Demonstration Plant Team

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Abstract

The demo plant team is responsible for design, construction, and troubleshooting of the AguaClara Demo Plant. The successful operation of this plant is crucial in order to demonstrate the process of AguaClara plants to all stakeholders, including students, faculty, staff, community members, business partners, and potential sponsors. This spring semester, our research team focused on fixing issues with the current demo plant design, such as an unreliable flocculator and dose controller, unstable frame, and concerns with differences in hydraulic head. Our research includes conceptualizing and testing a more efficient and stable plant assembly and start-up for those unfamiliar with the technology; resolving issues with improper coagulant dosing and head loss differences; designing and implementing a new flocculator design; testing new fittings for the stacked rapid sand filter (SRSF); and providing thorough documentation of the demo plant so that future teams would have less difficulty familiarizing themselves with the AguaClara demo plant. The redesigned demonstration plant is more stable with the addition of a middle beam and a contiguous bottom support. Overflow issues in the flocculator were addressed through the manufacture of a new flocculator, which contains an overflow weir and outlet. Inconsistencies with head loss were resolved by creating a Mathcad calculation file to determine the necessary lengths of "long, straight" tubing from the constant head tanks. Increasing the capacity of the raw water stock tank from less than one liter to two liters allowed for an increase in continuous operation without interruption.

Literature Review

No formal literature review has been conducted by our research team this semester, but we have read the user manual and final reports from previous semesters. The demo plant team is committed to building a small-scale model demonstrating the technology of an AguaClara plant. This job requires a full understanding of the mechanisms of each part of the process, and creativity in scaling down the mechanics into a working demonstration. From previous teams' reports, research, and design plans, we have learned how to incorporate the necessary fluid mechanics and energy laws into the design. Most of the necessary design is already known, and we want to improve upon individual parts to ensure the process runs smoothly and with fewer failure modes. Most of our knowledge stems from the final report from the Spring of 2013, and the layout of the existing physical design. From the AguaClara wiki page we have found the needed documentation on the fill and backwash techniques for the SRSF; fabrication methods of the flocculator under design and construction; and information on the calculation of plant flow rates, coagulant dosing, and raw water turbidity measurements. Given that we plan on changing the frame and configuration of the current design, we will update the user manual and assembly guide. Additionally, we will update plant flow rate and coagulant dosing values with those we measure with the larger run-time objective.

2011 Plant Report
Spring 2012 Users' Manual
Spring 2012 Final Report
Summer 2012 Plant Report
Fall 2012 Plant Report
Spring 2013 Plant Report

Introduction

Figure 1: Old Demonstration Plant

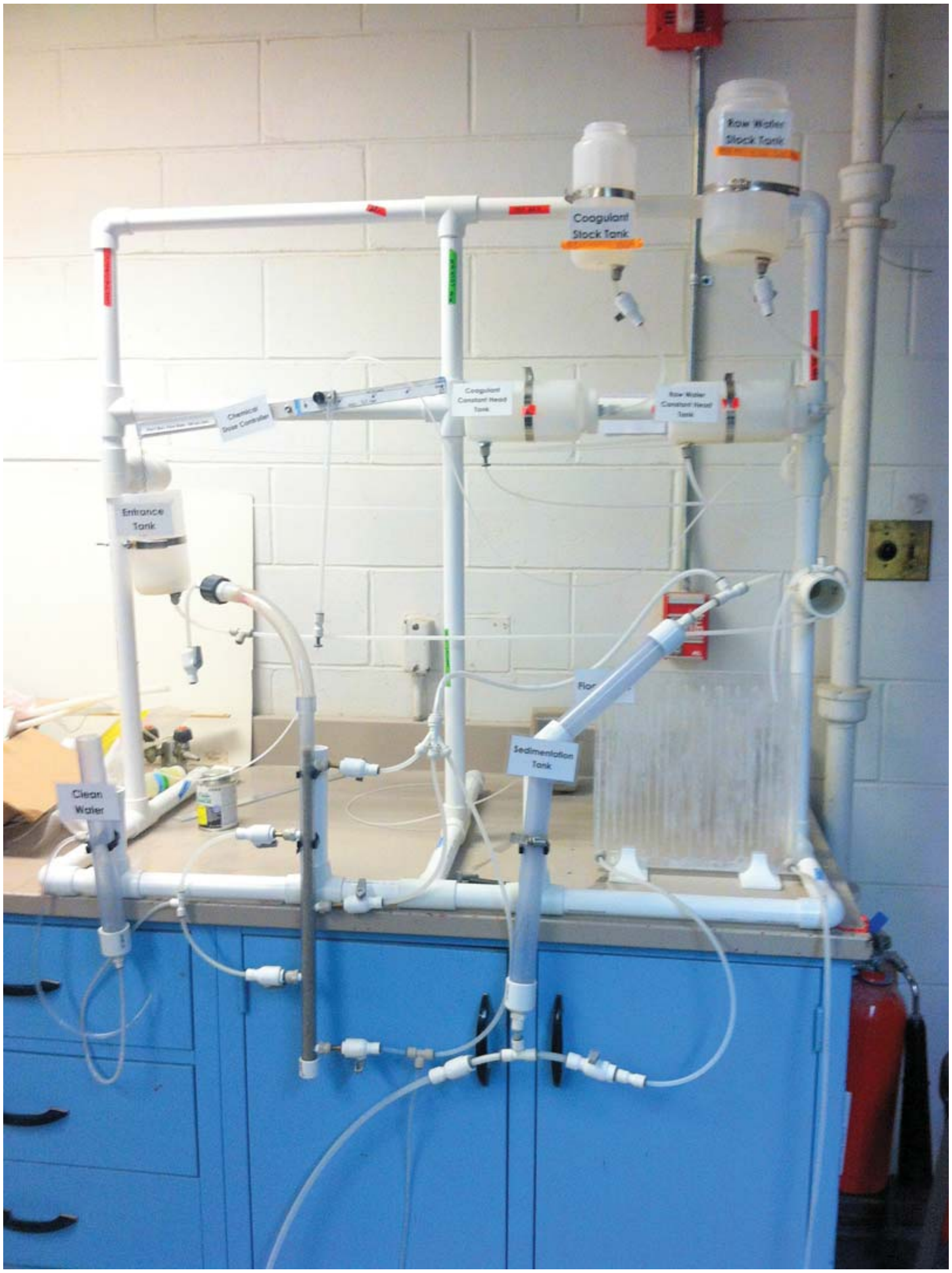

Figure 2: Redesigned Demonstration Plant with Attachments

The Demonstration Plant (see Figures1 and 2) is the most effective way to teach and, as its name implies, demonstrate how the AguaClara Plant works. The establishment of a reliable, visually pleasing demo plant will be a valuable tool in both convincing stakeholders to implement the technology in their communities as well as gaining support from potential sponsors. It will also be easier to explain and to use if the demo plant works effectively every time. AguaClara will advance and grow from the completion of this task because we will be able to more easily demonstrate the enormous benefits of a full-scale plant.

Our main goal this semester is to improve the current demo plant so that it works effectively and can be quickly and easily set up. Though the demo plant theoretically provides the correct functions of a real AguaClara plant, the current demo plant has many design flaws. We will build upon the previous team's design, as they correctly implemented the necessary fluid mechanics in order to run the plant. We will work on changing the physical design of the plant in order to avoid problems such as cumbersome packing and building, overflow of the flocculator, and air bubbles in the tubing. This may require an overhaul of the materials used in areas such as the support pipes and the flocculator. Lastly, we will leave behind a template Mathcad design file that clearly documents all calculations.

Methods

Flocculator

The flocculator of the last plant operates ineffectively, with a clear failure mode of overflow. The difference in head within the control volume from the flocculator to the Y-tube attached to the sedimentation tank keeps the plant from performing properly. After discussions with Monroe and Paul Charles, we developed a few potential solutions. The most promising option we conceived was to re-manufacture the flocculator using different technologies. As mentioned by Paul Charles, there are alternative fabrication techniques for the flocculator design, including Computer Numerically Controlled (CNC) technology; vacuum-formed plastic; laser cutting and 3D printing. We created a draft in AutoCAD and Google SketchUp of the redesigned flocculator. Two main changes in the flocculator design include the addition of an overflow well and rounded bottoms, as depicted in Figure 3. The overflow well is located where the first two baffle channels were and is intended to eliminate the overflow failure mode. Rounded bottoms are meant to facilitate more effective cleaning of the accumulated flocs.

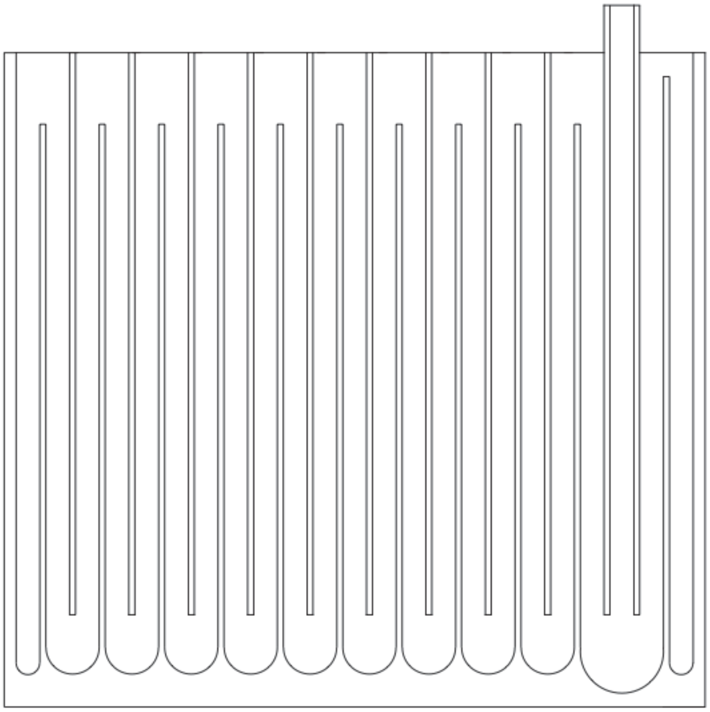

Figure 3: Cross Section of Flocculator Design

We presented our SketchUp model to Rodney Bowman of the LASSP Machine Shop in Clark Hall and received a quote of \$54/hour for CNC labor costs and \$25/square foot of acrylic. Rodney Bowman estimated that the fabrication of our proposal would take between 4-6 hours, which is a greater cost than could be justified for this one item on the demonstration plant. Future teams should be aware that the cost of fabrication is discounted by 20-30% if ordered in bulk. Given the unreasonable cost to CNC the flocculator in the LASSP lab, we investigated the Cornell Creative Machines Lab, run by Hod Lipson. The student run Rapid Prototyping Laboratory (RPL) in Rhodes Hall worked with us to laser cut our designed flocculator from acrylic at no cost save for materials. (It should be noted that the use of services in the RPL will be free to students and project teams for just one more month and possibly into the summer of 2014). The undergraduate monitors in the RPL lab tested a few different styles of cutting in order to determine which would work best for our purposes. After one run using the "stamping" method in a 0.5-inch thick acrylic, it was determined that it would take 30 continuous hours of run-time to cut the flocculator with this method, which was uneconomical for the RPL in terms of energy use. Switching to a thinner sheet of acrylic (0.25 inches), the monitors laser cut the channels out of one sheet and adhered it between two other 0.25-inch acrylic sheets, in order to keep it water tight.

Due to the estimated cost of constructing our proposed flocculator and time involved in that process, we calculated the projected fluid properties of this flocculator to determine if the new flocculator is justified. From equations found in lecture "Flocculator Design" from the CEE 4540 class website, we determined and compared head loss, residence time, and collision potential for both the current flocculator and the proposed flocculator.

For our current flocculator, we measured many parameters in the lab:

$H = 22.5cm$; water height as the flocculator is in use
$S = 1cm$; distance between baffles
$T = 7min$; flocculator run time
$L = 5.625m$; total path length for one particle
$N_b = 25$; number of baffles
$N_{BaffleSpaces} = 24$; number of baffle spaces
$K_b = 2$;
$V = \frac{Q}{A} = \frac{5.625m}{7min} * \frac{1min}{60sec} = 0.09375\frac{m}{sec}$; velocity in the flocculator

The residence time, or the amount of time that one particle remains in the flocculator, was determined by the following equation:

$\theta = \frac{HN_b}{V} = 419sec$

The head loss, which results mainly from the 180 degree turns that water particles must make around the baffles, was determined by the equation:

$Headloss_{CurrentFlocculator} = N_{BaffleSpaces}K_b\frac{V^2}{2g} = 0.044cm.$

The collision potential, which corresponds to the likelihood of floc formation in the flocculator, is a function of residence time, flocculation efficiency, and energy dissipation. It can be written as a formula in terms of the water height in a single baffle. Using a water height, H, of 0.225m, the collision potential through all the baffles is:

$\varphi_{CurrentFlocculator} = 0.96H^{\frac{2}{3}}(N_{BaffleSpaces} + 1) = 8.878m^{0.667}.$

Our new flocculator has the same parameters, except for the number of baffles. We changed the number of baffles to 21 for two reasons: (1) we have included an overflow potential baffle and (2) the flocculator must fit on a 12x12-inch sheet of acrylic for laser cutting. To fit the flocculator within these dimensions, one set of baffles was removed without a significant change in head loss using our initial design of 23 baffles (head loss of 0.042 cm). Using this assumption, the head loss in the proposed flocculator will be $0.037cm$. It is difficult to simulate the variable H because the height of the water in the flocculator will depend on the head loss from the entrance tank as well as the parameters of the new flocculator. We will calculate H using the necessary parameter of H/S $>$5, which is a condition for the relationships used above. Using the initial assumption that H remains the same, the collision potential of the new flocculator is $7.458m^{0.667}$.

The newly fabricated flocculator was successfully laser cut by the RPL monitors, although they adhered the three sheets together without our consent. Therefore, we were unable to confirm that their gluing process would result in a water-tight product. Our new design increased the width of the ribs (baffle channel dividers) from less than 1mm to 2.54mm in the hopes of ensuring a tight seal between channels. Unfortunately, there are leaks due to hairline fractures in the baffles. This was not entirely surprising because the width of the baffles are so small that cracks are likely to occur during handling when the laser cutting team wrestled the acrylic from the laser cutter surface upon completion. The flocculator still functions, however. According to Monroe, the leaks represent failure modes in an actual AguaClara plant, so we are not concerned given the flocculator functions overall and no longer has an overflow failure mode. It should be noted, however, that our design addition of the overflow well leading to a collection bucket does not function as intended due to the fractures through the baffle channels. The flocculator is supported by two acrylic feet rather than a continuous piece on the bottom, which will support the heavier flocculator more effectively than the parallel base in the previous design. Additionally, the exit holes are drilled into the side rather than coming from the bottom, which allowed for easier drilling through the thinner side walls. 4 shows the newly fabricated flocculator.

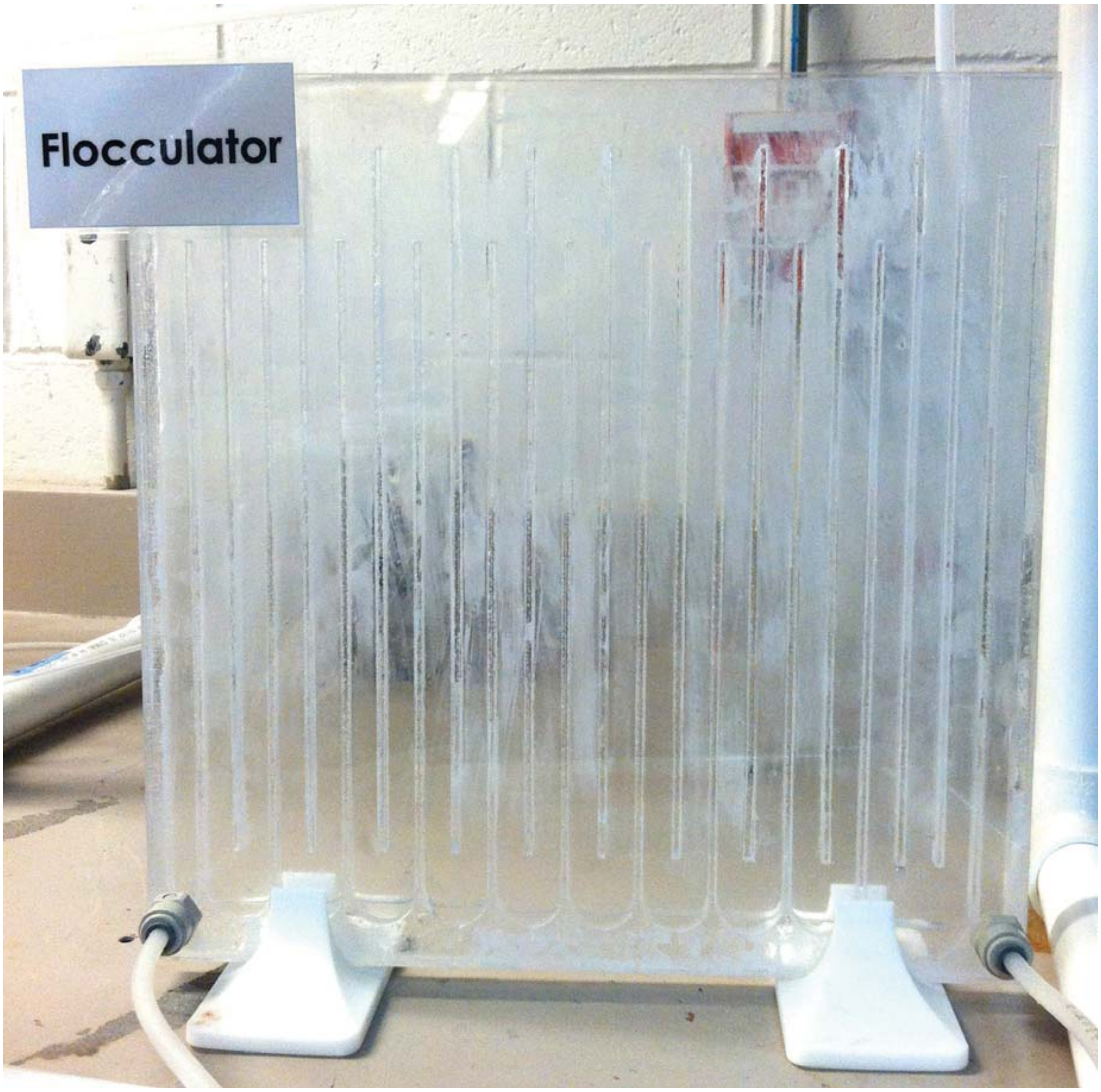

Figure 4: New Laser-cut Flocculator

Frame

The frame is complete and has proven to be stable- despite the slight increase in height -when placed off the edge of a supporting desk. In order to maintain the “long, straight” tubing from the raw water and coagulant head tanks to the entrance tank, we connected two T-connections (which extend away from the plane of view of the rest of the demonstration plant) to the upright end supports with a 3.5-inch length of 2-inch OD PVC. The long, straight tubes were then wrapped around these jutting connections. These jutting connections were placed behind the frame itself because of space issues resulting from the placement of the dose controller at the same height as the long tubing. Placing them behind the frame ensures that they do not interfere with the doser's movement. We added a third, middle vertical piece of PVC for support to hold up the horizontal bars that kept slipping out in the last design. Additionally, we connected the bottom support (on the base) so that it is continuous, rather than being attached to just one side. We have ordered 1-inch OD PVC instead of 0.75-inch OD PVC used previously; we hope this will make the overall structure sturdier.

Plant Calculations

We have calculated the plant flow rate using the SRSF as the controlling factor with the equation 1 below:

$$Q_{plant} = (11mm/s) * (A_{cross-section_{of}SRSF}) \tag{1}$$

Additionally, we calculated the ideal coagulant flow rate using the "long straight tube" assumption (see Equation 2 below):

$$Q_{coagulant} = \frac{h_f g \pi D^4}{128 \nu L} \tag{2}$$

where

- h_f is the head loss;
- D is the diameter;
- ν is the viscosity;
- L is the tube length.

In order to calculate the necessary tube lengths, we utilized head loss equations found in notes from CEE 4540 regarding flow rate calculations.

For the raw water calculations, we had several known variables. We used a design diameter of $\frac{1}{8}$" and a viscosity of $1\frac{mm^2}{sec}$. An error rate of 10% (Π_{error}), a minor loss coefficient of 2 and a head loss value of 10 cm were also assumed. The head loss of 10 cm was due to the fact that we want the water level within the entrance tank to vary by up to 10 cm. Therefore, the equation for the maximum flow rate through the raw water dosing tubes was the following:

$Q_{max} = \frac{\pi D^2}{4}\sqrt{\frac{2h_L g \prod_{error}}{\sum K_e}}$

Plugging in the known values resulted in a maximum flow rate through the raw water dosing tubes of $2.479\frac{mL}{sec}$.

The length of the tube necessary for this flow rate, head loss, and diameter was determined by the following equation:

$L = \frac{gh_L \pi D^4}{128\nu Q_{max}} - \frac{Q_{max}}{16\pi\nu}\sum K_e$

This assumes that the pipe is not running at full flow. Plugging in the known values resulted in a length of tubing for the raw water doser of $1.406m$.

We used the same calculation process for the coagulant dosing tube, using a desired pipe diameter of $\frac{1}{16}''$ maximum; a maxiumum headloss of 10cm; a viscosity of $1\frac{mm^2}{sec}$; and the assumption that $Q_{coagulant} = 0.05Q_{plant} = 4.986\frac{mL}{min}$. Additionally, we used the coagulant dose and concentration from previous teams' notes ($6.5\frac{mg}{L}$and $650\frac{mg}{L}$, respectively). From these calculations, the necessary coagulant dosing tube length was $1.836m$.

SRSF

Another update that we made on the overall plant concerned the efficiency of the SRSF. Because it has been used over such a length of time with so many runs of water of different cleanliness, there are pockets of air within the sand layers (see Figure 5). These air pockets are detrimental because they reduce the efficiency and ability of the SRSF to filter the water through to the clean water tank. The backwash tube, which is supposed to clean and settle the tank by getting rid of these pockets, is difficult to handle and does not efficiently perform. On a suggestion by Monroe, we decided to fill the SRSF with soapy water through a tube at the bottom before attempting to run it. The soapy water is sucked into the SRSF through a tank held above the height of the SRSF by positive pressure. We saw as the soapy water filled the SRSF, it broke the surface tension of the water remaining in the pockets, allowing the sand to settle onto itself. The soapy water was then pumped back out using a pipet bulb, and another run was performed with clean water to remove the soap. Since the soap had already broken the surface tension bonds, the sand resettled smoothly after the clean water run (see Figure 6), and upon integration with the rest of the plant, performed much more smoothly and quickly. We are going to take videos of the SRSF functioning both with and without the soapy water run, and try to produce data that proves the improved efficiency of the SRSF with the soapy water run. Below are two photos, the first showing the air pockets that existed within the tube before the soapy water test, and the second photo showing the settled sand layers after a run of soapy water and a run of clean water.

Figure 5: SRSF before soapy water test

Figure 6: SRSF after soapy water test

Analysis

Most of our work is connected to fundamental fluids properties and laws. Some of the key concepts include mass conservation, head loss, water level balance, and laminar flow. Mass conservation applies to our work because we must consider the total flow of inputs that we add to the system, and know that we must account for all volumes in our various filtering and outflows. The head loss throughout a full-scale plant is controlled by the LFOM, which extends from the entrance tank to the flocculator. The demo plant has a straight, short tube that provides the same function, though our current design does not have this piece and we need to add one. There is also a Y-tube that balances water level throughout rest of plant (equalizer) and is meant to prevent overflow from the flocculator, though we must test this in more scrutiny and apply height and length measurements to improve its effectiveness. As flow throughout the pipes are laminar flow, with no radial motion (cannot be applied to ends of tubes where there is head loss), we can calculate the average velocity,

$$V_{average} = \frac{Q}{\pi R^2}, \tag{3}$$

and the coagulant flow rate (equation 2). The flow rate of the coagulant depends upon the viscosity of the fluid, the diameter of the pipe, the length of the pipe, and the head loss coefficient.

The leaking outlet connection of the flocculator has been replaced. Also, the curled tubing between the entrance tank and the flocculator will be removed and replaced with a long straight tube because rapid mix on a scale as small as the demo plant is not necessary and the long tube controls the flow rate of the coagulant dosing.

Currently, there is no documentation of major and minor head losses in the demo plant. In order to remedy this, we measured the flow rate through the flocculator and calculated flow rates through the dosing tubes and determined optimal tubing lengths. The y-tube connected to the end of the sedimentation tank controls the head in the flocculator, and the long, straight tube running from the entrance tank to the flocculator controls the flow rate of the coagulant dosing. In order to ensure that the float in the entrance tank does not get stuck to the bottom of the tank at zero-flow conditions, the head will be set such that at zero-flow it is 10cm. At maximum flow, the head in the entrance tank will be set to 10cm. These constraints were used in the calculations of the necessary pipe lengths. In order to keep this head loss constant at over 10 cm in the entrance tank we also added a jutting piece of 2-inch PVC pipe to the opposite vertical support which the tube from the entrance tank was wrapped around. A Y-tube was inserted to this tube and rests on the top of this PVC addition, setting the head loss in the entrance tank.

We have implemented several changes in the design layout of the current plant. We have added the middle support beam which keeps the horizontal beams from sagging and slipping out. We have added pipes that jut out behind the frame, which balances weight as well as lowers the height of the overall structure and acts as a means for wrapping the long straight tubes around. In regards to fluid mechanics, we have implemented the changes necessary to account for proper head loss in a real plant. This can be seen in the long straight tubes extending from the head tanks and the entrance tank, and the calculations can be followed on our Mathcad writeup, found in the folder labeled "Flocculator" on the AguaClara server within the Demo Plant section.

We have also completed our work with reconstructing the flocculator. The finished product from the Rapid Prototyping Lab (RPL) in Rhodes Hall is made of three sheets of acrylic, adhered together. Paul Charles was able to thread holes for our exit tube as well as the exit for the overflow well that we added to the new design. The base, or "feet", of the flocculator have been 3D printed in the RPL facility out of a white plastic, which we hope will increase the stability of the flocculator by providing a base perpendicular to the longest length of the flocculaor. Though there are still some issues with micro-fractures in the baffles, we did solve the overflow problem, which was the biggest discrepancy between the plant and a real functioning plant, since, as Monroe pointed out, a real plant has leaks as well.

Future Work

A video documenting the effectiveness of a "soapy run" through the SRSF must be taken and uploaded to the AguaClara YouTube site. We are in the process of re-writing the User's Manual since there are many intricacies to account for which the person setting up the plant must take into consideration, otherwise our calculations will be inaccurate. Additionally, we must also label every piece so that it is easy to put together and ensure that it will fit into a carry-on bag. Future AguaClara teams may wish to make a new backdrop layout sheet to replace the old one in order to give a close-up and explanation of each part of our new system. More work must be done on the chemical dose controller, which still does not properly function. One way this may be achieved is to calculate the necessary moment arms for a balanced weight on the lever arm when the drop tube is at both extremes. Also, since the new flocculator does have internal fractures, this impedes the filling of the sedimentation tank, which will need to be worked around or adjusted. Future teams should maintain and update the Mathcad file as changes are made. A remaining issue is the presence of air bubbles, which disrupts even flow through the plant. Future teams may look into eliminating as many air bubbles as possible before running by using a pipette bulb. Lastly, a different exit connection from the stock and head tanks which would be flush with the bottom of the tanks would eliminate a standing layer of water.