Ram Pump, Spring 2016

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Abstract

The Ram Pump team was created to design, construct, test, and ultimately implement a hydraulic ram pump for AguaClara plants. The Ram Pump is located at the lowest level of the plant and is used to pump water either to a storage tank or directly to chemical stock tanks located at the top level of the plant. The team's goal for the semester was to finalize designs for a self-contained pump, which is intended to maximize space efficiency. The team confirmed the viability of an enclosed vertical ram pump design over the course of several iterations. The team also redesigned the spring manipulation system and has a design that is ready to be implemented in AguaClara plants.

1 Introduction

The ram pump redirects a portion of the clean, treated water headed to the plant's distribution system back for use at AguaClara treatment plants. The water pumped allows operators to use the bathrooms and fill chemical stock tanks without carrying buckets of water up two flights of stairs. Although the layout of each plant is different, the ram pump is flexible enough that it can fit into any design. Located in the basement (see Figure 1), the ram pump can be turned on or off as needed.

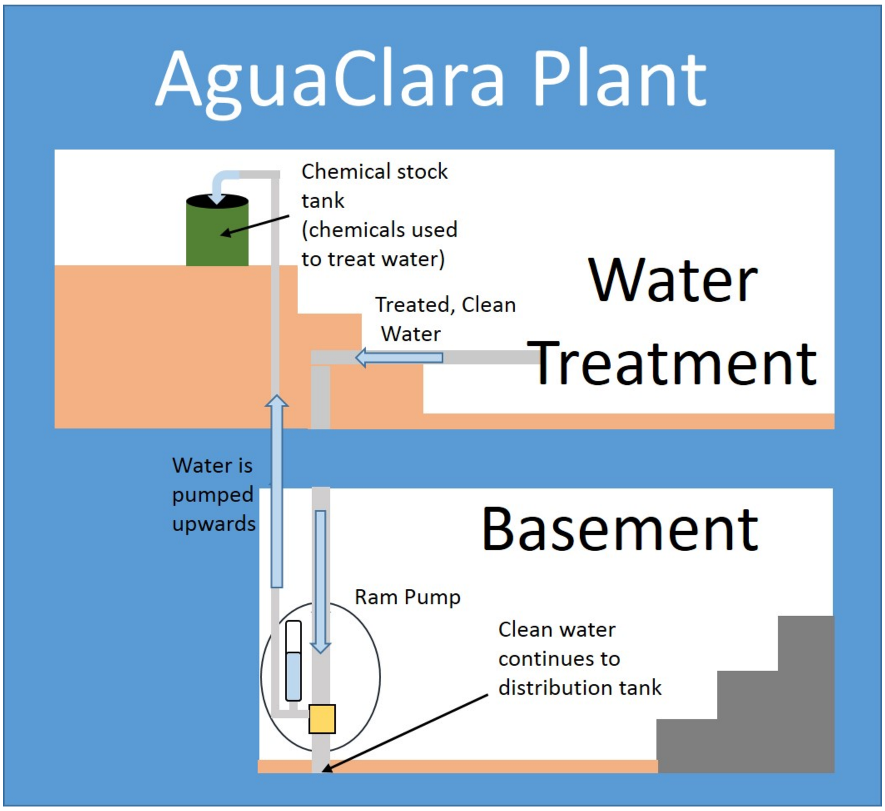

Figure 1: A general schematic for the location of the ram pump within a plant. This schematic shows how the team hopes to implement the vertical design. Currently, the horizontal (not self-contained) ram pump in use in Honduras is located in the same place, but is contained within a concrete box to contain splashing.

The team worked on finishing a completely enclosed vertical design system. The team went through different design phases, but once a design was finalized, tests were done to calculate the flow rates provided by the pump at different heads. This data was collected in order to determine the efficiency of the pump. Higher flow rates are desired to reduce the time needed to fill the chemical stock tanks and storage tanks. The new design will be implemented in future AguaClara plants and modeled, documented, and retrofitted in existing plants.

2 Pump Theory

2.1 Understanding the Ram Pump

Fundamentally, the ram pump converts kinetic energy into potential energy through the use of a check valve (a valve which only allows flow in one direction) and a spring, which combine to counteract the force of the incoming water (see Figure 2). This system moves between two states: open and closed. While the system is open, water flowing down the drive pipe, the pipe that carries water to the ram pump, collides with the plate and flows around its edges and out of the system ('Open' in Figure 2).

The collision between the water and the plate exerts a force on the plate, causing it to move downwards onto the constriction while simultaneously compressing the spring ('Closing' in Figure 2). This continues until the plate completely covers the constriction. When this occurs, the water previously flowing through the drive pipe can no longer pass through the check valve and its velocity abruptly decreases.

A decrease in kinetic energy combined with an impassable check valve induces a pressure spike, which propels the water through the stop valve (which is also technically a check valve, but referred to as a stop valve to avoid confusion), and into the effluent pipe ('Closed' in Figure 2).

The flow of water through the effluent pipe releases the pressure in the check valve, allowing the compressed spring to lift the plate off of the constriction (shown in 'Opening' in Figure 2) until the cycle begins again, and the stop valve prevents the pumped water from returning to the system.

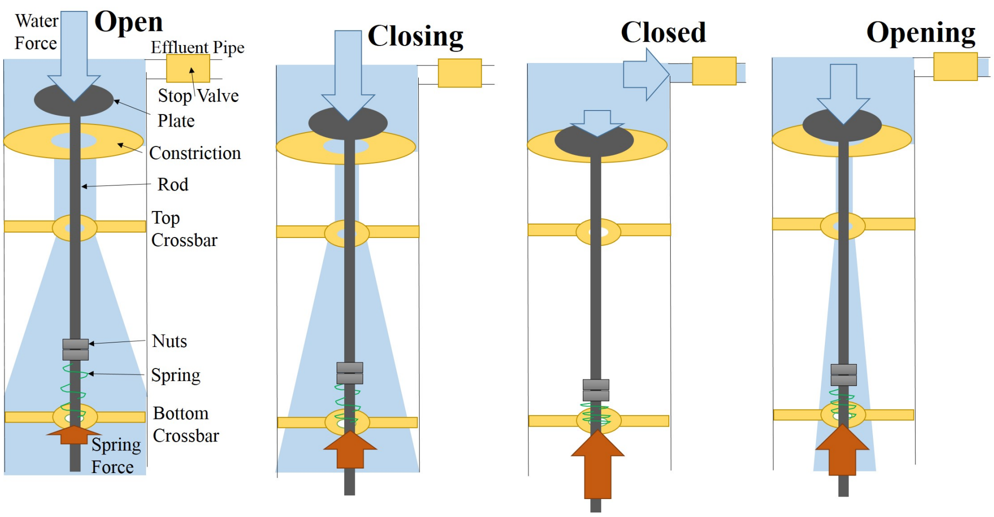

Figure 2: Water from the drive pipe collides with and flows past the plate, exerting a downwards force which moves the plate onto the constriction and compresses the spring. The pressure spikes within the check valve and induces the water to move through the stop valve and into the effluent pipe. The released pressure combined with the compressed spring move the plate off of the constriction and back into the open position, where the cycle repeats.

2.2 Understanding the Air Chamber

The system described in the previous section only pumps water when the check valve is closed, and therefore only pumps water in spurts. Previous ram pump teams determined that attaching an air chamber to the effluent pipe both increases the effluent flow rate and allows for consistent pumping. Figure 3 includes a 'Pressurizing Effluent Valve', which serves only to simulate pumping water to a higher head by pressurizing it. Pumping eight to fifteen meters upwards would be impractical in a lab setting due to a lack of space.

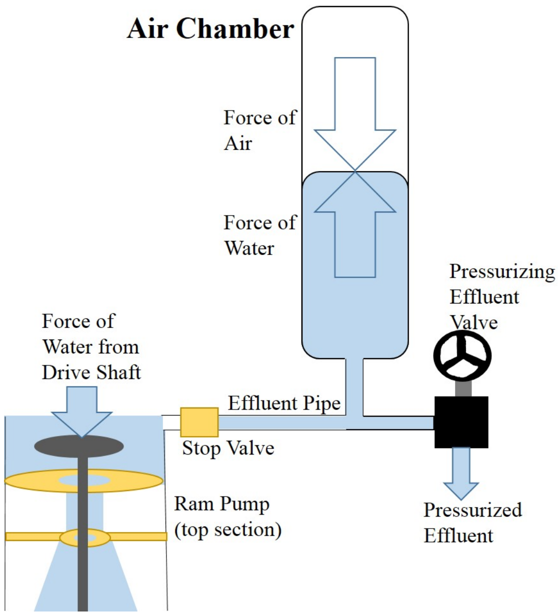

Figure 3: Located along the effluent pipe immediately after the stop valve and before the pressurizing effluent valve, the air chamber allows for continuous pumping instead of intermittent pumping. Additionally, the presence of an air chamber substantially increases the pump's effluent flow rate.

The air chamber is located immediately after the stop valve (see Figure 3). The chamber serves to normalize the pumping by allowing for water to be pumped while the check valve is both open and closed. Additionally, the air chamber raises the water pressure when the check valve is closed, increasing the flow rate and overall efficiency.

In order to understand the air chamber, one must first understand how gases act under pressure. A constant mass of gas (such as in the air chamber) can occupy any amount of volume. However, the gas will exert more force on its surroundings when it is confined to a smaller volume. The air chamber utilizes this effect, as the volume of air is expanded and constricted during each of the ram pump's cycles.

Before the ram pump begins to function, the air chamber is filled with air at zero gauge pressure. As the pump operates and the check valve closes, highly pressurized water enters the chamber and compresses the air within it ('Closed Check Valve' in Figure 4). When the check valve opens and the water depressurizes, the force of the now-compressed air pushes the depressurized water out of the air chamber, through the effluent pipe, and to the effluent valve ('Open Check Valve' in Figure 4). This effect produces a steady effluent and increases the pump's effluent flow rate.

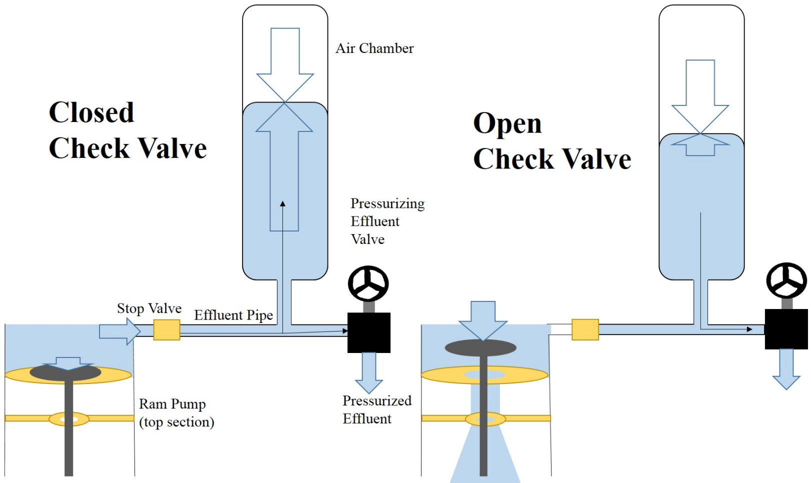

Figure 4: When the ram pump is pumping (the check valve is closed), pressurized water flows into the air chamber and compresses the air. When the check valve is open, the pressurized air forces the water out of the air chamber, through the effluent pipe, and out of the effluent valve.

2.3 Physics of a Pump Cycle

Figure 5 is a graphical representation of what is happening in the pump. The blue curve represents the terminal velocity of water in the drive shaft, or the velocity of the water if there were no ram pump to inhibit the flow. The red curve represents the velocity of water in the drive shaft when the ram pump is functioning. When the check valve is open, the speed of the water is increasing (as the water can flow downwards); when the check valve is closed, the speed of the water is decreasing.

Once the check valve closes, water is pumped, as explained in the previous subsections. The volume of water pumped is equal to the cross-sectional area of the drive shaft multiplied by the average distance the water moves while the check valve is closed (an area times a length). This volume is represented by the pink triangle in Figure 5. Unfortunately, when the water is being pumped through the stop valve, some of the already pumped water escapes from the pumped side of the stop valve to the un-pumped side. This water that leaks from the valve is shown in dark red.

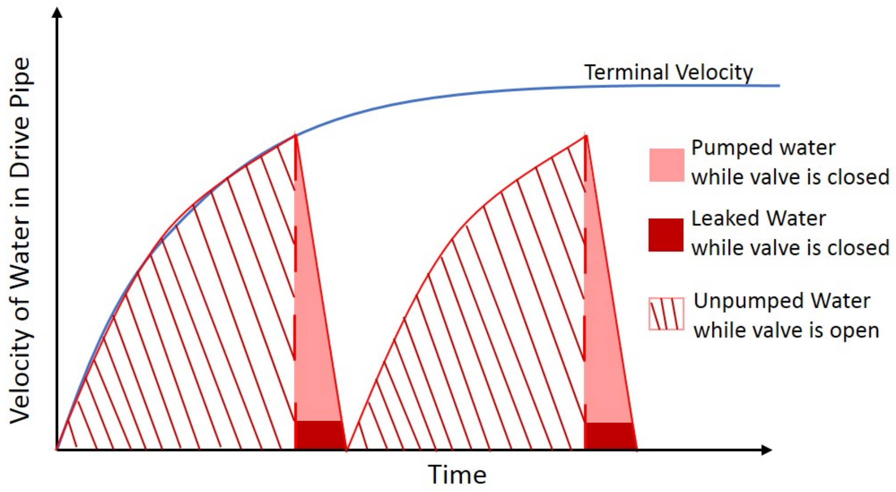

Figure 5: The figure shows two pump cylces. The shaded regions indicate volumes of water. The figure shows that more water will always be un-pumped than pumped in a ram pump.

Figure 5 shows the velocity going to zero during each cycle, as that is what the team believes happens in the current pump. However, the team also believes that this is not as efficient as it could be. Simple geometry shows diminishing returns in terms of pumped water as the velocity approaches zero (lower triangle height implies lower area). Therefore, if the velocity were to only drop halfway to zero and the cycles would speed up accordingly, the pump should produce a higher flow rate.

3 Previous Work

3.1 Ram Pump Setup

The Fall 2015 ram pump team constructed a lab-scale pump setup such that it could easily be taken apart, moved, or adjusted (Aggarwal et. al., Fall 2015). The team accomplished this by adding unions to all of the connections in the system. For this setup (see Figure 6), water is pumped to the head tank with an electric pump. Water then travels down the drive pipe from the head tank to the ram pump. Then the water is either pumped, going through an air chamber and out as effluent, or it goes directly into the lower right collection bucket, where it finally refills back into leftmost bucket. If the electric pump is pumping water too rapidly to the head tank, there is an overflow funnel located within the head tank to both maintain a constant water level and to return excess water back to the lower collection buckets.

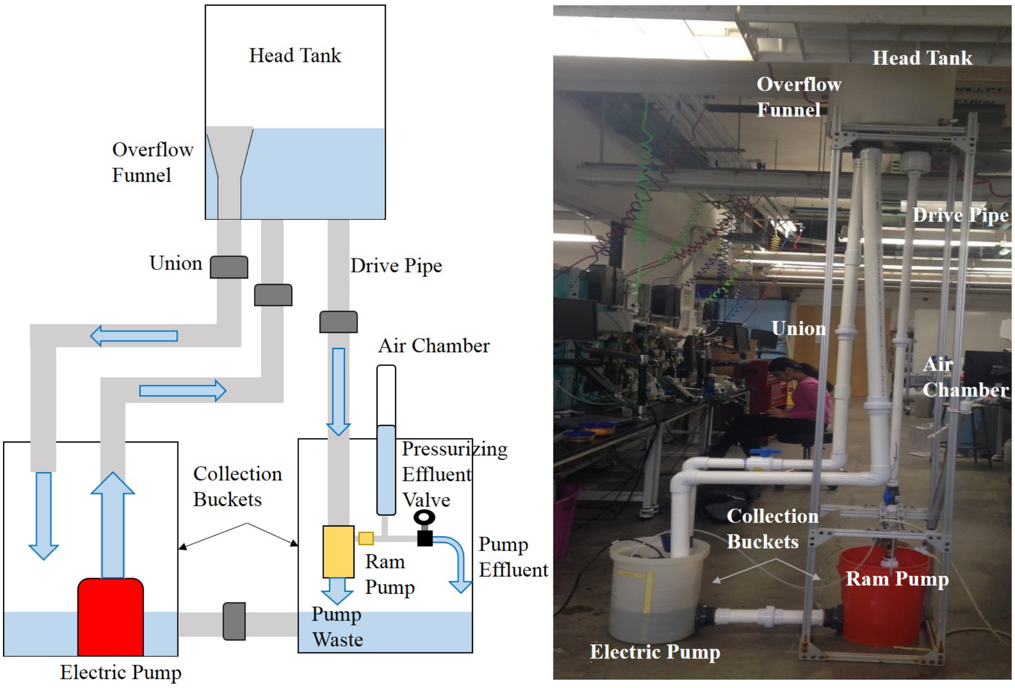

Figure 6: The team's current ram pump set up. Water moves from the electric pump to the head tank, and then down the 1" drive pipe. From there, it flows to the ram pump itself, where it is either discarded into the collection bucket as unpumped water or is pumped through the air chamber and becomes effluent.

Since pumping water 4 to 10 meters above the ram pump is impractical in the lab, the setup includes a pressurizing effluent valve which pressurizes the water being pumped, thereby simulating pumping water to a higher elevation. The setup also includes three pressure sensors which measure the pressure in the ram pump, air chamber, and effluent (see Figure 7).

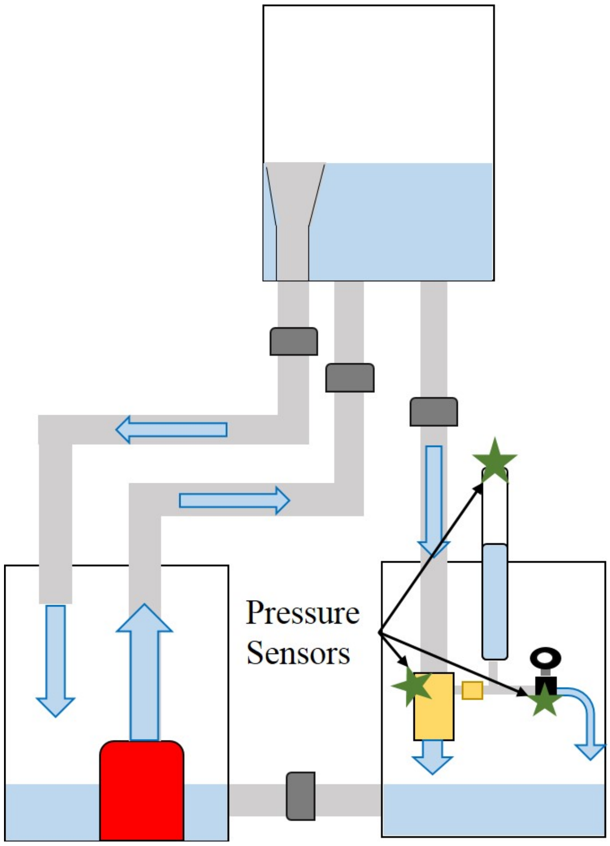

Figure 7: Pressure sensors connected to ProCoDa software measure the pressure at various points in the pumping system. Of critical importance is the sensor connected to the effluent valve, which allows the team to determine the altitude to which the ram pump is pumping water.

These sensors are linked to ProCoDa, a software which controls pressure sensors and electric pumps. When the team is running tests on a design, data from ProCoDa is used to determine the average effluent pressure over the test's duration. Simultaneously, a team member measures the volume of water pumped during the test and divides it by the duration of the test to obtain an average flow rate. A plot is then created with flow rate on the y axis and effluent pressure (head) on the x axis (see Methods).

3.2 Acceptable Spring Forces

As the Spring 2015 team was testing the vertical ram pump prototype, they accumulated data for various spring constants, lengths, and forces. While they did not irrevocably conclude anything about the spring forces for which the ram pump will function, the current ram pump team has used the Spring 2015 team's data to create a rough estimate of spring forces for which the pump is able to operate (Nistal et. al, Spring 2015). The range of forces was found to be between 3 and 8 pounds, with the best flow rates obtained at a force of about

5 to 7 pounds. When the spring force was either higher than 8 pounds or lower than 3 pounds, the ram pump never began a cycle, and thus did not operate. These values were used by the current team to test improved vertical designs.

3.3 Amplitude restricting collar

During the Winter of 2016, the ram pump team traveled to Honduras with AguaClara to visit operational plants. One such plant had a ram pump that was not functioning. The plate within the check valve jammed in both the open and closed positions, requiring significant outside force (team members pushing and pulling) to switch between open and closed. Professor Weber-Shirk solved this problem by not allowing the plate to open to its maximum amplitude. Intrigued, the ram pump team decided to test restricted plate amplitude in the Spring 2016 semester. The metal collar is constrained by two nuts and the check valve's crossbar to control the distance that the plate can rise above the constriction (see Figure 8).

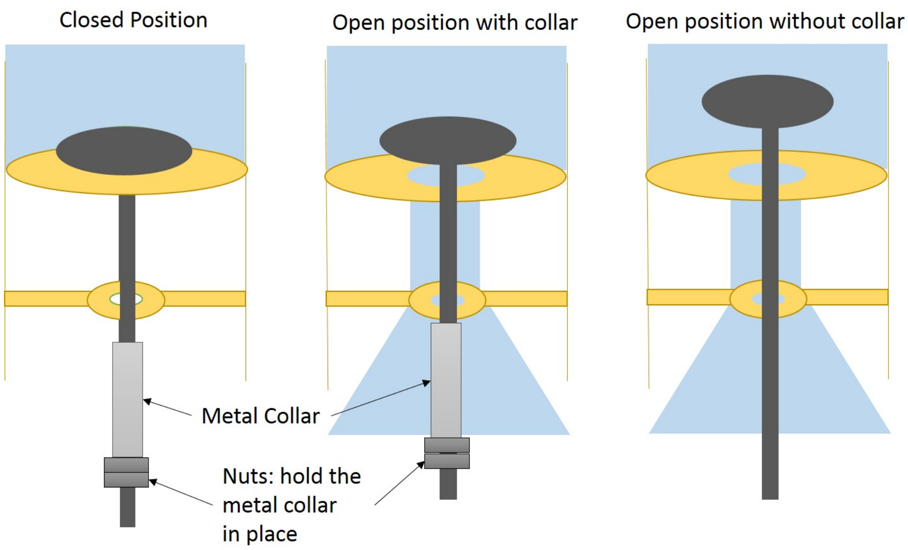

Figure 8: The figure shows a setup for testing an amplitude restricting collar. Having shown great potential to increase efficiency in Honduras, the team tested this idea in the lab.

3.4 Prototype

3.4.1 Apparatus

At the beginning of the semester, the team was using a vertical ram pump prototype (see Figure 9) designed by the Spring 2015 Ram Pump team. The main advantage of this prototype was convenience; the spring's compressed length could be easily changed by moving the nuts, and the spring itself could be very easily replaced without having to remove the rod from the system. The spring was compressed by the nuts and a constriction plate at the bottom of the oval holes, which was wide enough to allow the rod to pass through but narrow enough to restrict the spring. Water would exit the system through the notched hole so that the spring would not be exposed to water. These factors made it very straightforward and practical to test various springs and compressed lengths for the new vertical system.

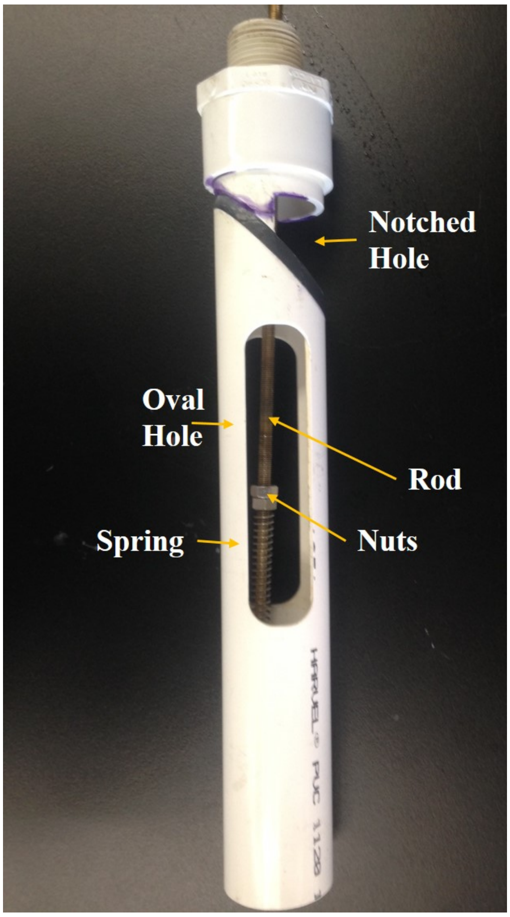

Figure 9: This figure shows the Vertical Prototype design. The check valve would be attached at the top via the threads. Water not pumped would leave through the notched hole just below the check valve. The oval holes through the middle of the design allowed for easy access to the spring.

3.4.2 Results

As the team began the semester with the intent of creating an enclosed design, they did not run tests on the vertical prototype. All of the data presented here was gathered by the Spring 2015 ram pump team (Nistal et. al, Spring 2015). The Spring 2015 team ran tests on three springs with different spring constants for various compressed lengths. Their results are shown in Figure 10.

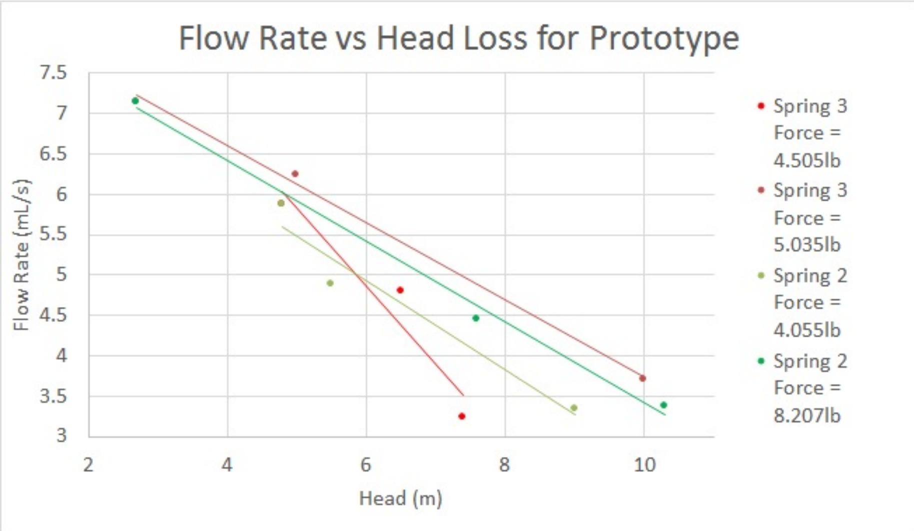

Figure 10: This figure shows the flow rate vs head for the vertical prototype. Spring 2 had a spring constant of 19.31 lbs/in, whereas spring 3 had a spring constant of 10.6 lbs/in. This figure shows that there is not a clear trend for different spring forces as all of the springs and spring forces provided similar results.

As the data shows, spring 3 yielded a slightly higher flow rate than spring 2. Additionally, there did not seem to be a correlation between the spring force and the flow rate. Whether or not this is statistically significant is unknown, but the team used spring 3 over spring 2 in the hopes of obtaining a higher flow rate from the ram pump.

3.4.3 Discussion

While the prototype was perfect for the lab, it could not be implemented in Honduras to the capacity the team would like. Since the team's goal is to create a self-contained, robust ram pump that does not eject water out of the system, all of the holes in the prototype would have to be removed. However, removing the holes presented another problem. With no holes, it is very difficult to manipulate the spring without disassembling the entire system. Additionally, the team needed to find a way to allow water to pass through the system (an enclosed pipe), while simultaneously providing a point fixed in space on which to compress the spring.

4 Methods

This semester the team worked on creating an enclosed vertical ram pump design. Throughout this section, all of our designs are using the same check valve, located at the top of the system. Differences between designs are the ways in which each design compresses the spring (between the nuts and some fixed surface) and the ease of access to the spring. The following sections will outline the designs constructed this semester.

4.1 Enclosed PVC Design

4.1.1 Apparatus

In the Enclosed PVC Design (see Figure 11), no water is ejected out of the system. This is accomplished by adding an empty check valve (a pipe with a crossbar) after the actual check valve and combining the two with PVC. The crossbar in the empty check valve serves as a fixed surface on which to compress the spring. Since the crossbar has a very minor cross sectional area, water can flow through the lower valve when the check valve is open.

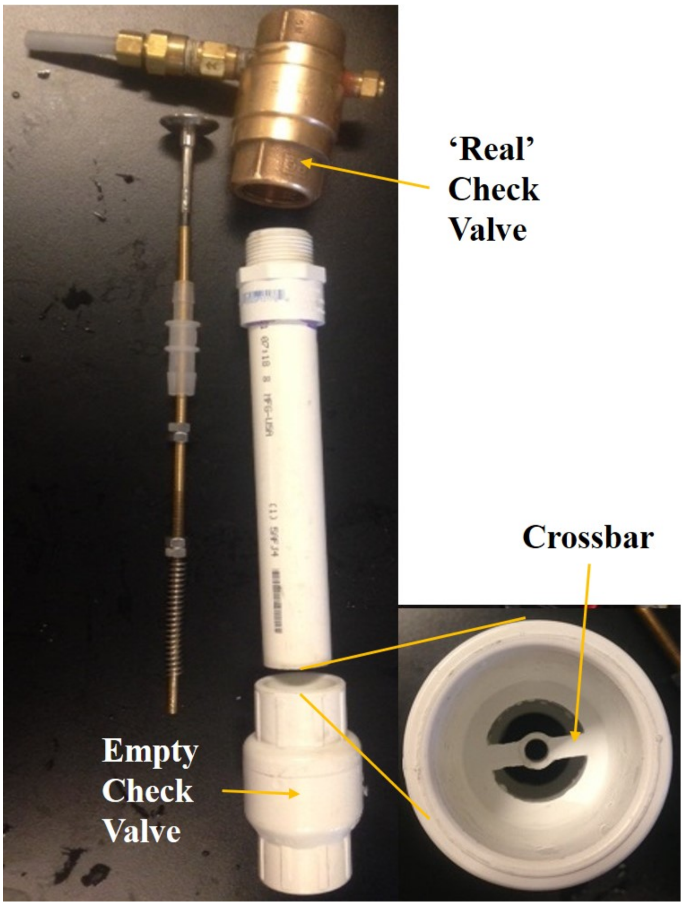

Figure 11: The enclosed PVC design keeps all un-pumped water within the system through the use of an empty check valve below the actual check valve. The crossbar within the empty check valve serves both to compress the spring and allow for the passage of water through the valve.

As the ultimate goal for the design was to implement it in Honduras, the team hypothesized that the new enclosed vertical system could be connected directly to the distribution piping. The pump would still be located in the basement, but instead of needing a collection bucket, unpumped water could continue on its way to the distribution tank through the bottom of the pump.

4.1.2 Discussion

The team was advised by Professor Weber-Shirk to assemble as much of the system as possible with metal parts. These metal parts would be far more stable than the PVC, and would both reduce energy loss due to vibrations and increase the system's durability. The team thought the design was close to a finished product, and that the next steps were to ensure structural integrity to lengthen the lifespan of the pump. Therefore, the team moved to an Enclosed Brass design.

4.2 Enclosed Brass Design

4.2.1 Apparatus

The Enclosed Brass Design (see Figure 12) was functionally identical to the previous Enclosed PVC Design with all PVC piping replaced with brass piping. Even though brass is a bit more expensive, compared to the total cost of the plant, an increase in the cost of the pump is insignificant therefore the switch to brass would not greatly affect the cost of the plant. Furthermore, the team thought the increase in stability would prolong the life of the pump thus reducing repair costs in the future.

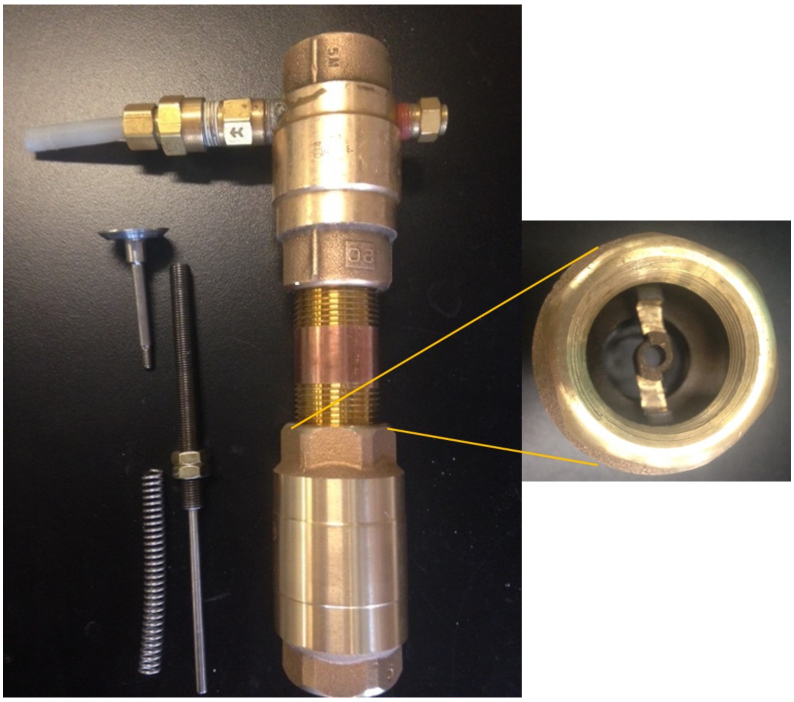

Figure 12: The figure shows the Enclosed brass design. This design differed from the previous enclosed PVC design only in the composition of materials. Both used the empty check valve's crossbar to constrict the spring while allowing water to flow freely.

4.2.2 Discussion

When attempting to test this design, the team ran into difficulties. When the team would unscrew the brass nipple from the check valve to adjust the spring, they found it near impossible to screw the nipple back in the same amount as previous to the adjustment. This would change the distance from the check valve to the empty valve's crossbar, which would affect the spring's compressed length. The team obtained wildly differing data for the same spring parameters because of this, which was unacceptable. Therefore, the team decided to add a union to the design to remedy this problem.

4.3 Enclosed Union Design

4.3.1 Apparatus

The enclosed union design was created to address the problem with the enclosed brass design: the perfect precision needed when assembling and disassembling the system. The union design includes a PVC union in between the check valves (see Figure 13). With a union in place, there is no need to ever unscrew the check valves or the union itself. The only action required to disassemble the pump is to separate the union (which will always be a constant length). Not only did this change solve the problem, it also allows for convenient access to the spring itself. The reason why a brass union was not used was due to cost. A brass union is significantly more expensive than a PVC union, so much so that the team decided the extra stability would not be worth the extra cost.

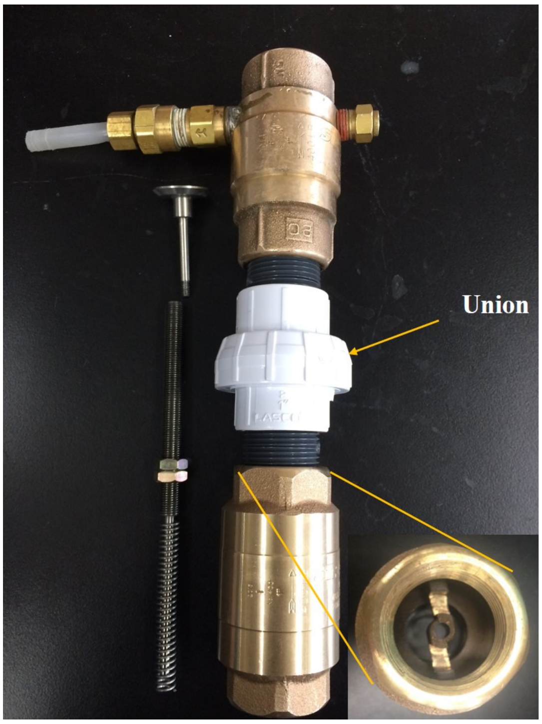

Figure 13: Enclosed union design. This design maintains precision through adjustments to spring parameters through the use of a fixed length union. It also allows for easy access to the spring, as simply separating the union reveals the spring.

4.3.2 Results

In order to gather flow rate results for the design, the same spring, with a spring constant of 10.6 lbs/inch, was used. For the first test, the spring was compressed by 0.625 inches, exerting a maximum spring force of 6.625 lbs. The spring force was calculated with Hooke's Law:

$$F = k\Delta x = (10.6\frac{lbs}{in})(0.625in) = 6.625lbs$$

For the second test, the spring was compressed by 0.75 in, yielding a spring force of $F = (10.6\frac{lbs}{in})(0.75in) = 7.95lbs$. The flow rate results are shown in Figure 14.

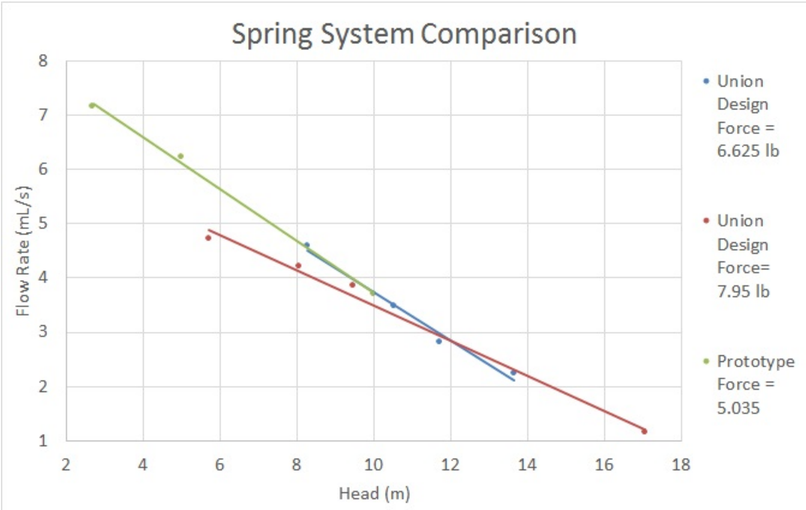

Figure 14: The figure shows a graph of flow rates from the pump vs head. The graph shows that exposing the spring to water does not have a significant effect on the flow rate since the results obtained are similar to the results obtained from the prototype design.

While two tests do not yield enough data to draw a conclusion, the team believes that adjusting only the force will not result in a significant impact on the flow rate for any particular head value.

When the data collected this semester is compared to the tests run on the Prototype design (Green line in Figure 14), the flow rates are nearly identical for any given head value, and the slopes are similar as well. This is highly encouraging, as it implies that having the spring exposed to flowing water does not affect the system's performance.

4.3.3 Discussion

A potential reason why the slopes are similar is that the water inside the spring manipulation system does not affect the spring's performance. As the spring is only oscillating a small amount, the addition of water around the spring does not change its movement by a significant amount. With an accessible spring, a precise disassembly method, and promising results, the enclosed union design is nearing a final product. The team's next step was to test the effect of the collar on the pump's efficiency in the hopes of obtaining a higher flow rate. Should the collar prove to not have a significant effect, the team is confident this design can work well in Honduras.

4.4 Enclosed Union-Collar Design

4.4.1 Apparatus

The Enclosed Union-Collar Design was similar to the Enclosed Union Design with the primary difference being the ability to adjust the amount the plate can open (see Figure 15), or the amplitude of the plate. Additionally, the Union-Collar Design implements a long nut as part of the jam nut that restricts the spring, and the bottom of the rod has a longer unthreaded length. These supplemental changes still allow for compressed length adjustment, but eliminate contact between the threads and the spring since the contact causes long-term damage to the threads.

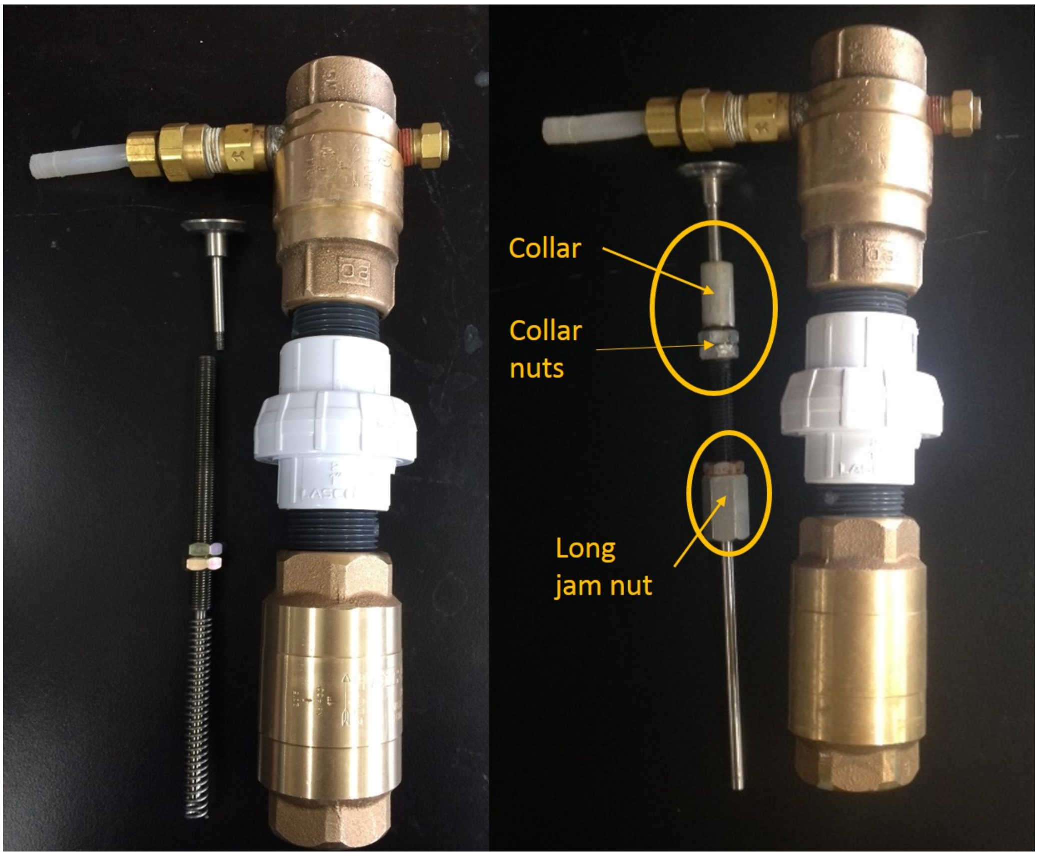

Figure 15: The new Collar Design is shown on the right. Changes from the Union design on the left include a collar and nuts to adjust the plate's amplitude, a rod with a longer unthreaded length, and a long nut to keep flexibility in spring compressed length despite the longer unthreaded length.

4.4.2 Results

The addition of the collar to the design was tested to see if restricting the amplitude could increase flow rate. Theoretically, this would decrease the cycle time significantly, which would increase the flow rate.

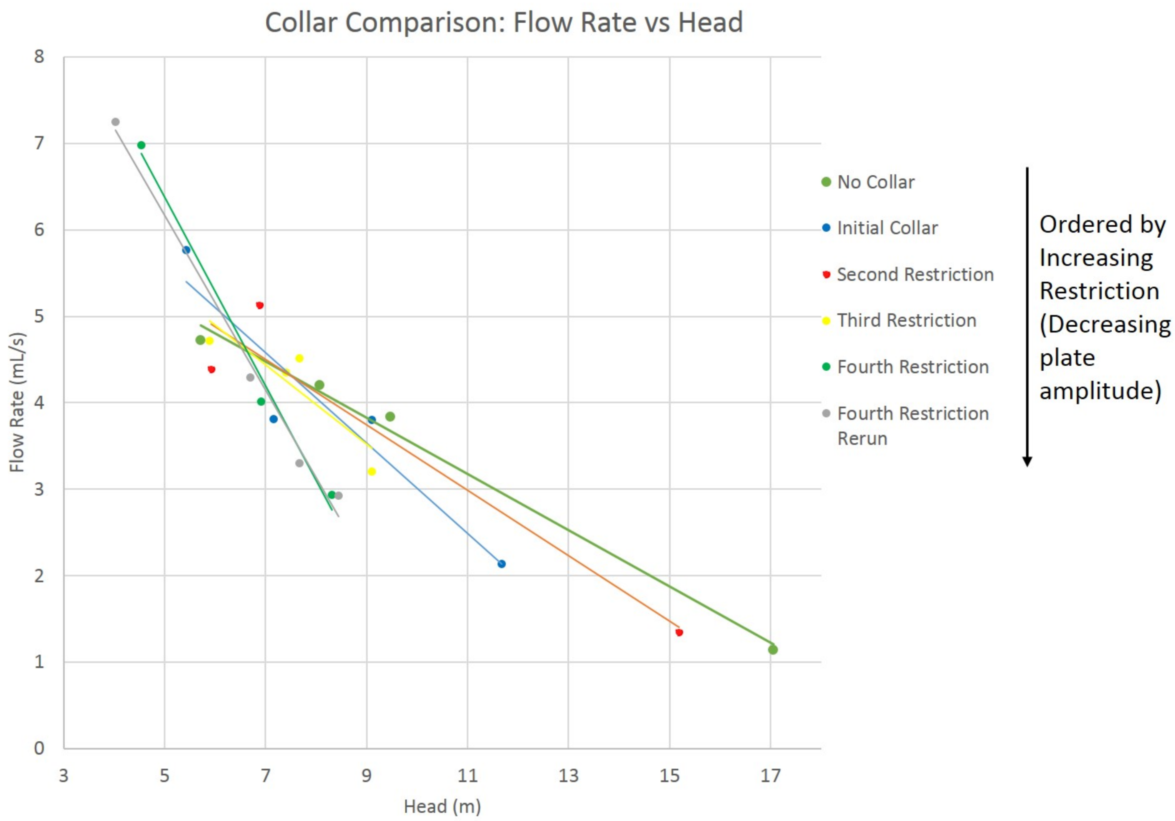

Figure 16: The graph shows the flow rates collected for different plate amplitudes. Intriguingly, changing the amplitude changed the slope of the flow rate vs head plot, which was a completely unexpected result. Regarding the magnitude of the restrictions, the second restriction was 0.168 inches greater than the initial, the third was 0.262 inches greater than the first, and the fourth was 0.278 inches greater than the first (the plate opened a few millimeters).

At the head to which most plants pump (approximately 7m), the graph shows that the collar does not make much of a difference in the flow rate. At greater heads though, greater amplitudes provided greater flow rates. At lower heads, smaller amplitudes provide greater flow rates.

To better understand what is happening as a result of of the collar, a graph of shorter (collar-restricted) vs longer (no collar) cycle times is shown in Figure 17. Figure 16 shows that shorter cycle times are more efficient when pumping to lower heads, and less efficient when pumping to higher heads. This is not what the team thought would occur. As shown in Figure 17, short cycles pump less water than long cycles, but have more frequent cycles to compensate. The team's initial idea was that there would be an unequivocally preferred cycle time, but this is not the case.

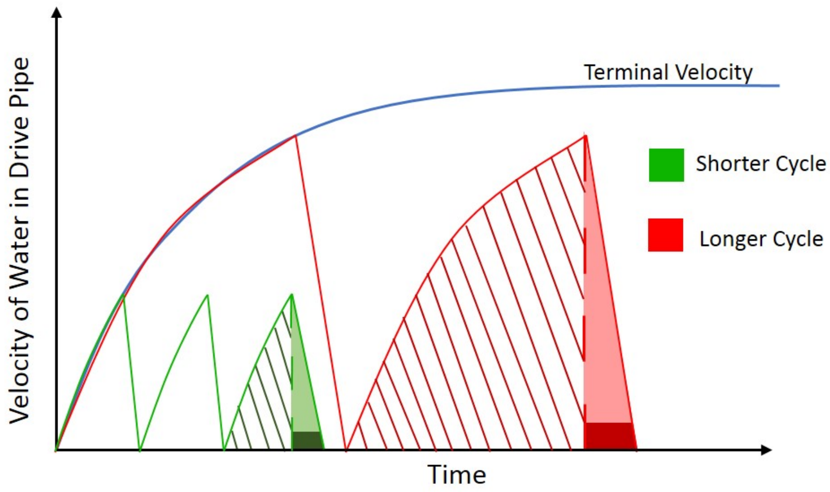

Figure 17: This graph displays the difference between short and long pump cycles. While the short cycle pumps less water in each cycle, in a given amount of time there will be more short cycles than long ones.

After some thought and assistance from Professor Weber-Shirk, the team came up with a new hypothesis to explain the data: variable leakage (see Figure 18). The hypothesis is as follows: when pumping to higher heads, the pressure on the opposite side of the stop valve (on the other side of the check valve) is significant. As a result, when the check valve closes and the stop valve opens, a sizable volume of high-pressure water (water that has already been pumped) on the opposite side of the stop valve leaks back into the check valve system. When pumping to lower heads, the pressure on the opposite side of the stop valve is not as great, and therefore the pump does not leak as much.

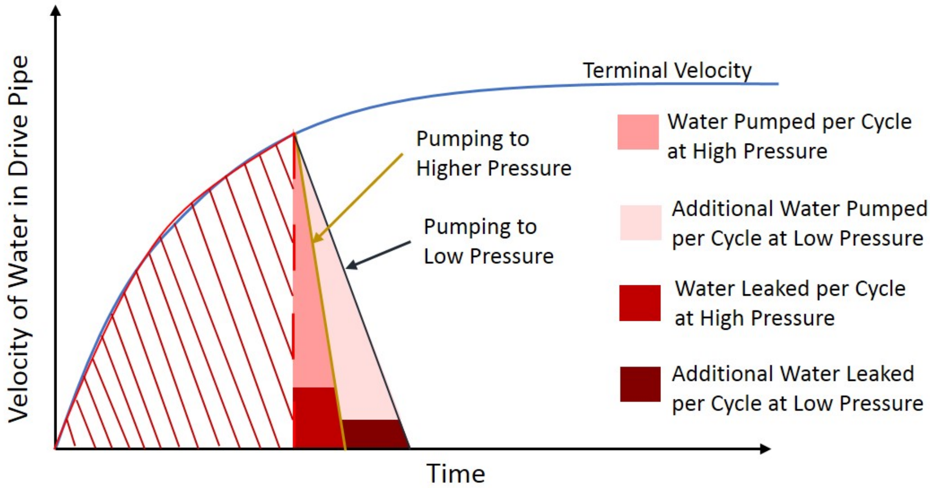

Figure 18: Demonstrates the increased leakage effect at higher heads/pressures. While the volume of water pumped naturally decreases with increasing head, it further decreases as the volume of leaked water becomes even more significant.

Relating this back to short and long cycles, the team believes that shorter cycles lose efficiency far more rapidly than longer cycles because of this phenomenon. Shorter cycles pump less water per cycle than longer ones and have more cycles in any given time interval to compensate. However, this means that there are more cycles during which the stop valve will leak. At higher heads, this leakage quickly inhibits the efficiency of short cycles. On the contrary, low heads have low leakage per cycle. Since short cycles are more efficient than long ones at lower heads (closer to the ideal non-leaky system), the team therefore concludes that shorter cycles must be intrinsically more efficient under ideal conditions (no leakage).

4.4.3 Discussion

Testing this design led to very interesting findings, and an increased understanding of the physics of the ram pump. Since the collar showed promise in increasing pump efficiency, the team recommends that this Union-Collar design be taken to Honduras over the Union design. The team has had some trouble in adjusting the collar nuts, however. The collar is too short, to the point that the team must remove the rod from the system to adjust the collar nuts. Ideally, only the union would have to be undone to adjust these nuts. Looking forward, the team would like to improve the design by adding some regular PVC between the union and the lower, empty, check valve, and increasing the length of the rod and the collar itself. This would make it such that the collar nuts could be adjusted simply by undoing the union, as opposed to removing the rod from the system, and would make the adjustment far more practical.

Conclusions

Regarding the final implementation in AguaClara plants, the Enclosed Union-Collar design would be added to the distribution line in the basement after chlorination (see Figure 19), on the way to the distribution tank. This has many advantages to the currently used ram pumps in Honduras. Most important among them is the connection to the distribution tank. The new union design can also be retroactively added to any vertical pipe with minimal effort and is expected to function after slight modifications to the spring force. These advantages should make the ram pump far more simple to implement, and therefore allow all plants to benefit from the technology.

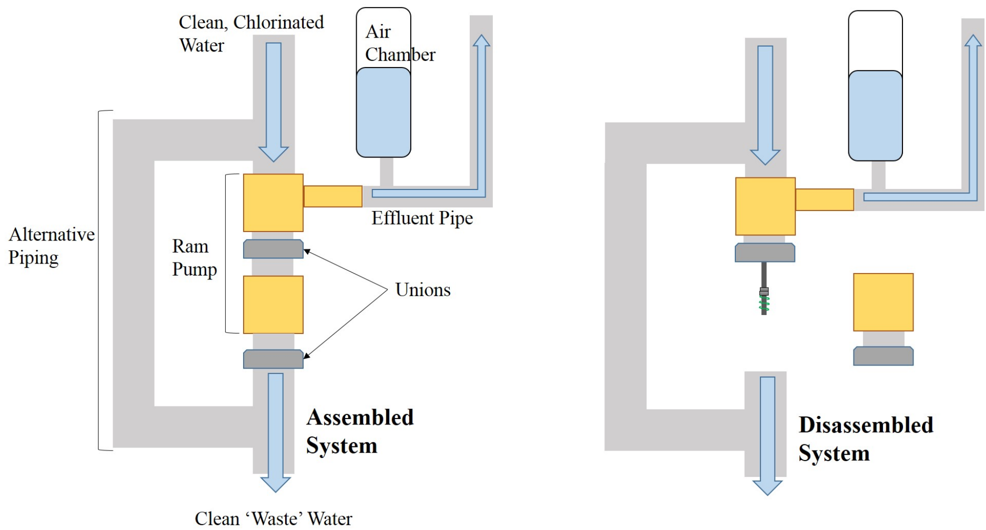

Figure 19: This is how a vertical ram pump could potentially fit into an AguaClara plant. The system is added onto the piping after chlorination and in the basement, and returns un-pumped water back into the distribution pipe. Should the plant have no further need for the ram pump at any point (if the stock tanks are full), then water can be directed around the ram pump through the alternative pipe. To replace or adjust the spring, two unions need to be undone.

Future Work

Moving forward, the team will prove consistent functionality and outline a manual and schematic for ease of use within the plant. Using the understanding of the physics gained by testing the collar, the team will work on doing further analysis of the forces within the system in order to provide each AguaClara plant with an estimate of a spring force that will be necessary for the specific plant parameters. Furthermore, the Union-Collar design needs to be modeled in AutoCAD, which the team also hopes to accomplish next semester. Moreover, future teams should test the effect of having the ram pump connected to the distribution piping. It is thought that perhaps an outlet for air will be needed as un-pumped water is not constantly coming out of the pump, but comes out in spurts. In addition, future teams can look into trying to restrict the water inside the pump from reaching a zero velocity when the plate is closed to increase pump efficiency.

References

Aggarwal, P., Guzman, J., Ringquist, J. L. (2015). Ram Pump, Fall 2015.

Nistal, P., Suri, K., Sakiyama, L., Aggarwal, P. Ram Pump, Spring 2015.

Semester Schedule

Task Map

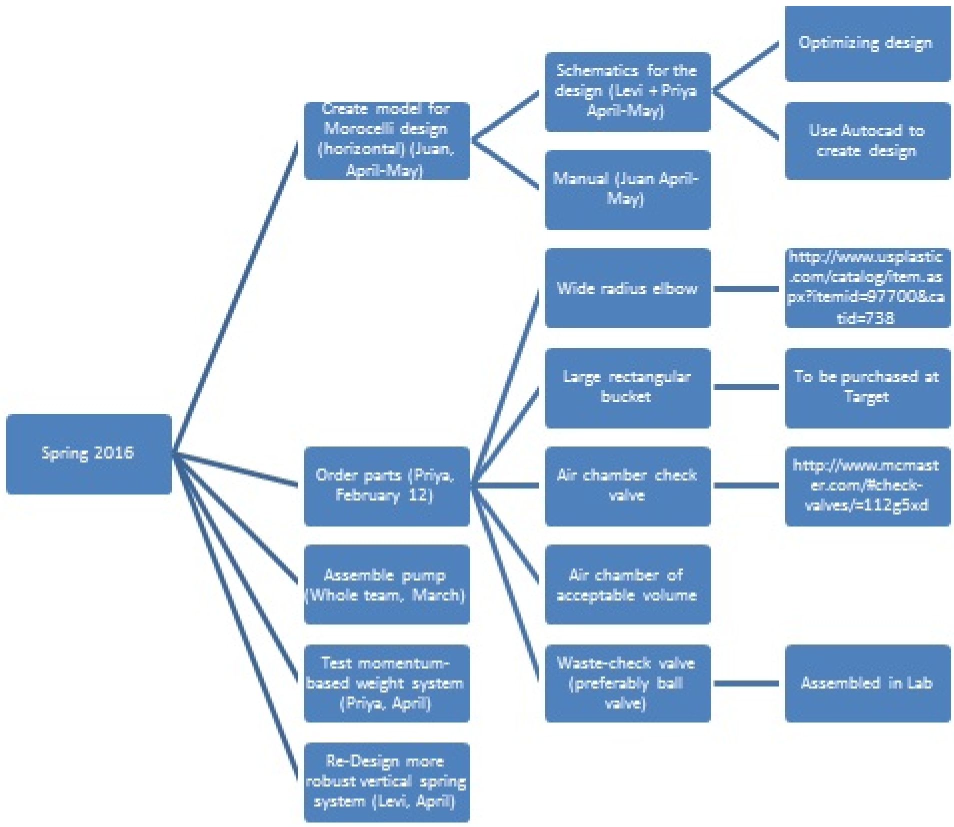

Figure 20: Ram Pump Task Map Spring 2016

Task List

1. Construct model for Vertical design (Juan, Priya, April-May)-Completed
   - Design Schematics for the pump (Priya April-May)-In progress
   - Write a manual (Juan April-May)- In the process
2. Assemble pump (Whole team, March)-Completed
3. Re-Design more robust vertical spring system (Priya and Juan, April) - Completed

Report Proofreader: Juan Guzman