscillatory period itself) and occasionally the spring would stop oscillating and required a manual reset to continue running. No apparent reasons for these phenomena were found, though the team would like to investigate them, as understanding these events will lead to greater mechanical knowledge of the pump. This phenomena was also observed by the previous semester's team, but more work must be done to form concrete conclusions as to why this occurs.

Air Chamber

The team also has decided to research the effects of the air chamber. Previous research indicates that an air chamber with a larger height produces a higher effluent rate. However, the previous teams did not research the effects of the radius of the air chamber. The team asked whether enlarging the air chamber always increase effluent rate? The team hoped to answer this while manipulating the radius of the air chamber. The team also explored the idea that the effluent rate is related to not the air chamber size, but the ratio of air chamber height to air chamber radius.

The team tested three air chamber diameters: 1", 2", and 3". The height of each air chamber was the same. The following figure shows the flow rates of all three pumps at a variety of different heads.

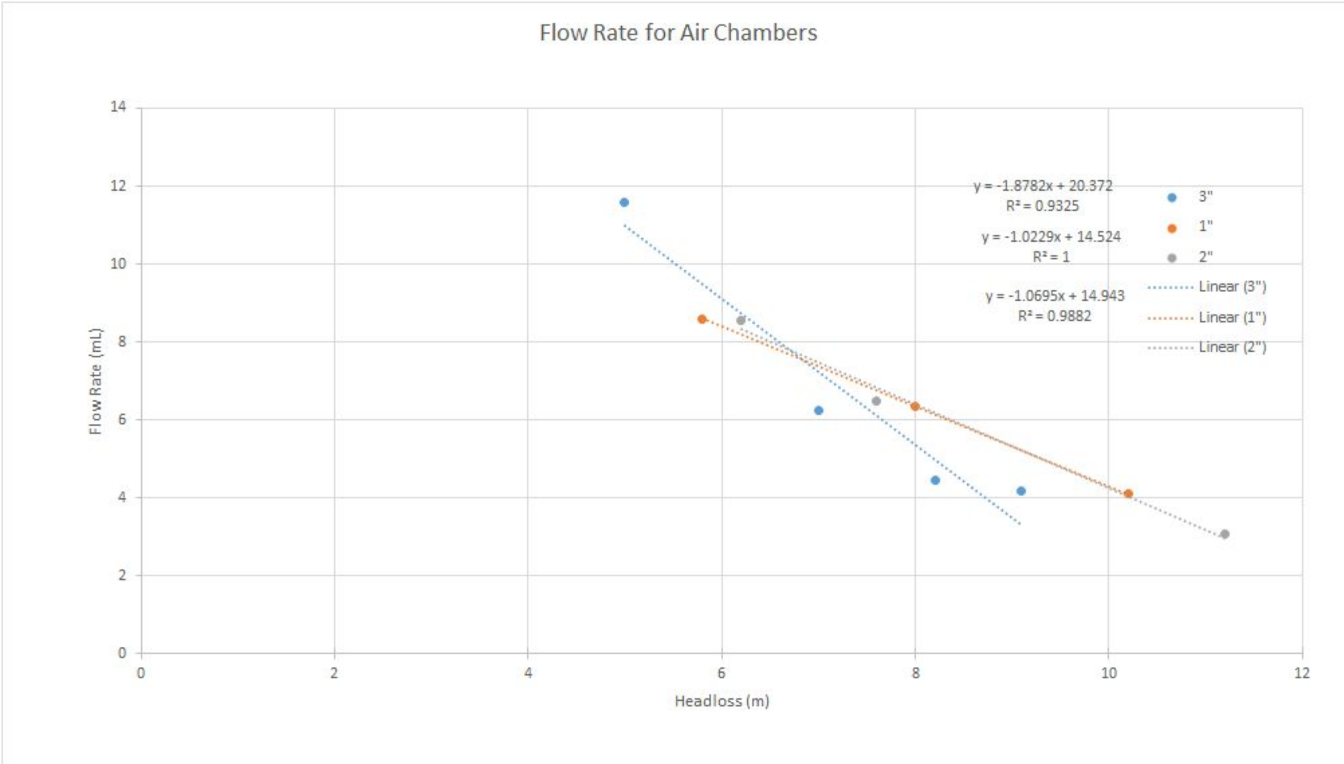


Figure 2: Air chamber comparison

This plot reveals that there was no correlation between the flow rate and the radius of the air chamber. This disproved the initial hypothesis that an air chamber with a larger radius would have a smaller flow rate. This hypothesis was developed without a proper understanding of how the pressure of the air in the chamber makes the pump more efficient. The hypothesis did not account for the fact that the pressure change inside the air chamber is simply due to the change in volume that the air occupies when the water enters the chamber. This led to a new hypothesis which the experiment verified. The new hypothesis stated that the flow rate will increase as the air chamber volume increases until the air chamber becomes significantly larger than the volume of water pumped in one cycle. This is because the flow rate should be largest when the pressure inside the air chamber remains constant. The change in pressure in the air chamber originates with the change in volume of the air. The change in volume of the air in each cycle is the volume of the water being pumped through each cycle. In the ram pump, each cycle pumps approximately 1 mL of water. The smallest air chamber has a volume of about 155 mL, so the volume of the water in each cycle is insignificant. The results showed that there was no significant change in flow rate with a change in air chamber, and the air chambers were all large enough that the volume of water per cycle was insignificant. This means that the data support this hypothesis. The calculations for water volume per cycle follow.

$$\frac{6mL}{1sec}\ \frac{1sec}{6cycles} = 1\frac{mL}{cycle}$$

The following figure shows the pressure inside the air chamber. The pressure is seen to be fairly constant, showing that the air chamber is large enough to be modelled as infinitely larger than the cycle volume of water pumped.

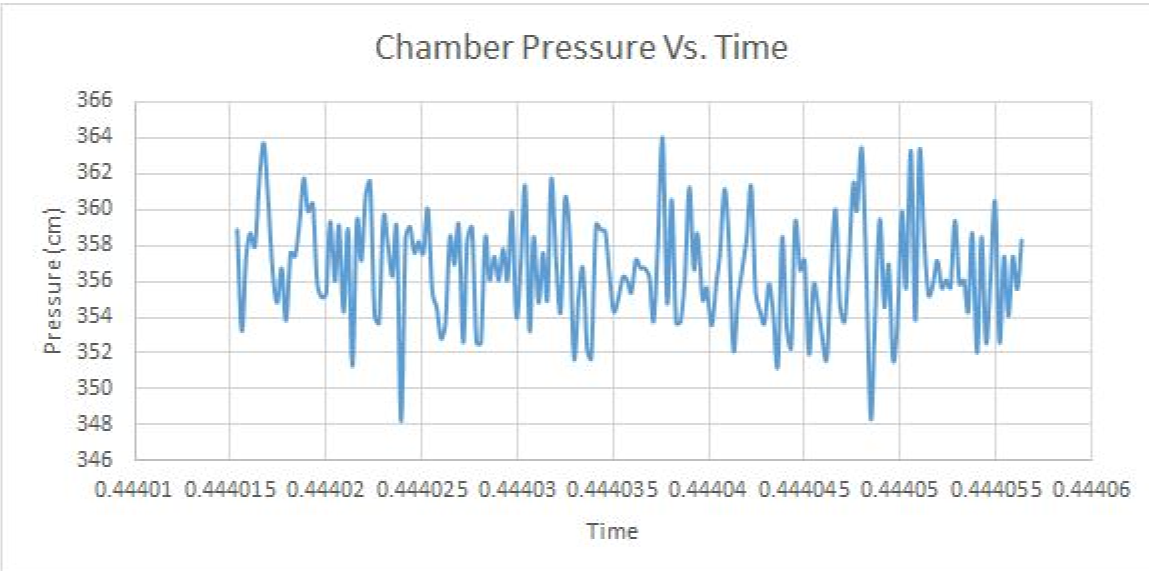


Figure 3: Air chamber pressure (cm) vs. Time (Day Fraction, each vertical line represents a change in 0.432 seconds, the graph spans 4.32 seconds total)

The small, sinusoidal fluctuations correspond with the small changes in pressure as the pump cycles. They are small enough that the pressure can be treated as constant.

Pump Analysis

The desired effluent flow rate should be a constant stream with a near constant pressure. Pressure values, which correspond to head loss values, for the effluent found have an odd fluctuation which one large peak followed by two smaller peaks as shown by the figure below. When taking a measurement of the flow rate at a headloss, an average value between the peaks is taken. The team will continue to research new methods in order to attempt to achieve a constant flow rate delivered.

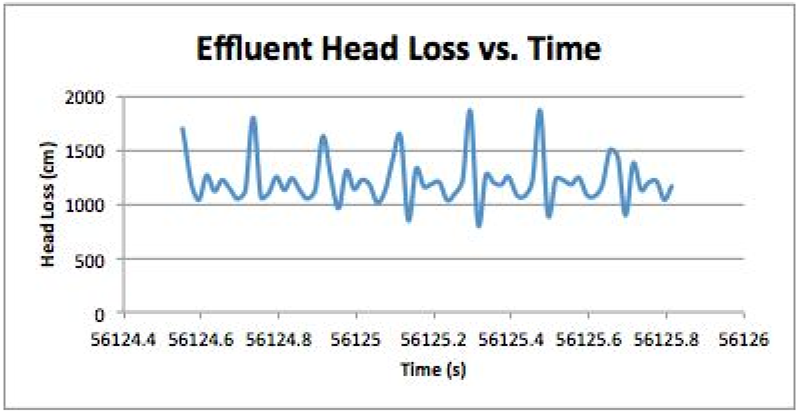


Figure 4: Effluent vs. Time

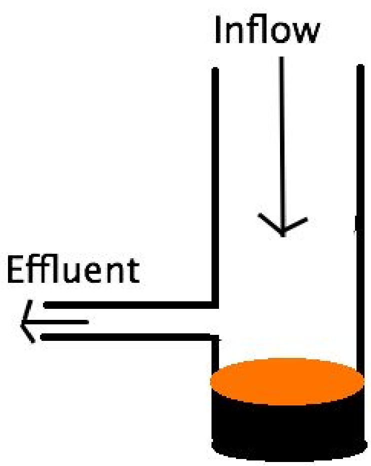
Pump Theory/Physics

While the team was deliberating over a method on which to continue last semester's work with springs, it became apparent that the pump operates with more mechanisms than had been previously accounted for.

The team's hypotheses on the result of changing certain variables was sometimes startlingly wrong. For example, while running, the drive shaft oscillated both horizontally and vertically by about half a centimeter. It was theorized that this oscillation caused increased losses, so holding the shaft in a more rigid position would increase the flow rate. However, when one or two members held the pipe in place with their hands, the waste valve's period increased noticeably, but the effluent flow rate decreased measurably. While it makes sense that the period should increase upon increasing the flow rate being provided to the pump, the team is at a loss regarding how to rationalize an increasing inflow rate and cycle time leading to decreased effluent. It may be possible that the pump is oscillating at such a high period that water does not have time to get through the valve therefore decreasing the flow rate.

Another oddity that escapes the team's knowledge of fluid mechanics is the waste valve's variable cycle time. When the spring force at the valve's closed position is near its lower limit (by changing spring 3's compressed and uncompressed length), the cycle time of the waste valve begins to change with time, running normally for a few seconds then running very slowly for another few seconds and repeating that trend indefinitely.

These seemingly unexplainable phenomena caused the team to analyze the ram pump operation more precisely. To this end, the team will consult with fluids professors at some point to see if an expert opinion can lead the team in the right direction. In the meantime, the team will try to make sense of how the pump actually works using the knowledge of fluid mechanics gained this semester in external classes.



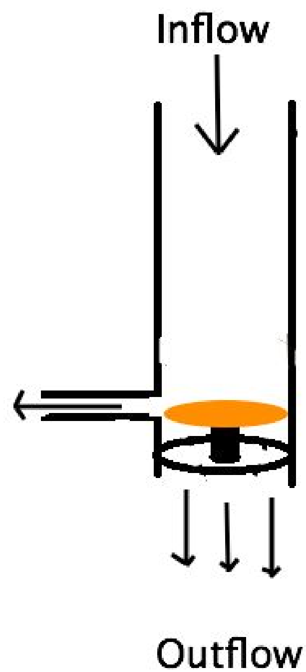


Figure 5a (left): Represents the ram pump when the waste valve is closed
Figure 5b (right): Represents the ram pump when the waste valve is open

The team then moved away from testing air chambers to testing different springs, spring constants, and spring lengths. Before actually manipulating the spring, the team members tried to determine what the force and pressure interactions are by the waste valve and the effluent valve. Initially, the piston head is up, and water cannot travel out of the effluent valve, so pressure builds and eventually presses the spring down. The spring hits the bottom, preventing water from escaping out through the bottom of the ram pump. When this happens, water accelerates as it flows out of the effluent. As the velocity builds, the pressure at the top of the plate decreases until the spring can overcome the force due to the water pressure. At this point, the waste valve closes. Once the pressure builds back up on the piston head, the process will restart. This is the current hypothesis about how the ram pump is operating. The hypothesis regarding flow rate is the following: if the time with the waste valve closed can be increased, the flow rate will increase as well.

For the current tests, the following are true

- The spring constant is the same
- The change in length of the spring during compression is the same
- The uncompressed length is changed

- The compressed length is changed

The first couple tests were done to find the range where the pump operates. The delta x for all of the following was 0.747 cm which was chosen because it produces a force that works well for the pump. This delta x was chosen due to the data that was collected by the previous semester's team.

When running the pump different behaviors were observed, which are described below.

- Uncompressed length=5.25 cm--the pump did not have a regular flow. The period was not constant. Sometimes the waste valve would stay open for seconds at a time. The spring would then have to be manually compressed in order for the pump to run again.
- Uncompressed length=5.02 cm--worked briefly then the waste valve stayed open.
- Uncompressed length=4.826 cm--worked well. Period suddenly increased halfway through testing.
- Uncompressed length=4.48 cm--the pump did not run consistently. Most of the time the waste valve was open. When the pump was running, the period was slower than the other lengths.

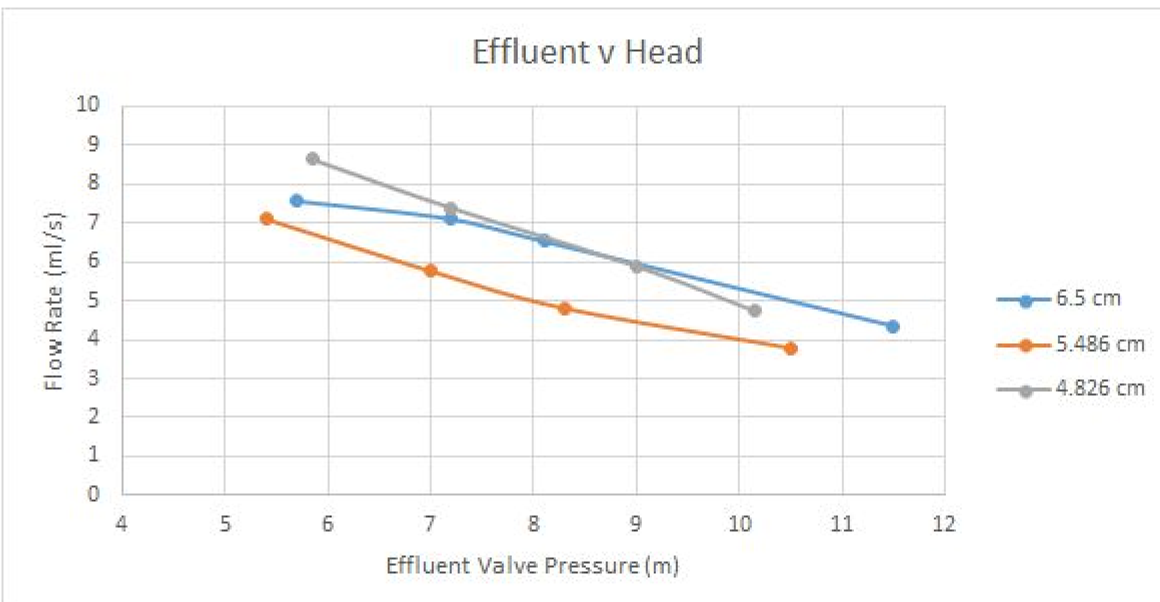


Figure 6: Effluent v Head for different uncompressed spring lengths

While changing the uncompressed length of the spring audibly changed the cycle period, the data does not appear to indicate any correlation between uncompressed length and effluent rate. This is an interesting finding with regards to our hypothesis that the more time the waste valve is closed, the higher the flow rate. Theoretically the waste valve at a lower uncompressed spring length would spend more time closed, as the valve's cycle gets interrupted closer to the closed position, but our data does not seem to lend credibility to that hypothesis. The plate will theoretically be closed for longer because although the delta x is the same the distance between the plate and the bottom of the inside of the pump will decrease as the uncompressed length decreases. The amount of conflicting theories and difficult to rationalize phenomenon has led the team to seek contact with a fluid mechanics professor to see if an expert opinion can shed light on the observations and data trends.

Future Work

Changing the spring parameters is done with the goal of affecting the cycle time of the waste valve, which the team believes to have a significant effect on the effluent flow rate. A very long cycle time will result in most of the water leaving the system without ever having gone through the pump, while a very short one won't pump very much water since the waste valve will be constantly changing state. Our tests are intended to find a cycle time to optimize the flow rate. The cycle time can be changed by varying either the length of the spring or its spring constant. After a brief discussion, it was decided that the team would begin by altering the spring constant and determining its effect on the flow rate. It is theorized that increasing the spring constant will increase the cycle time, and hopefully increase the flow rate. One aspect that the team will be careful to consider is if spring constant is being changed 'too much'. For example, if the current spring is too close to the 'low spring constant side', it is possible that the next (higher) spring constant will overshoot the optimal point and the pump will have a lower flow rate than before. Thus the team will be careful to increment the change in spring constant by small but significant values.

Another possible idea that the team will look to explore in the future is of having two springs within one another. The inner spring would initially be stretched within an outer bigger spring. The outer spring would be unstretched initially and it would go directly into the pump as usual. It is theorized that this setup may increase the amount of time that the valve is closed allowing water to flow through the pump more often. This idea will be explored further and developed next semester.

References

Jennings, Gregory D., PhD. "New Hydraulic Hand Pumps." *World Pumps* 2001.422 (2001): 6. Mar.-Apr. 1996. Web. 25 Sept. 2015.

"Hydraulic Ram Pumps." - *Appropedia: The Sustainability Wiki*. N.p., n.d. Web. 25 Sept. 2015. <http://www.appropedia.org/Hydraulic_ram_pumps>.