Ram Pump, Fall 2014

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Abstract

The Fall 2014 ram pump team is working on expanding and improving upon the work of previous ram pump teams, which includes fabricating and implementing a working ram pump design in a plant in Honduras. The team has completed literature research, fabrication of the ram pump designs to be tested, basic experimentation, and data collection. The literature review has determined that while experimentation done on ram pump components like the spring check valve indicate that these parts will last for decades, the non-ideal conditions of the use of the spring valves in AguaClara plants means that more experimentation is needed to determine how long the valves will last while in use in AguaClara plants. Additionally, the team has found other points of wear within the valve during testing this semester. Ideas for potential improved designs have resulted in the fabrication of air chambers of varying sizes and drive pipes of different lengths and diameters. The most efficient pump model was determined by taking data for different models with varying numbers of weights on pressure within the system and flow rates at various head loss values. The team found that the optimal system for the ram pump is to use as few weights as possible without causing the ram pump to stop, along with either one of the two tested outlet possibilities, and as large an air chamber as desired or available. However, this system does not result in an adequate output flow rate, due to losses within the system. More work still remains to be done - the team is currently working on a vertical system alternative which may eliminate the need for a horizontal drive pipe and may reduce the number of losses within the system that is affecting the output flow for the system currently in use.

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Task List

Task Map

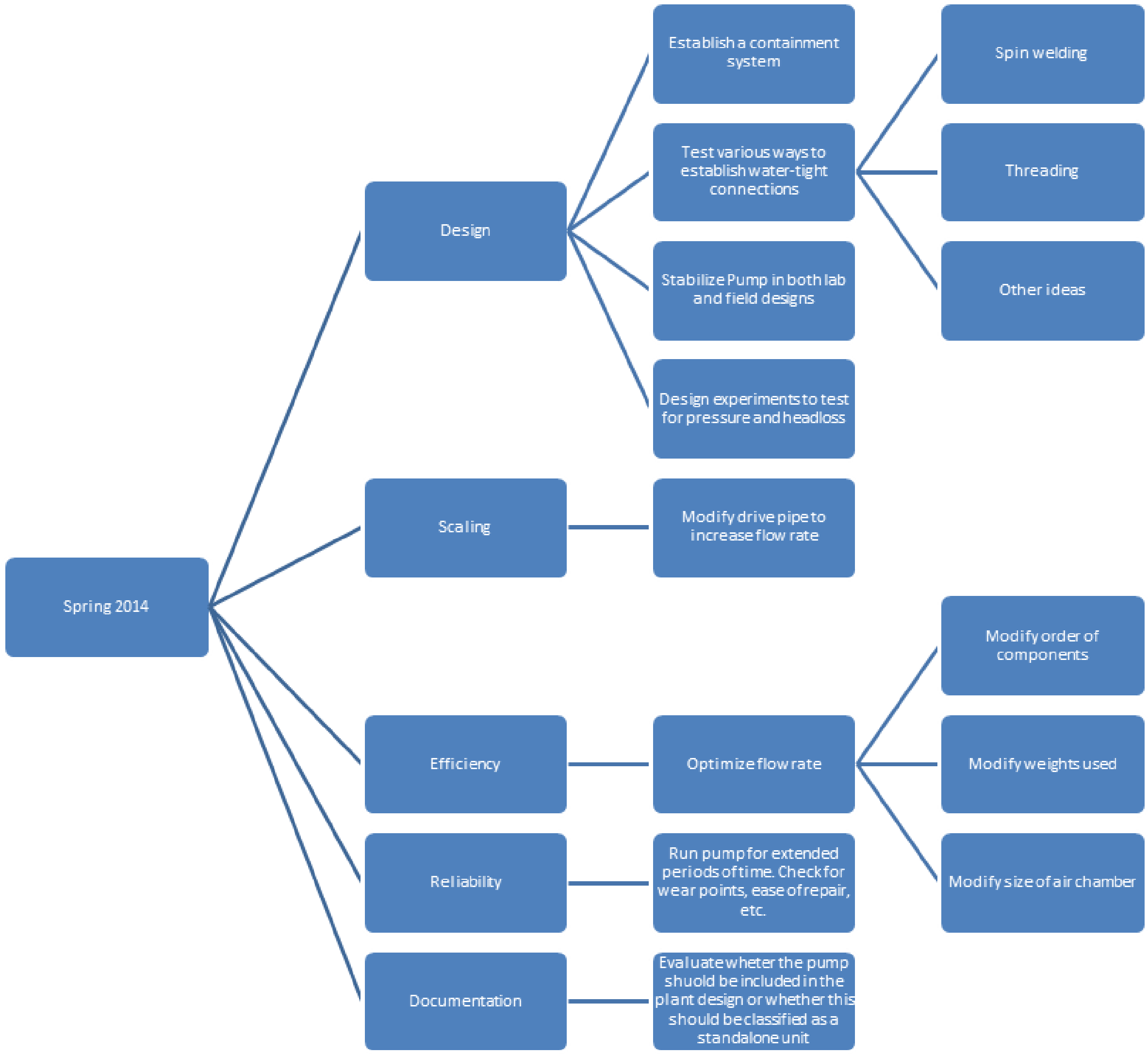

Figure 1: Task map.

Task Details

- *Water Containment System (Kiddie Pool)/* Early September -- Abby. Design a containment system in order to minimize floods within the lab. [COMPLETED]
- *Re-Think Connections*/ Mid-October -- Whole Team. Test various ways to establish water-tight connections such as spin welding, threading, etc. [COMPLETED]
- *Stabilize Pump*/ Mid-October -- Pablo. Stabilize pump in both lab and field designs. [COMPLETED]
- *Scaling*/ Mid-November -- Whole Team. Modify drive pipe to increase influent flow rate.
- *Determination of Efficiency*/ On-going -- Whole Team. Optimize flow rate through modifying (and experimenting) the order of components, weights used, and size of air chamber. [COMPLETED]
- *Experimentation of Variability*/ End September -- Bari & Annie. Design experiments to test for pressure and head loss in the different models. [COMPLETED]
- *Reliability*/ On-going -- Whole Team. Run pump for extended periods of time and check for wear points, ease of repair, etc.
- *Durability*/ Mid-September -- Abby. Check durability of components from online sources, etc [COMPLETED]
- *Documentation*/ By The End of the Semester-- Whole Team. Evaluate whether the pump should be included in the plant design or whether this is a standalone item that with a detailed design on the website.

Introduction

The success of AguaClara plants stems from their ability to not only produce clean, drinkable water, but also to do so via electricity-free methods. This usage of hydraulics and the force of gravity, however, becomes tricky to implement when the desired procedure works against these exact principles. To mix stock concentrations of coagulant and chlorine for treatment processes and to use water for plant plumbing, plant operators need to transport some of the treated water from the outlet, at a lower elevation, to the plant, at a higher elevation.

One technology that is able to circumvent the problem of gravity, with no use of electricity, while being able to perform the required function is the ram pump. Through a series of interlocking valves controlling synchronized pressure systems, the ram pump utilizes the water hammer effect to drive water against gravity; this makes it possible that no external energy needs to be used to pump the water to a higher altitude.

The recent installation of a ram pump in San Nicolas, Honduras, shows that the most important metrics to experiment on are efficiency, durability, self-sustainability, and compactness. This semester, the team will experiment on a lab-scale version of the AguaClara ram pump designed by previous teams to obtain real-time data (such as influent flow rate, delivery rate, and head loss). Using interchangeable parts, the team experimented with different ram pump designs to determine the optimal version to implement in the field. Along with the design, further improvement to the scalability, efficiency, and reliability or longevity of the ram pump was done.

Literature Review

Lifespan of Pump Parts

To better understand the overall lifespan of the pump, the approximate longevity of individual pieces was investigated. The pieces of most concern are the modified brass spring valve and PVC spring valve as these are two pieces that are not solely comprised of PVC piping, and have moving parts that are more likely to wear out over time.

The brass spring valve was investigated to determine the longevity of brass when used with water. Brass piping will degrade quicker if the water supply is corrosive, but is found to generally last over 50 years.[1] Brass piping is also known to clog if there is a high mineral content in the water, but does not easily clog from rust, as is the case in other types of pipes.[1] High mineral content is not a particularly large problem for the ram pump because the influent water will be clean water from the AguaClara plant. Additionally, the spring within the brass valve is not of concern because it was removed during modification to make the valve suitable for its purpose in the pump.

The major concern for failure in the PVC spring valve is the spring. It is assumed that the spring in the PVC spring valve from McMaster Carr is made of stainless steel. Although not stated on the McMaster Carr website, stainless steel was found to be a common material for springs within PVC spring valves.[5] To test fatigue of a spring made of a certain material, the spring is repeatedly compressed and released to determine the general time to failure. The tests are then used to create a Goodman diagram - a graph of the fatigue limit.[2] According to Goodman diagrams, stainless steel does not have a fatigue limit.[6] This is further explained by the S-N (Stress/Number of Cycles) Curve. The S-N Curve of stainless steel shows that as maximum stress increases, the number of cycles before fatigue sets in decreases.[4] In view of this, it can be determined that under ideal conditions the stainless steel spring has no set fatigue limit and is instead highly dependent on the maximum stress. However, this information about stainless steel springs is limited since all testing was done under ideal conditions; conditions in the ram pump are not ideal because the spring is constantly exposed to water.

Since the pump is not running under ideal conditions, a few other factors must be taken into account. A specific concern is that water used to run the ram pump is dosed with chlorine immediately before entering the pump. Chloride ions are known to break down the water resistance of stainless steel.[3] Because the spring is constantly submerged, this may cause corrosion and therefore more wear on the spring than initially predicted based solely on ideal data.

Once pressure in the most efficient system is experimentally determined, stress on the spring as well as number of cycles to failure will be deduced. Additionally, the effect of chloride ions on the spring should be experimentally researched to try to limit this effect and increase the longevity of the spring.

Pump Efficiency

One of the empirical formulas given by ram pump fabricants that describe the flow rate that produces is:

(1) $$Q = \frac{ESF}{L}$$

where Q = outflow rate; E = energy efficiency; S = inflow rate; F/L is the ratio between the height to source and the height to destination, both from the ram pump.

The team checked this equation by testing one of the pump models. The outflow rate is maintained for a constant height ratio and varies linearly with the head loss (that simulates the increase in height of the destination). The efficiency coefficient in the equation is a constant for each of the different designed systems and the main goal of the project was to increase it up to competent levels. However, a theoretical 100% energy efficiency is not easily obtained. The commercial rates vary between the 60% and up to 80% according to different providers.

Water Hammer Effect

The impact of the water hammer effect can be simply represented by the following figure:

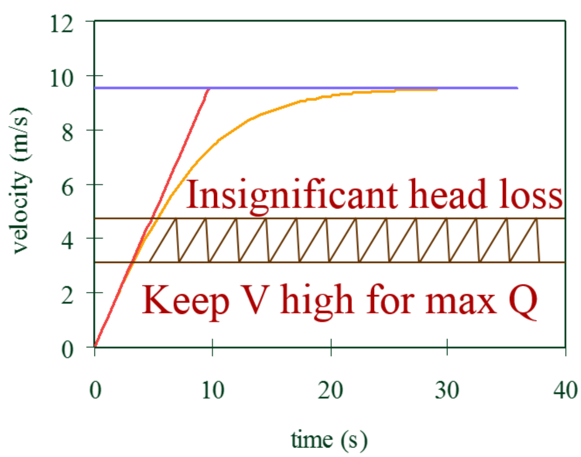

Figure 2: Velocity vs Time relationship for water under gravity acceleration.

Source: Hydraulic Transients - Monroe L. Weber-Shirk

The figure demonstrates the relation between velocity of water and time at which acceleration is solely due to gravity. The red and blue lines represent the theoretical behavior and the yellow one the real behavior. The goal of the AguaClara ram pump system is to obtain the performance represented with the brown lines. As the water flows through the drive pipe, it accelerates such that the velocity increases and therefore the pressure in the waste valve increases. At a certain point, the valve closes such that the the velocity of the water drastically decreases and, during this deceleration period the water enters the air chamber. When the pressure has decreased beyond a certain point, the valve opens and the process restarts. However, the changes in velocity cannot exceed certain limits; if the velocity is too high, unwanted loss is accumulated and if the velocity goes too low, unwanted losses due to decreased flow rate are accumulated. Furthermore, it is important to adjust the pressure needed to open and close the valve in order to obtain a good performance-- this is the main reason for using adjustable weights on the waste valve. Another consideration of importance is the amount of water that will flow into the air chamber per cycle; a system favoring a rapid deceleration will provide a higher rate of cycles but less volume of water on each one. The theoretical formula that represents this behavior is:

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

where g = gravity constant; L = length of the pipe; p = pressure; ρ = density of the water;$\triangle z$= elevation; h_l = head losses.

Applying the equation for the acceleration period and the deceleration period (assuming no head losses):

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

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

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

These equations are used in order to calculate the theoretical volume of water that goes into the air chamber per cycle. However, there are some losses, like those in the opening and closure of the check valve, that are unaccounted for but can be found in the process.

Previous Work

This semester's design is based off of previous ram pump teams research, calculations and sketches.

Air Chamber Sizing

For the air chamber sizing, the previous team provided the following equation:

(3) $$V_{air} = \frac{cQt}{n}$$

where V = volume of air in the chamber; c = constant in the range 20 to 50 (yet to be determined); Q = pumping rate; t = time interval; n = number of cycles in the time interval.

The intention of the constant c in the formula comes from the increment in pressure inside the air chamber. If the air in the chamber is assumed to be an ideal gas and temperature is assumed constant:

(4) $$P_1 V_1 = P_2 V_2$$

where P = pressure inside the chamber; V = Volume of air inside the chamber.

The variation of volume of air inside the chamber per cycle is, as a function of the pumping rate:

(5) $$\triangle V = Q\, t_c$$

where tc= time per cycle, that can be obtained as shown before (t/n).

Therefore, rearranging the terms:

(6) $$\frac{P_2}{P_1} = \frac{V_1}{V_2} = \frac{V_1}{V_1 - \triangle V}$$

If the volume of air inside the chamber to be proportional to the variation in volume the variation in pressure can also be controlled.

(7) $$V_1 = c \triangle V$$

(8) $$\frac{P_2}{P_1} = \frac{V_1}{V_1 - \triangle V} = \frac{c \triangle V}{c \triangle V - \triangle V} = \frac{c}{c-1}$$

Then, the value of the constant c is such that the increase in pressure is small enough for the outlet to be continuous. Somewhere in the range 20-50 for c will provide an increment in pressure of 5%-2% per cycle.

The designs of the different air chambers are based on the equation provided and the measurements performed at the beginning of this semester for the pumping rate and the time per cycle. A goal of the end portion of the semester was to get a reliable value for the constant in the equation by testing different sizes of air chambers. These results were then be compared to previous research. Three different air chamber models were tested: one that fits to a value of c equal to 45, one with a value of 20, and one chamber that falls in between the two (check Models and Results for more information). Here is an example for the calculation of the height of the air chamber according to equation 3:

Volume of Air in the Chamber	3.13	L
Optimal Flow Rate Output	4.17	L/min
Number of cycles per minute	60	
Constant c (20 to 50)	45	

Diameter of the Air Chamber	4	in
Height of the Air Chamber	3.85	dm
	15.18	in
Area in the Air Chamber	12.57	in^2
	0.81	dm^2

Figure 3: Calculation of volume of air inside the chamber and height of the chamber for known outflow rate, cycles per minute and constant c where Optimal Flow Rate Output = expected flow.

Head Loss System

The head loss system was also provided by the previous team. The idea of this system is to gain head loss while making water go up through ½ inch tubing and avoid the loss of head by adding air in the free fall through the tubing. However, it has been determined that this system is not working properly because the size of the tubing isn't adequately large enough for the flow rate. A new system has been developed that utilizes a valve at the end of the head loss system tubing that can be manually adjusted to control the output flow rate.

Methods

Apparatus

A scheme of the ram pump can be seen below in Figure 4. Water is pumped through a 1-½ in. pipe up to the overhead drive tank (a) while the outlet manual valve (b) is closed until water level reaches the overflow weir (i). Then, the manual valve is opened so that water can flow through the 1-½ in. pipe all the way down to the contraction into the 1 in. drive pipe (c). As water flows from the overhead drive tank to the drive pipe, as a result of gravity, velocity increases. The spring check valve (e) is initially closed and the waste brass valve (d) is open. Water flows through the waste valve and, as a consequence of the increase in velocity, it is lifted and closed (see Figure 2). This sudden interruption in the flow produces a high pressure wave known as the water hammer effect, which travels back through the water and forces the check valve open. Water then flows through the valve into the air chamber (f), compressing the air enclosed inside, forcing the water back, and closing the check valve again. The water hammer's effect is reduced enough such that the waste valve opens back up, starting the cycle again (see Figure 5). The high pressure existing in the air chamber pushes the surface of the water in the air chamber down, what allows for a constant flow rate delivery out of the system rather than in discrete pulses. Then, water flows through the ½ in. delivery pipe (g) into the head loss system (h). This system consists of a wide variety of looped tubing and valves that simulates the 7.0 meter design head loss for treatment plants in Honduras. Waste water is collected in a small pool under the whole apparatus, which prevents leaking and flooding in the lab, and is then pumped into the recycling tank (j), with the delivery water, to be reused in filling the overhead tank.

Different models have been developed with variable pipe, valve and air chamber sizes for doing research on what combination of units results the highest efficiency and lowest resultant head loss.

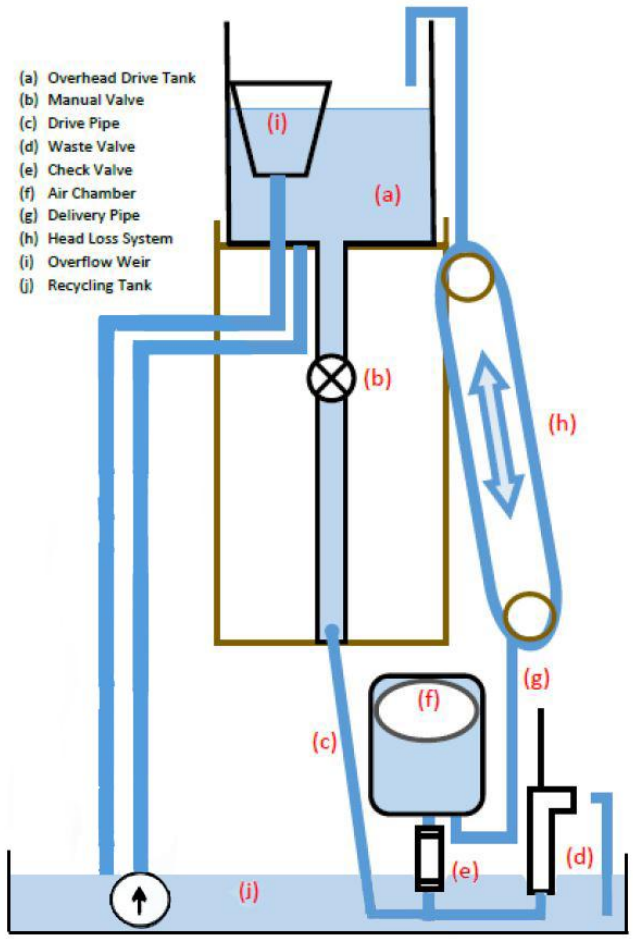

Figure 4: Schematic of Ram Pump Apparatus.

Figure 5: Waste Valve

Models

The results of the different models were compared with a main focus on effluent flow rate, to establish a pump that would allow for the highest probable efficiency and to gain a better idea of how the system is behaving. The different models (M) to be tested include:

9" AC																			
¾" WV										1" WV									
W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
M 1	M 2	M 3	M 4	M 5	M 6	M 7	M 8	M 9	M 10	M 11	M 12	M 13	M 14	M 15	M 16	M 17	M 18	M 19	M 20

12" AC																			
¾" WV										1" WV									
W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
M 21	M 22	M 23	M 24	M 25	M 26	M 27	M 28	M 29	M 30	M 31	M 32	M 33	M 34	M 35	M 36	M 37	M 38	M 39	M 40

15" AC																			
¾" WV										1" WV									
W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
M 41	M 42	M 43	M 44	M 45	M 46	M 47	M 48	M 49	M 50	M 51	M 52	M 53	M 54	M 55	M 56	M 57	M 58	M 59	M 60

25" AC																			
¾" WV										1" WV									
W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
M 61	M 62	M 63	M 64	M 65	M 66	M 67	M 68	M 69	M 70	M 71	M 72	M 73	M 74	M 75	M 76	M 77	M 78	M 79	M 80

Figure 6: Table of arrangements to be tested.

The different fabricated interchangeable components are shown below:

Two different waste brass valves, with 1 inch and ¾ inch diameters. Testing waste valve diameter establishes a relationship between the amount of water entering/ exiting through the waste valve at the [set] initial flow rate and the resulting effluent flow rate.

Figure 7: Waste valves - 1 inch (L) and ¾ inch (R).

Four different air chamber heights (9, 12, 15 and 25 inches) which will accommodate the different input and output discharge, as well as the different timing between water hammer pulses. From this the effect the volume of air in an air chamber has on the flow rate can be determined.

Figure 8: Two of the different air chambers available - 15 inch (L) and 12 inch (R).

Another variable is drive pipe dimensions and distances between valves. At this point there are two different arrangements. The more compact system is fabricated with clear PVC piping so the inside of the pipe is visible.

Figure 9: Drive pipe systems - shorter distance between valves (Top) and longer (Bottom).

The number of weights- weighing 50 g each- was tested to determine the effect weight has on cycle time. The hypothesis is that each air chamber will require a different optimal weight in order to induce the water hammer effect.

All of the configurations and components listed above can then be combined with an additional change in the flow effluent outlet. In all previously tested systems, the water that flows into the head loss system exits the ram pump apparatus directly through the air chamber. This means that the water has to flow from the waste valve and into the air chamber before it can leave through the head loss system. A proposed new design would potentially eliminate the need for the water to enter the air chamber before leaving, which may decrease the amount of head loss due to flow as well as minor losses. Instead of leaving through a tube attached to the side of the air chamber, a tee fitting will be inserted in between the check valve and the air chamber, with the effluent leading to the air chamber and the “plant” (or head loss system). The water will therefore not necessarily leave through the air chamber, and can directly flow into the head loss system as long as there is already water in the air chamber to provide the air pressure that forces the water through the head loss system.

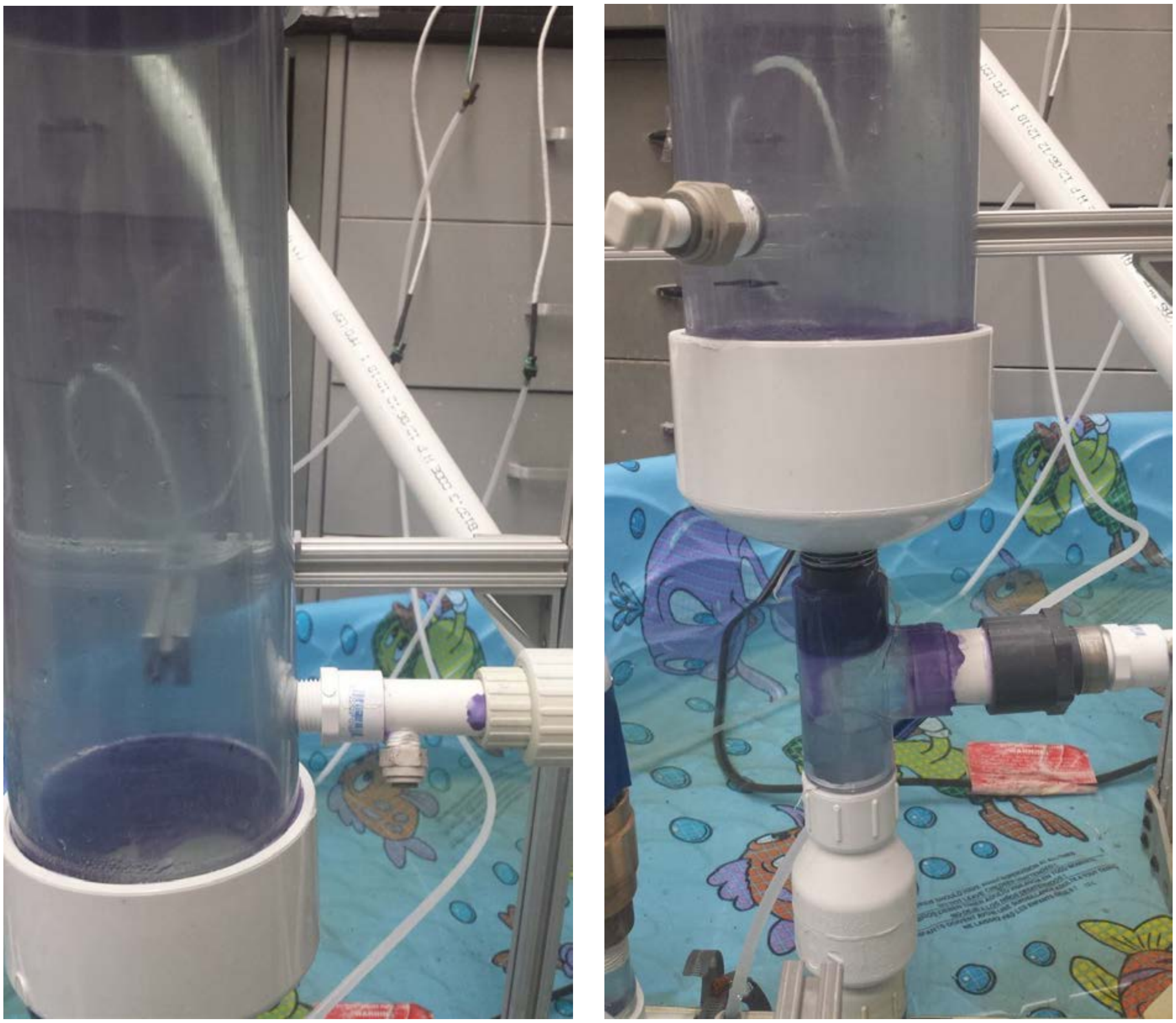

Figure 10: Flow Outlet Systems - direct (L) and tee (R).

At the conclusion of experimentation, each of these parameters will be optimized in the ram pump system.

Increasing Head Loss

Following the completed fabrication of all parts, a few different combinations of components were briefly tested to determine the steady state head loss of the system. At first, the system could not run long enough to determine the maximum head loss in the head loss system, as the rate of water exiting the waste valve greatly exceeded the amount of water that was returned to the reservoir. However, the head losses that were being measured usually started levelling out at around 4 or 5 meters, less than the 7 to 9 required to accurately imitate an AguaClara plant. More piping of a smaller diameter was added to the head loss system in an attempt to increase the total head loss, but did not result in a large increase in measurements. After brainstorming and asking other team members for input, it was suggested that a ball valve be added to the end of the pipe system. The ball valve can be partially closed to increase head in an easily controlled way. So far, the valve seems to work as intended; however, it has not yet been calibrated to ensure that correct amount of head loss is observed across the head loss system.

To address the problem of short operation times, the team considered alternatives, such as finding or buying another pump for water recycling. Nonetheless, a more efficient method was discovered: after reshuffling parts of the apparatus, the system was consolidated to fit entirely within the containment system, thereby eliminating the need for extra pumps for water recycling purposes, and allowing for prolonged operation times.

Increasing Flow Rate

At the beginning of the semester, the flow rate at the end of the head loss system was found to be 1L/min. This value is analogous to the water being delivered to the top of the plant in an actual AguaClara plant. After updating the ram pump system and head loss system, and testing with the different air chambers, the flow rate was measured and was once again found to be about 1L/min. The required flow rate at the top of an AguaClara plant is 70mL/s or 4.2L/min, which is higher than what is currently measured. This problem is currently being investigated; different system components are being tested to see which combination might give the flow rate needed.

Results and Discussion

Conclusions

Obtaining flow rates at a constant head loss is necessary in order to compare the performance of the different optimized systems. As this value is very difficult to control, a method was created to obtain the relation between head loss and outlet flow rate.

It is assumed that the relation between head loss and outlet flow is linear. To check this, different values of head loss and measured the discharges with the same combination of system components were measured. In this case with the shorter drive pipe, the 25 inches air chamber with the tee and four 50g weights.

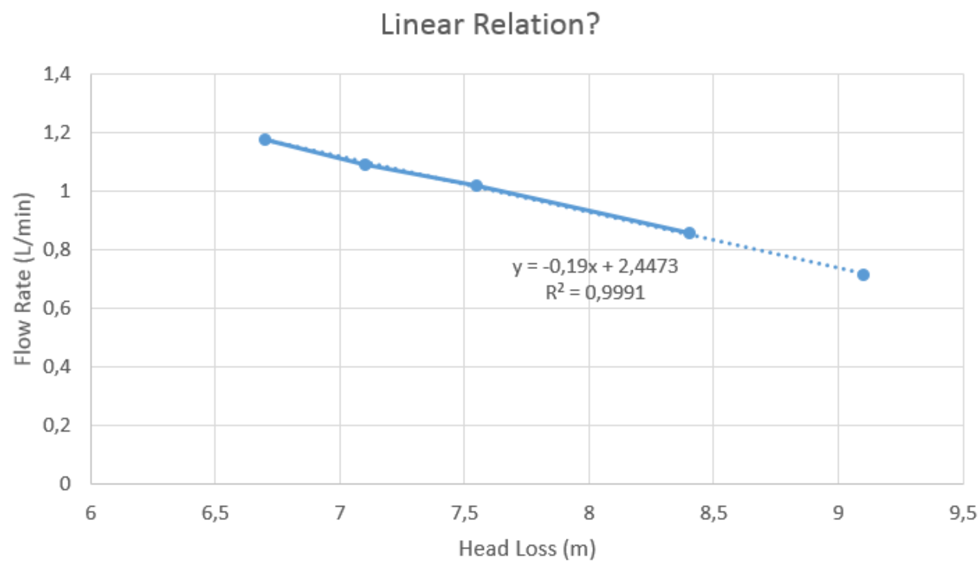

Figure 11: A graph of various flow rates measured at various head losses of the 25 inch air chamber and 4 weights (200 g), in order to determine whether or not a linear relationship exists.

Head loss values were set by incrementally adjusting the flow control valve and waiting for the system to reach steady state. The values tested ranged from 6.7 to 9.2 m, which encompasses the range of AguaClara plant head losses, which usually vary from 7 to 9 m. The value of the coefficient of determination between head loss and output flow rate is calculated to be 0.999, meaning that the assumption of a linear relation between the head loss and flow rate is likely valid for the range of experimentation.

Performing several tests for each of the different arrangements, the equation representing their behavior was found. Here is an example for one system with varying weights:

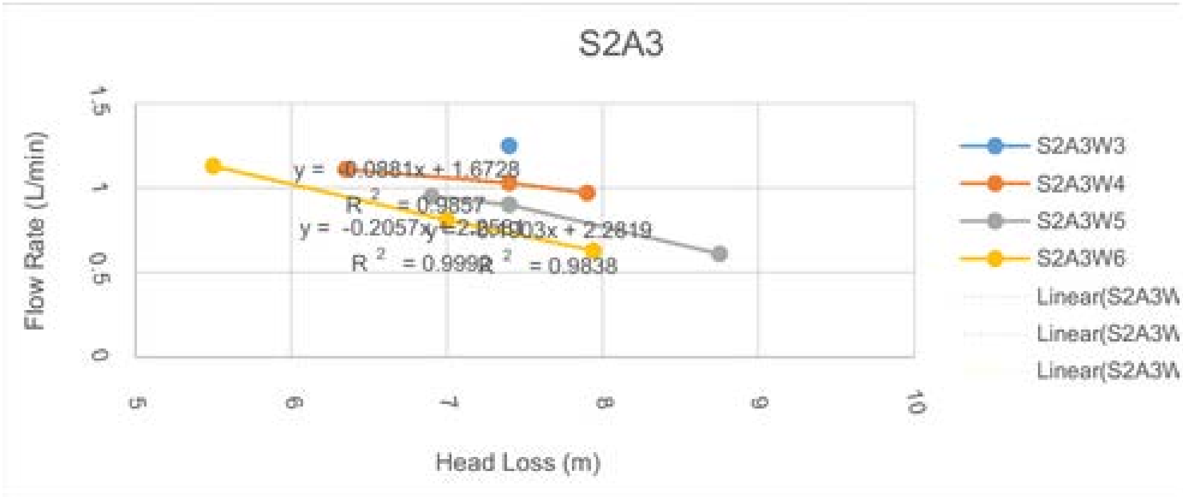

Figure 12: Relation between flow rate and head loss for different arrangements: “S#” stands for the number of the drive pipe system, “A#” is the number of air chamber and “W#” is the number of 50g weights.

This graph represents the performance of flow rate measured against head loss for the combination of Drive Pipe System 1, Air Chamber 3 and from 3 to 6 weights. As shown in this case, the less weights used, the better performance obtained. However, with less weights, the possibility of system failure grows - with too few weights, the weight on the rod may not be enough to force the waste valve back into the open position after the force of the water flow closes the valve, leaving the waste valve closed until it can be manually opened. After multiple tests on different system configurations, it was confirmed that using as few weights as possible is optimal. For the lab apparatus, this weight tended to be approximately 150-200 grams or 4 weights.

When testing the different sizes of air chambers, all other systems were kept the same. The same data was collected, and flow rates were analyzed (Figure 9). From the results, it appears that the larger the air chamber, the higher flow rates. However, this increase is minimal, and potentially not worth the cost of PVC and space. The 9” tall air chamber worked almost as well as the much larger air chambers, and can be used in AguaClara plant applications without much reduction in output flow rate.

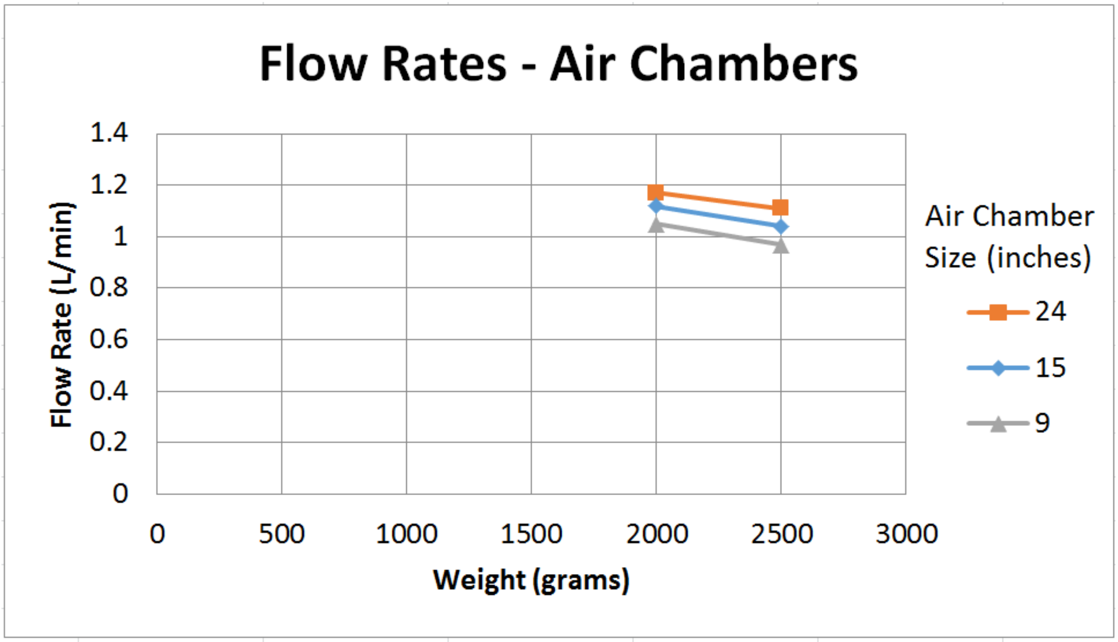

Figure 13: Flow rates from different air chambers

The two flow outlet systems were tested against each other using one system configuration that was otherwise the same. The results, shown in Figure 14 below, indicate that there is very little discernable difference between the effluent rates of the two systems. The direct system is more straightforward, but requires holes to be drilled or otherwise incorporated into the PVC of the air chamber. The tee system uses a tee fitting as the outlet, so therefore does not require any additional holes to be drilled into the air chamber. However, the tee makes the ram pump installation slightly larger, and requires more parts.

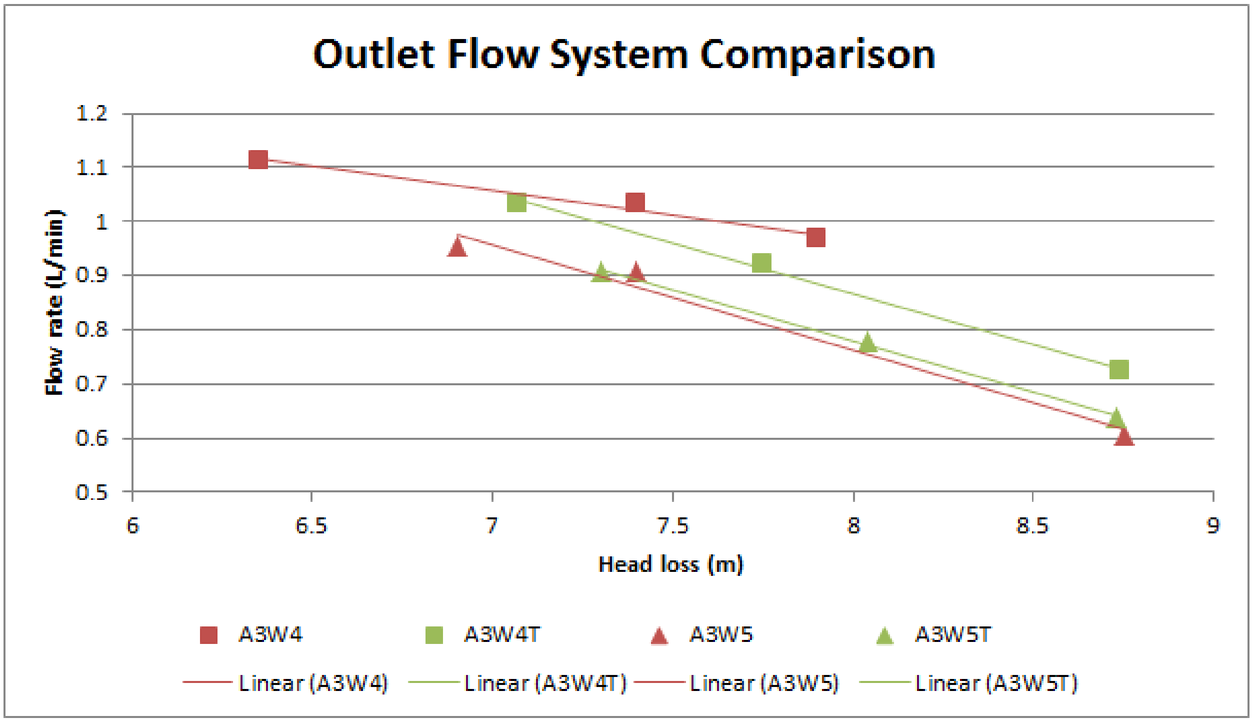

Figure 14: Comparing flow rates for the direct flow outlet systems (red is direct, green is tee) with two weight configurations (squares vs. triangles)

The team did not have the opportunity to directly compare the two drive pipe systems during the semester. It was hypothesized that the 1" drive pipe would perform better because of the shorter distance between the waste valve and the air chamber, but this hypothesis could not be proved or disproved using the data collected. Apart from this,it was found that the ideal configuration of the ram pump system is to use as few weights as possible while having the pump still run, a chosen size of air chamber, and either outlet system, depending on parts available (different air chamber sizes and outlet systems do not noticeably impact the output flow rate from the system).

Encountered Problems

About one month into testing, a problem arose with the ram pump apparatus. During a routine test, the waste valve began to behave erratically, then eventually stopped closing altogether, even with more weight on the rod than usually necessary for regular cycling. After taking apart the waste valve, it was discovered that as a result of repeated force being exerted on the end of the rod as it slams down when the valve is opened, the end of the metal rod had been caused to wear. Within the waste valve, there is a cylindrical hole (shown in Figure 15) into which the plate that opens and closes the valve is inserted via a small rod that is threaded into the longer rod that holds the weights on top of the waste valve (shown in Figure 16a). The two connected rods are normally free to move up and down together inside the cylindrical hole as the water opens and the weights close the valve, and the long cylindrical nature of the hole helps the rod stay in a vertical position to reduce loss of energy in a horizontal direction. Without this internal stabilization, the whole apparatus shakes more, dispersing energy that could otherwise be used to push water through the head loss system. However, due to the wear, the diameter of the rod was shaved down (as it came into direct contact with the inner edge of the brass cylindrical hole) until it became just small enough to fit in the hole instead of stop at first contact. There, the rod became stuck so that the plate is in the open position, but cannot be closed again by the flow of water through the valve. This comes back to initial concerns explored through the literature review section above: what is the lifespan of parts in the waste valve? The initially rod chosen to use proved to be too thin for the brass waste valve. A temporary fix of a small metal washer inserted between the two rods; the diameter of the washer is large enough so that it cannot be forced into the cylindrical hole (shown in Figure 16b). Although this fix has stopped the waste valve from sticking open, the added part is not tightly adhered to the rods, causing shaking and energy loss, as well as more irregular water hammer cycles. In future laboratory set-ups and implemented systems in AguaClara plants, it is recommended that either the waste valve have a smaller diameter hole or, probably more simply, to find a rod that has a diameter large enough that this problem is unlikely to be repeated.

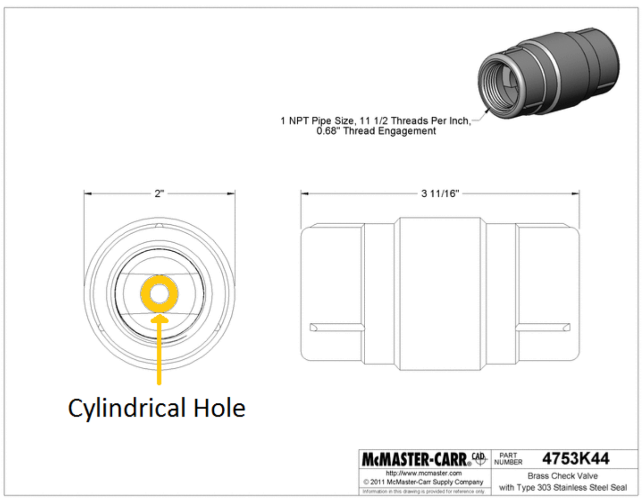

Figure 15: Waste Valve Schematic

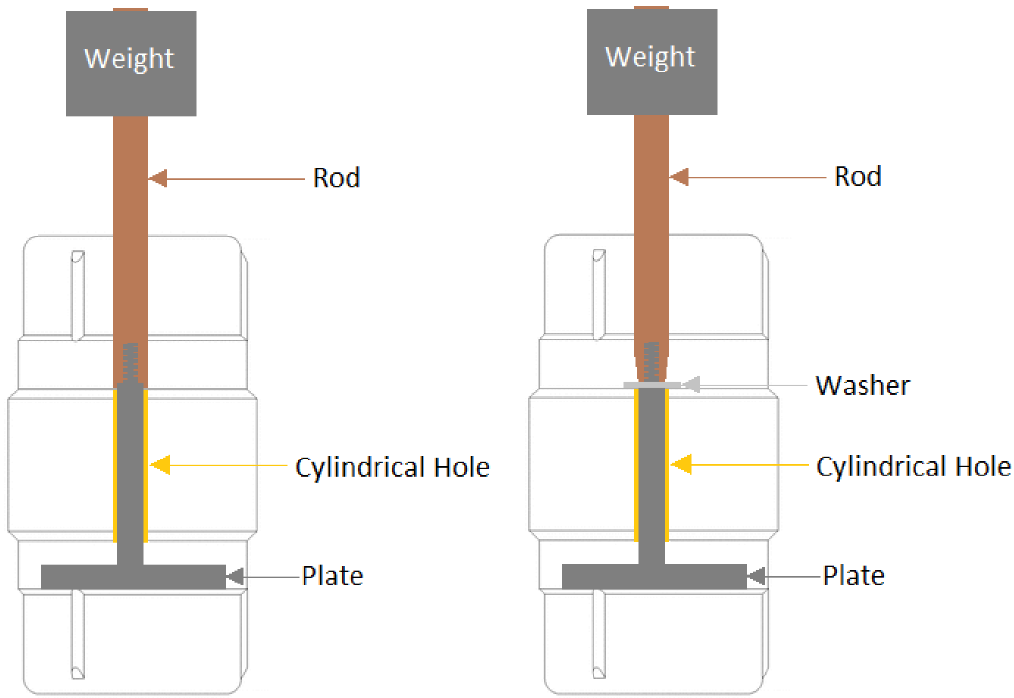

Figure 16: Waste Valve Detail (a) Normal Operation; (b) Temporary Fix

Future Work

A common testing issue has been low effluent flow rate compared to what is expected at the plant. This is thought to be caused by a few hypothesized flaws in the plant simulation apparatus. First off, as seen in the ram pump schematic, there is a 90 degree bend at the bottom of the influent pipe. Because of this, a large portion (yet to be determined numerically) of energy is lost before water enters the system. Additionally, there is thought to be valve leakage in the spring valve underneath the air chamber. Because only three to four weights are used on the waste valve, the cycle time is comparatively quick. As a result, only a small amount of water makes it to the air chamber each cycle. Therefore even if there is a small amount of leakage, it could cause a substantial proportion of the water per cycle to be lost- greatly decreasing efficiency. The final aspect of the current system that could be an issue is the actual cycle time itself. If the valve leakage turns out to be a problem, cycle time could be increased so that each cycle pumps more water and minimizes the effect of the valve leakage. As seen from the previous data though, this increase in cycle time decreases efficiency of the system on the whole, which is the larger issue.

In an effort to overcome these proposed problems, a new “vertical” ram pump design is in the works. The new design would completely remove the drive pipe and the elbow making the waste valve upside down from it’s current orientation. The waste valve would either be spring powered or lever powered as opposed the weights based system in place now. Investigation into which system- spring or lever- is more amenable is underway. If a spring system is used, the ideal spring constant, length and diameter of spring to create the cycle length desired must be determined. The waste pipe will be attached to the inflow pipe by a tee that will connect on the remaining end to the air chamber-which will still be upright. Hopefully with these changes and an investigation into valve leakage, the aforementioned problems can be resolved.

The immediate future work is to continue creating and testing the vertical ram pump set up with the spring method. The overall goal is to have a working system, either the current ram pump model or the new vertical ram pump to bring to Honduras and continue testing on.

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