1 Liter per Second Plant Testing Fall 2017

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November 9, 2017

Abstract

The 1 Liter per Second (LPS) Plant testing team is continuing the work done by previous semester's Pre-Fabrication team by attaching the ESTaRS to the 1LPS plant and flocculator. By doing this AguaClara will have a complete 1 LPS Plant running in the lab so that experimental data can be gathered. This data will be used to optimize and improve current designs as well as further iterations of the technology.

Introduction

AguaClara, which began building plants in Honduras in 2005, India in 2013, and most recently Nicaragua in 2017, provides gravity powered water treatment systems to thousands of people in rural communities. However, there were still populations that couldn't be targeted due to AguaClara technology only being able to scale up from 6 L/s. For towns and rural areas with populations smaller than a thousand, sustainable water treatment technology was still out of their grasp.

Recently a one liter per second (1 LPS) plant was developed based on traditional AguaClara technology, to bring sustainable water treatment to towns with populations of around 300 people. The first plant that was ever fabricated was sent to Cuatro Comunidades in Honduras and is currently operating without the filter attachment, known as ESTaRS. The Enclosed Stacked Rapid Sand Filter is the last step in the 1LPS plant processes before chlorination and completes the 4 step water treatment process of: flocculation, sedimentation, filtration, and chlorination.

At Cornell, an additional sedimentation tank, flocculator, and ESTaRS were built. The 1LPS Plant testing team will assemble them together to create a complete plant so that research can be done on improving the performance of this technology.

Literature Review

Traditional Stacked Rapid Sand Filters

Traditional sand filters filter between 4,000-12,000 liters per hour per meters squared. They use very little land, have no limitations on influent turbidity, and can be cleaned almost instantly with backwashing. Their basic function is to be an intermediate step between pre-treatment, flocculation and coagulation, and disinfection, usually with chlorine.

Sand filtration works through two physical processes: larger suspended solids get stuck between sand particles, called mechanical straining, and smaller ones adhere to the surface of sand grains due to Van der Waal forces, called physical adsorption. As time goes on particles clog the sand filters, and require backwashing to clean them. Typical control systems for sand filters require a lot of maintenance costs due to the complexity of the systems requiring electricity and moving parts, resulting in high initial capital and operational costs. Stacked rapid sand filters were developed to create an alternative that is more reliable, economical, and sustainable.

Novel Fluidic Control System for Stacked Rapid Sand Filters

These papers from the Journal of Environmental Engineering, published in 2013, describe the studies and experimentation involved in developing a novel way to control the transition from filtration to backwash in AguaClara SRSF (Stacked Rapid Sand Filter). The same system, consisting of a siphon pipe and air trap, is used in EStaRS, as the current team is developed off of the studies done in the paper. The document also includes the heights of the inlet box and exit box, determined by differential pressure and head loss measurements.

Previous Work

EStaRS, Spring 2017

In the previous semester, the ESTaRS subteam built the ESTaRS with design parameters that would fit the 1 LPS plant. The report details the fabrication methods used to build the ESTaRS column and manifolds that make up the sand filter.

Pre-Fabrication 1 L/s, Fall 2016

In the Fall of 2016, the Pre-Fabrication 1L/s fabricated a new 1LPS in order to replace the 1LPS that was fabricated in the summer of the same year as it was shipped to Cuatro Communidades in Honduras. The team developed better fabrication techniques to reduce the overall cost of the plant and labor in Honduras. The sedimentation tank, which was described as the "centerpiece of the plant", was cut first with the help of I-Beam supports and jigs. The team created a plywood board jig, which was utilized to make a 30°cut in the 0.91 m pipe. The team also created a jig to keep the reciprocating saw used to cut the tank parallel to the plywood board jig and another additional jig to cut the plate settlers.

Small Scale Plant Testing, Fall 2016

In the Fall 2016 semester, there were two teams conducting research on the 1 L/s plant. The Small Scale Plant Testing team focused on confirming the functionality of 1 L/s plant built in Summer 2016. The team was able to confirm that the 1 L/s plant was working well and was able to ship it to Honduras. The results the team produced in clay testing were similar to a traditional AguaClara plant and Chemical Dose Controller (CDC) tests proved that the CDC was working as expected. The team also came up with a new flocculator baffle design. However, the baffle design was eventually replaced with a similar baffle design that was used in Spring 2017, as well as in the 1 L/s plant shipped to Honduras.

1 L/s Plant Testing, Spring 2017

The work done by this semester aimed to finish assembly of the plate settlers, weld the supports, base plates and jet reverser for the sedimentation tank, the majority of the entrance tank, water tested the tank and LFOM. The team was able to finish the large majority of the fabrication necessary to complete the 1 L/s plant and started a fabrication manual to help reduce the time spent on future teams searching for fabrication instructions for the plant. For further references see fabrication manual.

1 L/s Plant Testing, Summer 2017

During the summer, the EStaRS was completed and water tested. However, the filter and plant were not run in conjunction.

Fabrication Methods

Entrance Tank and CDC

The entrance tank of the 1 LPS team was previously fabricated. However, it was missing an overflow pipe, a lever that measures the flow rate of plant and the float that attaches to the lever. First, the lever was installed along with a 1.25 inch stopper to prevent it from moving in the horizontal plane. Furthermore, it was found that the lever when at it's highest point, hits the bottom of the CDC. To address this issue the CDC was attached to a plywood that would allow the CDC to be on the same facing side as the entrance tank. This also allows easier operator access.

Figure 1: LEFT: The hole on the top left was the overflow hole that was drilled. A PVC 1.5 inch pipe adapter was then glued into it. RIGHT: LFOM measurements are incorrectly labeled as cm but are actually mm.

Figure 2: A stopper was created out of a PVC rod that had a 1/4th inch hole drilled into it to fit the metal rod from the lever

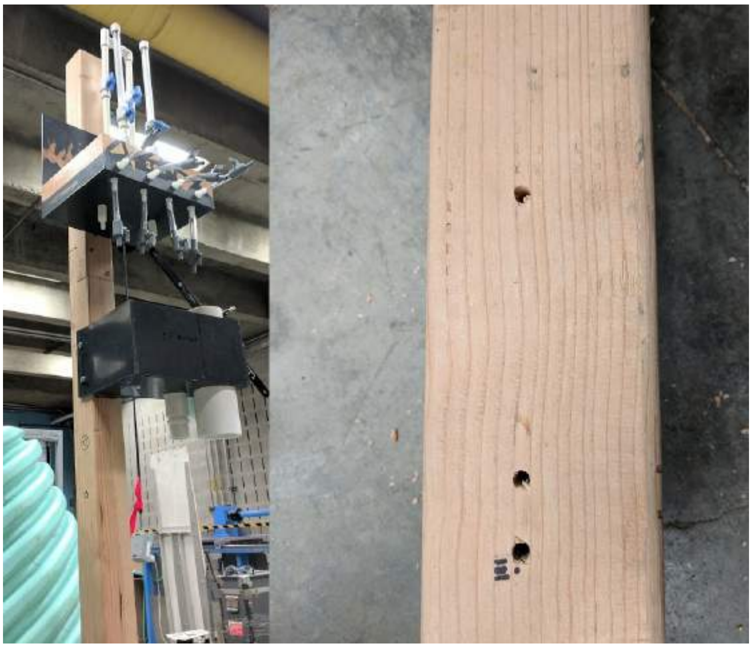

Figure 3: LEFT: Shows the Entrance Tank and CDC after the CDC was raised 3 inches. RIGHT: Shows the two new holes that were drilled with a hole saw. Holes were drilled with a 1/4 inch drill at 101 and 104.5 inches.

Adjustable CDC Height

The 1LPS team needed to make the CDC adjustable and accessible. A plywood piece was attached to the 4x4 to give the plant operator access to the CDC tank. To make the CDC adjustable, two 80x20 pieces were attached to the plywood. To provide stability, the 80x20 pieces were separated by 3 inches. The CDC was then attached to the two 80x20 pieces using screws and sliders. The slider will allow the operator to adjust the height of the CDC during initial set-up.

Figure 4: A plywood piece that is 17.5 in. x 19 in. x 5 in. was screwed onto the 4x4 using 2 hex crews at heights of 97 in. and 110.5 in. from the bottom (Left). The CDC was screwed onto the 80x20. Two new holes were made on the CDC. The holes were placed 3 inches from the existing holes (Right)

Coagulant Stock Tank

Calculations for the volume of a stock tank that the team required for running experiments were done for 12 hour experiments. We take the result of equation 6 and multiply it by 12 hours. The team then decided to place the coagulant stock tank on a piece of plywood screwed onto the top of the 4x4 wooden pole. 3 wood screws were drilled into a 9x12x.5 inch plywood. See picture for fabrication methods.

$$Q_{CDC} = \frac{Q_{Plant} * C_{DesiredCl}}{C_{StockPACl}} = 0.1543\, liter/hour \tag{1}$$

$$Q_{CDC} * Time_Experiment = 0.1543\, liter/hour * 12hours = 1.812\, liters \tag{2}$$

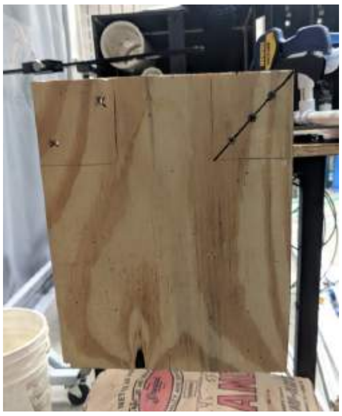

Figure 5: First it is orientated so that the plywood that sticks out will hit neither the CDC or the entrance tank lever. This was done so that if the pole was shorter the plywood wouldn't hit anything on the way down. Then a 3.5x3.5 inch box was drawn onto a corner of the plywood. Then a line was drawn diagonally across the box and each screw was drilled 1.2 inches from one another along the diagonal line.

Dosing Tube

The equations used in the following section are found in CEE4540 design course slides team used the following parameters to determine the dosing of PACl and dosing tube lengths. Flow rate plant (Q) is 1 Liter/s. The concentration of desired chlorine is 3 mg/L. The concentration of PACl is the standard stock concentration of 70 g/L in the AguaClara lab. For further references see 4540)Flow Control and Measurement from the course CEE 4540.

$$Q_{CDC} = \frac{Q_{Plant} * C_{DesiredCl}}{C_{StockPACl}} = 0.1543\, liter/hour \tag{3}$$

For the next equation, the following values were used to determine velocity in the dosing tube. Ratio Error was .1, Headloss was 10 cm, g was 9.81, and Kminor was 2. Headloss is the difference between the difference in elevation between the stock tank of coagulant and the outlet tube in the entrance tank.This value was chosen since this is the maximum difference in height that could occur. Kminor is 2; by summing together minors for the inlet and outlet of the dosing tube. The concentration of chlorine was determined based on the standard AguaClara plant chlorine concentration.

$$Velocity_{TubeMax} = \left(\frac{RatioError * 2 * Headloss * g}{K_{Minor}}\right)^{1/2} = 0.3132\, meter/second \tag{4}$$

Flow rates in 1/16 and 1/8 inch diameter tubing were then determined by multiplying areas of respective diameter tubing by the velocity in the dosing tube. The first flow rate is from the 1/16 diameter tube and the second is from the 1/8 diameter tube.

$$Flow_{TubeMax} = \frac{\pi * d^2 * Velocity_{TubeMax}}{4} = .62mL/s = 2.48\, mL/s \tag{5}$$

Finally length of the tube was determined by the following equation from CEE 4540 Flow Control and Measurement notes as stated before. We chose the 1/16 diameter that resulted in the .21 meter because it would use less tubing.

$$L = \frac{g * Headloss * \pi * d^4}{128 * NuPaCl * Flow_{TubeMax}} - \frac{k_{Minor} * Flow_{TubeMax}}{16 * \pi * NuPaCl} = .21\,meter = .82\,meter \qquad (6)$$

Contact Chamber

The contact chamber for the 1 LPS plant was previously fabricated. However, the chamber was shortened because the tubing to connect the entrance tank and contact chamber wasn't flexible enough to fit within the space available between the tank and the chamber. The contact chamber was placed against a wall and a jigsaw was used to cut the 10.00 inches from the top. An 8 inch Fernco was used to connect both pieces together. A separate Fernco was used to connect the contact chamber with the entrance tank. This would allow for easy removal of the contact chamber when it's needed.

Figure 6: The previous height of the contact chamber would not allow flexible tubing to be attached to the overflow pipe. Therefore, 10 inches were cut from the contact chamber.

Figure 7: After 10 inches were cut from the contact chamber, there is enough room for flexible tubing to connect to the overflow pipe of the entrance tank.

Faucet

The faucet that the team needed was already connected to a hose that was connected to an experimental apparatus that another research group was doing. So the team modified the faucet so that it would have two outlets, one to the original apparatus and one to the 1LPS plant. Using the head loss equation below, the area of the tubing was determined. A head loss of 2m determined by using the height of the entrance tank, a K value of 6 was used, and a value of 9.81 $\frac{m}{s^2}$ for g. The K value was estimated to be six; two coming from an inlet and outlet and the remaining four from the angles that the flexible tubing bends at.

$$H_L = \frac{K_{Minor} * V^2}{2g} \tag{7}$$

$$A = \frac{Q}{V} \tag{8}$$

Rearrange this to solve for A and then solve for diameter of tubing.

$$A^2 = \frac{K_{Minor} * Q^2}{2 * g * H_L} \tag{9}$$

$$d = \frac{16 * K_{Minor} * Q^2}{2 * g * H_L * \pi^2} \tag{10}$$

$$d = .022m = .866in \tag{11}$$

This diameter is the minimum diameter of the pipe to ensure that the head loss due to minor losses is not higher than the entrance tank. From this calculation, we used 1 inch diameter tubing.

Floc Hopper Valve

The Floc Hopper required a valve to be able to drain sludge from the sedimentation tank. The following calculation was done using these assumptions. Flow plant was assumed to be 1 Liter/second. The concentration of particles in the floc hopper was assumed to be 1/100 of the concentration entering the tank. Headloss was assumed to be 2m for the height of the tank and finally, the Kminor was assumed to be 2 for the inlet and outlet of the valve.

$$Q_{FlocHopper} = \frac{Q_{Plant} * Concentration_{Plant}}{Concentration_{FlocHopper}} = 10\,mL/s \tag{12}$$

$$Velocity_{FlocHopper} = \frac{4 * Q_{FlocHopper}}{\pi * d^2} = .219\,centimeters/second \tag{13}$$

$$Area_{Valve} = \frac{\pi * d_{valve}^2}{4} \tag{14}$$

Combine equation 14 and 15 to get flowrate of the floc hopper in terms of the diameter of the tube.

$$Velocity_{Valve} = \frac{Q_{FlocHopper}}{Area_{Valve}} \tag{15}$$

$$Q_{FlocHopper} = \frac{\pi * d_{valve}^2}{4} * Velocity_{Valve} \tag{16}$$

$$Velocity = \frac{2 * Headloss * g}{\Sigma K_{minor}} = 4.42\,meters/second \tag{17}$$

Plug in the flow rate of floc hopper into equation 18 to solve for diameter.

$$Diameter = (\frac{\Sigma K_{minor} * 8 * Q_{FlocHopper}^2}{\pi^2 * Headloss * g})^{1/4} = .0667\,inches \tag{18}$$

This is the minimum diameter valve needed for the floc hopper. The team ended up using a quarter inch valve. It was drilled sideways into the cap that encloses the end of the floc hopper.

Figure 8: Floc Hopper with the valve being installed on the side. Teflon was then applied to have a watertight seal to a coupling.

ESTaRS Valve

The 1LPS team also needed a method to drain the ESTaRS for when operation ceased and water has to be dumped out so a valve was installed on the lowest outlet pipe in between the 2nd and 3rd elbow of the piping section. Installing a valve at the lowest outlet pipe allows the ESTARS to be fully drained. First, a 3 inch section of the pipe was cut off and replaced with a PVC 1.5 inch T elbow. Then a coupling was installed to connect the T to a 1.5 inch valve. Finally, the valve was connected to a 1.5 inch fernco with another coupling.

Figure 9: The pipe section(first outlet from the bottom) without the valve installed(left). The same pipe section with the valve installed (right).

Flocculator Adjustments

When water testing the 1LPS, the head loss in the flocculator increased to a point where there was overflow in many of the channels. To solve this issue, 3" pipe stubs were added to the top of each channel to handle the head loss building in the flocculator. During testing, the team was able to observe and estimate the amount of water overflowing from the flocculator. Based on these observations, the team determined 25 cm pipe stubs would be a sufficient height for the first channel. Based on previous uses of this method in the field, the pipe stub's height decreased in increments of 5 cm between each channel since head loss through the flocculator decreases with each channel.

4 Pairs of 25 cm, 20 cm, 15 cm and 10 cm pipe stubs were fabricated in total. They were inserted on top of the flocculator T-elbows in order of descending height as it got farther from the entrance tank and toward the sedimentation tank.

Figure 10: The method of adding pipe stubs to the flocculator was taken from 1LPS pilot plant in Cuatro Comunidades, Honduras to prevent overflow. Pipe stubs will prevent the flocculator channels from overflowing. The use of pipe stubs allows the system to be open to atmospheric pressure.

Experimental Procedures

Water Distribution System

To run experiments properly, a water source that provides at least 1 LPS flow was needed. The closest source that could provide the required flow was being used by a graduate student. To prevent having to disassembly the student's hose and attaching the team's hose, a durable water distribution system was created. The system is made up of two on/off valves, one gate valve, three nipples, and three elbows that are 1 1/2" diameter copper piping.

Figure 11: A water distribution system was made to provide 1 LPS and lab members to utilize the source simultaneously without conflict.

Backwash ESTaRs

Procedure:

1. Initiate backwash
    a. put pipe stub in exit to increase water level in filter
    b. open top valve to release any air in the column
    c. open backwash valve and close top valve simultaneously to start backwash
    *should start siphon and cause water level in entrance tank to drop
2. Close top 3 inlet valves (planned to move valves closer to bottom so there is no air trapped when valves are closed)
3. Turn off backwash
    a. close backwash valve and take out pipe stub
    *water in entrance tank should rise
    b. once water fills above tallest pipe stub, open inlet valves.
    *if entrance tank level is rising too fast open inlet valves as they are filled.
4. Return to filtration mode

Prevent Reverse Flow!

Figure 12: Instructions from Fall 2015 ESTaRS. It has not been updated to the current design, which will only use one valve to control backwash

Results

Since the semester's work mainly focused on fabrication and creating a plant that is easily accessible and operated by operators, the team was unable to conduct experiments.

Analysis

The team was unable to analysis data since there were no experiments conducted.

Conclusions

One of the items the team designed and tested was the water distribution system to the plant. The system was about to supply water to the plant and simultaneously feed neighboring lab research. The CDC's height adjustment system was also easily adjustable with minimal effort from operators (by unscrewing and re-tightening bolt at desired height).

Future Works

Next semester, the 1 LPS team will have to create pipe stubs to place on top of the flocculator. The pipe stubs will prevent water from overflowing when the 1 LPS plant is running at full capacity. The 1 LPS team will also have to add the chemical stock tank on top of the 4x4. Once added, the hose connected to the water pipe will have to be attached securely to the entrance tank. Once the plant has been water tested, the plant will be ready for performance testing.

Task Map