Demo Plant Team

Breann Liebermann, Sahana Balaji, Muhammed Abdul-Shakoor

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Abstract

The technology behind the AguaClara water filtration process features filtration through coagulation, flocculation, and sedimentation and flow/chemical dose control using gravity. Currently, an LFOM has been fabricated and tests have been done to see if a linear relationship exists between flow rate and height of water. Final touches will be put on the chemical doser. Currently, we are in the middle of fabrication of the sedimentation tank and tests will be done shortly to see if a floc blanket can in fact form.

Background:

Project Objectives

The goal of the demonstration plant team is to create a demo-scale version of the technologies presently being implemented in AguaClara plants that are set up in several rural communities in Honduras. The demonstration plant currently in use effectively shows how water moves throughout the plant, however there are technologies that have not been incorporated into the demonstration plant which would further aid the educational aspect of AguaClara.

Since many of the modules in the AguaClara plant are being updated and created anew, there is no reliance on the current demonstration plant for designs and measurements (such as the flow rate). New parts need to be machined and tested based on a new set of constraints that will inform the decision on allowable flow rates through the plant. Research on the tube flocculator system is going to be done; however, the flocculator is going to essentially be the same and the team focus will be on the flow measurement through an Linear Flow Orifice Meter (LFOM), the chemical dose controller (CDC), and the sedimentaion tank with an operable floc blanket.

Flow Control and Chemical Dosing

MathCad files from the AguaClara design team are available to us for the full scale LFOM. Initially we hypothesized, based on the output from the old MathCAD files, that the LFOM at this small scale would not generate a linear relationship between flow rate and water height; however since it has been looked over and updated by Mickey, Professor Monroe, and another Agua Clara team member, we have gotten usable results.

For the LFOM, we have designed a system to simulate a Sutro Weir with a rectangular base, which will maintain a linear relationship between the height of the water and the flow rate of the plant. We have calculated the sizing for the Sutro Weir based on the recent results we have obtained from the MathCAD file. We have also implemented a chemical dosing using a lever, with a float attached and a slider (as the full scale plant does).

Sedimentation Tank

The main components of the sedimentation tank that we need to implement are the floc blanket, floc weir, floc hopper, and plate settlers (or tube settlers). The biggest challenge will be to create a floc blanket, because no one has accomplished this task on such a small scale before. In order for the floc blanket to be formed, an upflow velocity of 1 mm/s is required. The floc blanket's success is based on the energy dissipation rate of the incoming flocculated water. The maximum energy dissipation rate must be less than 10 mW/kg, which is a given constant based on the diameter of the inlet. With higher energy dissipation rates (as from smaller diameter jets), flocs are broken up into tiny fragments that get carried out instead of settling on the bottom. We need to prevent this from happening, and this will largely depend on inlet geometry. To ensure flocs won't get carried out, the flocs need a sedimentation velocity greater than or equal to upflow velocity (1 mm/s). Plate (or tube) settlers seem to be a necessary component because they willhelp capture particles varying in size, including the ones that would not have otherwise have fallen to the bottom of the tank. . In large scale AguaClara plants, the capture velocity for plate settlers is 0.12 mm/s. The relevant formula for the overall capture velocites in horizontal and vertical flow sedimentation tanks is the following:

$$V_c = \frac{Q}{A_s} \tag{1}$$

where V_c is capture velocity, Q is flow rate, and A_s is the area over which particles can be settled, which equals length times width. Alternatively, capture velocity can be calculated for plate or tube settlers as the following:

$$V_c = \frac{V_{plate} S}{L \cos\alpha \sin\alpha + S} \tag{2}$$

where V_{plate} is the vertical velocity componenet between the plate settlers, S is the distance between plate settlers, and is generally 5 cm or 2.5 cm in AguaClara designs, α is the plate angle which can be assumed as 60 ("Plate Settler Sourcing"). Moving on to the floc blanket, it is suggested from the team assignment that the floc blanket height remains between 30 and 60 cm deep, with the maximum height set by the floc weir. Although the floc blanket is more efficient at capturing flocs at deeper heights, the demo plant needs to be as small as possible, therefore we may reconsider the 30 to 60 cm height requirement. Thinking about the actual setup of the sedimentation tank, it could be contained in a cylindrical clear tube with the settled flocs on the bottom in a triangular or cone shape, and the jet will resuspend the settled flocs.

References

[1] Agua Clara. (May 2009). “Plate Settler Sourcing.” Retrieved from: https://confluence.cornell.edu/display/AGUACLARA/Plate+Settler+Sourcing

This article summarizes relevant sedimentation tank designs and constraints that are applicable in current filtration plants.

References

[1] Manrique, J. C. (October 2010). “Preliminary Design for NY, USA.” Retrieved from https://confluence.cornell.edu/download/attachments/127828383/Design+Specifications.pdf?vers

This article explains how the Chemical Dose Controller operates. Primarily, the water is treated by adding alum as the chief coagulant. CDC is devised to make an accurate dosage of alum independent of the change in the plant flow rate. The CDC apparatus is capable of three dosage levels, which corresponds to changing the orifice sizes. The operator is at the liberty to pick an orifice size based on the turbidity of water.

This article also explains how the sedimentation tank works. In the equipment, the sedimentation tank is used to provide a suitable adequate environment for the flocs to settle. It is necessary to design the inlet channel orifices so that they don’t break the flocs or don’t drop the flocs. We should ensure that the water is distributed uniformly and we create a jet that resuspends settled flocs. The plate settlers have walls at an incline. This sort of inclination is given to increase the up-flow velocity at the inlet manifold so that the suspended flocs can be made to form as a blanket of flocs. Additionally, the sludge drain is provided so that the tank can be flushed and cleaned for any maintenance activity.

References

[1] Buerman, L. and Weber-Shirk, M (December 2008). “Linear Flow Orifice Meter for Application in AguaClara Drinking Water Treatment Plants.” Retrieved from https://confluence.cornell.edu/display/AGUACLARA/LFOM+Scientific+Paper

This article goes into detail about the LFOM. It is mainly placed at the entrance of the pilot scale drinking water plant. It is based on the concept of Sutro Weir. Evaluation was done on the LFOM to get accuracies over a range of flow rates - 20 to 140 L/min. The flow rate is directly proportional to the water height. The addition of LFOM shows a momentous accomplishment in improving the productivity of the equipment and clean water without the need of electricity.

Methods:

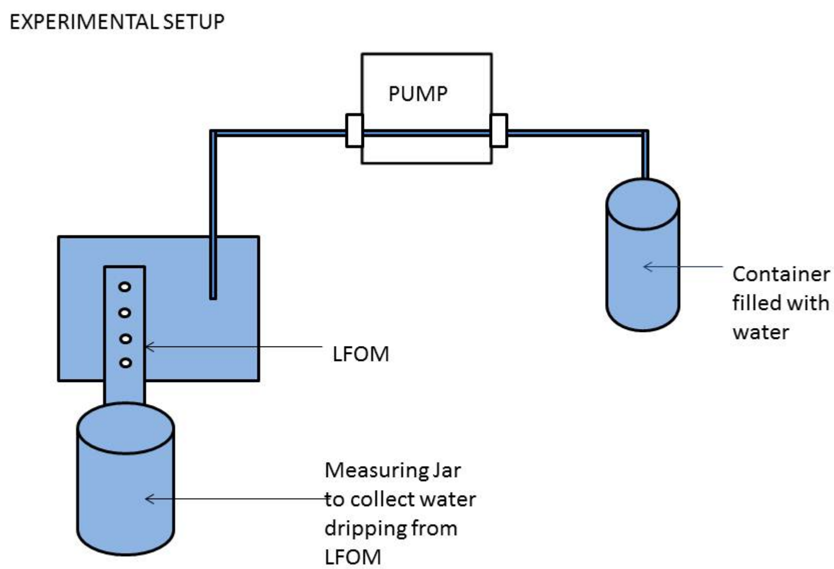
Flow Control and Chemical Dosing

We calculated the flow rate for the old demo plant by measuring the volume of fluid that flows through the plant in 60 seconds; however this is largely invalid becasue we will be updating it significantly and adding new components (specifically the filter) which will set new constraints for flow rate. We emailed the code developer who previously worked on the LFOM MathCAD file, who has agreed to assist us in updating the code. The old code had spacing between each orifice roughly equal to the size of each orifice. Our demo plant will have orifices of a significantly smaller diameter and therefore needs proportional spacing in between each orifice. Once we update the MathCAD files, we can determine if it is feasible to make an LFOM with small holes to model the Sutro Weir which will serve as a great measurement tool because of the linear relationship between water level and flow through the plant. The miniaturized array of holes will need to match the approximate area of the Sutro Wier for the LFOM to work properly. To test if our LFOM works, we will conduct experiments to observe if the LFOM adequately corresponds to the flow rate through the plant.

In order to better inform the design process, the AguaClara design tool files are being used to calculate the necessary values for designing modules of the Demonstration plant while allowing space for comments to present a clear thought process through the program. With the help of masters students Michael Adelman and Adam Salwen, and Professor Monroe Weber-Shirk a MathCAD file was updated to account for design calculations on the Demonstration Plant scale.

After inputting estimated values of flow rate, pipe heights, and the number of rows that we wish to accomplish the Sutro Weir with, we were able to find out some different possible configurations of the LFOM that are worth testing. The range of flow rates were from 8 ml/sec to 0.8 mL/sec . For that range of flow rates we were able to input different combinations of pipe height and the row numbers that yielded variable outputs of pipe diameter, hole diameter, and number of holes per row. The different outputs will be tested against varying flow rates in order to evaluate the precision of the LFOM to be used as a measuring device at the Demonstration Plant.

We fabricated a model LFOM and performed an experiment to test out the relationship between flow rate and height in the entrance tank, in the hopes that we would find a linear relationship. Water was allowed to flow into the fabricated LFOM tank at a constant rate from another tank that functioned as an entrance tank. An electric pump was used to transfer water at a constant flow rate from the entrance tank to the LFOM tank. We calculated the flow rate as the amount of water collected after passing out from the LFOM in ml over time in seconds. Simultaneously, we measured the height of water in the tank at each flow rate. Our observations are explained in more detail in the following section. Below is a diagram of the experimental setup.



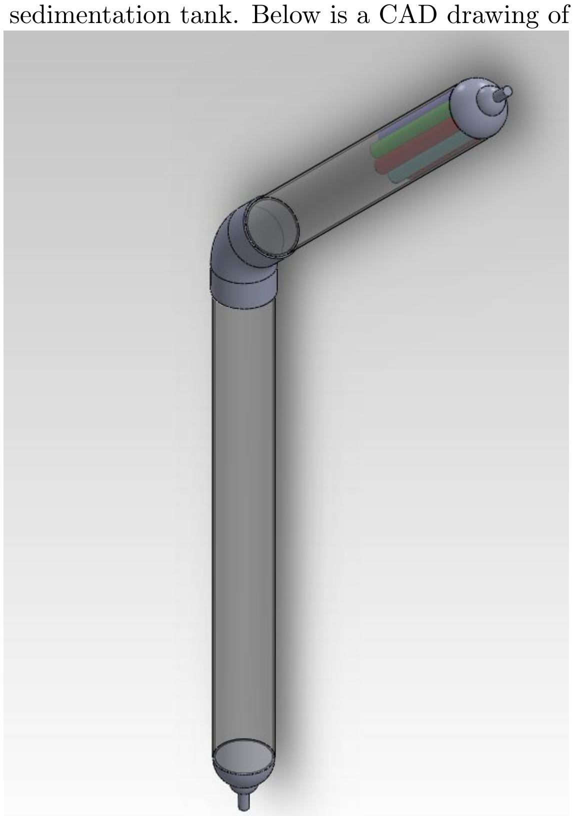
We are using a lever for our dosing method, with a small wooden float hanging off at one end that sits in the water entrance tank with the LFOM. This raises or lowers based on the height of water in the entrance tank. If the depth in the entrance tank is high, the float will rise, lowering the other end of the lever, increasing the head level and dosing more alum. Recently we attached the lever to the column with the entrance tanks and constant head tanks, as this keeps the Demo Plant small.

Sedimentation Tank

We have recently updated our design for the sedimentation tank based on sedimentation tank designs we observed in the teaching lab. In our initial design, we had to worry about using a reducer, a connector to go from 6 tubes to 1 tube, something to support the tube settlers so they were at a 45 degree angle, and a way to attach the cone dictating the inlet geometry. To avoid these complications, we decided to use one clear pipe of the same diameter for both the sedimentation tank and extending up as the tube settlers. We will put straws in the tube settler pipe. The main piece and the tube settler will be connected by a 45 degree angle connector. Although it is not the ideal 60 degree angle, for the demonstration plant it will suffice. At the inlet, we will have a tube entering from the side and coming straight up into the pipe. The bottom will be closed off by a removable cap, allowing the operator to conveniently empty out and clean the sedimentation tank. The diameter of the clear pipe is restrained by the diameter of the filter pipe. Because the filter backwash velocity is 11 mm/sec and the upflow velocity is 1mm/s (given in our team assignment), we have come up with the following (using a plant flow velocity of 90 ml/min and using D_{filter}= .519in which was solved for in the filter section) :

$$D_{sedTank} = \sqrt{11} D_{Filter} = 1.721 in \tag{3}$$

The closest sized pipe that exists is a 1.5 inch pipe. We are still unsure of exactly how high the sedimentation tank will need to be in order to successfully form floc blankets; this will be determined by future tests where we can attempt to form a floc blanket. Since the sedimentation tank size is constrained by the filter size and necessary velocities, we have shifted our current focus to design and fabrication of the filter. When this has been completed, we will fabricate the sedimentation tank. Below is a CAD drawing of our current design.



Filter

We are planning to use 1.3cm diameter pipe as the mainfilter. We will be attaching a inlet box, and 4 inlet pipes from the bottom ofthe box connecting to the bottom of the sand filter. We will also be attaching a outlet box and 3 outlet pipes in the same fashion. The filter inlet andOutlet control boxes will be designed so that water level changes during backwash will cause all of the manifold pipes to be hydraulically separated andthus no valves will be required to turn off the inlet or outlet pipes. A pipe which makes a 90 degree bend is connected from the top portion of the sandfilter to the outlet with a valve connected to it to help during backwash. The water level in the inlet box should beadjusted to be the same level as the pipe with a valve attached to it. The first pipe is shorter in length since it will be the first one to fill the column.

The maximum water level at the end of the filtration cycleshould be the same height as that of the inlet box. Water level at the beginning of filtration cycle should be above the height of the pipes and the maximum water level during backwash should be just above the first pipe, sothere is no need to use plugs to shut off the inlets to the filter. The waterlevel during backwash is low enough that the 3 upper inlets are effectivelyisolated. Starting from the bottom of the filter, the first pipe has the lowestheight coming up through the inlet box. The outlet pipes will not need to be closed off during backwash because the water level during backwash will be below the channel bottom effectively blocking flow between pipes. 2 more outlet pipes attached are filter to waste drain line and filter to clear well.

The demonstration plant is proposing to treat approximately 1mL/s to mL/s with 6 2cm deep layers of sand with effective size 0.5mm and uniformity coefficient of 1.6. The backwash velocity is 11mm/s. We have defined many of the necessary inputs for the filtration analysis below.

$Q_{Plant} = 90\frac{mL}{min}$
$\rho_{FiSand} = 2650\frac{kg}{m^3}$
$k_{Kozeny} = 5$
$H_{FiLayer} = 2cm$
$\rho_{Water} = 1000\frac{kg}{m^3}$
$Nu_{Water} = 1\frac{mm^2}{s}$
$N_{FiLayer} = 6$
$D_{FiSandES} = 0.5mm$
$UC_{FiSand} = 1.6$
$\epsilon_{FiSand} = 0.4$
$V_{FiBw} = 11\frac{mm}{s}$
To calculate the total sand depth:

$$H_{FiSand} = H_{FiLayer} * N_{FiLayer} = 0.12m \tag{4}$$

To calculate the D.60 for the sand grain size:

$$D_{60} = D_{FiSandES} * UC_{FiSand} = 0.8mm \tag{5}$$

To calculate the filter bed plan view area:

$$A_{Filter} = \frac{Q_{Plant}}{V_{FiBw}} = 136.364mm^2 \tag{6}$$

To calculate the diameter of the filter :

$$D_{Filter} = 2 * \sqrt{\frac{A_{Filter}}{\pi}} = 0.519in \tag{7}$$

To calculate the filtration velocity:

$$V_{Fi} = \frac{V_{FiBw}}{N_{FiLayer}} = 1.833\frac{mm}{s} \tag{8}$$

To calculate the headloss through the filter at the beginning of the filtration run with a clean filter bed :

$$h_l = 36 * k_{Kozeny} * \frac{(1 - \epsilon_{FiSand})^2}{\epsilon_{FiSand}^3} * \frac{Nu_{Water} * V_{Fi}}{g * D_{60}^2} * H_{FiLayer} = 5.915mm \tag{9}$$

To calculate the velocity at the inlet :

$$V_{inlet} = \sqrt{2 * g * h_l} = 107.711\frac{mm}{s} \tag{10}$$

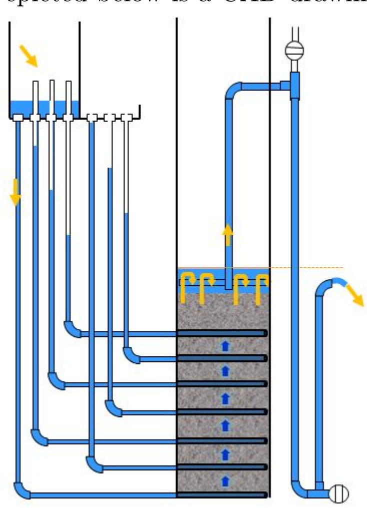
To calculate the area of the inlet:

$$A_{inlet} = \frac{Q_{Plant}}{V_{inlet}} = 13.926mm^2 \tag{11}$$

To calculate the diameter of the inlet :

$$D_{inlet} = 2 * \sqrt{\frac{A_{inlet}}{\pi}} = 0.166in \tag{12}$$

Depicted below is a CAD drawing of our current filter design.



Analysis:

LFOM Design

The flow rate is calculated initially using this equation :

$$Q = \pi_{vc} * A_{or} * \sqrt{2 * g * h} \tag{13}$$

which bases the flow rate on the area of the circle. A given flow rate was used (between 0.8 mL/s and 3 mL/s) to calculate the correct orifice area. The area of the orifice was found using the LFOM MathCAD file. The area of the orifice was be determined using the following function in the LFOM MathCAD file:

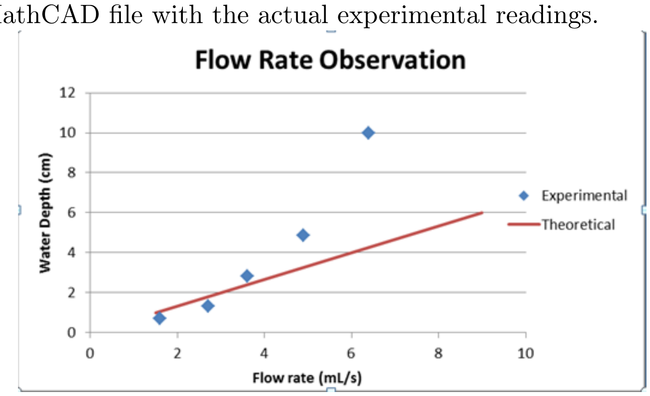
$$A_o = Q_o/(\pi_{vc} * \sqrt{2 * g * h_o}) \tag{14}$$

These calculations are essential to the correct operation of the orifice assembly that models the Sutro Wier, and this will be important to the operation of the small scale demonstration plant.

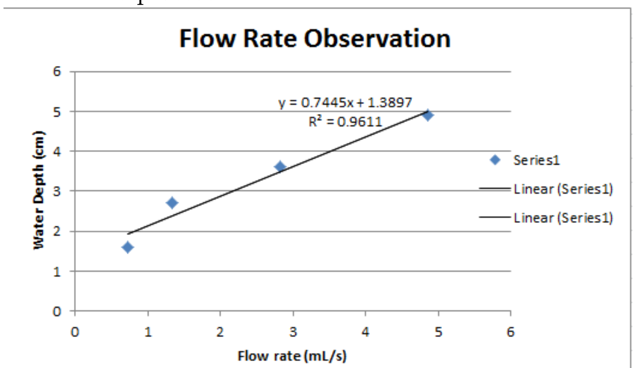
LFOM Fabrication and Testing

Using the output from the MathCad LFOM file we were able to determine the approximate dimensions for an LFOM for our given range of flow rates. An LFOM was built and tested to show a linear relationship between the water depth and effluent flow rate from the LFOM pipe. Depicted below is a 3 dimensional CAD drawing to show the pipe with the holes correctly spaced in each row.

As shown above, the top two rows each have just one orifice, and then there are three rows below that with two orifices, and then a final row of holes with four orifices. The spacing between rows, number of holes and approximate flow rate out at each level was all calculated on MathCad in the LFOM file. The orifices were all calculated to be 1/32"; however we were not able to find a drill bit that small and thus decided to use the 1/16" drill bit. Shown below is a graph that depicts a comparison between the theoretical numbers from the MathCAD file with the actual experimental readings.

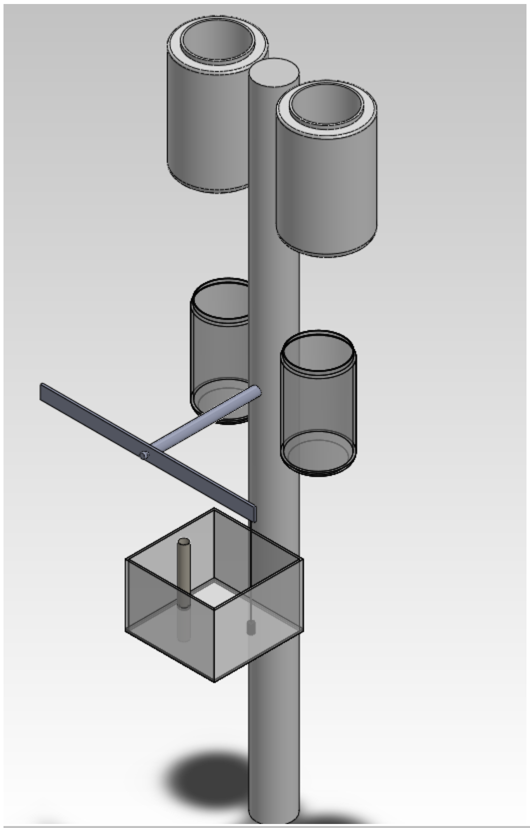


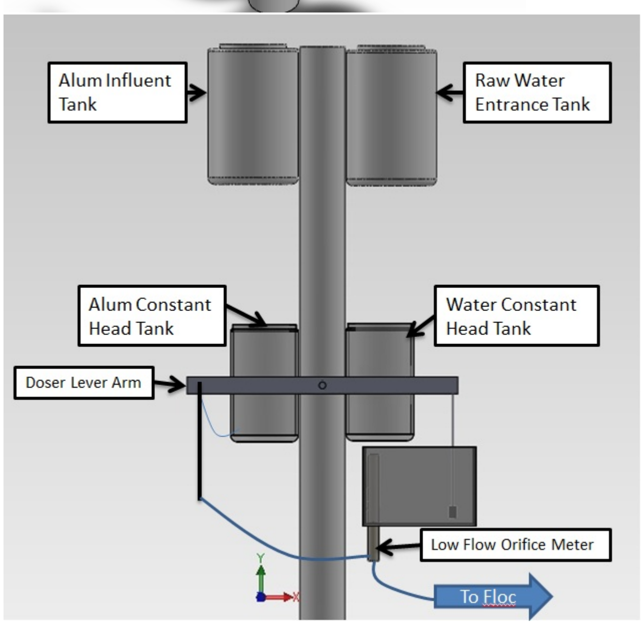
Also shown below is a graph of our first four data points with a linear regression line plotted.



Due in large part to a high error encountered with the higher flow rates that we measured, there is a great difference between the theoretical and experimental values. We believe that this is a result of human error and variables that weren't accounted for. However the Demonstration Plant is predicted to run between 2 and 4 mL/s and at these flow rates the experimental values are much closer to theoretical values.

The LFOM was then put into a tub with dimensions to account for a spacing constraint required by the float that will be used for the doser. Additional space was required for the movement of the float attached to the lever that sets the dose based on the height of the water in the tub. Depicted below is a CAD drawing of the LFOM in the tub with the float attached to the lever arm. This CAD depiction will be developed further to simulate the changing dose based on how the lever interacts with the changing water level in the tub.




Alum Influent Tank
Raw Water Entrance Tank
Alum Constant Head Tank
Water Constant Head Tank
Doser Lever Arm
Low Flow Orifice Meter
To Floc

Conclusion:

With the creation of a new demonstration plant, there are a new set of constraints that need to be worked around in order to make the demo plant perform educationally as a realistic model. For example, the water running through the plant will not be as well treated as in the real plant, however it is more important to make the processes observable and understandable. We have realized that some details need to be compromised in order for the demo plant to be realistic. For example, the Stacked Rapid Sand Filter has been significantly scaled down to a reasonable size, but is most likely not as effective as it would be if it were taller. Also, the sedimentation tank is kept at a reasonable height as well, which may hinder the ability to form a floc blanket. Additionally, as of now it appears as though we may need a larger suitcase for the new demo plant, which makes sense since we are added the filter, a brand new component. However, we realize the importance of keeping the plant small, so we will try to redesign elements that are smaller or can be taken apart to take up less space.

Future Work:

We have changed our initial task order and are now focusing on the filter, and then will fabricate the sedimentation tank. This makes sense because the size of the sedimentation tank pipe is constrained by the Stacked Rapid Sand Filter. Currently, we are in the middle of ordering parts and fabricating the filter. When this has been completed, the sedimentation tank can be fabricated and tested to see if a floc blanket will form. Further work may include exploring the possibilities of a coiled tube flocculator.