Ram Pump Fall 2023 Final Report

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Abstract

The Ram Pump sub-team's primary investigation is centered around experimenting with a flat spring by varying the length, thickness and width of the flat steel spring and assessing its performance and stability. However, recent issues had occurred with both maintaining a consistent flat spring along with other issues within the ram pump system that needed to be solved before continuing with further data collection. Future goals are to finish resolving issues within the ram pump system, resume data collection using different flat springs, and develop a CAD model of the ram pump in the laboratory using the software Onshape.

Introduction

The Ram Pump subteam has designed the proprietary AguaClara Vertical Ram Pump (ACVRP) system that allows for water to be brought up from a lower elevation to a higher elevation through the use of a flat spring system. As water goes through the treatment process it reaches the basement and goes through the ram pump at a lower height with a certain velocity correlating to large kinetic energy. The water has to be pumped up approximately 4 meters and higher from this point, to use for other purposes. Due to the water increasing in elevation, there is an increase in gravitational potential energy with a decrease in velocity. Therefore, there is a change in energy from kinetic energy that the water enters the pump at a lower elevation to more potential energy as the water increases with elevation and water pressure, which is what opens and closes the valves in the system and allows the water to flow.

To develop a deeper understanding of how a traditional hydraulic ram pump system operates, provided is a video for reference: https://www.youtube.com/watch?v=zFdyqTGx32A.

Our ram pump however, is different from other ram pumps due to the fact that it is a vertical system instead of a horizontal one. The horizontal ram pump design causes approximately 90% of the initial water it uses in the system to be wasted. The ram pump is not only vertical, but utilizes a sheet of steel to oscillate the check valve opening and closing the system. The key purpose of using a flat spring design is to minimize costs so that the system can be more accessible in third world countries at water plants while not sacrificing the efficiency of the system. This is a key feature because there are already existing AguaClara plants that require a ram pump so by implementing a cheaper and just as efficient system results in a more viable system that can be implemented in water plants.

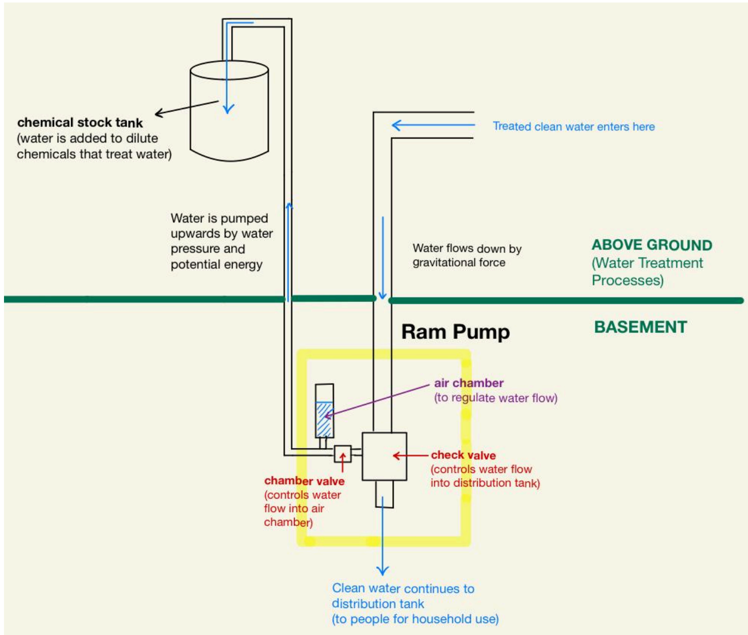

Figure 1: Ram Pump's role within AguaClara Plant

Within the context of AguaClara as a whole, the ram pump in the water plant facilities and carries the water from the basement of the AguaClara plant to the chemical stock tank (on a higher level of the AguaClara plant) where the treated water is used to dilute concentrated amounts of chlorine – a chemical used to treat water.

Literature Review and Previous Work

The summer 2023 subteam focused on analyzing the ACVRP lab system when guided by a flat spring. Research was both conducted into the guiding fluid mechanical principles that can be used to model systems states and the beam deflection behavior under the influence of the dominant transient hydraulic force. Notably, the team found that the ram pump cycle can be modeled as a system that is in one of two states: closed or open. In the open state, the water is free to flow through the system downwards. However, the flowing water applies a drag force to the metal plate in the reversed check valve, causing it to be pushed down (into a more closed position). Accordingly, the check valve will close as a result of the force of the flowing water. When closed, the velocity of the downward flowing water will experience a rapid deceleration causing the kinetic energy of the water to be transferred into pressure, in the form of a pressure wave. This phenomenon is commonly referred to as a "water hammer effect". Since the pressure wave will propagate isotropically in the pipe, the check valve in the pipe to the right of the system will be opened. In result, the energy of the water will be reconverted into kinetic energy, causing a portion of the water to flow upwards in the system.

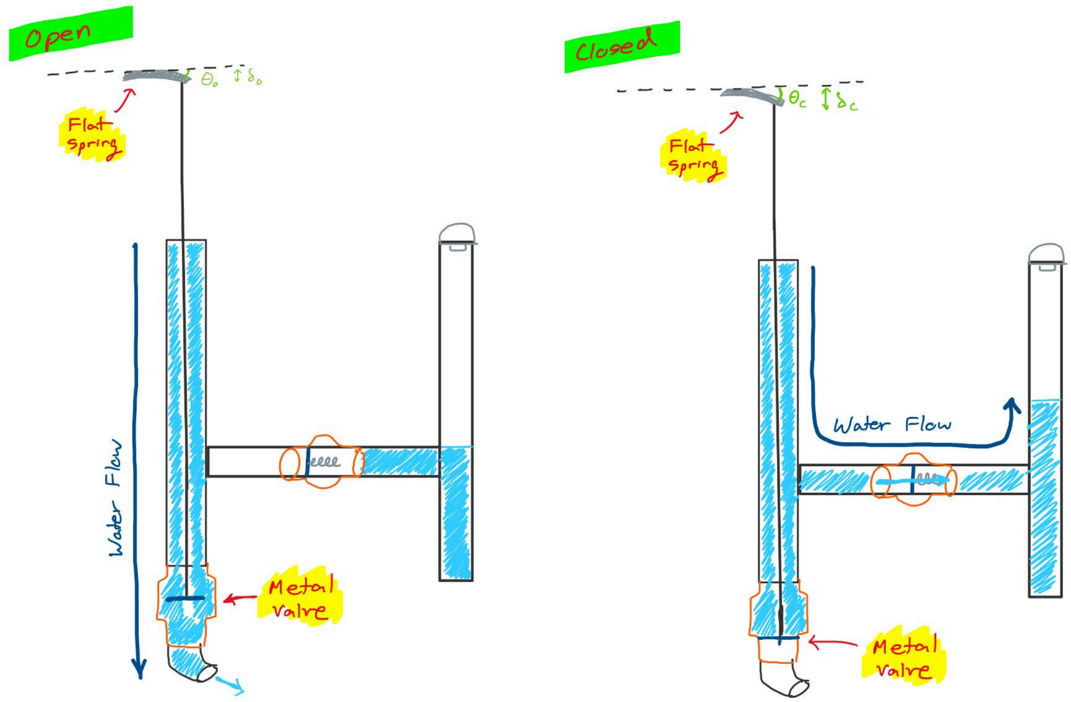

Figure 2: Open and Closed state of Ram Pump

After the pressure wave subsides, which usually occurs quite quickly, the flat spring in the system, which has up to this point been neglected, will become the dominating force. Since the closing of the flat plate has deformed the flat spring over some angle and length, the spring will apply an upward force on the plate. This allows the ACVRP system to return to its original state in which the reverse check valve is open. The success of completing this cycle largely depends on a precisely calibrated spring, one that is able to overcome the force of the hydrostatic water in the drive pipe when the pressure wave subsides, but is weak enough to be displaced by the drag force of the flowing water. Since the upward force that the flat spring applies at a given angle and displacement depends on several spring and system parameters-length, width, thickness, calibration height-a series of experiments were set up to optimize these parameters.

The first experiment was designed to identify springs of particular interest, or springs that were able to successfully run the ram pump cycle. Since there exists a large number of independent parameters, there are many set ups at which the pump will run. The number of solutions are limited by a few physical limitations, spring thicknesses are only manufactured at certain lengths, spring widths can only be between 0.5 cm and 10 cm due laboratory constraints, and spring lengths cannot exceed 70cm. Applying these constraints and reducing the number of independent variables, the team was able to come up with a range of spring thicknesses that would be possible to experiment with in the lab.

The results of experiments for springs at thicknesses 0.015 in and 0.020 in, are shown below. Multiple trials for springs of different widths at these thicknesses were tested to examine the effects of success depending on both parameters.

The summer experimental procedure used to standardize each red trial first consisted of defining important starting points. Before beginning the experiments, the spring clamp and arm were attached to the 80-20 hardware such that the spring experienced no deflection when the flat plate was in the maximum open position of the reverse check valve. This system height is referred to as the neutral height or zero position. This height was measured to be 1.8cm above the position at which the plate will close the check valve. After calibrating the system to this height, the spring was clamped down and the length of the spring was set to the estimated length output by the code. Each run was conducted twice to ensure the validity of the results, and if the results of runs differed a third run was conducted. If the run was successful, then the spring was adjusted to a longer length by 0.1-0.3cm. This process was repeated until the spring began to fail due to being too long. Next, the process was repeated but by shortening the spring's length by 0.1-0.3 cm, until the spring was too strong. In doing so, a range of lengths at which the spring successfully operated at was generated.

Preliminary Data Results

PARAMETERS	
Max. Angle (deg)	12.1
Max. Displacement (cm)	1.8
Width (cm)	3.5
Thickness (in)	0.02
Estimated Length (cm)	8.4
Interia	3.82365E-13
Cut was at 13 cm	

Length (cm)	Fail/Success	Notes	Trial No.
8.9	Fail	Failed twice in closed state, would run with operator assistance du	4
8.8	Success	Succesful (3x)	3
8.6	Success	Succesful (2x)	2
8.4	Success	Succesful (2x)	1
8.1	Success	Succesful (2x)	5
7.8	Success	Succesful (2x)	6
7.7	Success	Succesful (2x)	7
7.6	Fail	Failed twice in open state	8

PARAMETERS	
Max. Angle (deg)	14.5
Max. Displacement	1.8
Width (cm)	2
Thickness (in)	0.02
Estimated Length (c	6.9
Interia	2.18494E-13
Cuts were all 11 cm \	

Length (cm)	Fail/Success	Notes	Trial No.
7	Fail	Both runs failed in the closed position. Both ran with operator assitance d	3
6.9	Success	Ran succesfully two times	2
6.8	Success	Ran succesfully two times. Already noticeable deformation in spring	1
6.7	Fail	Failed in closed state (2x)	5
6.5	F/S	Two runs failed in the closed position, one success. Both fails ran with ope	4
6.2	Success	Two succesful runs	6
6	F/S	Failed in closed state once and ran succesfully twice	7
5.8	Success	Ran sucesfully twice. NOTE: Readjusted and retightened system to be allign	9
5.6	F/S	Failed in closed state twice and ran succesfully twice	8
5.4	Success	Ran succesfully twice	10
5.3	Success	Ran succesfully twice	12
5.2	Fail	Failed in open state	11

Figure 3: Preliminary example data for 0.015 in and 0.02 in thick springs

In a quick analysis of the preliminary data collected, the results indicate that the expected working length of the spring and the experimental range of lengths that successfully operate the pump generally agree. However, the working ranges of the flat springs seem to be somewhat inconsistent, with failures occurring in what is expected to be a range clearly defined by an upper and lower bound. Most importantly, the springs of all widths and for the two thicknesses tested has resulted in permanent spring deformation of the flat spring, a phenomenon that causes the behavior of the spring to be disturbed from what the theory of the model suggests. In order to prevent spring deformation from occurring the only solution is to use springs that will not permanently deform under the force of the water. The team is currently testing springs of thicker length, which give rise to solutions that should experience little to no deformation.

Method

Edits to procedure

The overall procedure is very similar to the one from Summer 2023. A change is that system height is now regularly checked to ensure that it is not dipping down while running. It is also important to make sure that the testing is standardized and everything is up to date, so there is a big focus on replacing parts that are not working properly. For example, the team is looking into new cheaper and smaller sump pumps after the previous pump repeatedly tripped the GFCI. The team is also working on solving the issue with the wire/carabiner, as vibration causes the carabiner to unscrew and open, leading to the wire becoming unattached. Additionally, for the future, the goal is to test springs of larger inertia values and experiment with different dimensions, so that relationships between spring inertia, thickness, and width could be determined. The strain gauge is to be used to keep track of force measurements and calculations, as further adjustments to the procedures and code are made.

Improving Computer Aided Design Model

The only current computer-aided design (CAD) model of the subteam's ram pump that was recently created was in the software Onshape over the summer which only shows the clamping system that holds the flat spring still and gives it the ability to oscillate. However, since there had been changes to the physical design that are not reflected, such as the certain connections of the 80-20 beams, and overall more to the design of our ram pump system that would be beneficial to have in a CAD form when it comes to analyzing the system, our goal this year is to create an entire model of the physical ram pump.

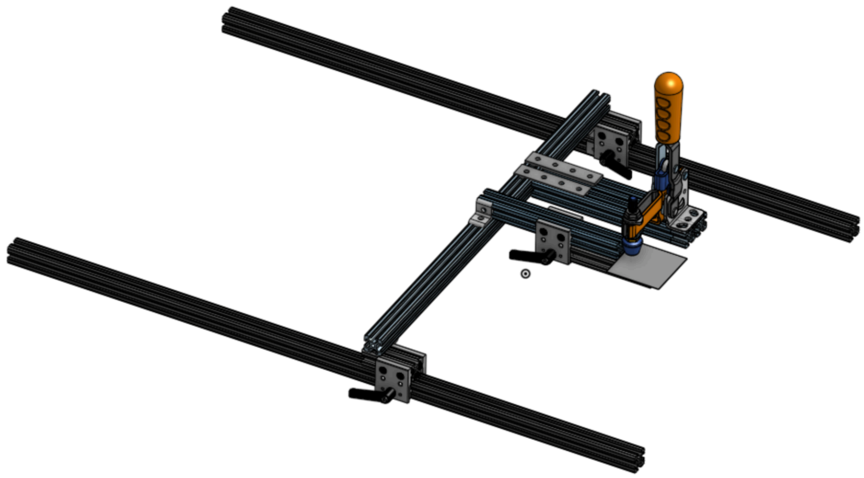

Figure 5: Current Clamping Design on Onshape

To achieve this main goal, three steps are going to be taken as a roadmap to creating a full model. The first step is to become much more familiar with the Onshape program through the use of the tutorials provided by Onshape itself. Honing the skills of software in general, will allow the Ram Pump subteam to create a more accurate model in less time. After becoming comfortable with the software, individual parts will be modeled such as the head tank, waste water containers, a redone clamping design, and other parts that need to be modeled for the team's specific system. Lastly, the assembly of the system will most likely be the most complicated as the method of connecting each part requires the most precision and patience. After taking each of the individual pieces modeled, the team will use the physical model in the laboratory to work backward to create the CAD model. By completing this goal, in case of future possible modifications to the ram pump system, there can be a model where the changes can be explicitly seen and analyzed before having to make any physical changes or purchases.

Results and Analysis

The primary steps taken this semester were largely focused on gathering experimental data. The team had begun the semester by testing springs of larger thickness (0.025in), and the results were lackluster. Namely, the spring was not operating close to the expected length (over 2 cm from expected) whereas all other springs tested were well behaved. The team believed that the erratic data results were caused by underlying experimental error as well as inherent problems related to the setup. In performing an extensive review of the procedure as well as the setup, there were significant improvements made to the procedure as well as the lab set up. The large portion of the latter half of the semester was spent on the set up improvements in order to create a more reliable testing environment. First, the team examined the reasoning behind the carabiner coming unlocked frequently, and diagnosed the issue as one around carabiner orientation. In order to keep the spring from breaking the team reoriented the spring such that the tension of the wire would not try to pull the carabiner open. Additionally, the team applied metal adhesive to the threaded locking mechanism in order to permanently keep the carabiner locked.

After fixing the locking mechanism for the carabiner, the team intended to resume testing, keeping in mind that the system will gradually dip downwards as testing occurs. In order to combat this effect, the system would be systematically reset after every 50 trials run. However, as soon as testing was set to resume, the sump pump in the lab began to malfunction. In more detail, the sump pump would cause the GFCI to fault whenever it was turned off. Eventually, the sump pump was unable to run without tripping the GFCI on the outlet. Without a sump pump, the team was unable to experiment anymore, meaning that the problem had to be solved. After much research, the solution proposed by the team was to clean out the water in the system, as it contained a significant amount of rust. Over many years, the team has observed that the water will quickly rust after an annual clean out, and may contribute to the sump pump tripping the GFCI. Although seemingly simple, cleaning out the water in the system was an involved process that at the time required the back pipe to be cut and the parts replaced. In order to streamline the process, the team devised a new part that made it easier to clean out the waste bucket. The part replaced a straight PVC pipe connecting the sump pump to the head tank with two shorter sections of PVC connected via a midline valve coupler. The midline valve coupler allows for the pump to be easily unscrewed from the back pipe instead of having to cut it, and in turn the waste bucket can be more easily cleaned.

Lastly, while the set up was broken, the team spent significant time refining a detailed plan for the upcoming semester, in order to maximize time once everything is fixed. To start, the ram pump team's overarching goal is to present a final computer aided design (CAD) that could be used for implementation in AguaClara plants. In order to accomplish this goal, there are three main steps that need to be taken: an experimental understanding of what springs can be used to operate the lab set up and meet deformation requirements, a physical understanding of how to change system dimensions in order to meet the pumping and size requirements, and a design requirement to assess feasibility and cost by creating a revising designs on CAD. The ability to use software such as Onshape makes the collaboration aspect of modeling significantly easier as multiple members can work on different aspects of an assembly or just update the components/assembly without having to create new revision files as the data is all stored online. The main drawback to this feature is the requirement of internet connectivity as in the case of traveling to countries with less accessibility to stable wireless connection, working on the model could become difficult. However, the models can be transformed into other file types allowing for offline work to be done either on the software or another software if need be.

Before being able to use Onshape to create a complete model of the ram pump system, the fundamentals needed to be learned to understand how to use the program to its fullest potential. The first step came in multiple tutorial courses that were available from the Onshape website which taught about the general layout of software, how to start sketching, how to make a 3D model, how to assemble multiple parts together, and how to easily share files amongst a team. The tutorials were extremely detailed and made for a great introduction to the software being able to comfortably use the software to start designing the ram pump system. Now that the foundations of the software has been set, the next goal is compiling the components needed on Onshape which includes: the head tank, drive pipe, flat spring, waste bin/avenue, chamber valve, and waste valve. Some of these components will need to be made by the team in the future on Onshape or outsourced from pre-existing models depending on accessibility of some of the smaller parts that can typically be bought at stores. However, each bigger component, such as the check valve or flat spring, needs to be dynamically scaled to fit the needs of an AguaClara plant which without having access to an AguaClara plant directly, creates a difficulty in understanding how exactly the ram rump should be designed and assembled to fit the needs of the plant. Two members of the team will be traveling to Honduras in January 2024 to obtain a deeper understanding of the plant which will then allow further progress in creating a viable CAD model for the real-life water plants.

Discussion

The results of the team this semester have made it so the team will be able to test with thicker springs more confidently going forward. Specifically, the team's accomplishments make the lab setup more flexible so not only are the current issues able to be resolved, but also will make it easier to resolve future issues. Going forward, the team will be able to reliably test with thicker spring in an attempt to analyze the effect that using larger has on the lab setup along with gathering the associated performance data. Since the ram pump will only operate under the guide of a spring that is able to overcome the force of the static water when fully displaced, but unable to overcome the force of the water as it is increasing in speed, the springs that will lead to success obey a relationship that correlates to a nearly constant spring force. The flat spring experiment is designed to identify springs that meet this condition, and additionally to not experience visible permanent deformation after running. Since the effective spring constant of the flat spring depends on a large number of independent parameters, there are a significant number of springs that meet this requirement. This gives us a lot of options with the configuration of the flat spring. For instance, we can choose different thicknesses or lengths depending on which one will lead to less deformation. It is also significantly easier to test a wide range of springs as we only have to adjust the length of the slider to test a spring of different length.

Once necessary performance data is gathered, the next step is physical analysis. Since the laboratory model of the ram pump is much smaller than the actual AguaClara plants. For perspective, the lab setup outputs water at 60 L/min, whereas the average AguaClara plant outputs water at 60 L/s. In order to scale up the ram pump, an extensive physical understanding of the fluid behavior and corresponding forces, and the spring physics is necessary. From physical models already generated, the team has estimated that for absolutely zero deformation to occur in the lab setup, a 60cm long spring is needed. Scaling up would indicate that the spring needed would be extremely long, on the order of 10s of meters. In order to make the system feasible, the team is aiming to determine what parameters of the lab setup could be changed in order to make everything literally fit into the plant, and minimize economic costs.

As stated before in sections before, the last goal is to create a computer-aided design (CAD) of the ram pump system that would be implemented into the real AguaClara Plants. A CAD model would allow for the team to see how the work they are doing will actually be utilized in a larger picture and further put the system's importance in perspective. Having a CAD model of the system also benefits the brainstorming process of future possible modifications by allowing for the changes to be represented on the model initially before anything else. To make a viable model takes a significant amount of time and should be done with a high degree of caution as a simple mistake in just one component of the system can lead to detrimental impacts on the overall system. The tutorials despite the simplicity at some points were taken very seriously as the program as whole is not entirely intuitive on a first time use. So, by taking the time to go through the tutorials and understand the basics of sketching, creating a 3D model, navigating the website overall, and assembling pieces are skills that all the team members need to develop to fully utilize Onshape properly.

The model so far is still in a very early planning stage, but will be developed at a much faster pace after seeing the water plants in person and understanding how exactly to make the ram pump model a viable pumping system for the plants. However, the current lab model is able to give some guidance in how the system generally should be laid out with the head tank having an elevated position to allow gravity to pull the water down and close the waste valve and then reopened by the flat spring creating the oscillations and allowing the water to reach increasing heights through the chamber valve. The components themselves will be dynamically scaled to a much higher proportion, however that comes with its own challenges as systems grow bigger which will need to be brainstormed such as the design of the flat spring how large can the spring be that can feasibly constantly open the waste valve without significant bending overtime. These solutions will start to be developed as the components are designed, but understanding the overall picture of the system in the plant is the biggest priority for the team when making the CAD model. As members from the ram pump team examine the plants in January 2024, they will be able to speak directly to the plant owners and also receive their input and feedback on how to properly implement the system effectively in the plants. By receiving their perspective as an experienced plant operator, it allows the team to better cater the model to their specific needs.

Conclusion

In order to successfully implement the ram pump, experimental data, a physical understanding of scale up, and a proposed model needs to be created. The steps taken this semester have been largely focused on collecting data, which has been hindered by laboratory failures. However, the lab setup is now fixed with the hope that many of the lingering problems will no longer be an issue. We hope to go farther in making a CAD model of the ram pump system to be able to scale up our ram pump model in the lab to the model in the AguaClara plants. To do so, visiting the physical plants will allow for a deeper understanding of how to help the plants while also understanding the avenues that should be taken when dynamically scaling the components.

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Manual and Appendices

Manual

Lab Set-up

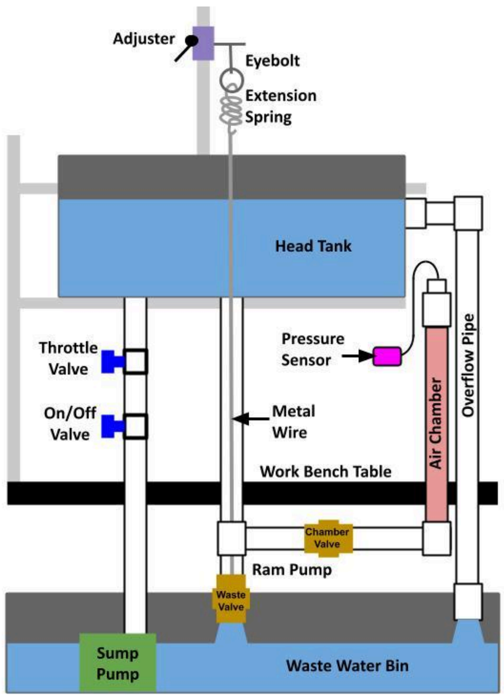

Figure 1: Schematic of Entire Ram Pump System

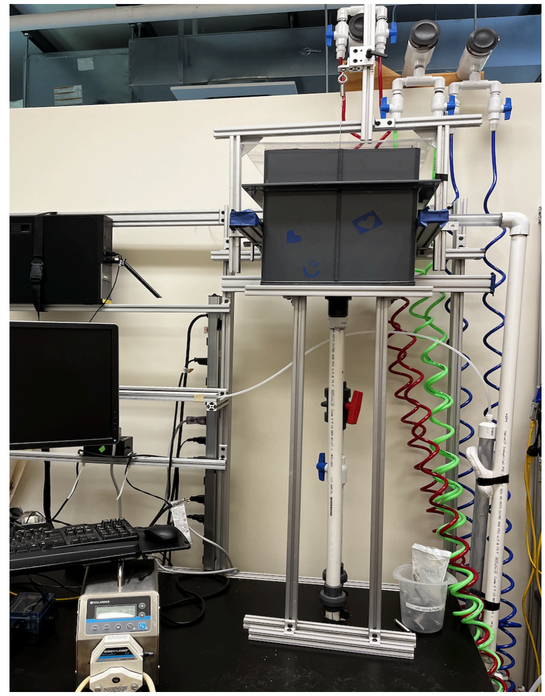

Figure 4: Ram Pump System in Lab

Walking through the schematic and how the ram pump works, it can be seen that the system functions through a valve system. The water flow cycle begins at the head tank, traveling from the head tank in the PVC pipe containing the metal wire and into the intersection of where the chamber and waste valves meet. As the water travels down through the pipe, it gains more and more velocity. Once the water gains enough velocity, the force of the water will overcome the force needed to close the waste valve, consequently bringing it shut. As a result of the closed waste valve, pressure builds up in the pipe intersection. Once the pressure is greater than the pressure in the air chamber, the chamber valve opens and water will continue to flow through until the pressure equalizes, which is when the chamber valve will close shut and cause the spring to tug on the metal wire and reopen the waste valve. The process consequently restarts.

Ram Pump System Components

There are three total "pumps" within the ram pump system - the Golander Pump, the Sump Pump, and the physical ram Pump. The Golander Pump is a peristaltic pump that pumps water, in either direction, at an adjustable flow rate. Within the context of the lab, the Golander Pump is used to remove water from the air chamber and into the waste bucket, ensuring that there is sufficient water to flow from the waste water bin to the head tank. The Sump Pump pumps water upwards once the water in the waste water bin reaches a certain level. The Sump Pump is not used in the actual implementation of the ram pump within the water plants, but it is used in the lab for running experiments. The actual ram pump within the ram pump system is the valve system that was described in the previous paragraph.

In terms of piping, there are three essential pipes within the ram pump system as well - the back pipe, the drive pipe, and the overflow pipe. The back pipe is the PVC pipe that runs from the waste water bin to the head tank, containing the throttle valve and the ON/OFF valve. The drive pipe is the PVC pipe that connects the head tank to the ram pump, which also holds the metal wire attached to the spring system. The overflow pipe is the PVC pipe that connects from the head tank at about ¾ its height so that water does not overflow in the head tank and is then redirected to the waste water bin.

Outside the ram pump, there are two other significant valves - the throttle valve and the ON/OFF valve. Both valves ensure that the flow rate of the water through the back pipe is controlled and does not cause the head tank to overflow.

Lastly, there is an air chamber and pressure sensor within the lab setup. The air chamber is not a part of the ram pump system that would be implemented within an AguaClara plant, but it is used to determine the pressure as it pertains to water flow, which can be translated into how high the water can be transported upwards with a pressure to meters conversion. The aim is to record a pressure that corresponds to about 4-6 meters with all of the experiments because that is what is required for the AguaClara plants. The pressure sensor collects the pressure data and stores it in ProCoDA; the lab software turns on all the pumps simultaneously to run the ram pump system and generates graphs and data to analyze regarding air pressure and flow rate.

ProCoDA allows an export of data points taken at set time intervals, and from there, a graph of the pressure readings can be constructed to see when the average height is reached and about how much time it takes to reach this height. At a higher frequency of data collection, the height of the water column during each oscillation and the behavior of the water as the waste and chamber valve opens and closes can be read.

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