Demonstration Plant Team

Susan Chen, Owen Guldner, Diana Kelterborn

August 3, 2012

Abstract

The Demonstration Plant (Demo Plant) is an important educational tool to explain and publicize AguaClara technologies. In the Spring of 2012, a new Demo Plant was constructed, tested, and documented which included the two lastest AguaClara technologies, a chemical doser and a stacked rapid sand filter (SRSF), as well as the older flocculator and sedimentation tank. However there were still problems with the overall plant layout, the chemical doser, and the SRSF, all of which were dealt with this summer. We completely revised the demo plant structure and system; the SRSF now can completely backwash all four layers, the chemical doser is labeled to include coagulant concentrations, and the overall plant is streamlined for transport and assembly.

Project Objectives

The goal of the Demo Plant team is to create a demo-scale version of the technologies used in full-scale AguaClara plants in several rural communities in Honduras. The Demo Plant is an important tool used to promote AguaClara in the Cornell community, at national conferences such as the EPA P3, and for community workshops in Honduras. The current Demo Plant effectively shows how water flows through the plant; however, there are flaws in the plant which, if corrected, would further aid the educational and outreach aspect of AguaClara.

Currently the doser works for a few flow rates and doses, but it would be best if it could cover all doses and flow rates like the large-scale doser. Next, the overall plant layout is cluttered and difficult to assemble; it needs to be streamlined and more aesthetically pleasing. Finally, the SRSF cannot backwash properly so further research is required to determine if this is possible on such a small scale.

Overview of Previous Demo Plant (Spring 2012):

Flow Control and Chemical Dosing

The purpose of the chemical doser is to control the amount of coagulant added to the influent water based on the plant flow rate. AguaClara has designed a chemical doser that uses a lever and float system. The flow rate is determined by the height difference between the height at which water enters the entrance tank and the water level in the raw water constant head tank. While the flow rate is set simply by changing where the entry point is for the raw water, the lever allows the alum dose rate to change automatically based on the height of the water in the entrance tank (determined from the float). This is depicted in figure 1 below. In addition, in order to allow for the doser to cover a wider range of dosages, the drop tube can be moved along the lever arm using a slider. However, moving the drop tube changes the moments applied to the lever so counterweights are needed to balance it.

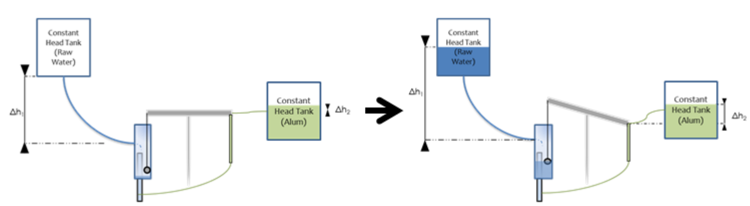

Figure 1: Schematic of the coagulent dosing system in no flow and flow conditions

Sedimentation Tank

The purpose of the sedimentation tank is to remove large particles from the water. The Demo Plant achieves this by using a floc blanket and tube settlers, which are corollaries of the large-scale sedimentation tanks with plate settlers used in the real AguaClara plants. Although a full floc blanket has yet to be achieved in a full-scale AguaClara plant, floc blanket theory is the driving factor behind sedimentation tank design, and thus the illustration of a floc blanket and its functionality in the Demo Plant is a useful way to educate the public about AguaClara technologies. At the scale of the Demo Plant, tube settlers are more practical and fully analagous to the full-scale plate settlers from the point of view of solids in the water.

The purpose of the floc blanket is to grow flocs, making them easier to capture. The tube settler acts to capture flocs grown in the floc blanket, cleaning the effluent water and feeding flocs back into the floc blanket. The floc blanket works by preventing flocs from setttling out: water enters at the bottom of a vertical column, and flows upward, acting to counter the gravitational force on the flocs and fluidize them. The balance of the upward flow rate with the downward gravitational pull on the flocs means that flocs must circulate throughout the column, rather than simply passing through. This forced circulation causes increased particle collision, meaning that the flocs grow. Flocs that grow to the point where the gravitational force is strong enough to cause them to settle out are resuspended by the influent jet. The floc blanket thus consolidates particles in the water into large, capturable flocs.

The majority of those flocs are drained out by a floc weir at the top of the floc blanket column. The resultant, cleaner water, then travels through the tube settler, an angled pipe of the same diameter as the floc blanket column. The angle of the tube settler's walls causes flocs traveling in the water to settle out on the sides of the tube. Gravity then rolls them back down into the floc blanket, where they will grow and be drained out. The combination of the floc blanket and tube settler effectively removes a large portion of particles from the water before it is processed by the stacked rapid sand filter. The current sedimentation tank is shown in figure 2.

Figure 2: Sedimentation Tank

Stacked Rapid Sand Filter

The purpose of the SRSF is to remove small particles that did not settle out in the sedimentation tank. The advantage of a stacked rapid sand filter over a traditional rapid sand filter is that the backwash process is more efficient. Since backwash of the layers occurs in series, the SRSF uses significantly less water to clean the filter. During filtration, water flows into the inlet tubes, out slotted pipes and through the sand layers. The purpose of the slotted pipes is to allow water to flow out but prevent sand from clogging the pipes. Therefore, the slots have to be smaller than a grain of sand for this to work. As water flows through the sand layers, any remaining particles stick to the sand effectively filtering the water. The water then flows back into a slotted pipe and out through outlet tubes. After a while, the filter performance decreases due to particle buildup in the sand. At this point, it is necessary to backwash the filter.

During backwash, water only flows through the bottom inlet tube, creating a backwash velocity equal to the filtration velocity times the number of layers with the same flow rate used for filtration. This high water velocity fluidizes the sand bed, washing flocs out of the sand and through the backwash outlet. Last semester's SRSF is shown in figure 3.

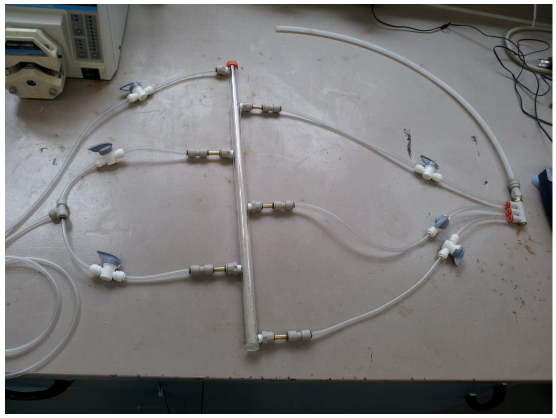

Figure 3: Assembled SRSF

Demo Plant: Full Configuration

A frame from Spring 2012 was constructed out of modular pieces of aluminum from the company 80/20 to house the new processes, replacing the old system of a table and PVC piping. Although better than the old frame, it appears very cluttered and leans over. A user manual which fully describes this frame can be found online. The fully assembled Demo Plant is shown below in figure 4

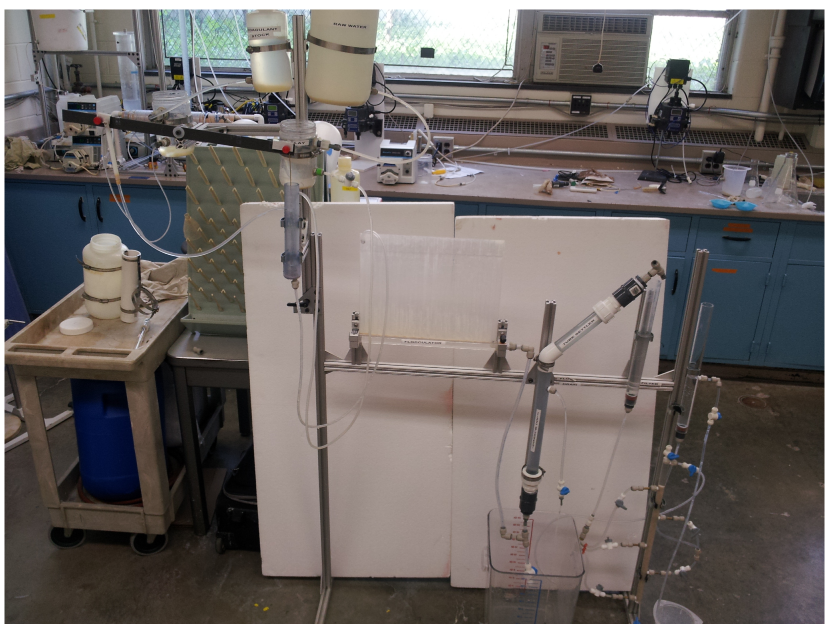

Figure 4: Overall Old Demo Plant

Literature Review

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.

Hurst, Matthew. (April 2010). "Evaluation of Parameters Affecting Steady-State Floc Blanket Performance."
Retrieved from http://ecommons.library.cornell.edu/handle/1813/14755.
This paper describes variables affecting floc blanket performance, based on a laboratory water treatment simulation. It discusses the effects of varying hydraulic flocculation conditions, raw water turbidity, coagulant doses, upflow velocity through the floc blanket, floc blanket height, and the bulk density and solids concentration of the floc blanket.

Manrique, J. C. (October 2010). "Preliminary Design for NY, USA." Retrieved from https://confluence.cornell.edu/download/attachments/127828383/Design+Specifications.pdf?version=1&modificationDate=1288019650000.
This article explains how the Chemical Dose Controller operates. Primarily, the water is treated by adding alum as the coagulant. The CDC was 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 from a set of three based on the turbidity of raw water.

This article also explains how the sedimentation tank works. 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 do not break the flocs or allow them to settle. We should ensure that the water is distributed uniformly and create a jet that resuspends settled flocs. The sludge zone on the bottom of the sedimentation tank has walls at an incline. This sort of inclination is given to increase the upflow 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.

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 from 20 to 140 L/min. The flow rate is directly proportional to the water height.

The addition of LFOM was a momentous accomplishment in improving the productivity of the equipment and the ease of producing clean water without the need for electricity.

Adelman, Michael J., Monroe L. Weber-Shirk, Anderson N. Cordero, Sara L. Coffey, William J. Maher, Dylan Guelig, Jeffrey C. Will, Sarah C. Stodter, Matthew W. Hurst, and Leonard W. Lion. "Stacked Filters: A Novel Approach to Rapid Sand Filtration." Journal of Environmental Engineering (2012). American Society of Civil Engineers, 27 Feb. 2012. Web. This article explains how a stacked rapid sand filter works. It explains the basic geometry of the filter including how the inlet and outlet pipes create layers through which the water flows. Included are basic equations that can be used to calculate filter and backwash velocities, given the filter area, the number of layers, and the plant flow. Furthermore, the article describes how stacked filters can perform backwash using the same flow rate as filtration, as opposed to traditional filters that require different flow rates for the two operations. It also details successful laboratory experiments and field experiments which demonstrated that stacked rapid sand filtration is a viable water treatment method.

Mays, Larry W. "Headlosses, System Components." Water Resources Engineering. 2005 ed. John Wiley & Sons, Inc., 2005. Print. This textbook contains various minor loss coefficients for different valves and connectors used in the demo plant. In particular, values from Table 4.3.1 and 4.3.2 were helpful. We interpolated coefficients from these tables that were then used for head loss calculations throughout the plant. This source also contains formulas for contraction and expansion headlosses that were used to calculate head losses for different fittings.

Methods and Design:

Flow Control and Chemical Dosing

The current doser float doesn't float at all dosages; this is because float isn't heavy enough to counteract the weight of the slider and drop tube on the other side (and isn't big enough to support a possible counterweight for these objects either). Furthermore, the water line of the float is not constant. Like any float, its bouyancy is dependent on how much of it is under water. This is usually not a problem, however, the small scale of the demo plant means that any shift in weight of the doser causes the water line of the float to vary greatly. This in turn affects the dosage rate beyond what the user is setting it at, resulting in either more or less coagulant than desired. We decided a maximum acceptable error (change in the water line of the float) is one centimeter; this means that as you move the drop tube slider from one end of the lever arm to the other, the water line will only move this distance. Overall, the float must be both heavy enough to counteract the weight of the drop tube and corresponding slider and large enough to not cause error during dosage changes.

Figure 5 shows the current lever arm and the mass of each component. Using these weights and a moment balance, the size of a float that would satisfy the criteria described above was calculated. Assuming a cylindrical float, the float needs to be at least 6.7 cm in diameter (about 2.6"). We have purchased a plastic float of this size and are now working to find a larger entrance tank that can accommodate it.

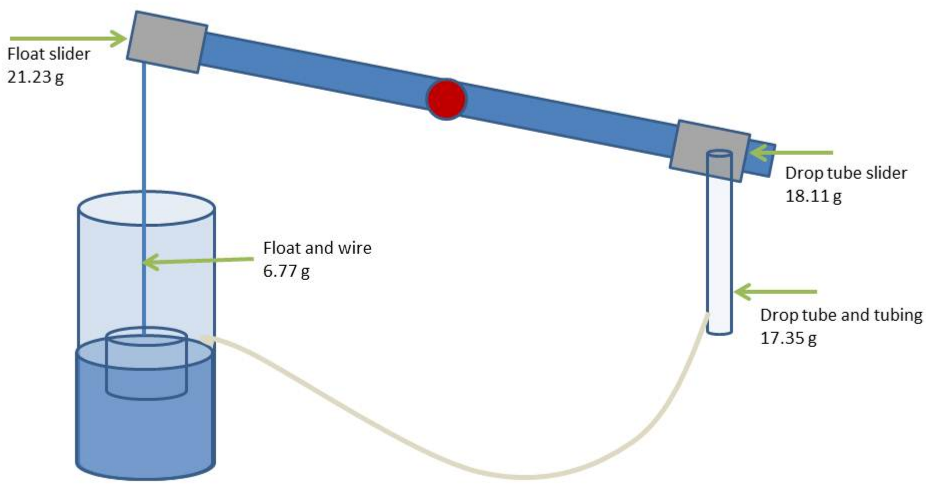

Figure 5: Doser Weights

We decided that the float should have half an inch of clearance on each side when in the entrance tank, and thus a residence time of 1.4 minutes was solved for. This is the shortest possible residence time. If the residence time gets to be too big, clay will settle out of the water and collect in the entrance tank. Given that we calculated the very minimum residence time, clay will probably settle out. We considered a tank with a slanted or curved bottom to prevent clay from settling; however, this is much more difficult to find and would need to be custom built. We fabricated an entrance tank using acrylic tube to match the rest of the tanks on the plant. The current entrance tank is 4" in diameter and 6" in height. The float fits well in the entrance tank and it is heavy enough to counteract the weight of the drop tube slider so we decided to use a small chain instead of a wire to attach the float to the doser. After building the whole plant, we experimented with the flow rates. We adjusted the heights of our tanks to find an optimal plant flow rate of 70 mL/min, with an adjustable coagulant flow from 3 to 4.5 mL/min. After, we consulted with Karen Swetland and she recommended that a 200 NTU solution would be most appropriate for our set up. To obtain 200 NTU, we need about 400mg/L of clay. We then experimented with the coagulant dose (PACl) and found that the ratio of clay to PACl should be 20:1 in the entrance tank. Thus, the concentration of PACl in the stock tank, taking flow rates into consideration, should be 600mg/L. In order to make mixing coagulant stock easier and possible without a scale, we ordered .25 mL spoons. Rougly six leveled spoonfuls of clay in a liter of water yeilds 200 NTU and 7 spoonfuls of PACl in a liter of water yeilds the corresponding coagulant concentration.

Overall Layout

The current Demo Plant layout is rather cluttered, unstable, and difficult to move around both assembled and disassembled. Our new design must rest on a table, not be taller than six feet, assembled and disassembled easily, show the processes left to right, and look professional. Using SolidWorks, we designed several possible layouts that attempt to satisfy the above constraints, but each design has its own advantages and disadvantages. The designs are shown in figures 6789, and the pros and cons are in table1. The yellow triangle on the table is for reference; it is exactly one foot in length. We've included the new, larger chemical dose system in these designs but the other components (the flocculator, sedimentation tank, and SRSF) will remain the same for now.

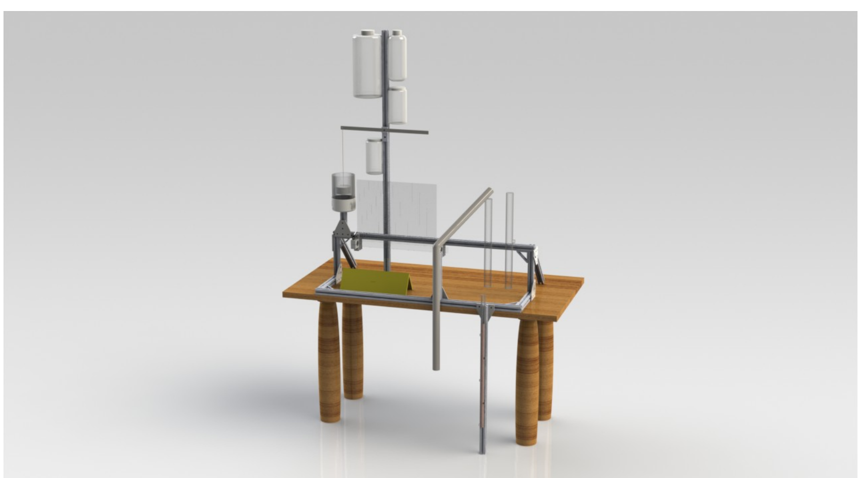

Figure 6: Design 1

Figure 7: Design 2

Figure 8: Design 3

Figure 9: Design 4

	Pros and Cons
Design 1	Folds easily, very sturdy, all one piece, a lot of 80/20, bulky, widest of 4 designs, fairly tall.
Design 2	Less 80/20, less complex, easier to replicate, clean and contained look, folds and snaps together, two pieces, shorter than Design 1.
Design 3	Minimizes space from Design 2, similar to Design 2 (see comments on Design 2), may be difficult to adjust heights of containers, shortest of the designs.
Design 4	All one piece, sacrifices the sturdiness and folding ability of Design 1 for a slightly cleaner look, doesn' t fold, must snap together, wide, requires many very long and very short pieces, not ideal for packing

Table 1: Pros and cons for each design

After discussing our options with Monroe, we decided the best approach would be to start constructing a design and then improve it. So we started with a combination of Designs 2 and 3, shown in figure 10. From there we wanted to add paneling, spread out the plant, and contain everything in one outer border to give the plant a cleaner look, so we came up with our final design, figure 11.

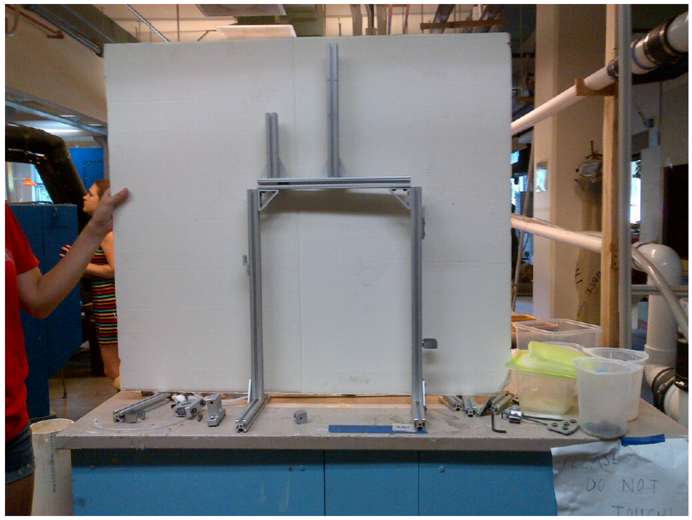

Figure 10: Fabrication Process

Figure 11: Final Design

We have ordered acrylic to fabricate our own stock and constant head tanks. We chose to make our own acrylic tanks because we need to satisfy the following constraints: straight sides, wide mouth, clear with no markings, and matching each other. We have looked at many options online and have tested tupperware and take-out containers. We decided the acrylic would look the most professional and hold up the best. We constructed the acrylic tanks using a circular acrylic sheet as the bottom of each tank. While the acrylic discs look good because it is flat and flush against the side of the tanks, it does not solve the problem of clay or coagulant settling on the bottom of the tanks. It was hard to stir the old tanks because of small openings. While it is easier to stir the new tanks, we thought that having spoons or traditional stirrers would look out of place so we decided to look for another solution. We tried using two magnetic stir bars, one in the tank and one on the bottom of the tank. This method yielded desirable results in terms of aesthetic appeal and efficiency in stirring the solutions.

Sedimentation Tank

The previous sedimentation (sed) tank was very large due to unnecessary fittings. We changed the fittings to be much simpler and switched the tubing from schedule 80 to schedule 40 which makes the tubes easier to see into. Furthermore, we shortened the bottom section of the sed tank because there was no reason for it to be so long. By having it shorter more of it can be seen without having to crouch down. The two tanks are shown side by side (old design on the left and new design on the right) in figure 12. As we changed the overall layout, we found it difficult to place the freefall column between the sed tank and the SRSF. We replaced it with a T connector at the top of the sed tank followed by 1/2" tubing to the SRSF.

Figure 12: Old and New Sedimentation Tanks

Stacked Rapid Sand Filter

The previous filter was not able to backwash the bottom two layers and when the top two layers were backwashed water gaps formed and pushed the sand up and out the backwash valve. We believe the water gaps are caused by sand sticking together to essentially block the entire cross-sectional area of the filter and then rising up with the water. To fix this problem we tried two different methods. The first was to tilt the filter column and use gravity to break up the sand, and the second was to use different size sand grains both bigger and smaller than the ones currently in the filter (1/2 mm).

We experimented with sand size; all experiments were done with clean water and sand. We tried using coarser sand first. There were a lot of water gaps when the filter was vertical, but when it was tilted we were able to get fluidization through almost the entire column. There were, however, a few spots where the sand wasn't moving. When we tried the finer sand we were very successful. There was a lot of fluidization when the column was vertical, though still a few water gaps. But as soon as the column was tilted the water gaps disappeared and the entire column was fluidized. The sand would travel up the top side of the column and down the back side. The only issue was that the sand expanded enough to get washed out the backwash valve.

We concluded that the finer sand would be the best choice for the demo plant SRSF, but the column, currently 55 cm, would need to be replaced with a longer one. To determine how tall to make the new filter, we experimented with backwashing fewer layers of sand at two different head levels. We then plotted our data and using different regressions, the graphs showed that we should not need a column taller than 70 cm for vertical backwashing or 65 cm for angled backwashing. This data is shown in figure 13. We built a column 75 cm in length to allow for errors in our data. We also decided to use the valve on the top of the column for our backwash outlet instead of having an extra threaded hole and fitting just for backwash. This provides extra height for the sand to expand and simplifies the filter by eliminating unnecessary parts.

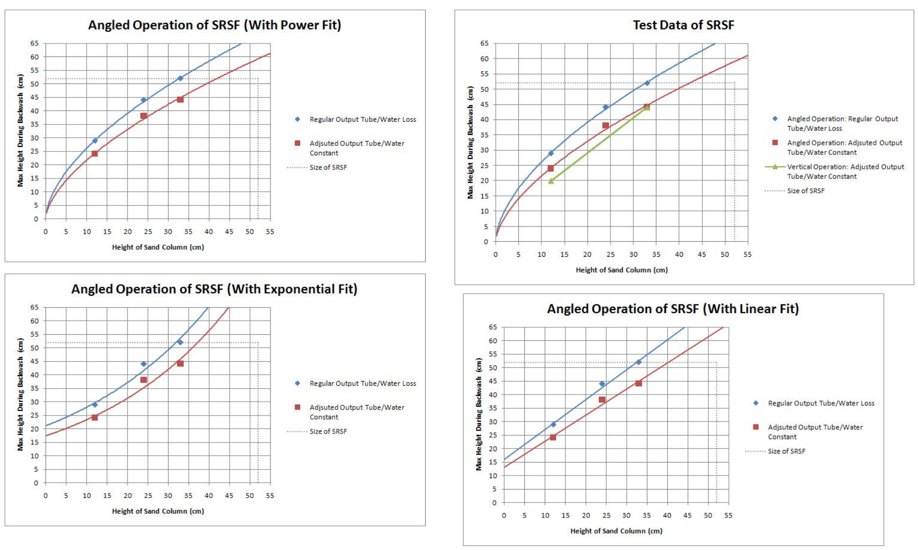

Figure 13: SRSF Data

The new filter is shown in figure 14. It works very well; to start fluidization during backwash the filter should be held at an angle but once underway it can be put back.

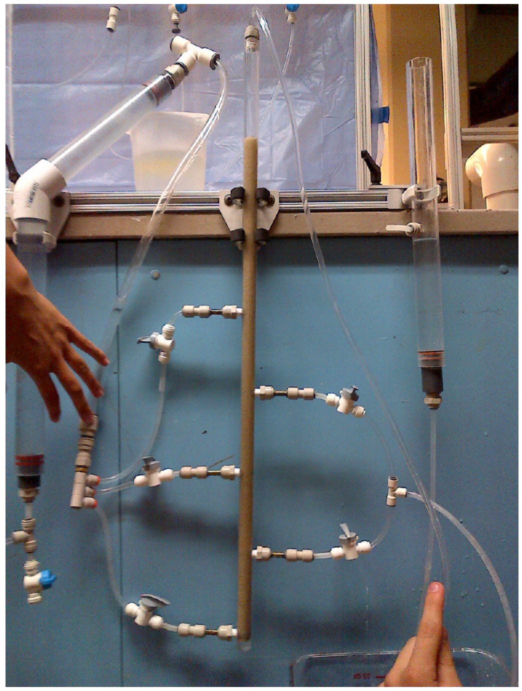

Figure 14: New SRSF when sand is fluidized

Backdrop and Labels

After consulting with Monroe and Harrison, we thought having panels behind the demo plant will keep the focus on the plant instead of what's behind it. We purchased and installed white corrugated plastic panels in the slots provided by the 80/20 frame. The panels look clean and professional but were complicated to cut to size and install. It is not ideal to have to install and uninstall the panels often. The panels will function better as a permanent solution because of their sturdiness and tight fit. Due the difficulty of cutting the panels and installing them around the stock tank supports and certain corners of the frame, we looked into several other options for a backdrop. We tested out shower curtains. While they are easy to fold and transport and provide a clean solid backdrop, they are flimsy and might rip easily with use. We wanted material that is waterproof and foldable but would not fray from use or cutting to length. We looked into tarps, fabrics, and tablecloths and evaluated each material using our constraints. Our final backdrop consists of a 35"H x 37.5"L sheet of vinyl with 1/4" grommets along the edges for attachment. This provides a simple and effective wall which helps observers focus on the plant rather than the noise behind it. Furthermore it is both waterproof and easily foldable.

Labels were also added to each section of the plant (for a total of ten labels) as well as a title sign and a ruler on the chemical doser displaying the coagulant concentrations in the entrance tank. All labels are laminated to protect them from water, printed on cardstock to be more sturdy, and attached to the plant with velcro to allow for easy installment. Figure 15shows the final plant.

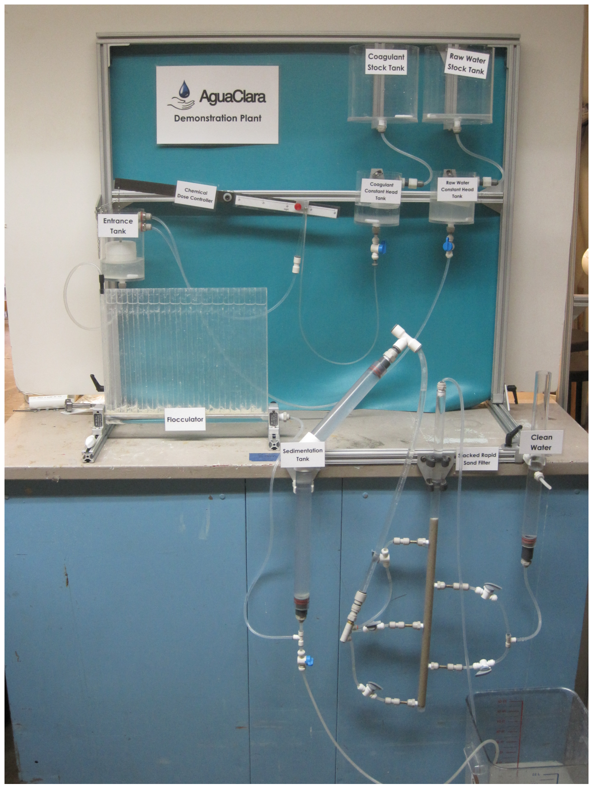

Figure 15: The New Demo Plant

Additional Documentation

User Manual

The user manual describes both initial construction, easy assembly and dissasembly (in relation to transportation), and troubleshooting. Although the assembly and dissasembly instructions are what usually would be used, the construction section is included just in case a part falls off that is not supposed to - especially important are the heights of each tank. Although it is not necessary to dissasemble them completely for transport, if they somehow shift in position the plant will not function properly.

Cost Sheet

The cost sheet outlines every part used in the demo plant and gives its supplier, price, cost per package, and actual cost. In summary, a new plant costs about \$640, though only \$512 is used to fabricate a single plant. This is due to the fact that some materials can only be ordered in larger quantities than we need; the remainder of the investment is put towards the next plant. In the future if multiple plants are being built they will be at the lower cost. The cost is broken down by section in table 2 below.

	Total Cost	Actual Cost
Frame Parts	\$254.13	\$228.62
Plant Parts	\$254.66	\$156.99
Tubing and Fittings	\$94.08	\$93.01
Other	\$34.01	\$34.01
TOTAL	\$636.88	\$512.62

Table 2: Cost Sheet