AguaClara Mini-Plant

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Abstract

Conventional water treatment technology often have fixed costs too high for small communities with demands less than 5 L/s. The goal for the 2016 AguaClara summer program was to design scaled-down processes and fabricate an inexpensive 1 L/s plant. This pilot plant employs conventional flocculation, sedimentation, filtration, and disinfection methods, but accomplishes each step using innovative materials and methods to maximize space efficiency and minimize cost.

1 Introduction

A 1 L/s AguaClara mini-plant was created to provide water treatment technology to smaller communities than AguaClara plants typically do. Most small towns do not have the means to finance surface water treatment because the upfront cost of digging and pouring the concrete for a hydraulic flocculator and sedimentation tank is too high; hence, it was necessary to employ an alternative to in-ground flocculation and sedimentation. The mini-plant marked a new chapter for AguaClara, as it provided safe drinking water for communities that use less water than is usually treated with standard water treatment plants and sources that have too much turbidity to use the AguaClara stand-alone solution, the Enclosed Stacked Rapid Sand (EStaRS) Filter.

The team created a new flocculator and sedimentation tank and used previous EStaRS filter technology. The flocculator produced mixing comparable to a conventional design by means of crimped constrictions spaced close together on a long coiled pipe. It was made out of a succession of crimped 3 inch diameter PVC pipes made into a coil using elbows. The sedimentation tank was made using a 213.36 cm (7 ft) section of 91.44cm (3 ft) diameter corrugated PVC pipe.

Furthermore, the summer 2016 team worked to establish fabrication and testing techniques that were time efficient and could be repeated without specialized equipment. This allowed the design to be easily communicated and reproduced globally. Upon completion, the 1 L/s mini-plant provided the same safe drinking water as a full-sized treatment plant would produce, but with a far lower cost, expanding water treatment options to many new communities with limited space and resources.

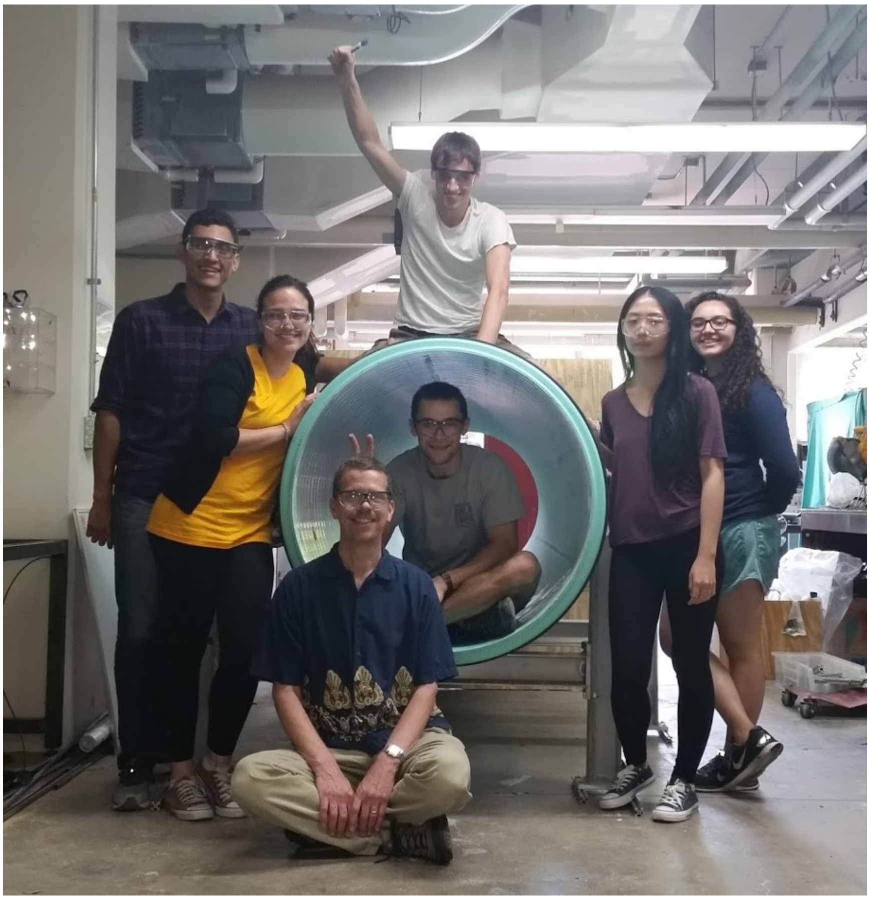

Figure 1: Summer 2016 AguaClara Mini-plant fabrication team

2 Entrance Tank

The plant's entrance tank is where the water will be dosed with a poly-aluminum chloride coagulant, which is the 'glue' that helps bind flocs together during flocculation. The entrance tank requires four components: an inlet for the untreated water, a chemical dosing arm that regulates coagulant added based on the amount of water coming into the tank, and an exit pipe with a linear flow orifice meter (LFOM).

2.1 Fabrication

There is no residence time requirement for the water in the entrance tank. As a result, the tank was designed to be light and small enough to be easily handled, moved, and placed within the plant. The tank also needs to be large enough to have a water level that won't change immediately if the flow into the plant changes drastically. In accordance with the previous requirements, the tank dimensions were chosen to be 38.1cm x 25.4cm x 19.08cm (15in x 10in x 7.5in, see Figure 2) to hold at least 17 liters (4.5 gallons) of water.

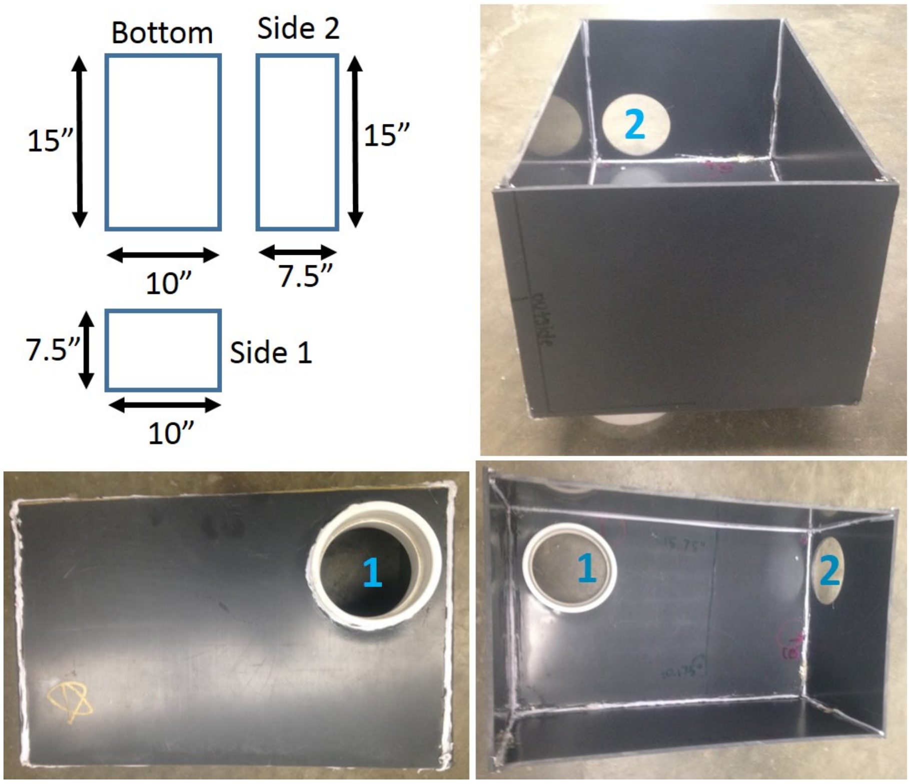

Figure 2: Entrance tank with dimensions (top left), side view (top right), bottom view (bottom left), and top view (bottom right). Orifice 1 is the outlet from the entrance tank. It is a 3 inch pipe coupling welded onto the bottom of the tank, intended to hold the LFOM within the tank and the flocculator connection below it. Orifice 2 is the inlet to the entrance tank, welded onto a 10in x 7.5in wall opposite orifice 1.

2.2 Linear Flow Orifice Meter (LFOM)

The purpose of the LFOM is to change the relationship between water level in the entrance tank and flow into the flocculator from quadratic to linear. If we removed the LFOM and simply had a hole in the bottom of the tank, the flow to the flocculator would increase with the square of the water level in the tank, due to the Bernoulli principle converting water level to velocity.

$$Head = \frac{P}{\gamma} + \frac{v^2}{2g} + z \tag{1}$$

As the Bernoulli principle shows, a linear increase in water level (z) is proportional to a quadratic increase in velocity (v) and therefore flow rate.

To counteract this, the idea was proposed to create a parabolic opening perpendicular to the water level such that the result was to linearize the relationship between water level and flow rate. The result was the LFOM shown in Figure 3

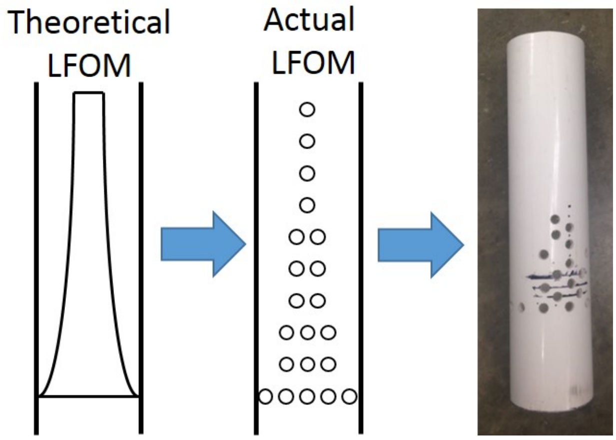

Figure 3: The 'theoretically perfect' LFOM is shown on the left. Since a parabolic opening would be difficult and impractical to create, the parabola is approximated with a series of holes, shown in the center. The final product is shown on the right. Since only the vertical location and number of holes per 'row' is important, the holes can be placed off center along a horizontal line, which is why the actual LFOM on the right does not entirely resemble a parabolic shape. CITE MONROES 4540 LECTURE ON FLOW CONTROL AND MEASUREMENT AND THE PUBLICATION ON LFOMS

3 Flocculator

3.1 Large Scale AguaClara Design

Since AguaClara began, the flocculator design has not changed significantly. Consisting of winding channels with baffles of alternating orientation to increase mixing and travel time (see Figure 4), the AguaClara flocculator takes up significant space in a plant.

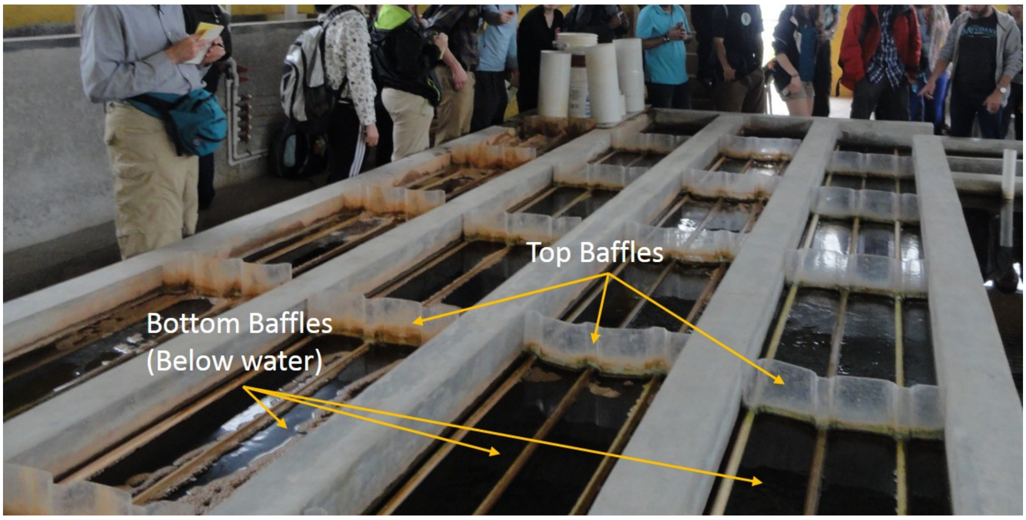

Figure 4: Standard AguaClara flocculator. Water flows around baffles and through channels to maximize contact time with coagulant to form bigger flocs.

3.2 Small Scale Version

In creating the mini-plant version of the flocculator, three things were necessary: space efficiency, high energy dissipation, and high residence time. To achieve all of these goals, the idea for a crimped-pipe flocculator was conceived.

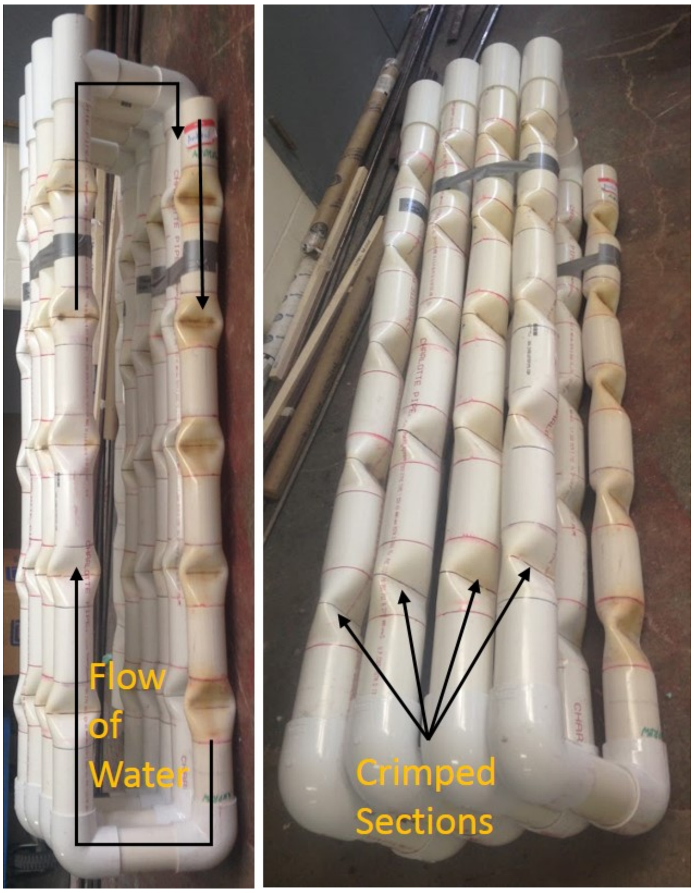

Figure 5: Crimped-pipe flocculator (on right). Water flows through loops of pipe to maximize residence time to space ratio. Crimps cause increased turbulence and energy dissipation, allowing for necessary mixing within this minimal space setup.

3.3 Design Choice

3.3.1 Iteration 1

The water velocity was compared against the 10 States Standards (?CITATION?) minimum scour velocity of 15 cm/s to estimate minimum operational flow rate. This value is intended to be a minimum to prevent floc settlement in the bottom of the pipes. CITATION?? http://courses.cit.cornell.edu/cee4540/Sedimentation

$$V_{scourMin} = 0.15\ m/s \tag{2}$$

Cross-sectional area inside the pipe was calculated (Eq 3) to find the velocity during full flow conditions of 1 L/s (Eq 4) and the ratio of the full velocity to the minimum scour velocity was used to find the minimum plant flow rate (Eq 5). This demonstrated that floc settlement would not be a concern during operation above 71.5% of the design flow rate.

$$A_{pipeInner} = \pi \left(\frac{D_{pipeInner}}{2} \right)^2 \tag{3}$$

$$V_{full} = \frac{Q_{plant}}{A_{pipeInner}} \tag{4}$$

$$Q_{min} = Q_{plant} \frac{V_{scourMin}}{V_{full}} = 0.715\ L/s \tag{5}$$

The primary design parameters were $G\theta$ and G targets identified by Garland (??? REF???) which demonstrated the best effluent results for a compact flocculator connected to a floc-blanket clarifier. The primary constraining paramater was the peak energy dissapation rate, which (?CITATION?) strongly suggested should be below 1000 W/kg to avoid breaking up flocs and reducing performance.

$$\varepsilon_{max} = 1000 \frac{mW}{kg} \tag{6}$$

$$G\theta = 20,000 \tag{7}$$

$$G = \frac{250}{s} \tag{8}$$

Average energy dissapation rate was extrapolated from G target.

$$\varepsilon_{mean} = G^2 \times \nu_{water} = 62.5 \frac{mW}{kg} \tag{9}$$

Residence time for the flocculator was found by extrapolation from $G\theta$ and G targets, and by continuity, reframed as a flocculator length.

$$\theta_{flocculator} = \frac{G\theta}{G} \tag{10}$$

$$L_{flocculator} = V_{full} \cdot \theta_{flocculator} = 16.8\ m \tag{11}$$

Head loss target for the flocculator was calculated by transforming the mean energy dissipation rate target.

$$H_{L-flocculator} = \frac{L_{flocculator} \cdot \varepsilon_{mean}}{g \cdot V_{full}} = 51\ cm \tag{12}$$

The friction loss in the pipe was calculated with the Swamee-Jain equation for turbulent flow (Eq 14), using an e_{pvc} of 0.1 mm, input into the Darcy-Weisbach equation (Eq 15). The amount of head loss predicted by Eq 15 was trivial, indicating that it would be necessary to use minor losses to meet the target of 51 cm.

$$Re = \frac{4Q}{\pi D \nu} \tag{13}$$

$$f_{major} = \frac{0.25}{\left(log \left(\frac{e_{pvc}}{3.7D} + \frac{5.74}{Re^{0.9}} \right) \right)^2} = 0.02983\ cm \tag{14}$$

$$H_{L-major} = \frac{fLV^2}{2Dg} = 1.439\ cm \tag{15}$$

The initial design iteration planned for flocculator sections approximately 1.8m in height would require 9 sections of pipe to meet the length found in Eq 11. It was not initially known if the pipe crimps were sharp enough to produce a vena contracta and if so, how large the effect would be on head loss; hence it was necessary to perform tests. A crimping device was fabricated and initially set arbitrarily to crimp the pipe at distances of 30.48cm (1 ft) apart. Then two test sections were made with different crimp heights and subjected to head loss tests. The data showed that in the range of usable crimp heights (1cm-2cm), it was reasonable to model head loss without a vena contracta effect if incomplete flow expansion was accounted for.

Table 1: Minor Loss Test Results

Test Pipe	**Crimp Height in cm**	**Flow Rate in mL/s**	**Mean Head Loss in cm**	**K Observed**	**K Predicted**	**Percent Error**
1	1.24	851	5.4	8.2	8.5	3.7
1	1.24	807	6	8.2	8.5	3.9
1	1.24	744	5.3	8.5	8.5	0.2
1	1.24	761	5.4	8.3	8.5	1.8
1	1.24	625	3.8	8.7	8.5	2.1
2	2.2	773	1.3	1.9	2.2	0.2
2	2.2	698	1.1	1.9	2.2	0.3
2	2.2	423	0.5	2.5	2.2	2.4
3	1.56	773	3.2	4.7	5.1	8.4
3	1.56	669	2.5	4.9	5.1	4.5

The general equation for minor losses after a pipe constriction (Eq 16) had to be multiplied by an expansion coefficient. The length of spacing between crimps was smaller than the length needed for the flow to expand fully in the pipe before the next crimp. (CITATION) demonstrates that expanded height of a jet is a linear function of crimp height and the spacing length (Eq 17), which can be used to find the percentage of fully expanded flow prior to the crimps (Eq 18). Constriction area was taken as a rectangle with constriction height as the vertical dimension and pipe diameter as the horizontal, which input into Eq 16 with Eq 18 gave the final minor loss equation used in design (Eq 19).

$$K_{expansion} = \left(\frac{A_{pipe}}{A_{constriction}} - 1 \right)^2 \tag{16}$$

$$H_{expansion} = H_{constriction} + \frac{L_{spacing}}{10} \tag{17}$$

$$R_{expansion} = \frac{H_{expansion}}{D_{pipeInner}} \tag{18}$$

$$K_{expansion} = R_{expansion}\left(\frac{A_{pipe}}{H_{constriction} \cdot D_{pipeInner}} - 1\right)^2 \tag{19}$$

Using the 30.48 cm crimper spacing would allow for 5 crimps per pipe section, which given 9 sections implied 45 crimps with a loss of 1.133 cm each (20), which was used to to solve the expansion loss equation (21) for the K of a single constriction. Rearranging (21) into a form that could be solved for K (22) enabled (19) to be iteratively solved for $H_{constriction}$.

$$H_{L-crimp} = \frac{H_{L-flocculator}}{N_{constrictions}} = 1.133cm \tag{20}$$

$$H_{L-crimp} = K_{crimp}\frac{V_{full}^2}{2g} \tag{21}$$

$$K_{crimp} = \frac{2g \cdot H_{L-crimp}}{V_{full}^2} = 5.055 \tag{22}$$

$$5.055 = R_{expansion}\left(\frac{A_{pipe}}{H_{constriction} \cdot D_{pipeInner}} - 1\right)^2$$
$$\Rightarrow H_{constriction} = 1.56\ cm \tag{23}$$

$$A_{constriction} = \frac{A_{pipe}}{\frac{\sqrt{2g \cdot HL_{expansion}}}{V_{full}} + 1} \tag{24}$$

$$H_{constriction} = \frac{A_{constriction}}{D_{pipeInner}} \tag{25}$$

3.4 Fabrication

The primary difficulty in creating the flocculator was creating consistently deep and accurate crimps in the pipes. To ensure that this was done correctly for each crimp, a device was created to help place the crimps and control the depth to which the pipe was crimped (see Figure 6). The process of crimping a single 177.8cm (5'10") section of 3" pipe fully (5 crimps) took approximately one hour.

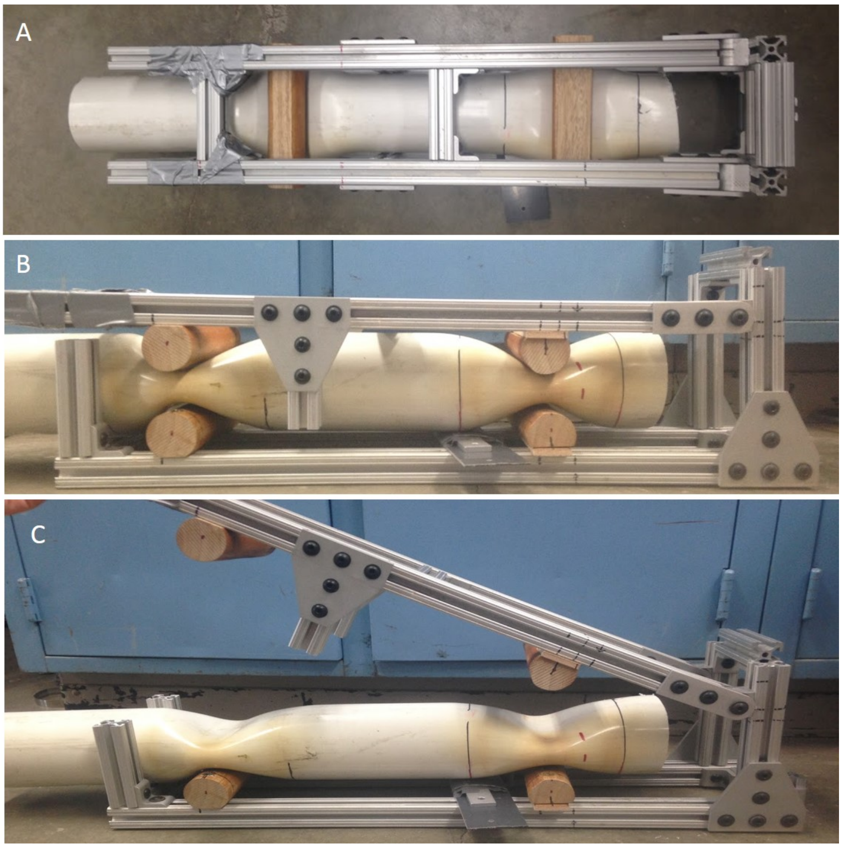

Figure 6: Crimping Mechanism: top view (A), side view (B), action side view (C). The pipe is fed into the mechanism from left to right as shown in the figures. The second (rightmost) set of crimps is to ensure that the pipe does not rotate while the next crimp is being done, thereby ensuring that every crimp along the pipe is along the same axis.

In order to soften the pipe enough to make a permanent crimp, the pipe first needed to be heated with a welding rod. The team constructed a wooden oven, which fit tightly around the PVC on the ends and very loosely in the middle. A small hole was drilled near the middle of the oven to insert the PVC welder. The pipes were heated for 4.5 to 5 minutes with the welder set at 450 degrees Fahrenheit (232 degrees Celsius). The pipe was rotated while in the oven to ensure an even heat distribution along the area in the section of the wooden oven.

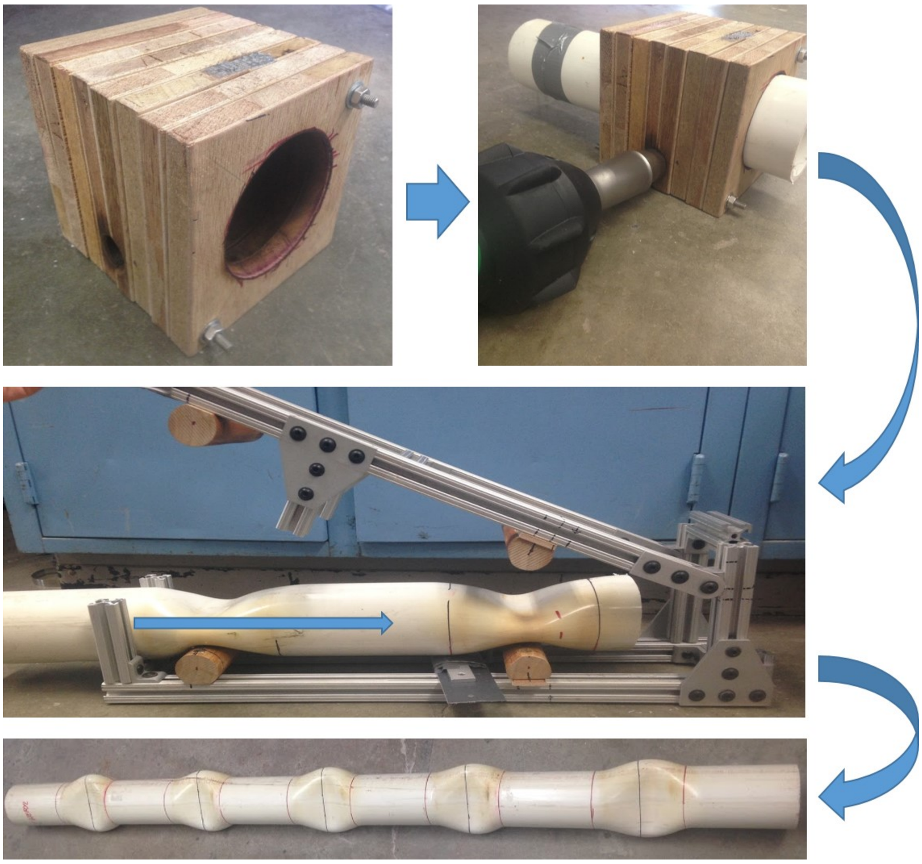

Figure 7: The pipe fits into the oven (top left) and is heated by the PVC welder via the small hole in the bottom-center of the oven (top right). The heated pipe is then inserted into the crimping mechanism (center) and crimped, ultimately becoming a full flocculator section (bottom).

Once heated, the soft pipe was inserted into the crimping mechanism, as shown in Figure 7. The crimping mechanism was lowered onto the soft section and clamped in place while the next section was heated with the oven. After the current section was adequately heated, the recently-crimped section was held in place by the set of wooden dowels on the right, which held the pipe in place and prevented it from rotating while the next section was lined up.

3.5 Testing

At first the head loss was measured using ProCoDA to determine if the flocculator pipes were crimped to the correct depth. Pressure taps were placed at either end of the pipe and water was pumped through the pipes. However, due to incorrect readings from pressure sensors for pipes with known head loss, makeshift manometers were constructed to test for head loss. The tubing that was originally connected to either end of the pressure sensor was instead raised and attached to the ceiling. Instead of turning on the pump to a full 1 L/s, the valve on the pipe was slowly opened until the height of the water in the tubing almost reached the ceiling. The difference in the height of the water between the tubing connected to the beginning and end of the flocculator pipes was measured.

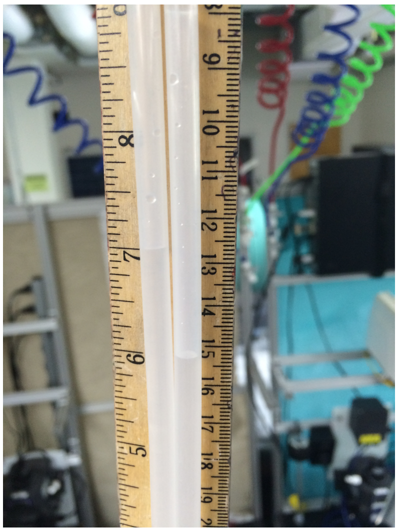

Figure 8: Manometer used to measure water height difference

The flow rate was then determined by filling up a large bucket, timing it with a stop watch, and weighing it. The difference in water height and the experimentally determined flow rate were then used to calculate the head loss. Different flow rates were tested to confirm the precision of the calculated head loss with manometers. Head loss was calculated for both the 0.9 cm and 2 cm crimped pipe. By interpolating between the data for a 0.9 cm crimp and a 2 cm crimp, it was estimated that a crimp of 1.55 cm would give the 5.67cm of head loss/section of pipe (1.13 cm/crimp) that is desired. When the head loss of two pipes crimped at 1.55cm was calculated at two different flow rates, the minor loss coefficient was found to be within ten percent of the desired head loss. Therefore, 1.55 cm crimps were used for the rest of the flocculator.

4 Sedimentation Tank

4.1 Design Choice

The sedimentation tank was the most difficult component of the plant to effectively scale down due to the precise nature of its components: the inlet manifold and diffusers, plate settlers, base plates, and sludge drain. The team chose to contain the entire system to a 91.44 cm (3 foot) diameter corrugated pipe, cut at an angle to fit in angled plate settlers (see Figure 10). The plate settlers are set at a 60 degree angle to the horizontal and placed in the top, angled portion of the sedimentation tank. To achieve a 60 degree angle for the top of the sedimentation tank, the pipe itself needed to be cut at a 15 degree angle and then rotated 180 degree on its axis. In order for the top of the tank to be flat, a 30 degree cut needed to be made to the previously cut part of the tank, so once rotated, the top of the sedimentation tank would be horizontal with the floor. Then, the tank was set upright on the bottom (shown in Figure 9). The team had to figure out ways to precisely cut the desired angles. Two jigs were made: one to keep the reciprocating saw level and another to set the angle for cuts.

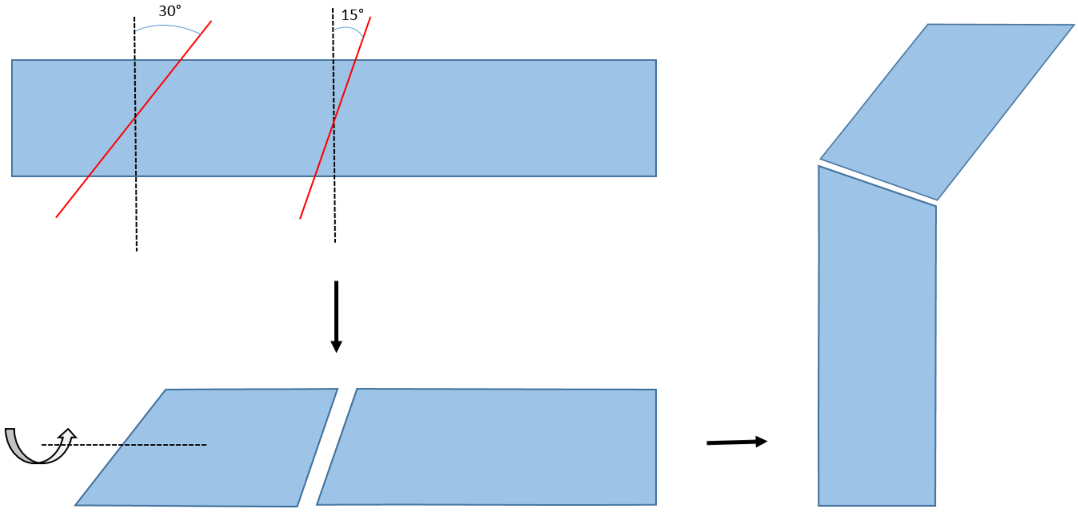

Figure 9: Figure showing the process of cutting the sedimentation tank. The red lines show where the pipe was cut.

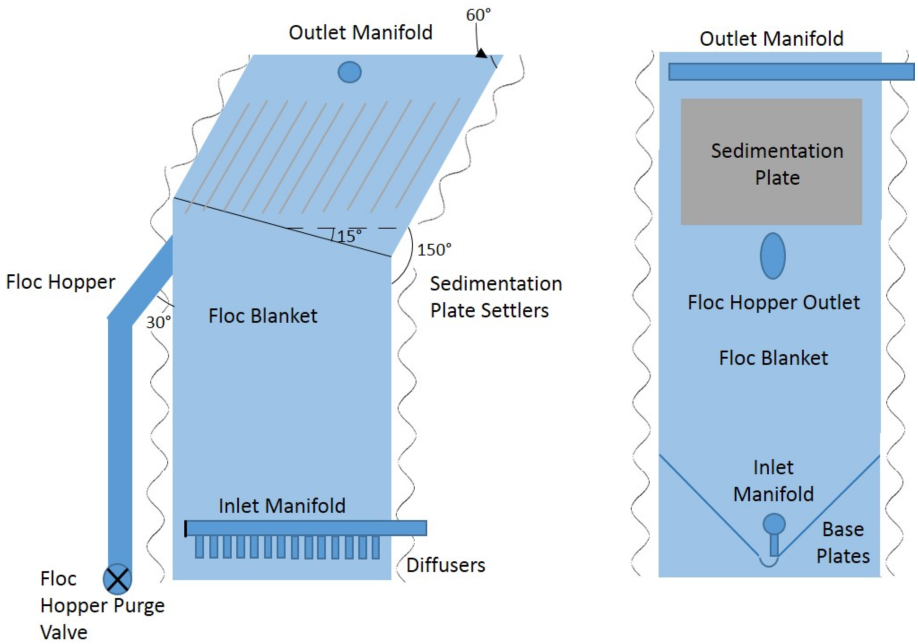

Figure 10: Schematic for sedimentation tank. Constructing the tank out of a corrugated 3 foot pipe is extremely space efficient but made the fabrication difficult due to unwieldy size and corrugations complicating angled hole drilling.

4.2 Fabrication

4.2.1 Wooden Reciprocating Saw Cradle

In order to accurately cut the corrugated 91.44 cm (3 foot) diameter PVC pipe, a jig was necessary to keep the reciprocating saw (Milwaukee Tool, M18^{TM} HACKZALL®) stable. The cradle was made specifically to fit the dimensions of the reciprocating saw, allowing the head to fit snugly, and a screw was placed at the opposite end to keep the reciprocating saw from rotating in the cradle.

Figure 11: The empty wooden reciprocating saw cradle.

Once the reciprocating saw is placed in the cradle, the saw is level and immobile, allowing it to move smoothly along the surface of the plywood jig (described below) used to aid in cutting the pipe.

Figure 12: The wooden reciprocating saw cradle. A screw is placed so the bottom of the reciprocating saw, the battery pack, does not shift out of the head of the cradle when pressure is applied from the top.

4.2.2 Angled Cuts

In order to make precise angled cuts on the 91.44 cm (3 foot) diameter pipe, a jig, consisting of a an ellipse cut out of a plywood sheet, 1 cm by 4 cm wooden planks, and aluminum 80/20 bars was created. This would allow for a steady, precise cut at a specific angle with the wooden cradle, containing the reciprocating saw, held flat against the plywood ellipse and rotated around the pipe.

Figure 13: Plywood jig used to cut the 91.44 cm pipe. The pipe was inserted through the hole and attached to the jig using the aluminum 80/20 bars located at the top, bottom, and sides of the ellipse.

An ellipse was drawn on the plywood by placing two nails at the two foci. A string was wrapped around the two nails and tied so that the farthest point of the string reached the major axis. A marker was placed within the string and stretched tautly to draw the ellipse.

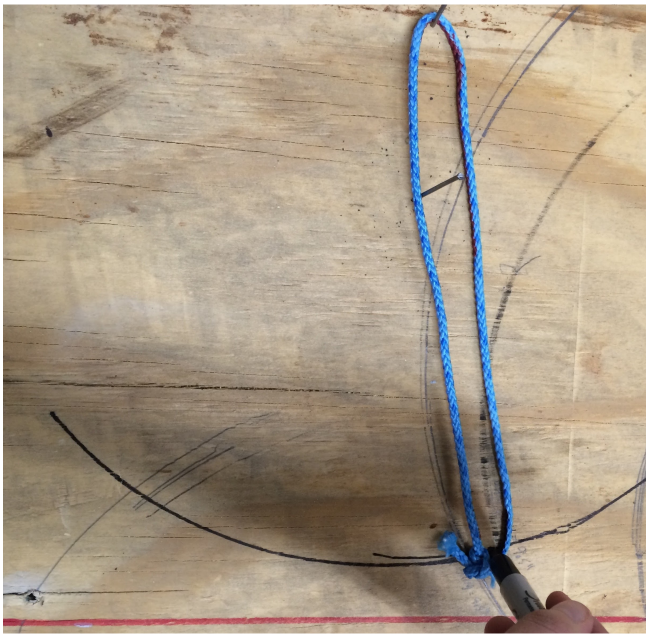

Figure 14: The method of drawing ellipses on plywood to create the jig used to cut the 91.44 cm PVC pipe. The string was pulled taut and the marker was rotated around the center point.

The ellipse was then cut out of the plywood with a reciprocating saw by drilling two half inch holes near the border of the ellipse. A frame was also attached to the ellipse to stabilize the plywood out of four 1 cm by 4 cm planks of wood, which made a border around the ellipse (shown in Figure 13, right).

The plywood was then attached to the 91.44 cm pipe using angled aluminum 80/20 that was screwed into the corrugations of the pipe and plywood on the four quadrants of the pipe. Once the plywood jig was connected to the pipe, hinge joints were added to the aluminum 80/20 pieces so an angle can be set using a protractor. The hinge joints could be loosened, adjusted using a protractor, and then tightened once again to set the angle. The distance along the 91.44 cm pipe can be decided using the top and bottom aluminum 80/20 attachments and the angle could be adjusted using the left and right aluminum 80/20 attachments. In order to ensure that the 30 degree and 15 degree cuts were parallel with each other, a horizontal line (shown in Figure 15, lower half), was drawn along the midpoints of the left and right side of the tank that acted as a reference point to line up with the minor axis of the plywood.

Figure 15: Plywood jig attached to the 91.44 cm pipe, set at an angle. Aluminum 80/20 pieces connected with a hinge joint set the angle of the future cut.

After the 91.44 cm pipe was cut at 15 degrees, one of the pieces would be rotated 180 degrees so that the horizontal lines on either side of the pipe lined up again. A 30 degree angle was cut to ensure that the pipe would have a flat top to contain the water after the rotation of the angled pieces.

The sedimentation tank needed 2 angled holes; one for the sludge drain, and another for the outlet manifold. As shown in Figure 10, the sludge drain (or floc hopper outlet) needed to protrude from the sedimentation tank at a 30 degree angle from the vertical, and the outlet manifold needed to lay horizontal to the floor, so an angled hole was cut at 60 degrees from the side of the angled, top portion of the sedimentation tank. First, in order to create the angled cuts, the corrugations that impeded the hole saw were cut away. It was not possible to cut away the entire corrugation with one cut, so a wedge was initially cut to get the saw in. Then, the left and right sides of the corrugation were cut off one side at a time. After the angled hole was partially cut, the corrugation on which the pilot hole was made interfered with drilling and needed to be cut off. Fortunately, the pilot drill bit is long enough to partially penetrate the tank wall so the cut can be resumed after stopping halfway through without losing the center.

4.3 Jet Reverser

As is convention in standard AguaClara plants, the transition from flow in the flocculator to the sedimentation tank is handled by an inlet manifold-jet reverser combination. This is shown in Figure 10 as 'Inlet Manifold', 'Diffusers', and 'Base Plates'. Water flows into the inlet manifold and down through the diffusers. The half-circle section joining the base plates redirects the water upwards, bringing about the important term 'upflow velocity', the average velocity with which the water moves upwards through the tank (1.25 mm/s in this case).

To create this jet reverser, two components are needed: the base plate-semicircle apparatus and the inlet manifold-diffuser pipe.

4.3.1 Base Plates

The base plate V-section is comprised of two PVC wings, which are each half ellipses intended to fit snugly in the interior of the sedimentation tank pipe. There wings are joined with a half-section of a 3 inch PVC pipe, which serves as the half-circle which reverses the flow of water (see Figure 16).

Figure 16: Bottom (left) and side (right) views of the V-section. The wing ellipses were duct-taped back onto the rectangular sheets from which they were cut for ease of moving and supporting the apparatus.

To create this V-section, two half-ellipses were drawn and cut using the same method described above for the pipe-cutting jig, with the minor axis being the same length as the diameter of the sedimentation tank pipe. The wings were then welded onto the half-section of 3 inch pipe (see Figure 17).

Figure 17: Material being added to the weld between the pipe section and one of the V-section wings.

The ellipsoid wings in Figure 16 were duct taped onto the rectangles from which they were cut for stability while welding and moving. Unseen in Figure 17 is the frame below the V-section, which held the wings at a constant angle while the welding took place. A closer look at the frame can be found in Figure 18

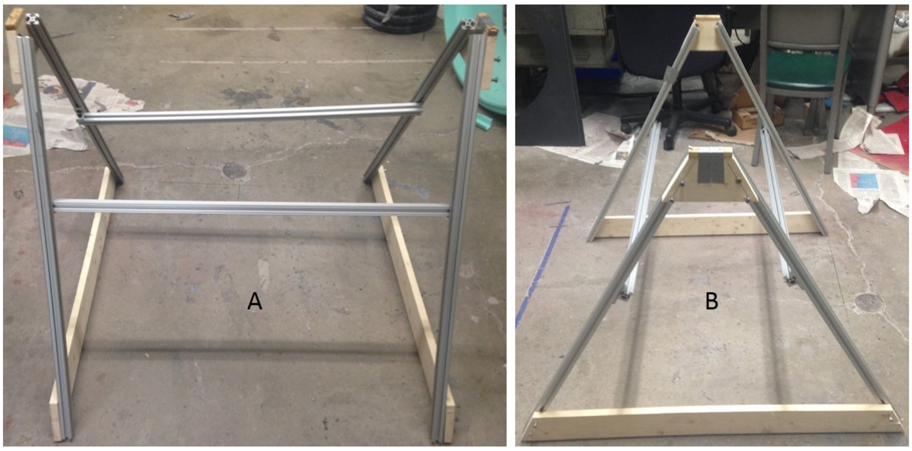

Figure 18: Front view (A) and side view (B) of the frame used to stabilize the v-section while it was being welded in place.

4.3.2 Inlet Manifold

The inlet manifold (as shown in Figure 10) consists of a 3 inch pipe, which is 20.32cm (8in) longer than the diameter of the sedimentation tank, so that it could be fixed to both the tank and the flocculator on the outside of the tank via flexible couplings (see Figure 19). The inlet manifold itself was sealed at its far end (not near the ferncos) to force the water from the flocculator to go into the diffusers, and held in place by another pipe stub welded onto the side of the sedimentation tank.

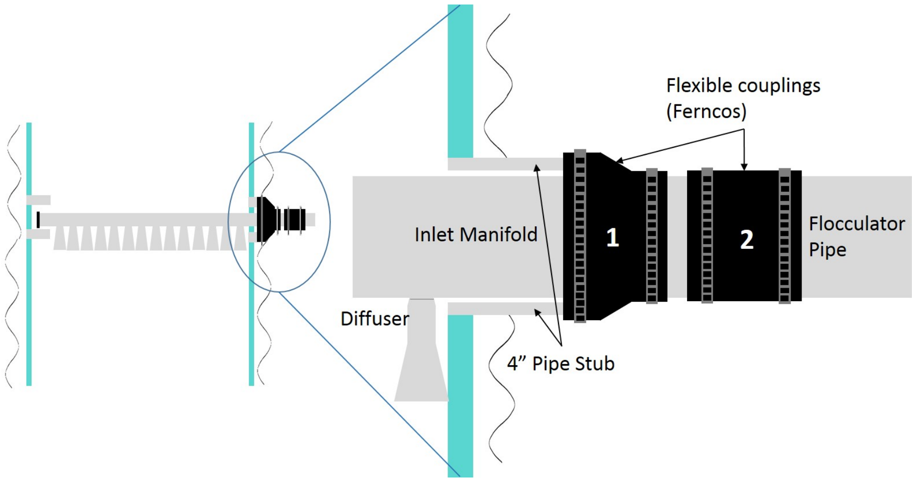

Figure 19: Connection between inlet manifold and flocculator. The flocculator pipe is connected to the inlet manifold pipe via fernco 2 (as shown in figure). A 4 inch PVC pipe stub is welded to the tank wall, and the inlet manifold is attached to the stub with fernco 1, a 4" to 3" reducing fernco.

The Diffusers themselves are 1 inch, each pipe 13.97 cm (5.5 inches) long. Each diffuser contains a narrow section to connect it to the holes in the inlet manifold and a wide section intended to have a long, thin cross section as close as possible to a line jet (see Figure 20). A line jet is desirable because it presents the most efficient geometry for flow redirection via the jet reverser (see Figure 21).

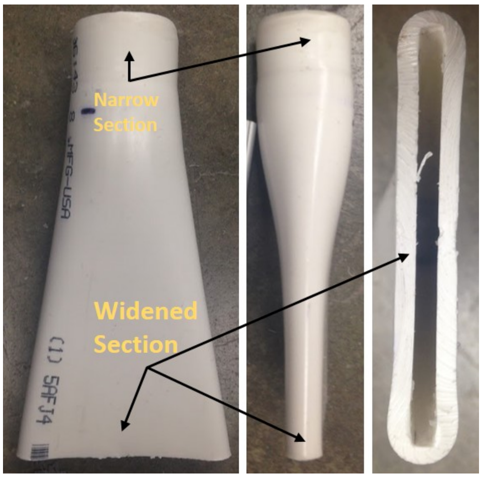

Figure 20: Front view (left), side view (middle), and bottom view (right). The purpose of the diffuser is to force the water going into the sedimentation tank to be as close to a line jet as possible, which is why the bottom widened section is long and thin.

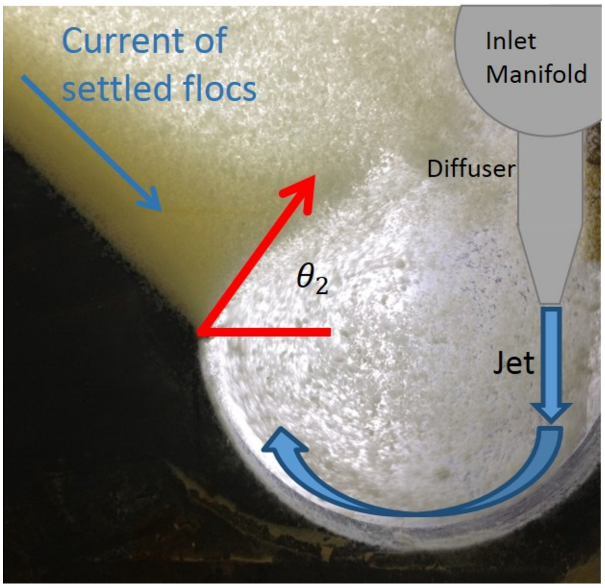

Figure 21: Jet Reverser in action. The water flows more smoothly if the initial jet from the diffusers is as close to a line (along the half-circle) as possible. CITE MONROE!! TAKEN FROM HIS 4540 POWERPOINT ON SEDIMENTATION

The inlet manifold will contain 13 diffusers, this number being the maximum amount of diffusers that fit within the diameter of the tank given our diffuser length of 6.67cm (2.625 in).

Diffuser count was determined by the following parameters: $ID_{tank} = 35.37in$,

$Diffuser_{length} = 2.625in$, $Diffuser_{ErrorSpace} = 1mm$.

Therefore, $Diffuser_{TotalLength} = Diffuser_{length} + Diffuser_{ErrorSpace} = 6.77cm$

$$num_{Diffusers} = floor(\frac{ID_{tank}}{Diffuser_{TotalLength}}) = 13 \tag{26}$$

$$Total_{length} = (num_{Diffusers} - 1) Diffuser_{ErrorSpace} + num_{Diffusers} Diffuser_{length} \tag{27}$$

As a result, the total length of the diffusers and the 1mm spacing between them ends up being $Total_{length} = 35.109in$, which leaves $35.37in - 35.109in = 0.261in/0.662cm$, enough space to account for nearly any error.

The diffusers were shaped by first submerging sections of them in hot (around 200 degrees Fahrenheit) oil for 2 minutes and 30 seconds, and then hammering them into either the narrowing or widening mold, shown in Figure 22

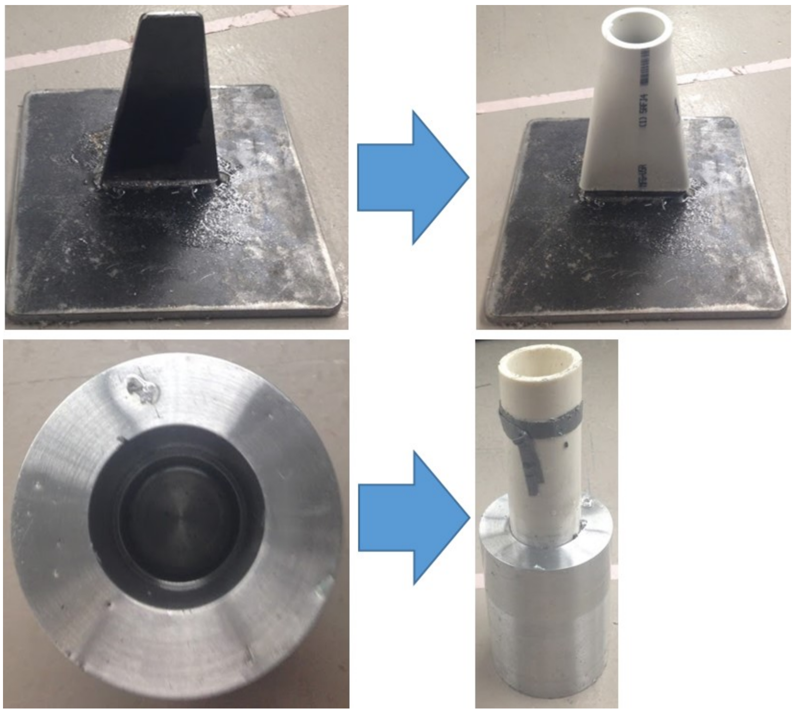

Figure 22: The 1 inch diffuser pipe was heated and first and hammered into the narrowing/tapered mold (bottom). Upon sitting in the mold for 30 seconds and being cooled with cold water, the bottom section was heated once more with oil for 2 minutes and 30 seconds and then hammered into the widening mold (top), left to sit for 30 seconds, and cooled once more.

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4.4 Plate Settlers

At the top of the sedimentation tank, located just below the outlet manifold are the plate settlers. The plate settlers serve as the final step in the sedimentation process, their purpose being to trap flocs that did not collide with and join the floc blanket and reintroduce them into the floc blanket, increasing the chance of a collision and subsequent removal of the floc through the sludge drain. The plate settlers work on the same principle as the rest of the sedimentation tank: that flocs are more dense than water. By having the plates at a particular angle and length, this part of the sedimentation tank can be sure to trap many of the flocs that rise above the floc blanket. For more detail, see Figure 23.

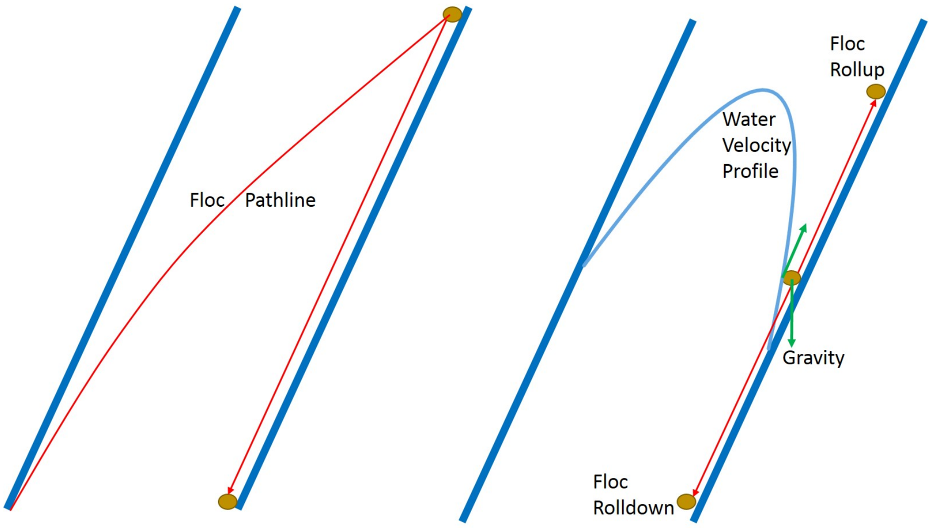

Figure 23: The plate settlers are created in the proper dimensions to trap flocs rising upwards with the water (shown on the left). Once a floc is in contact with a plate settler, the two forces acting on it are gravity pulling it downwards and the force of the water continuing its upward ascent (shown on the right). If the plate settlers are too tightly spaced or if the floc is too light or too large in diameter, the floc will experience what is called floc rollup, where it bypasses the plate settlers entirely and continues leaves through the outlet manifold. If these conditions are not met, then the floc will roll down the plate settler and be re-introduced into the floc blanket, where it will have another change to collide and form into a bigger, easier to settle floc. CITE MONROE!! TAKEN FROM HIS 4540 POWERPOINT ON SEDIMENTATION

4.4.1 Fabrication

The plate settlers are made of clear, 1/8 inch acrylic polycarbonate sheets and cut to the dimensions of the sedimentation tank. In total, there are 35 plate settlers and each of them are 0.6095 meters long at varying widths, depending on how close they are to the sides of the tank. Plate settlers directly in the middle of the circular tank will be larger than those near the sides.

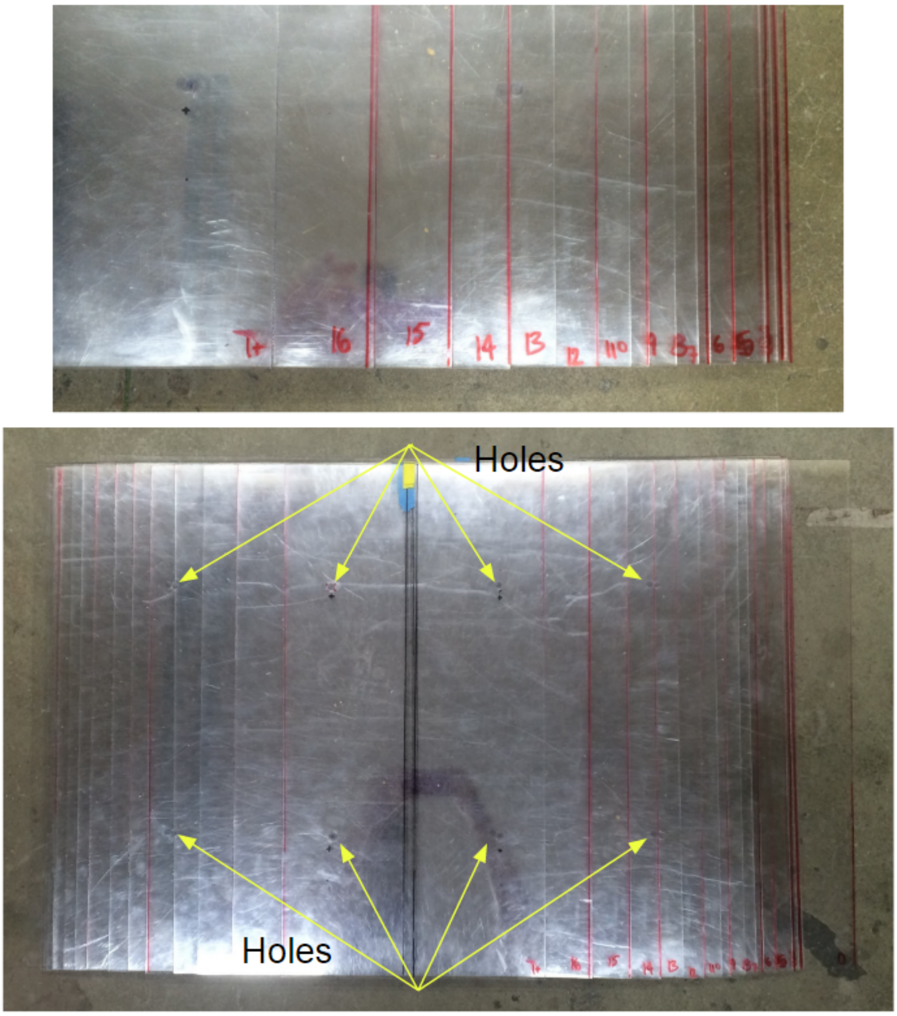

Figure 24: Half of the plate settlers in a stack, going from largest to smallest on top (bottom photo). The varying widths of the settlers are shown in the top photo. Arrows show where the 8 holes are placed for the stainless steel rods.

The plate settlers are held in place by 8 stainless steel threaded rods (1/4 inch, 20 threads per inch). The rods will be parallel to the floor, while the plate settlers will be at a 60 degree angle to the horizontal, shown in Figure 25. The plates were cut to size using a jump shear.

The holes for the stainless steel rods were drilled using a large drill press. The middle of each plate settler was marked off, and then the plate settlers were stacked together and clamped to prohibit them from moving. The location of the holes for the stainless steel rods are shown in Figure 26, a top view of the sedimentation tank. The holes were 13 cm from the top and bottom edges, and the first set of holes was 10 cm from the middle line, while the second set was 30 cm from the middle line. The holes were marked and then drilled. The size of the holes are 5/16 inch, which is slightly larger than the 1/4 inch stainless steel rods, to allow for the plate settlers to easily slide through. The plate settlers were held in place in the tank by rectangular strips of PVC that were welded around the inside of the tank.

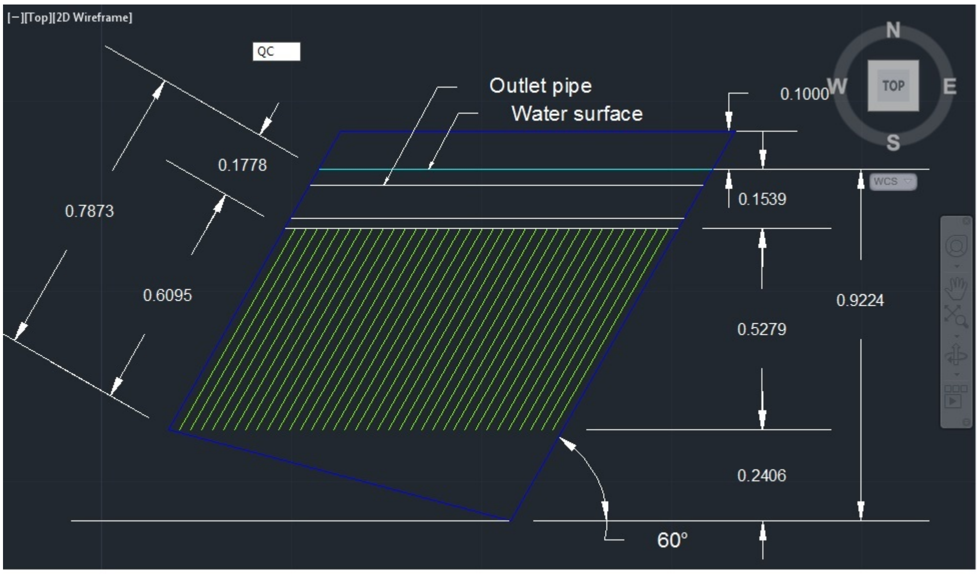

Figure 25: Dimensions of the plate settlers, and how they will sit in the sedimentation tank. The plate settlers are angled 60 degrees from the horizontal and are 0.6095 meters in length.

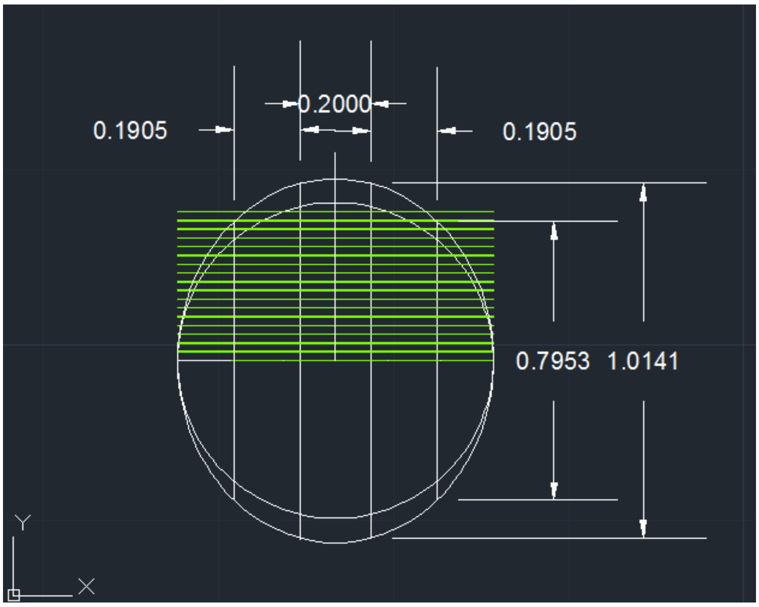

Figure 26: Dimensions of the plate settlers, and how they will sit in the sedimentation tank. The plate settlers are angled 60 degrees from the horizontal and are 0.6095 meters in length.

4.5 Testing

5 For Future Iterations

The team experimented with a two methods of welding pipe stubs into the sedimentation tank. One of which was to make a four inch hole straight through the side of the tank and have the pipe stub going through the hole, to be welded on the inside for waterproofing and on the outside if desired for stability.

The other method involved making a three inch hole straight through the pipe and a four inch hole around that center of the previous hole only going through the corrugations. Once the corrugations were removed, the pipe stub was placed on the side of the tank that still existed, but lacked corrugations. Welding was done along the inner circumference of the stub and the wall of the pipe in addition to the outer circumference and the remaining corrugations.

The first method of drilling a four inch hole straight through the wall of the tank worked far better than the second method. Pipe stubs inserted using the second method were very difficult to weld and experienced leaks that were difficult to fix due to the welding challenge.

There was also thought about changing the fabrication of the flocculator. Instead of crimped sections of the flocculator pipe, there could be orifices installed inside of the pipe to produce adequate mixing. The team briefly tried using a PVC sheets cut into a circle with a hole through the middle that were inserted into a coupling

When fully assembled, water was run through the plant to see if any leaks occurred. Once the leaks were identified, the water was drained from the tank so that the leaks could be fixed. However, the team realized that by draining the plant via the drain connecting the flocculator and the sedimentation tank, the flocculator itself did not drain completely. Instead, the water level in the flocculator stayed just below the top elbows when fully drained. This is because of the open tops of the clear one inch pipe attached to every other flocculator pipe. The purpose of the pipes is to easily measure the head loss through flocculator sections, but the air let in from these pipes broke the continuity of the water while draining and led to the flocculator not being fully drained.

MAKE PLATE SETTLERS BETTER, DRILL HOLES FIRST THEN CUT TO SIZE, FIND AN EASIER WAY TO HANDLE THEM, PLACE THEM IN THE SED TANK, ETC.