Ram Pump, Spring 2015

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Abstract

The Ram Pump sub-team was charged with designing and optimizing a pump to elevate a small amount of water in the plants to fill chemical stock tanks and to provide bathroom services. A common testing issue has been low effluent flow rate compared to what is expected at the plant. The Spring 2015 ram pump team has designed a new ramp pump system which allows users of the ram pump to adjust the size of the spring in the ram pump to provide for maximum efficiency. The team is working on testing each part of the system, seeing what can be fixed and changed, and then implementing those changes. The team has found that ultimately springs of varying spring constants and lengths provide similar flow rates. The team has also found that an air chamber greatly improves the flow rate of the system and bigger air chambers provide better flow rate than smaller ones.

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Introduction

AguaClara seeks to provide clean drinking water to communities in Honduras without using electricity to operate. Not using electricity becomes difficult when the water needs to be pumped from lower elevations to higher elevations. The water needs to be pumped to bathrooms and to mix stock concentrations of coagulant and chlorine present within the AguaClara plants. The ram pump is able to circumvent the problem of gravity in moving the water to a higher elevation. Through a series of interlocking valves controlling synchronized pressure systems, the ram pump utilizes the combination of gravitational force, hydrostatic force, and spring force in order to pump the water to a higher altitude without using electricity. This semester the team is worked on improving the revolutionary design in which the system is oriented vertically and a spring is used to provide the “reactive” force that was previously provided by the weights. The ram pump team seeks to increase efficiency, durability, self-sustainability, and compactness.

Literature Review

History of the Ram Pump

The ram pump was first invented in the late 1700s, before electricity could be used for electric pumps. The first record of a precursor for a ram pump was found in England in 1772 by Edward Mangio. This precursor for the ram pump was called pulsation engine. The first patented pump was invented in France by Joseph Montgolfier. Ram pumps are still used throughout the world today, although many people use electric pumps instead of hydraulic ram pumps. The basic principle all ram pumps follow involves a large amount of water falling a short distance and then a small amount of that water is pumped to a higher height. Ram pumps also have many limitations such as low delivery heads, low head loss, and low efficiency; the pump efficiency is usually between 50% to 60% but can be more or less depending on the pump. The amount of water that is successfully pumped to a higher elevation depends on the source flow, the heights involved, the length and size of the delivery pipe and driveline, pump efficiency, and the size of the pump.

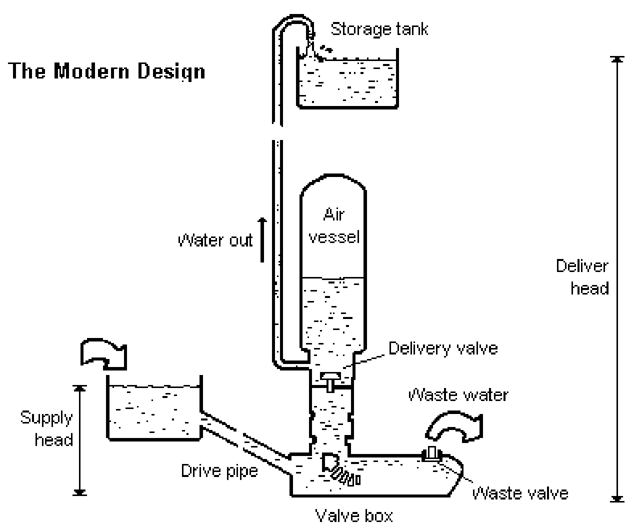

Figure 1. Ram Pump Basic Layout.

Conventional Ram Pump

A ram pump utilizes the falling of a small amount of water to lift a fraction of the supply flow to a greater height. It is mechanically very simple. Hydraulic ram pumps depend on the water hammer effect phenomenon and usually the only moving parts are two valves. Initially the water will flow from the water source through a drive pipe and the impulse valve (or waste valve) will be open under gravity. As the flow accelerates, the pressure under the impulse valve and the static pressure in the body are increased. The resulting forces will overcome the weight of the valve and start to close it. Immediately after, pressure in the body builds up rapidly and shuts the impulse valve. The velocity of the column of water in the drive pipe will reduce because it can no longer pass through the valve. Pressure then continues to rise, forcing open a delivery valve that gives to an air chamber. When the pressure exceeds the static delivery head, water will run up to the delivery pipe. Eventually, the pressure of compressed air inside the air chamber will relieve the pressure difference between the two valves such that it will stop the movement of the water below it and cause the delivery valve to close. Water will continue to be delivered until the compressed air in the air chamber is equal to the pressure in the delivery head. The reduced pressure in the body will allow the impulse valve to close and a check valve prevents the flow to return.

Figure 2. Commercial ram pump.

The air chamber improves the efficiency of the process by allowing delivery to continue after the delivery valve has closed, and also minimizes the shocks that would otherwise occur due to the incompressible nature of water. If water fills the air chamber completely, the performance suffers, and the hydram body, the drive pipe or the air chamber itself can be fractured by the resulting water hammer. The air in the chamber must be depleted by being carried away with the delivery flow. Different commercial ram pumps have different approaches for this problem. One simple solution is to stop the pump occasionally and drain the air chamber by opening two taps, one to admit air and the other to release water. A more sophisticated way is to include a ‘snifting valve’ which will allow air to be drawn into the base of the air chamber when the water pressure momentarily drops below atmospheric pressure.

Pump Efficiency

The following empirical formula is given by ram pump fabricants and was used by the previous team to describe the flow rate produced:

$$Q = ES(F/L)$$

Where:

Q = flow rate obtained (L/s)

E = energy efficiency

S = inflow rate (L/s)

F/L = ratio between the height to source and the height to destination, both from the ram pump.

The energy efficiency depends on the loss of energy through the transmission, but is constant for each of the different designed systems. The commercial rates vary between the 60% and up to 80%. A higher efficiency is not easily obtained. Throughout the semester, many flow rate measurements were taken varying the head loss, which simulates increase in height to destination. In accordance with the equation, a linear model fit well the flow rate data. One of the main goals of the project is to obtain higher flow rates, while maintaining the minimum head loss. That can be achieved by increasing the energy efficiency of the ram pump to competent levels.

Water Hammer Effect

The water hammer effect is a pressure wave caused by the sudden stop of a flowing fluid. This effect takes part in the ram pump when the water is stopped by the closing of the waste valve, reducing drastically the velocity of the water. However, for better performance the ideal behaviour would be something like this (red and blue lines are the theoretical behavior of the water accelerating in a frictionless pipe due to gravity, the yellow line shows the real behavior and the brown line the ideal behavior inside the ram pump):

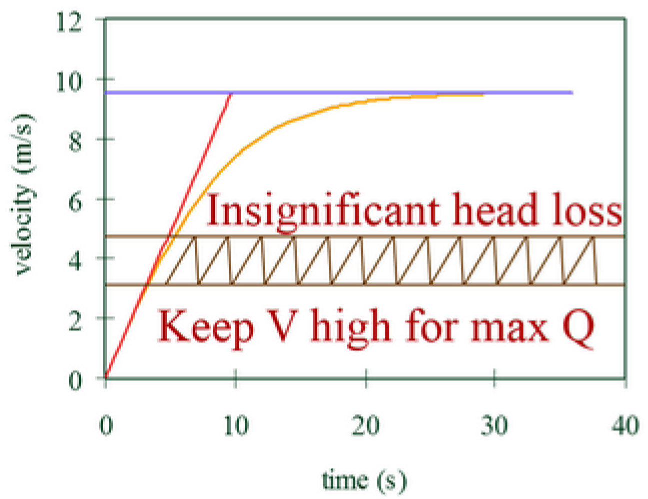

Figure 3: Representation of the relationship of velocity vs time when taking the effects of gravity into account.

Source: Hydraulic Transients - Monroe L. Weber-Shirk

The ram pump system aims to perform akin to the brown line; the acceleration of water results from the flow of water through the drive pipe, in the direction of gravity, and the deceleration of water results from the closing of the waste valve, when the pressure in the valve increases to a point where a pressure gradient is created such that there is a diversion of water into an area of lower pressure. When the increased pressure in the waste valve is relieved, the valve opens again and the water starts accelerating again. The theoretical formula that represents this acceleration is:

$$\frac{dV}{dt} = \frac{-g}{L}\left(\frac{\triangle p}{\rho g} + \triangle z + h_l\right)$$

g = gravity constant;

L = length of the drive pipe;

p = pressure;

ρ = density of the water;

$\triangle z$ = elevation difference;

h_l = head losses.

With the assumption that there are no head losses, the equations for the two periods are as follows:

Acceleration: $\frac{dV}{dt} = \frac{-g}{L}(-z_1)$

Deceleration: $\frac{dV}{dt} = \frac{-g}{L}(z_3 - z_1)$

z_1 = height to source from ram pump z_3 = height to destination.

Previous Work

The previous ram pump team (Fall 2014) attempted to establish a pump that would allow for the highest probable efficiency by testing the effect of variations in component sizes, the distance between components, and the magnitude of the external force on the check valve. The testing concluded such that the most efficient ram pump produced a lower effluent flow rate than what was expected or required. The reason for this was contributed to a loss of energy occurring in two primary locations: the 90 degree bend at the bottom of the influent pipe and the spring valve underneath the air chamber. The latter loss was contributed to short cycle times that only allowed small amounts of water to make it to the air chamber each cycle-- and a potential solution of increasing the cycle time would greatly decrease efficiency of the system as a whole.

In an attempt to minimize this, the previous ram pump team came up with a new "vertical" ram pump design such that the drive pipe and the elbow to the system would be completely eliminated. This new system would require the waste valve to be oriented opposite of its current alignment and to be spring-powered (rather than weight-powered). This would enable the closing of the waste valve to be dominated by the hydrostatic and gravitational forces applied by the column of water in the drive pipe, and the closing of the valve to be dominated by the force exerted by the spring in response to the release in the hydrostatic force that would then be oriented towards the low pressure area beyond the check valve. As a result of this, the check valve would be attached perpendicularly to the waste valve in the area of the waste valve above the inner plate and would allow for optimal usage of cycle times for the movement of water from this area, into the check valve.

This new system was brought down to Honduras for testing purposes. The conclusions made there was that it worked just as well, if not better, than the established system, allowed for a lot of improvement, and was more favorable in terms of space.

Methods

Apparatus

A schematic of the primary system used is shown in figure 4. Water is elevated with an auxiliary pump (F) up to the overhead storage tank (A), which simulates the initial situation of the liquid in the plant. Inside the tank there is a weir (H) in order to have a constant head for performing the experiments (2.25m of water height over the waste valve plate). This selection of a constant head has been implemented in order to be able to reduce the variables during the testing in the laboratory but, however, after the field research in Honduras carried by some members of our team it has been shown that this is not completely truth in the real plants where the head is variable most of the time and the flow is only close to continuous.
Once out of the tank, water flows down through a 1-inch vertical drive pipe (B) all the way down to the valve system, unlike the previous vertical-elbow-horizontal drive pipe which produced lots of energy losses. There is a manual valve (C) in the drive pipe in order to stop and start the cycle.

When the water reaches the valve system (D, detail in figure 5), the same process as before takes place but in a much smaller space. With the waste valve (the plate in the bottom of the valve system) initially open (stretched spring), the water coming from the drive pipe is accelerated due to gravity and, therefore, pressure in the area above the waste valve inner plate rises (the team has placed a pressure sensor in this specific point so that pressure readings can help determine the behavior of the water during this process). When the pressure on the plate is higher than the force exerted by the spring to the rod, the valve is closed. The sudden closure of the valve causes the water, an incompressible fluid, to reduce its velocity very rapidly create a huge wave of high pressure that travels through the fluid (the water hammer effect). This pressure is enough to open the check valve and force the water to go through it, reaching the delivery system (air chamber first if it is included in the system). When the pressure has decreased enough, the waste valve opens again. Due to the small cycle time, the proximity between both valves is critical - energy losses were the main problem with the previous design and the team is trying to minimize them.

Pumped water gets into a delivery system that also simulates the head loss found in Honduran plants. During this semester the team has tested two different systems:

- Flexible tubing: The team’s first approach was very flexible clear tubing that would absorb the pressure waves throughout its length providing a constant delivery. After the testing it was shown that this solution was not as practical as it was thought to be: the pressure wave was only slightly attenuated and delayed (it is originated at the valve system and the reading is located after the tubing, around 6 feet long).

- Air chamber: Located right after the check valve. Clear PVC pipe with caps on both ends filled with air which compresses under the action of the water entering the chamber. After the first two tests it was clear that an air chamber is needed in the system to obtain the best performance. Although the perfect sizing of the air chamber is still unknown, the impact of the air chamber on the results show that even a random-size air chamber can double the delivery obtained without the air chamber.

Either of these two systems need a final component shown in the schematic below, a needle valve (G), which is the responsible of creating the head loss that our pump has to overcome. The un-pumped water reaches the containment system (E) after going threw the waste valve. In order to control the pressure at which the water is delivered, the laboratory set up also includes a pressure sensor after the check valve (see figure 6 for more details). The readings from this sensor provides data for two different purposes: pressure difference between that point and the environment for determining equivalent head and pressure wave attenuation.

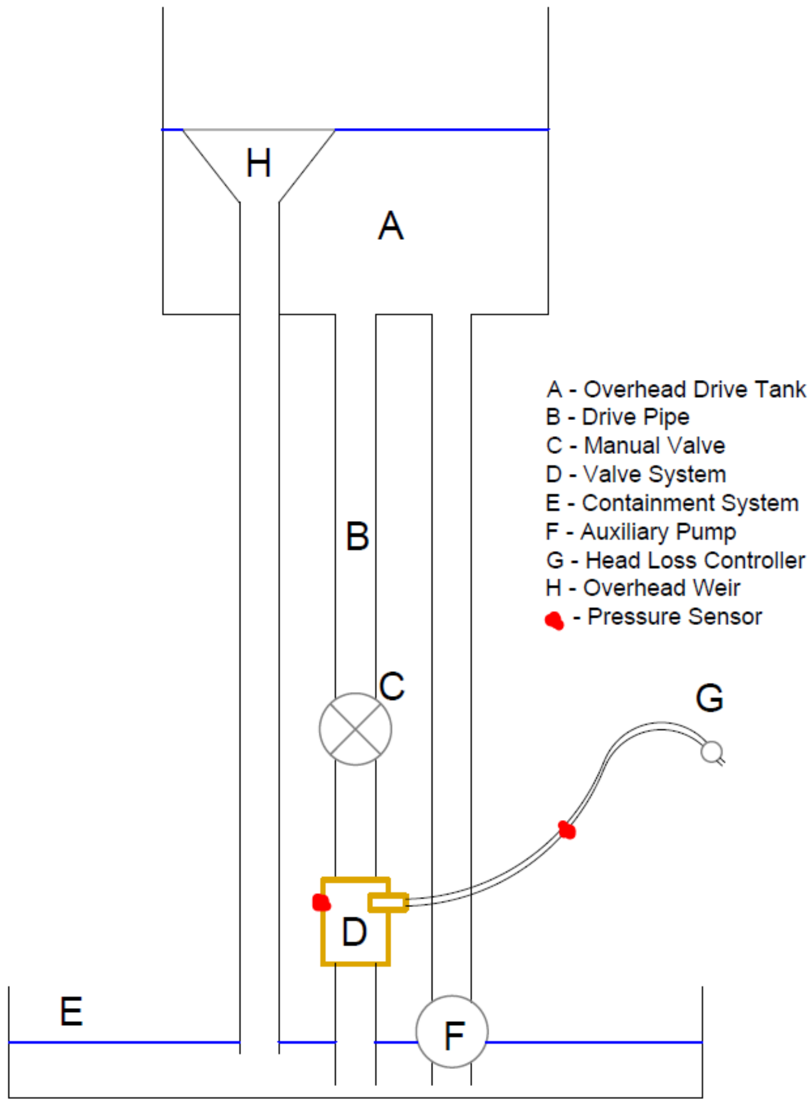

Figure 4. Schematic of ram pump apparatus.

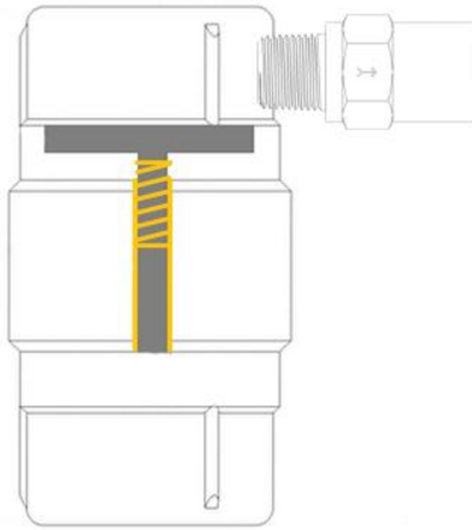

Figure 5. Waste and check valve system with previous spring location.

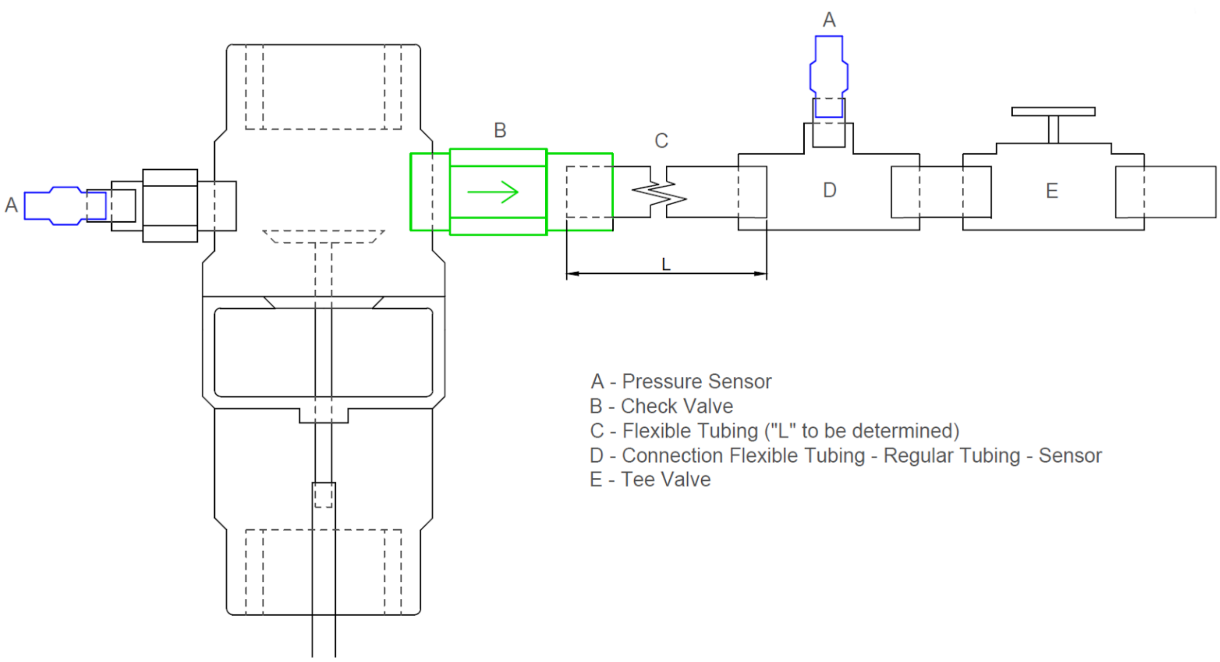

Figure 6. Laboratory set up with flexible tubing: waste valve, check valve, tee valve and sensors.

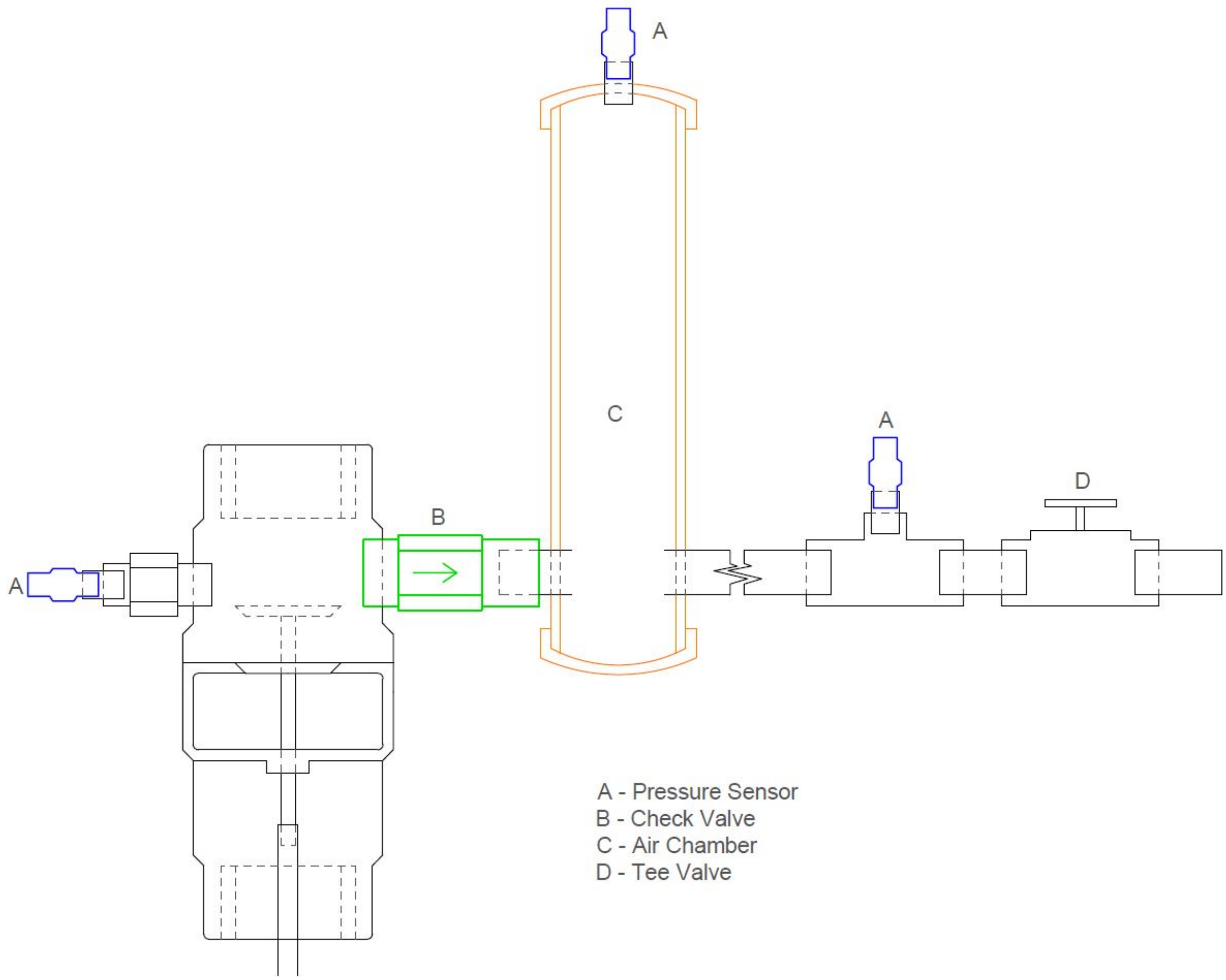

Figure 7. Ideal set up with air chamber: waste valve, check valve, tee valve and sensors.

Spring Manipulation System

The new design for the ram pump required a spring in order to open the waste valve against gravity. The previous team had placed the valve just below the inner plate (figure 5). However, for manipulation purposes, the team has decided to implement a new system with the spring out of the valve area so that its length can be controlled without having to disassemble everything. This way it is possible to know exactly what force is being implemented to the rod that lifts the plate and the overall system is more prepared to adapt in the field.

Two early sketches can be seen in figure 8, and the final design is shown in figure 9. The system is a 1-½ inch pipe located in the bottom part of the waste valve, allowing the water that is not pumped to go through. There is an opening in the pipe with a tilted plate that will take most of this water out of the system in one direction for better conditions near the area of the spring while, below on the other side, there is another opening for manipulating the spring. A rod is connected to the waste valve plate, passing through three different plates for better stability, and it counts with a threaded section in which two nuts are screwed, making it possible to adjust the compressed length of the spring, holding the upper part of the spring and transmitting its force to the plate. The other side of the spring is held by one of the guiding plates, which is attached to the pipe that forms the system.

The design that the team is building has taken into account the existing conditions in the research space but, for real field models, the design would be slightly different: the pipe would have no openings so that the water can flow through the system while it is working. In order to achieve this goal, both the upper and lower plates will be modified, and the adjustment of the nuts will be done by unscrewing the system from the valve. A proposed design can be seen in figure 10.

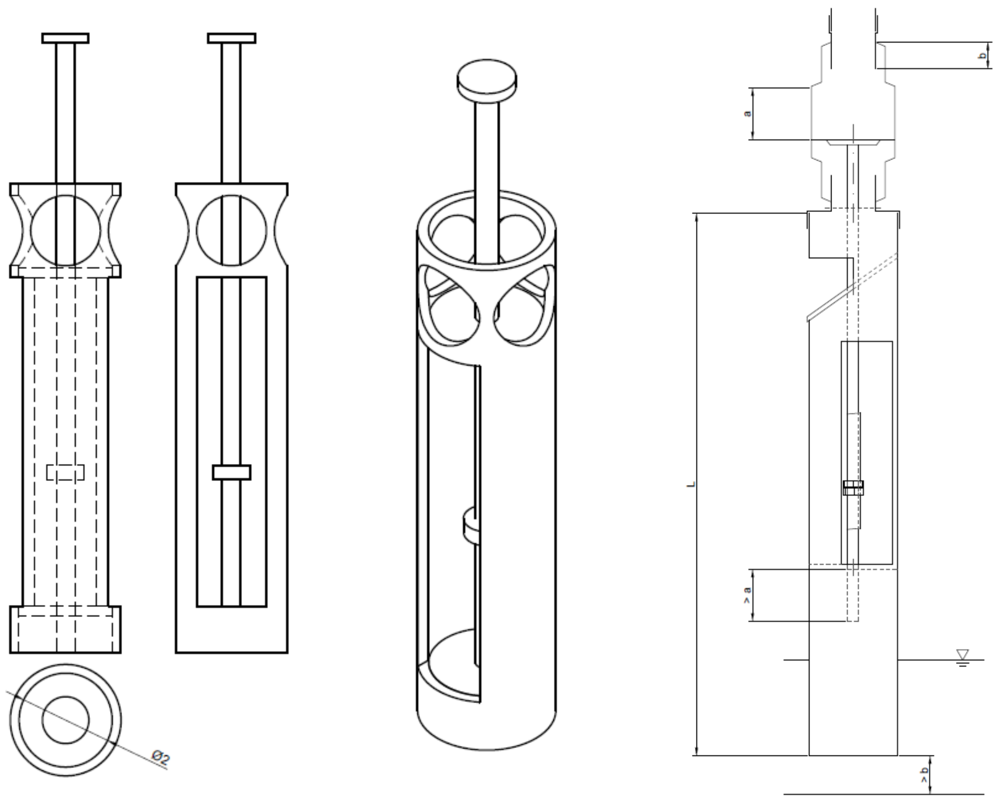

Figure 8. Early sketches for the spring manipulation system.

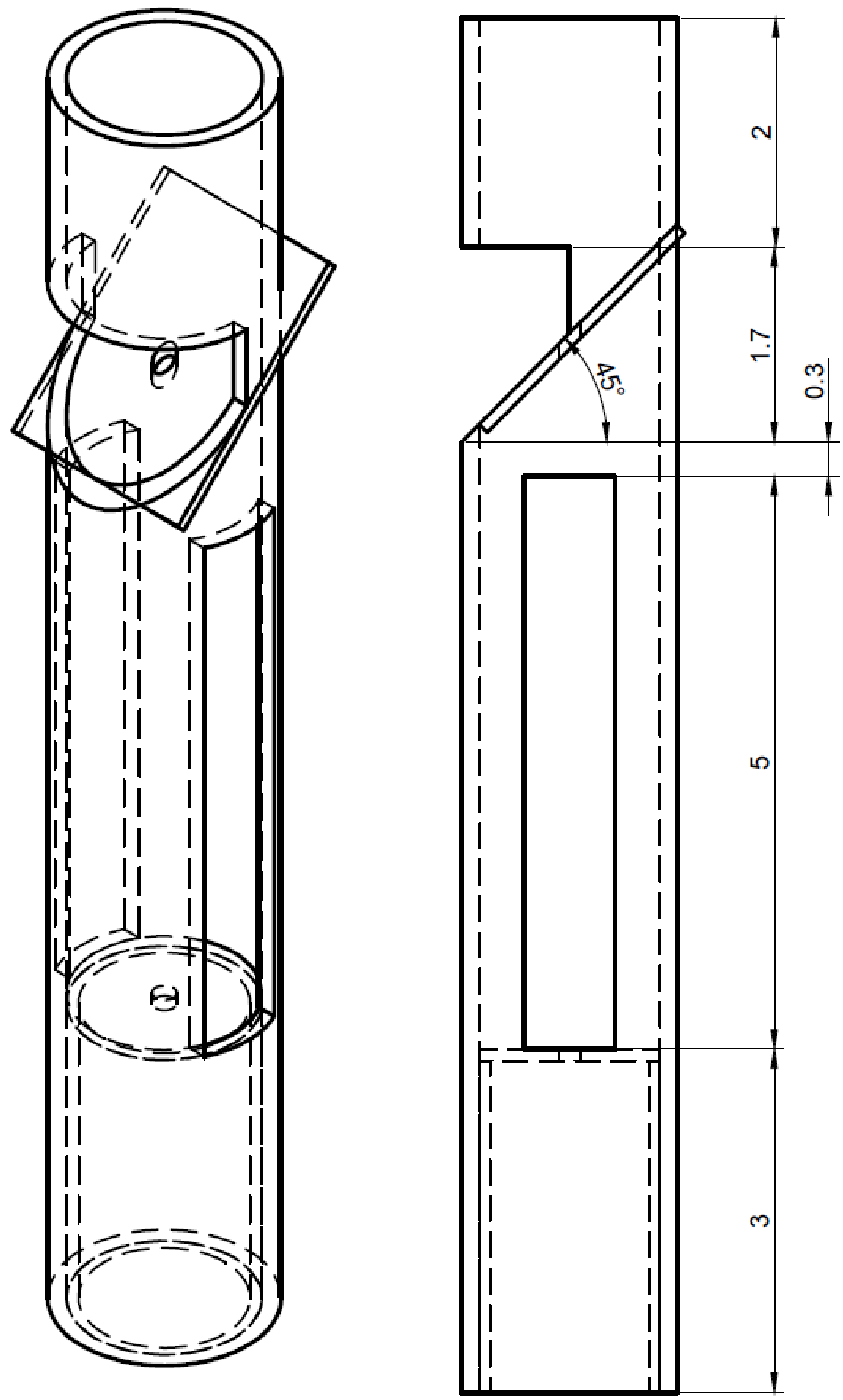

Figure 9. Final design for the spring manipulation system (dimensions in inches).

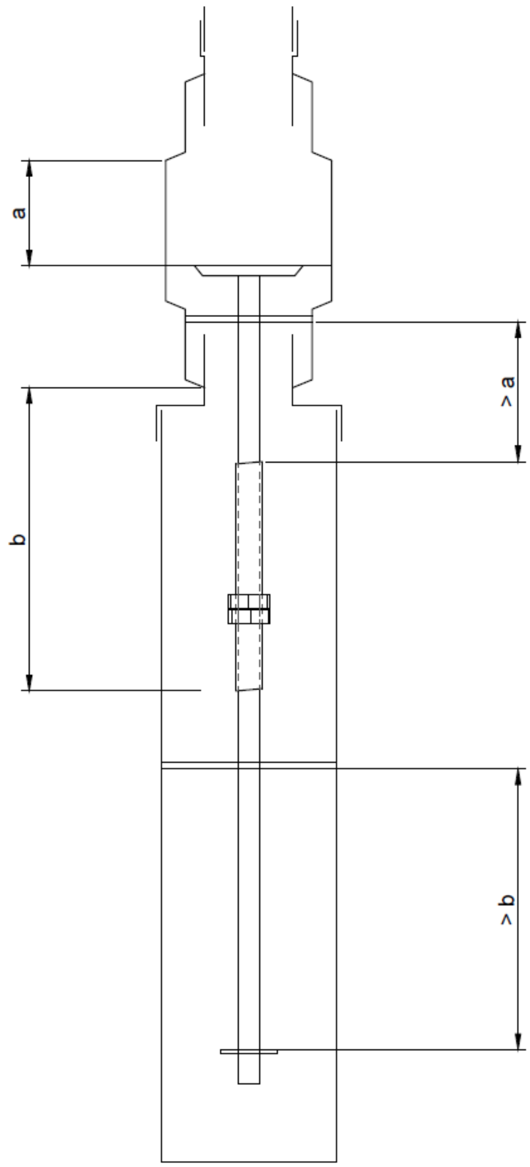

Figure 10. Proposed field design.

Results

Flexible Tubing System Early Tests

When we conducted our first two runs with our first spring we found that the spring would alternate between oscillating at a shorter period and a faster period (as can be seen in figure 11), which caused the pressure to build higher during the longer periods. However, after including the air chamber in the system this behavior seems to have disappeared. We also found that our head loss would fluctuate a lot at higher values (from 6 meters on) therefore we suggest looking to putting in another tee valve after the existing one which will help control head loss fluctuation.

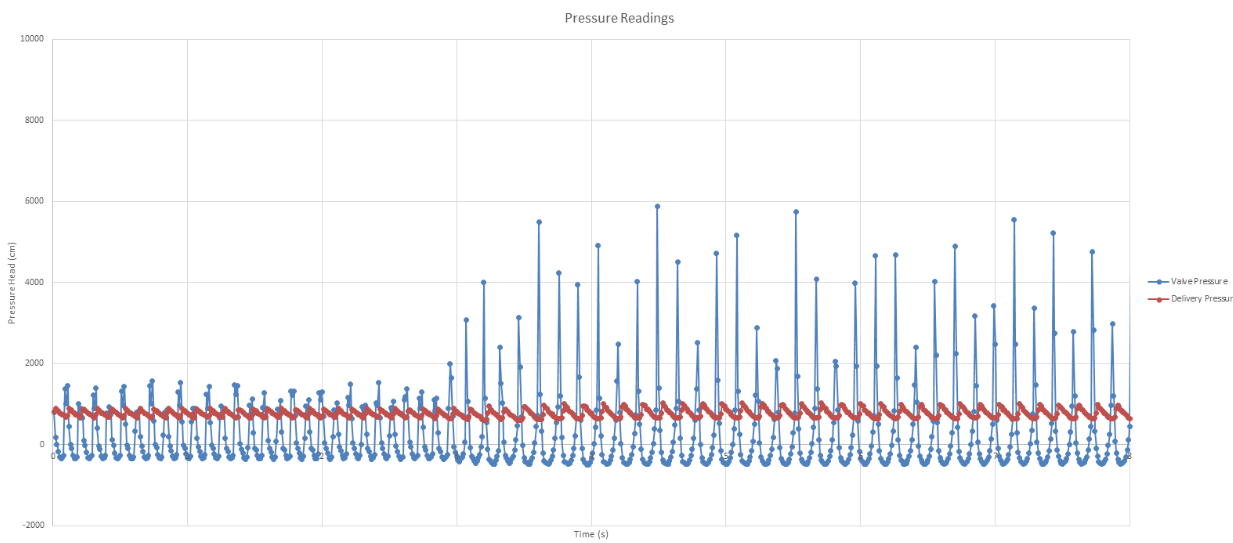

Figure 11. Valve pressure (blue) and delivery pressure (red) reading with two different periods found.

When the head loss was close to zero (when delivery rate is maximum), the measured effluent flow rate was 1.2 Liters per minute. This is a sign that our valve system is not working as we want it to be (if the maximum flow that we can obtain is 4 times smaller than the expected, the sizing of the valves should be reconsidered). When we tried to increase the head loss to approximately ten meters, the flow rate was reduced to about 0.1 Liters per minute. If we compare this result to the 4 Liters per minute that the new plant designs are asking for, it is obvious that improvement is needed. This will be achieved by increasing the amount of time that the pressure obtained inside the valve system (blue) is higher than the pressure in the delivery (red). Although the team has tried to explain it, the behavior is still not clear. The first results suggest that smaller spring constants but longer springs give a slower rate of pulses but the flow is pretty similar for every case.

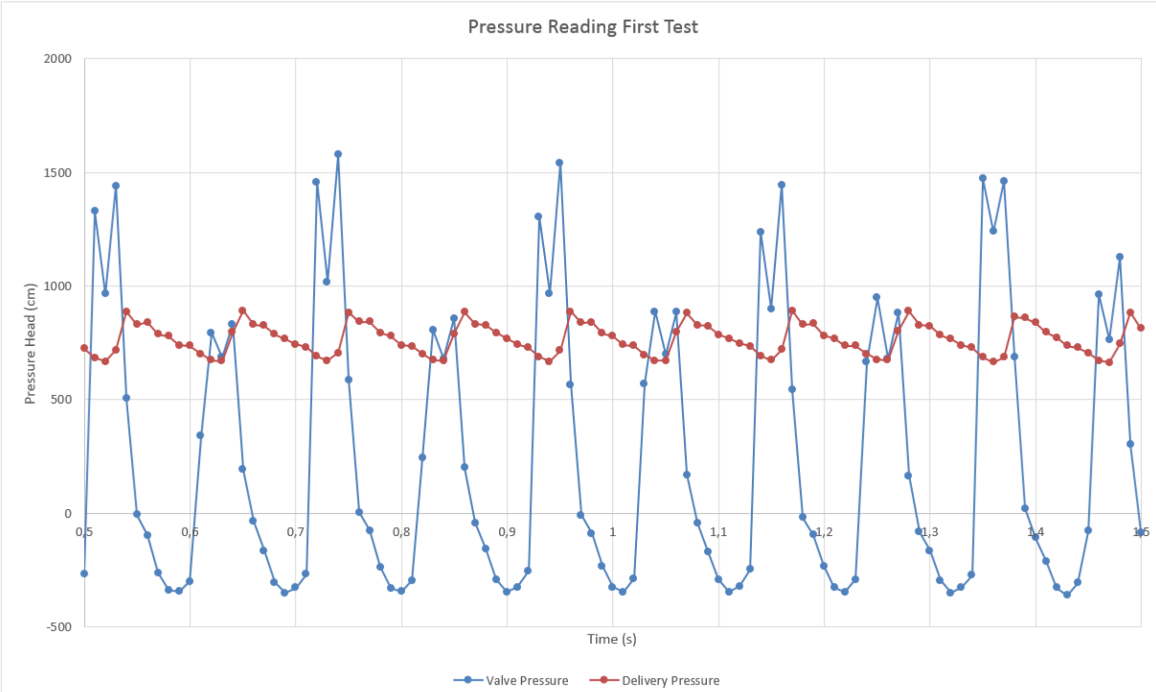

Figure 12. Closer view of the pressure reading, valve pressure in blue and delivery pressure in red.

As seen in figure 12, the tubing installed after the check valve is not performing as the team intended. Instead of a constant pressure value in the delivery (desirable for a constant output of water), the fluctuations due to the water hammer effect are found after each cycle with a small delay. In figure 13 it can be seen the actual periods of time that water is being delivered and the pressure difference between the valve and the delivery (note that when the pressure in the delivery is higher the check valve will close and no water will be pumped). The objective of the team is to maximize this two variables so that the water delivery rate can be increased.

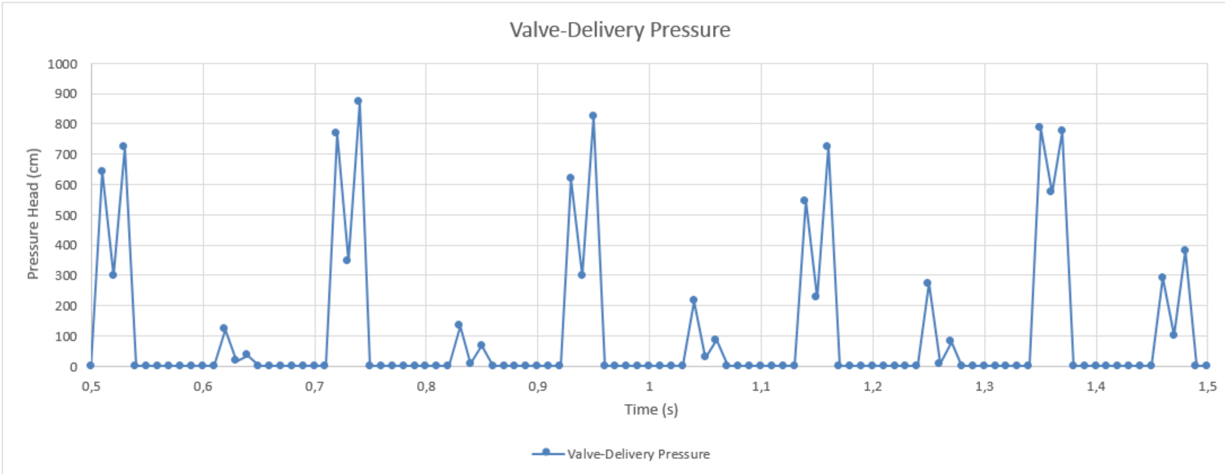

Figure 13. Valve and Delivery Pressure Difference reading.

When running the ram pump for the first time we noticed that the nuts holding the spring at a specific length were moving therefore we decided to tape the nuts to hold them in place in order to get more accurate results. The length of the spring is measured before and after the run to make sure the system is working as it should.

We also noticed that there were leakages in the ram pump which are also affecting our results. These leakages were fixed by putting in new connectors and tightening all of the connections before running the system.

We found that the valve was not closed for as long as we would have liked and the pressures obtained were lower than expected, therefore we tested different spring constants and spring lengths in order to find the optimal conditions that allow for the maximum flow rate. Quick tests were taken that showed that adding another check valve did not improve the efficiency of the system.

Flexible Tubing System Complete Analysis

After running some more trials, the results have been the following:

Table 1. Testing of springs with varying forces on the Ram Pump.

System Set-Up	Spring	Spring Constant (lbs/in)	Initial Length (in)	Compressed Length (in)	Change in Length (in)	Spring Force	Average Head Loss (m)	Average Effluent Flow Rate (L/min)	Linear Fitting	Expected Flow Rate @ 4m Head Loss
3/8" Check Valve 3/8" Peristaltic Tubing	1	4.1	2.955	2.040	0.915	3.75	3.20	0.48	y = -0.0345x + 0.5729 R^2 = 0.9594	0.43
							9.60	0.25		
							5.30	0.36		
			3.270	2.040	1.230	5.04	2.20	0.40	y = -0.0446x + 0.5056 R^2 = 0.981	0.33
							6.80	0.23		
							8.90	0.09		
			3.710	2.040	1.670	6.85	4.10	0.23	y = -0.0204x + 0.3158 R^2 = 0.9924	0.23
							8.00	0.15		
							2.60	0.27		
	2	19.31	2.955	2.040	0.915	17.67	--	--		
							--	--		
							--	--		
			2.250	2.040	0.210	4.06	5.50	0.29	y = -0.0332x + 0.4955 R^2 = 0.9409	0.36
							4.80	0.35		
							9.00	0.20		
			2.465	2.040	0.425	8.21	10.30	0.20	y = -0.0301x + 0.5061 R^2 = 0.937	0.39
							2.70	0.43		
							7.60	0.27		
	3	10.6	2.955	2.040	0.915	9.70	--	--		
							--	--		
							--	--		
			2.465	2.040	0.425	4.51	6.50	0.29	y=-0.0583x+6.417 R^2=0.92233	0.43
							4.80	0.35		
							7.40	0.19		
			2.515	2.040	0.475	5.04	2.70	0.43	y=-0.0286x+0.5105 R^2=0.99692	0.48
							5.00	0.37		
							10.00	0.22		

Note that from here on, the team will have a coded nomenclature for better understanding where: system refers to the set-up (system 1, with tubing and no air chamber, system 2, with a 6 in air chamber, system 3, with a 9 in air chamber), spring refers to the type of spring (1,2 and 3) and length refers to the different springs among one type (see more details in tables 1, 2 and 3).

First of all, using the assumption of linearity demonstrated the previous semester (see References, Ram Pump Final Report Fall 2014), we measured 3 different flow rates for 3 different head losses in order to find a line that demonstrates the behavior of each particular spring (see figures 14, 15 and 16). For the first spring, with a K value of 4.1lb/in, it seems that shorter lengths work better than larger ones. In this particular case, due to the small spring constant, the result can be altered due to buckling of the longer options. For the second spring, for a K value much higher (19.31), the behavior seems the opposite and for the third one, with an intermediate constant (10.6) the results show that there is a very small difference. In order to state a clear final conclusion more testing needs to be done but, so far, it appear as though the behavior is the same as the previous semester: lower force values work in general better but there is a limit at which having such a low force makes the system unstable causing sudden stops (at around 3.5 lb of force) and, apparently, this behavior is reversed when approaching the upper limit which causes the same problems (around 9 lb of force). During testing we noticed that the different lengths (even for the same spring) were giving different cycle rates and we are comparing them all in figure 17 taking as a reference the expected flow rate at 4m of head loss (from fitting on figures 14,15 and 16).

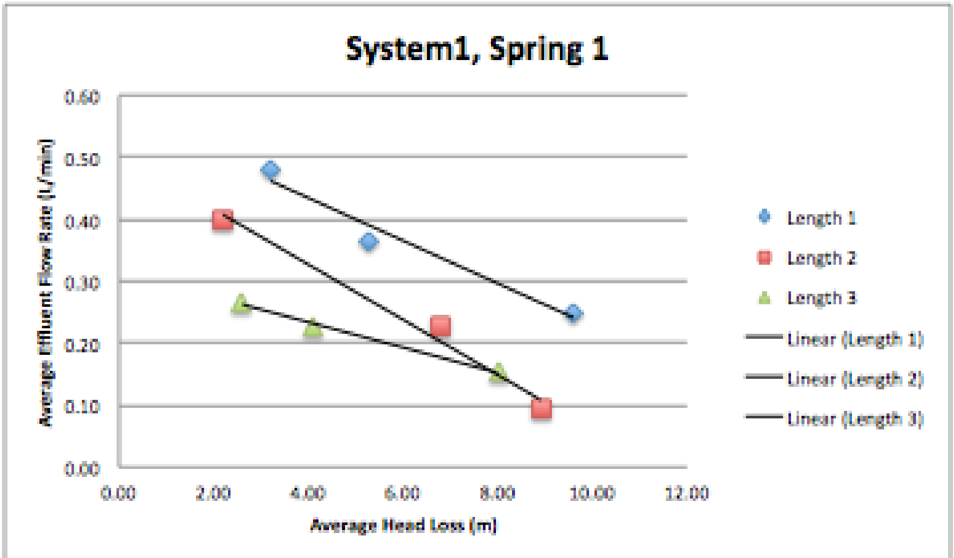

Figure 14. Characterization of the Spring 1, from System 1.

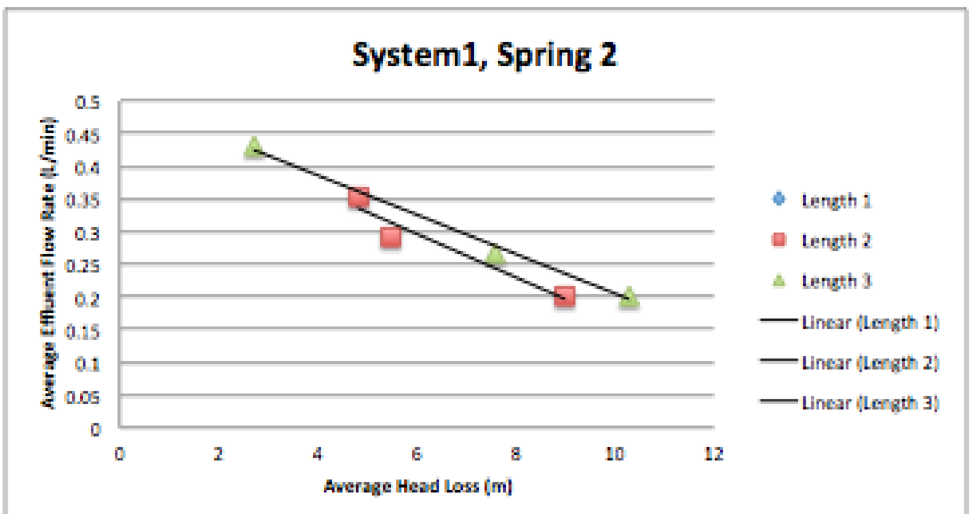

Figure 15. Characterization of the Spring 2, from System 1.

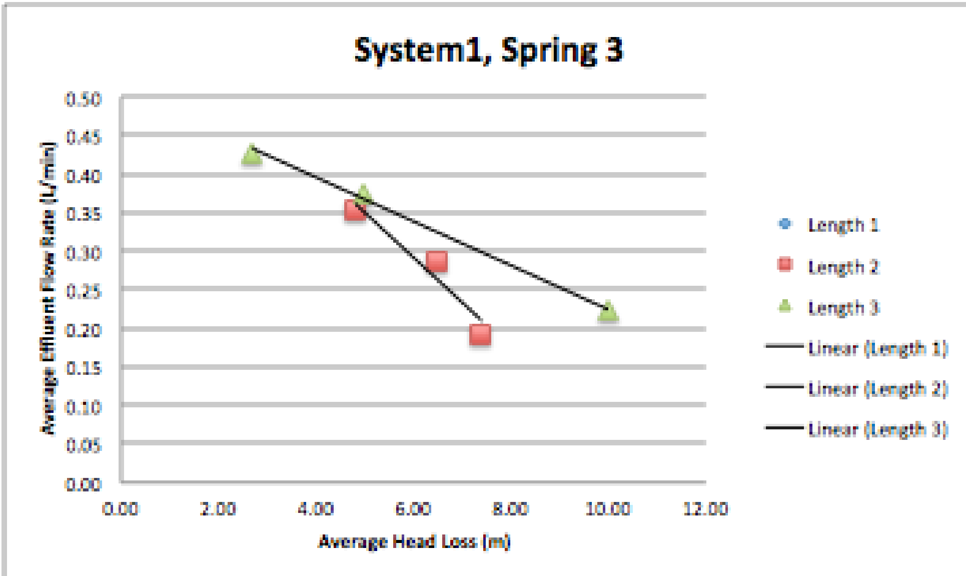

Figure 16. Characterization of Spring 3, from System 1.

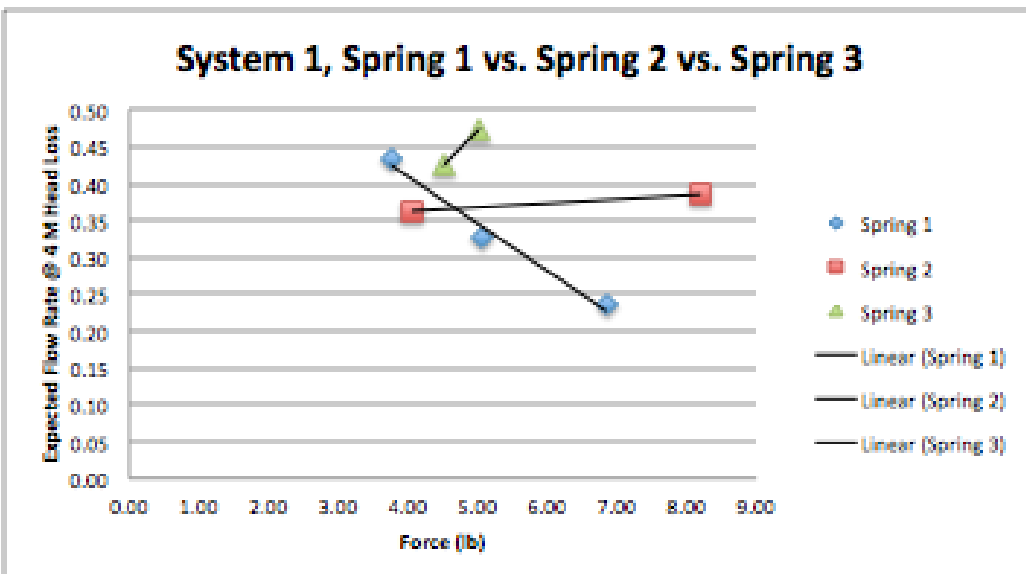

Figure 17. Comparison of Springs 1, 2, and 3-- with varying forces-- in System 1.

Note that the original length is measured with the spring fully stretched and the final length with the spring in position and the waste valve completely closed.

Our results show that all of the springs worked in very similar ways and there is not a clear best choice among them. The spring comparison graph shows that all three springs give around the same flow rate more or less. Because the testing was very fast and with low precision (the objective was not the complete characterization of all our springs but to get a general idea on how the variations on spring constant and lengths affect the efficiency of our ram pump) the differences are so small that it is difficult to know if they are due to the error in the measurements.

Regardless of the accuracy of the results one main conclusion was taken from this testing: even though there are small differences between the different combinations, the average effluent flow rate is far from the desired, changing the focus of the team towards other features like adding an air chamber to the system.

The tests we ran were with keeping the nuts fixed, which means each spring had the same compressed (when the plate in the waste valve is closed) length within the ram pump. By doing this and controlling the original length of the spring we can estimate what the height that the plate reaches is when the waste valve is open (the difference between fully compressed and fully stretched). For future teams we would recommend to continue with the same system and try to test different springs with the same lengths and varying force or the opposite, same force but varying lengths, in order to have a better idea on how this affects the cycle time.

Air Chamber System

Given that the system was not achieving great results with any of the tested springs and spring lengths, the team decided to add an air chamber. The initial air chamber had a 1.5" diameter and was 6" long, which is much smaller than the ones experimented with last semester. The first air chamber used was the result of a quick estimation of the size needed for the actual model. However, for a better sizing of the air chamber the team recommends reading the previous report (Fall 2014) where a sizing procedure is shown (but it also requires an iterative process of adjusting the air chamber to the effluent flow rate and cycle time). Figure 18 shows the new air chamber added to the ram pump.

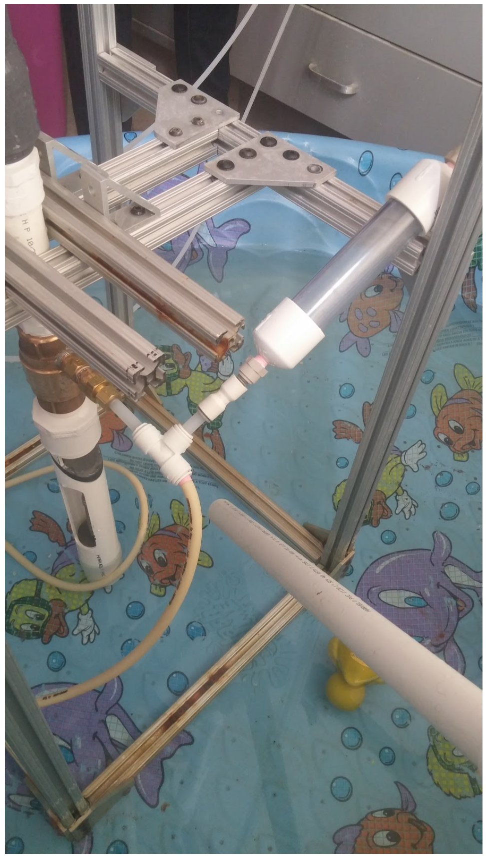

Figure 18. Set-up of the Ram Pump with the air chamber.

After testing the system with the air chamber the first results showed that the air chamber allows the pump to be more efficient. As it can be seen in figure 19, the pressure readings for the delivery (labeled as “Head Loss”) fluctuate a lot less than it did with the flexible tubing. These are not the ideal constant values that the team would like to see but the reason is clear: the air chamber is not directly connected to the check valve and part of the pumped water can reach the delivery without going through the chamber (see figure 18 for laboratory set-up and figure 7 for ideal air chamber location).

The very first trial with the air chamber was made with Spring 3, Length 3, because it had slightly better results in the fast trials described before.The flow rate was measured using five different head loss, varying from 2.6m to 14m. The expected flow at 4m head loss is 0.7158 L/min. This result is much better than without the air chamber, where the expected flow rate at 4m head loss was about 0.3961 L/min. The table below displays the flow rate with different head losses for testings before and after the air chamber was added.

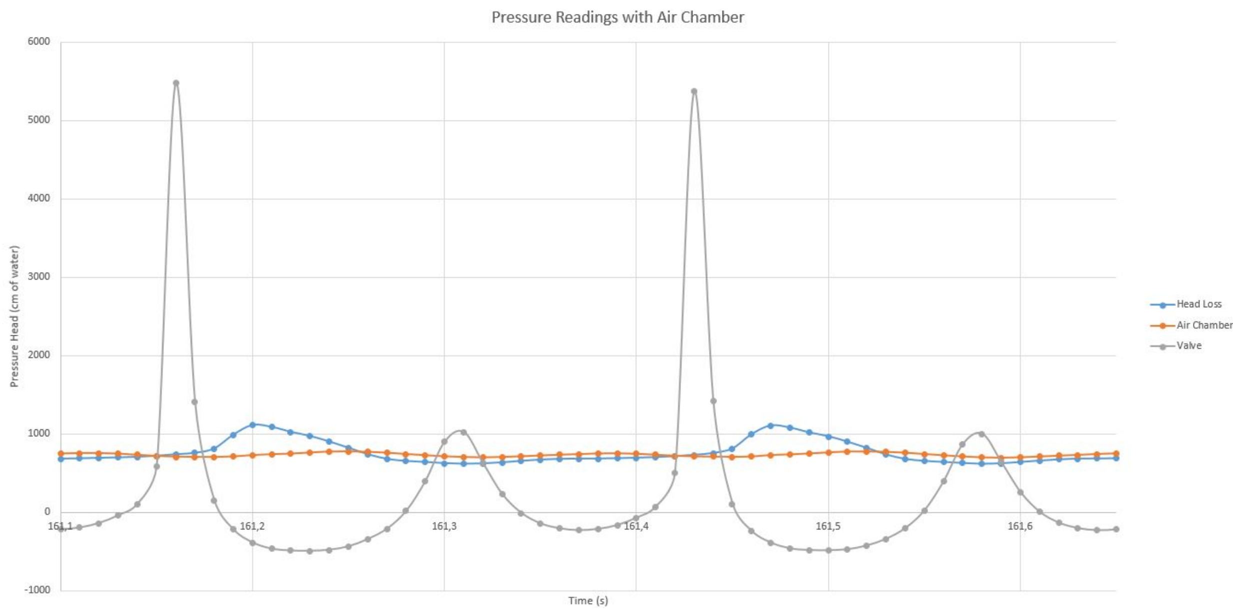

Figure 19. Pressure readings highlight for air chamber system

Table 2. Testing of springs with varying forces on the Ram Pump with a 6" Air Chamber.

System Set-Up	Spring	Spring Constant (lbs/in)	Initial Length (in)	Compressed Length (in)	Change in Length (in)	Spring Force	Average Head Loss (m)	Average Effluent Flow Rate (L/min)	Linear Fitting	Expected Flow Rate @ 4m Head Loss
3/8" Check Valve 3/8" Peristaltic Tubing 6" Air Chamber connected to check valve via 3/8" Felxible Tubing	1	19.31	2.465	2.040	0.425	8.21	6.6	0.56	y = -0,0498x + 0,884 R^2 = 0,9919	0.68
							8.6	0.44		
							9.6	0.41		
							11	0.33		
	2	10.6	2.515	2.040	0.475	5.04	4.5	0.64	y = -0,0548x + 0,8916 R^2 = 0,9994	0.67
							6.5	0.54		
							9.5	0.37		

Table 3. Testing of springs with varying forces on the Ram Pump with a 9" Air Chamber.

System Set-Up	Spring	Spring Constant (lbs/in)	Initial Length (in)	Compressed Length (in)	Change in Length (in)	Spring Force	Average Head Loss (m)	Average Effluent Flow Rate (L/min)	Linear Fitting	Expected Flow Rate @ 4m Head Loss
3/8" Check Valve 3/8" Peristaltic Tubing 9" Air Chamber connected to check valve via 3/8" Felxible Tubing	1	19.31	2.465	2.040	0.425	8.21	5	0.68	y=-0.0561x+0.9715 R^2 = 0.96544	0.75
							6.2	0.67		
							9.5	0.43		
							11.6	0.33		
							7.5	0.52		
	2	10.6	2.515	2.040	0.475	5.04	4.3	0.70	y=-0.0437x+0.8483 R^2 = 0.96496	0.67
							6.6	0.53		
							8.2	0.47		
							13.5	0.28		
							10.5	0.37		

Adding an air chamber significantly improved the flow rate. We no longer had bursts of water emitting from the pump, instead there is a much more constant stream of water. Figure 20 shows how much the air chamber increased the flow rate.

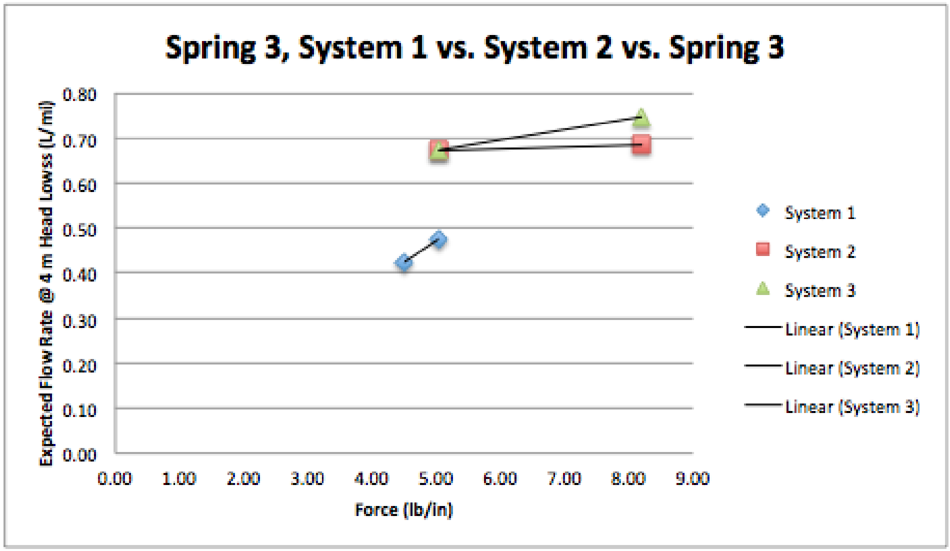

Figure 20.Comparison of Spring 3 in System 1, 2, and 3.

We tested air chambers of different lengths with the same radius and found that greater lengths provide better flow rate.

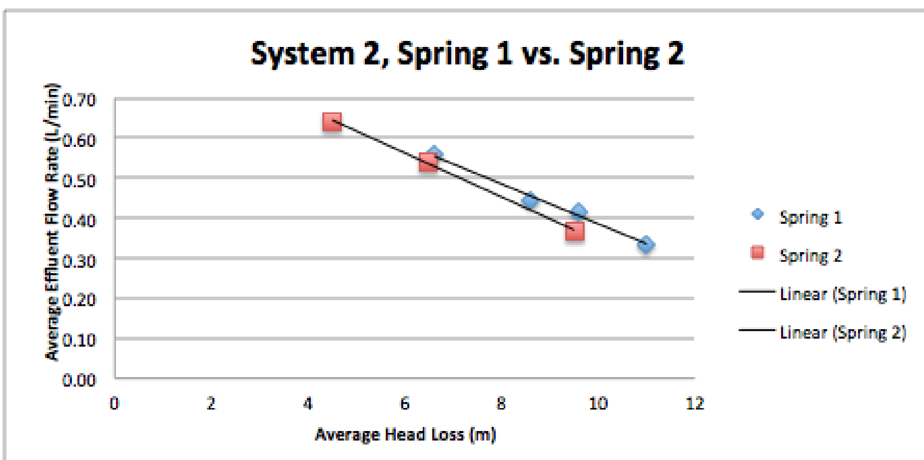

Figure 21. Comparison of springs with varying forces in System 2.

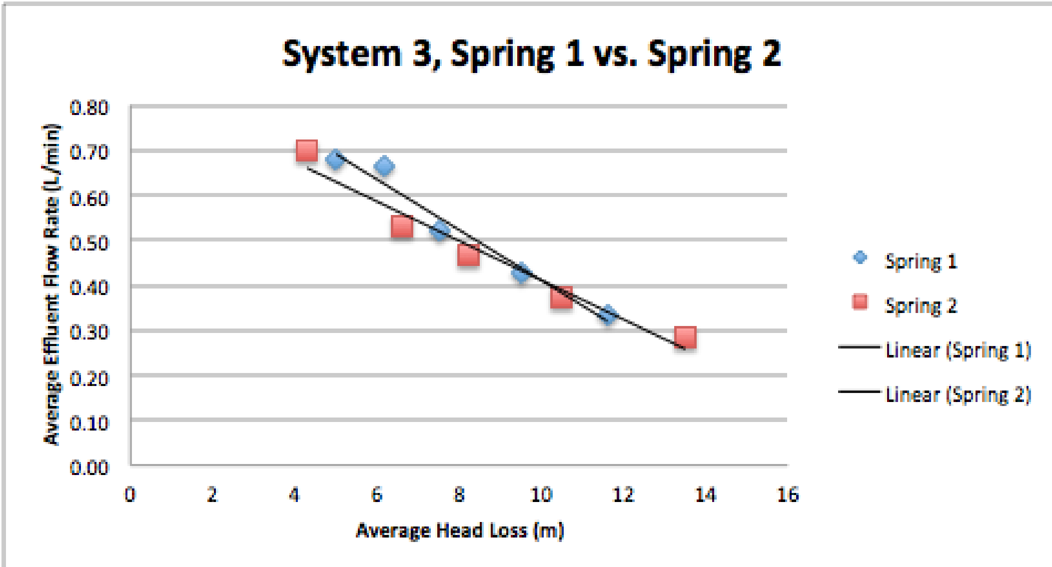

Figure 22. Comparison of springs with varying forces in System 3.

Unclear Noticed Facts

- After performing an analysis on the force that the selected spring would have to overcome in order to open the valve in a static closed position, the team noticed that the system was working with weaker springs. The weight of the column of water (90 in) over the 1.2 in diameter plate and the weight of the rod (0.19 lb) gives a total 6.6 lb of force that will make it impossible to open the valve for, for example, the first spring with a compressed maximum force of 3.75 lb. When the system was consciously brought to this static state, the valve stayed closed as expected but, however, when the process has started (move the rod manually in order to start the cycles for the first time), the valve keeps opening after each cycle. This means that there is a new force that we did not expect when performing our calculations, which the team thinks is a suction pulse generated by the water hammer travelling upwards through the drive pipe. This hypothesis has been based on the fact that the pressure readings in the valve show a negative section after each peak (shown previously on figure 19).

- During the testing the team noticed that the frequency at which the waste valve was opened and closed varied depending on the characteristics of the spring. It was also found that there were periods of time when the cycle time changed without apparent reason (mentioned previously) but this problem seems solved with the implementation of the air chamber. However, although we have solved the major problems, the cycle frequency keeps varying from cycle to cycle. Figure 23 shows the frequency spectrum of the pressure readings in the valve where the main frequency is clearly seen at 3.9 Hz, corresponding with the average cycle period measured (1 each 0.25 s), and the harmonics of a periodic wave (7.8 Hz, 11.7 Hz, etc). However, these peaks are not thin high amplitude regions but thick peaks that show the high deviation around the mean. This can be due to the vibrations found along all the system, caused by the violent pressure waves created by the valve closure.

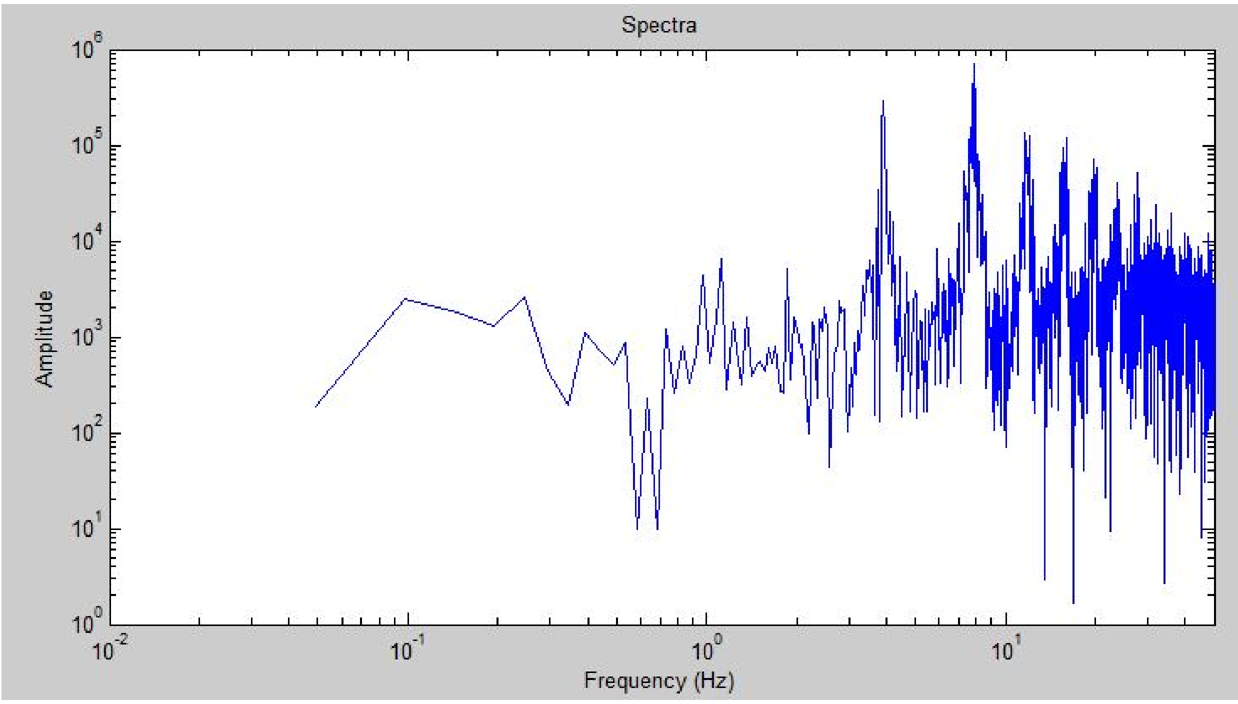

FIgure 23. Frequency spectrum of the pressure reading in the valve

Conclusion

After a semester of constructing the spring manipulation system while understanding how to perform with the vertical design proposed by the previous team, we have learned that this innovative ram pump can obtain almost the same results although it is the first of its kind developed by AguaClara.

The first results show that the tendency of this model is to follow the same patterns as the previous one: the force exerted on the waste valve varies the effluent flow rate but very slightly in comparison with other factors; an air chamber is needed for best performance and its size also produces small variations; and the overall efficiency of the pump is directly proportional to the closeness of the components.

Although the results are lower than desired and still far from the design goal, this new model has the capacity of improving previous results with a compact vertical design.

Future Work

The team plans to continue to test varying springs using the spring manipulation system and varying parts of the system, such as the compressed length, in order to make further concrete conclusions about the effect of varying different springs in the system. The team also plans to test the effect of varying the distance between the check and the waste valve. Furthermore, the team is in the process of testing more air chambers in order to determine what the optimal air chamber length is, though it has been shown that air chambers with greater lengths and the same radius provide better results. The team is now looking into making the air chamber closer to the check valve and possibly attaching it to the check valve itself.

Throughout the upcoming semesters, the team aims to implement a theoretical model of the vertical ram pump. The overall goal is to enhance the vertical ram pump such that we generate a working system that has an effluent flow rate that meets with what is expected at the plant.

References

Hydraulic Ram Pumps. (2002). Appropriate Technology (March 6, 2015)
http://cornell.summon.serialssolutions.com/

Hydraulic Ram Pumps, U.S. Department of Agriculture, Natural Resources, Conservation Service Portland, Oregon (September 2007)
http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_041913.pdf

Ramp Pump Final Report Fall 2014, AguaClara Project, Cornell University
https://confluence.cornell.edu/display/AGUACLARA/Home