EStaRS, Spring 2017

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Abstract

The Low Flow Stacked Rapid Sand Filter (LFSRSF) team was originally tasked with building a small, stand-alone sand filter to be implemented in small communities in India. This semester, the Enclosed Stacked Rapid Sand Filter (EStaRS) team fabricated a new filter based on the design the Fall 2016 team created. The new design modifies the original LFSRSF; the filter column itself is shorter, the manifolds are sized differently, and the entrance and exit plumbing is now rigid PVC instead of flexible PVC. Next semester, the new EStaRS filter will be connected to the 1 L/s plant that has been built in the lab.

Introduction

Advanced, consistent water treatment is typically a luxury that only developed countries can afford, leaving less wealthy countries unable to purchase and implement such technologies. Even for the poorer countries that are able to purchase them, it is often only the major cities that have these technologies, excluding the rural people that do not live near these urban areas. AguaClara, an engineering project team at Cornell University, aims to combat this directly by researching and providing low cost water treatment plants for small towns in Honduras and India.

AguaClara, which began building plants in Honduras in 2005 and India in 2013, has provided gravity powered water treatment systems to thousands of people in rural communities. Recently a one liter per second (1 LPS) plant was developed to bring sustainable water treatment to towns with populations of a thousand or less. The goal of the Enclosed Stacked Rapid Sand Filter (EStaRS) team in the Spring 2017 semester is to design and fabricate a sand filter based on the previous iterations of EStaRS that will connect to the 1 LPS plant to improve its effluent quality.

Literature Review

Traditional Stacked Rapid Sand Filters

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

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

Slow Sand Filters

Contrary to the name, slow sand filtration has nothing to do with the flow of the water being slower than the flow in rapid sand filtration. It is both a physical and biological process, removing both turbidity and pathogenic organisms through the a microbial community grown on the top layer of the sand, referred to as "schmutzdecke". These microbes are predatory bacteria that feed on water-borne microbes, effectively removing them from the water. Slow sand filtration is effective in removing most contaminants and is easy to maintain as it does not require backwash. However, it has drawbacks including: not removing a majority of chemicals, requiring a low initial turbidity level, large amounts of land, and moderate climate conditions.

Ceramic Filters

Ceramic Water filter technology is an alternative and sustainable water treatment technology widely used in Guatemala and is spreading to other countries. It functions similarly to sand filters, as it is a purely physical process. It requires a pot, made of only clay, sawdust and colloidal silver, to be produced in a local ceramic facility. The mix is fired in a kiln, and the organic material burns out, leaving pores of only 1 micron in size. Once water passes through these pores, they leave contaminants behind. Eventually the pores clog due to the contaminants and have to be cleansed manually.

Novel Fluidic Control System for Stacked Rapid Sand Filters

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

Previous Work

EStaRS, Fall 2013

With regards to the actual filter vessel, referred to as the trunk, no changes will be made between the previous Low Flow Stacked Rapid Sand Filter (LFSRSF) and the new EStaRS. The trunk design used in the LFSRSF is displayed in Figure 1, and the gasket and hose clamps setup was repeated in the new EStaRS.

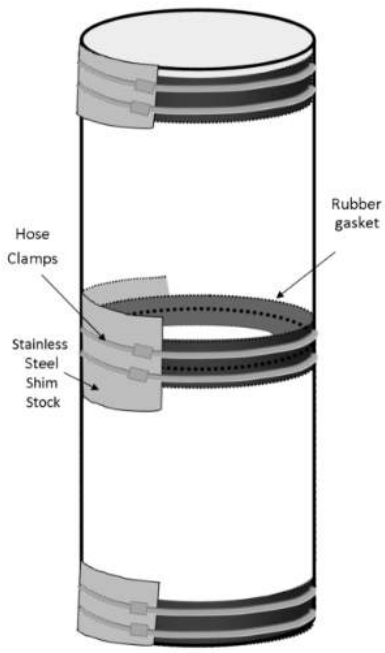

Figure 1: Initial LFSRSF and now EStaRS trunk setup. The trunk is sealed on each end by a 1/2 inch thick circular PVC sheet fixed to the trunk by a rubber gasket and hose clamps (known as a fernco).

The Fall 2013 LFSRSF team redesigned the filter's hydraulic controls, so that instead of using valves to control the inflow and outflow of water from the filter, a series of pipe stubs could be used instead. Their design involved connecting five pipes to the bottom of the entrance tank, with three of the pipes carrying water from the entrance tank to the inlet manifolds, one pipe carrying the influent water, and one backwash pipe carrying water from the entrance tank to the backwash manifold. The exit tank had a similar design, with three pipes carrying water from the exit manifolds to the exit tank, one pipe carrying effluent water, and one pipe carrying water from the backwash pipe to waste. All the piping used was flexible PVC tubing (Green et al., 2013).

Inside the entrance and exit tanks, the pipe stubs (the shortest being 15 cm) account for the 40 cm of head loss through the filter (Green et al., 2013).

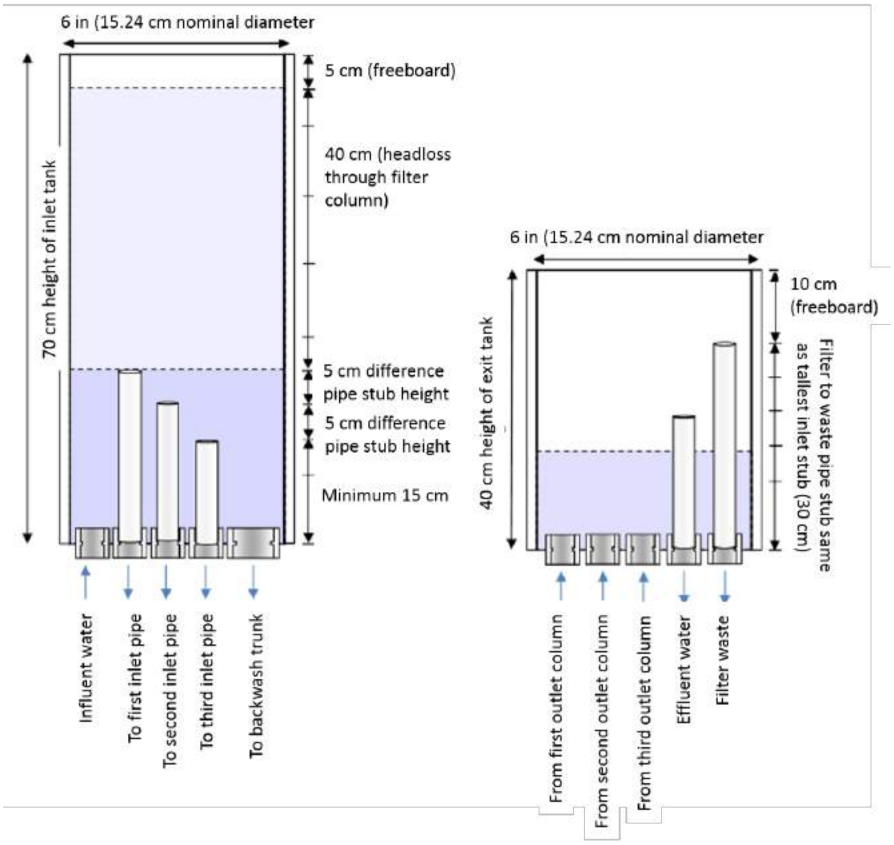

Figure 2: Schematic of the Fall 2013 team's design for the connections between the inlet tank, the main filter trunk and the exit tank.

Figure 3: The design of the LFSRSF entrance (right) and exit (left) tanks from Figure 2 after fabrication by the Fall 2013 team.

The Fall 2013 team used spacers (made from rigid PVC) and hose clamps to attach the entrance and exit tanks to the filter trunk.

Figure 4: The PVC spacer and hose clamp used to attach the entrance and exit tanks to the main filter trunk.

These designs were not changed for the EStaRS filter that was built this semester (Spring 2017).

EStaRS, Spring 2014

Previous reports that dealt with the design and fabrication of the last EStaRS proved to be very useful. These reports, from Spring 2014 and Fall 2013, contain tips and recommendations for fabrication that the current team utilized.

EStaRS, Spring 2015

The work done in this semester aimed to improve the filter by changing the inlet manifolds from using slotted pipes to orifices. This was done to reduce the high costs associated with fabrication and shipping of the slotted pipes to Honduras since this material cannot be produced in the country. MathCAD was used to calculate the necessary area for the orifices to maintain the filters desired flow rate and determine the dimensions of the branches in the manifolds (Bolander et al., 2015).

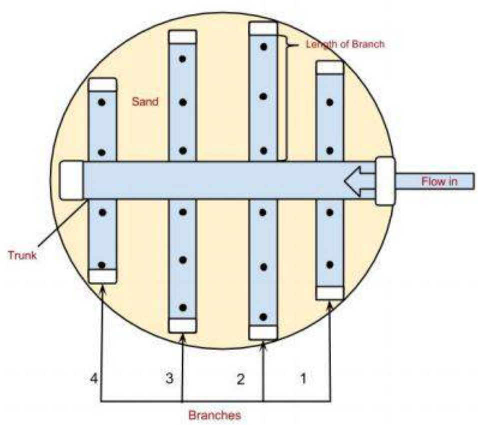

Figure 5: Inlet manifold design done in Spring 2015.

A change made to the inlet manifold design from Spring 2015 made the outer branches and inner branches the same length instead of making all four branches different lengths. This will make the fabrication process simpler for the lab and future implementation in Honduras (Aurteneche et al., 2016).

EStaRS, Fall 2016

The work done by the team this semester was primarily to design a new EStaRS compatible with the new 1 liter per second (1 LPS) plant. The entrance tank for the previous iteration of EStaRS, the LFSRSF was at a higher elevation than the outlet of the 1 LPS plant's sedimentation tank, and they could therefore not be used in conjunction without electrical pumping. This semester's team created a new EStaRS design in which the depth of each of the six sand beds is 15 cm, as opposed to the 20 cm of the LFSRSF. This change in filter length was determined to be sufficient to allow the filter to be attached to the 1 LPS plant, creating a full flocculation-sedimentation-filtration-disinfection modular plant that can be transported with relative ease. This team created an AutoCAD document modeling the new EStaRS, depicted below in Figure 6. This will be the basis for the current semester's fabrication of the new EStaRS iteration (Aurteneche et al., 2016).

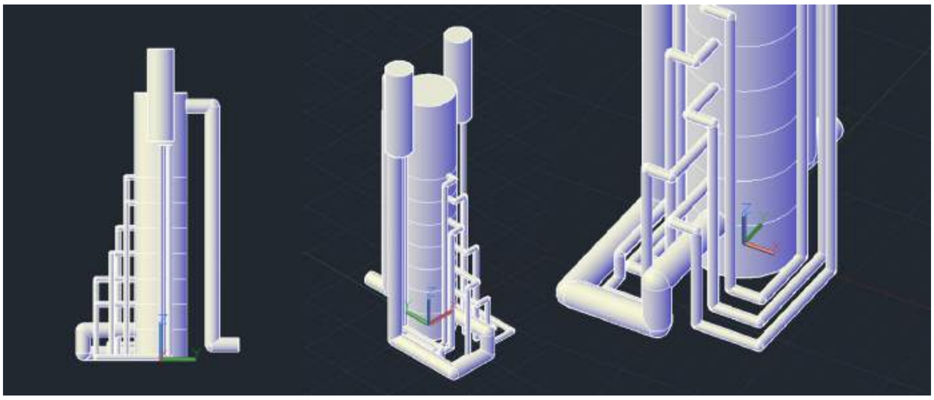

Figure 6: The new iteration of the EStaRS filter modeled in AutoCAD. The two tanks on the top of the filter opposite each other are the filter's entrance and exit tanks, and the bigger pipe that connects to the bottom of the filter is the backwash trunk. Shown is a side view (left) and a top angled (middle) view. Also pictured is a closer look at the spatial arrangement of the pipes connecting the entrance tank, filter, and exit tank (right).

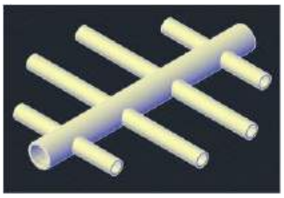

Figure 7: New inlet manifold design from Fall 2016.

Fabrication Methods

The goal for the team this semester, as previously discussed, was to fabricate an EStaRS filter based on the design from Fall 2016 team. This section was therefore concerned with the details and challenges encountered through the construction process, organized by three filter components. The central pipe which contains the six stacked 15 cm sand beds known as the filter trunk, manifolds to distribute water into and out of the trunk, and the entrance/exit tanks and plumbing connect the filter to a water source and distribution system.

Filter Trunk

Filter trunk specifications, including total height, width, and location of inlets and outlets were deemed acceptable and remained unchanged from their initial calculation in the Fall of 2016. These values are shown in Figure 8 below.

$Z_{FiEntWeir} = 1.873\,m$	$Z_{FiInlet1} = 1.075\,m$
$Z_{FiInletDrain} = 1.843\,m$	$Z_{FiOutlet1} = 0.925\,m$
$Z_{FiOverflowWeir} = 1.833\,m$	$Z_{FiInlet2} = 0.775\,m$
$Z_{FiEntTank} = 1.368\,m$	$Z_{FiOutlet2} = 0.625\,m$
$Z_{FiEntChannel} = 1.368\,m$	$Z_{FiInlet3} = 0.475\,m$
$Z_{FiExitTank} = 1.368\,m$	$Z_{FiOutlet3} = 0.325\,m$
$\boxed{Z_{FiTop} = 1.59\,m}$	$Z_{FiInlet4} = 0.175\,m$
$Z_{FiBwPipe} = 1.459\,m$	$Z_{FiBottom} = 0 \cdot cm$
$Z_{FiSiphonOutlet} = 56.54 \cdot cm$	

Figure 8: Taken directly from the governing MathCAD document, these are the important heights along the filter trunk. Z.FiInlet3, for example, refers to the height of the 3rd inlet. Inlet/Outlet number is counted from the top, while distance is measured from the floor. Z.FiTop is the height of the filter trunk added to the half inch base on which it stands.

The first steps taken were to cut the 12 inch diameter pipe to the correct size. Since the pipe was too large to cut accurately with any sawing tools in the Civil and Environmental Engineering Machine Shop (CEEMS), an alternative procedure was derived. First, a perfectly accurate line was drawn along the portion of the pipe the team wished to cut. This line was drawn by pushing the pipe length-wise against a stable surface perpendicular to the ground (the legs of a desk in this case) and placing a heavy, flat surface on one end of the pipe (a mini-refrigerator) to hold it in place. A permanent marker was then placed in contact with the pipe and the stable desk leg while the pipe was rotated 360° thereby creating a line perfectly perpendicular to the central axis of the pipe (see Figure 9).

Figure 9: The picture on the left shows the beginning of the line-drawing process. On the bottom-right of the picture is the mini-refrigerator used to hold the pipe in place. The marker being held against the pipe in the center of the picture was kept immobile in space as the pipe was rotated. On the right hand side is a picture of the end of the line-drawing process. Lines drawn with this method were essentially perfect.

Three lines were drawn with this method. One to cut the pipe to the correct size at the top of the trunk, one for the bottom of the trunk (the factory-edge bottom of the 12 inch pipe was tapered in such a way that would make it difficult to seal), and one located just above the first inlet to facilitate placement of the manifolds.

Regarding the cutting process, the team deemed the precision of the cut too important and challenging to perform without professional assistance. Once all three lines were drawn, the pipe was given to Tim Brock of the CEEMS to cut. Tim used the jig-saw shown in figure 10 combined with a very stiff blade intended to cut metal to make the cuts.

Figure 10: On the left is a side view of the jig-saw. The following picture (right) is a down-angled view of the same jig-saw to better show the cutting mechanism.

Next, the team drilled seven holes into the trunk to connect the manifolds to the plumbing, and therefore to the entrance and exit tanks. The size of these holes was determined by the size of the pipes used in the plumbing. The Fall 2016 team had designed the EStaRS system for 1 inch plumbing and a 2 inch backwash pipe. When considering these sizes, however, the team discovered a problem. The flow through the inlet pipes varied significantly, due to head loss terms caused by pipe size and number of elbows. Specifically, the inlet path also used for backwash (lowest in elevation) was designed with 2 inch pipe and contained 4 elbows, while the inlet path above it was 1 inch pipe and contained 7 elbows, both of which were factors that increase head loss for equal flows when compared to the lowest inlet. Tinkering with pipe sizes in MathCAD (see Figure 11), the team found that an acceptable path flow difference was obtained by replacing the 1 inch plumbing with 1.5 inch pipe and the 2 inch backwash pipe with 3 inch pipe..

For 1 inch plumbing

$$Q_{FiPath} := HL_{FiPath}\left(Q_{Fi}\right) = \begin{pmatrix} 0.188 \\ 0.155 \\ 0.155 \\ 0.148 \\ 0.148 \\ 0.205 \end{pmatrix} \cdot \frac{L}{s}$$

For 1.5 inch plumbing

$$Q_{FiPath} := HL_{FiPath}\left(Q_{Fi}\right) = \begin{pmatrix} 0.18 \\ 0.16 \\ 0.16 \\ 0.155 \\ 0.155 \\ 0.188 \end{pmatrix} \cdot \frac{L}{s}$$

Figure 11: MathCAD calculations displaying the flow through each path. On the left are the flows through 1 inch piping, with 33% more water going through the final flow path than the one above it. On the right are the flows through the 1.5 inch piping, with only about 10% of a difference between the previously mentioned paths, which the team deemed acceptable.

Once the correct pipe sizes were determined, holes could be made in the trunk to accommodate those pipe sizes. All seven holes were drilled with an appropriately sized hole saw (3 1/2 inch saw for 3 inch backwash pipe and 1 7/8 inch for the rest of the 1 1/2 inch inlets and outlets) and a hand drill. The filter trunk was supported by four offset I-beam assemblies (One is shown on the right in Figure 12), and required three people for precise drilling (see Figure 12, on the left). One team member drilled while the other two acted as spotters to ensure that the drill was exactly perpendicular to the tangent of the trunk.

Figure 12: The 3 1/2 hole being drilled for the backwash pipe (left). Behind the team member drilling (Juan) was another team member (Lilly) spotting to ensure that the drill was perpendicular to the trunk from her perspective. In front of Juan and out of frame to the left was another team member spotting the drill angle. With two spotters, any possible deviation from perpendicularity was corrected immediately.

With all seven holes drilled, the next progression on the trunk's fabrication became inserting and connecting the manifolds. Since the manifolds have not yet been fabricated, the trunk was set aside

(Figure 13) as work began on the entrance and exit tanks.

Figure 13: This is the filter trunk cut into its final sections. Since the manifolds have to be inserted manually, the trunk was cut in two pieces to make it easier for a team member to insert their arm into the trunk and place the top manifolds.

Manifolds

Fabrication of the manifolds began with determining the lengths and inner diameters (ID) of the pipes needed from the Fall 2016 design, shown below. Once the correct pipes arrived in the lab, the team used the band saw to cut the short branches and the reciprocating saw for the long branches. In order to cut the trunks, the team marked the pipe so that there was about a half inch of space between each trunk length. This was done so that the reciprocating saw could be used initially to cut the trunks, and then the bit of length remaining on each trunk could be cut with the band saw for a cleaner cut.

Following this, the team ran a trial run on the backwash trunk using a hole saw to make fits for the branches. In order for the branches to fit properly through the trunk, the holes for each branch must be perfectly opposite each other on the trunk. After consulting with Paul Charles in the CEE machine shop, the team folded a piece of 8.5 x 11" paper to fit perfectly halfway around the trunk. The center point and the points at which each branch hole needed to be drilled were marked on both edges of the paper. Then the paper was taped to the pipe (after marking the center of the pipe and lining that up with the center of the paper) and the markings on each edge of the paper were used to mark where the branch holes would go on the pipe.

Figure 14: This is the paper used to mark the holes needed for the branches.

Once the pipe was marked, small pilot holes were drilled as a guide for the hole saw, and then the hole saw was used to make the branch hole. After the trial resulted in a hole that was too large, a more precise measurement was made with the 0.5" and 0.75" PVC pipes to determine the best size hole saw. To keep the trunk piece, the team plans to weld the branch and trunk to close the gap. New hole saws sized 13/16" and 1 1/16" were purchased, to be used to drill the 0.5" and 0.75" branch holes respectively.

After the new hole saws were delivered, the team worked on marking and drilling the 1.5" trunks for the forward filter manifolds, using the same method detailed above. However, during this process it was noted that the trunks were slightly too long, and that some of the trunks had not been cut well. In the process of shortening the trunks, some were cut shorter than others and the whole batch had to be scrapped.

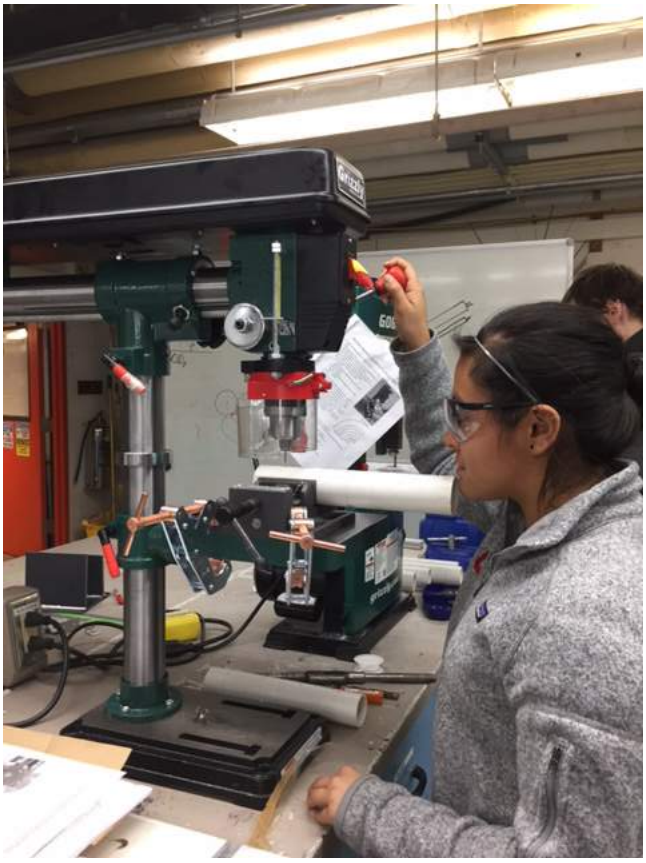

Figure 15: Lilly using the new drill press to make small pilot holes in the second batch of 1.5” trunks.

While waiting for new 1.5” pipe to be delivered, the team worked on finishing the branch holes for the backwash pipe. However, after drilling and fitting the branches into the trunk, the team saw that the branches were noticeably not perpendicular to the trunk. This prompted the team to figure out how to ensure that the holes for the branches were not vertically offset.

Once the 1.5” pipe arrived, the team set about re-fabricating the trunks for forward filtration. The trunk lengths were shortened to 10.5” and cut more precisely, and about 0.5” of the 1.5” pipe caps were also cut so that the trunks would fit in the filter column. In order to make sure the branch holes were not vertically offset, the team cut a sliver off a 1.5” elbow. The team slid this ring of PVC onto the 1.5” trunks and used it to draw lines around the pipe where the branch holes would be drilled. Then, when marking the pipe, the team used those lines to make sure the holes would be lined up vertically in addition to using the paper to make sure the holes would be lined up horizontally. The branch holes for all six forward filter trunks were then drilled successfully.

Figure 16: Lilly fabricating the PVC ring used to mark the trunks.

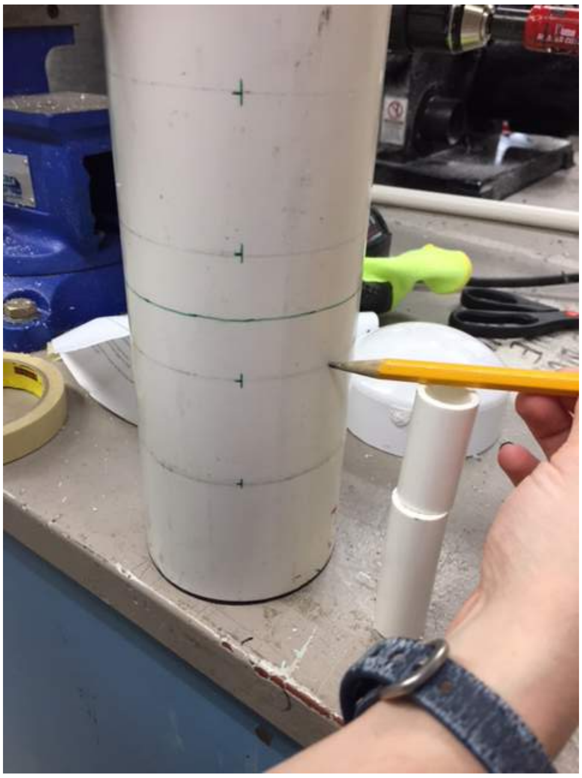

Figure 17: Another technique the team used to make sure the markings for the branch holes were aligned vertically.

After drilling the branch holes, the team had to drill a hole in the center of each branch to allow water to enter the branch from the trunk. This was done using the drill press and a 9/16" drill bit. The holes had to be drilled carefully, especially in the slotted pipes, because drilling too quickly caused the branches to break.

Figure 18: The results of drilling too quickly with the drill press. The branch on the left cracked during drilling, while the holes in the branches in the middle and on the right were drilled more carefully.

Orifice Calculations

SJM: [make sure this is all past tense for the final report] The engineers in Honduras informed the team that the orifices in the inlet manifolds cannot be larger than 1/4" in diameter, so the team had to recalculate the number and size of the orifices. For the three forward filter inlet manifolds, the calculations for the top manifold were different from the calculations for the two middle manifolds because the top manifold only distributes water downward, while the middle two manifolds distribute water downward and upward. This is because there is no outlet manifold above the top inlet manifold for water to flow to, while the middle inlet manifolds have water flowing to outlet manifolds both above and below.

Since more water has to flow out of the two middle inlet manifolds, this meant that either the middle manifolds would have more orifices than the top manifold, or that the diameter of the orifices in the middle manifolds would have to be larger than the diameter of the orifices in the top manifold. After experimentation in Mathcad, the team decided to follow what the LFSRSF team did and make the orifices in the middle manifolds larger than those in the top manifold. For the sake of convenience, the team set the number of orifices in each forward filter manifold to twelve, and set the diameter of the orifices in the middle manifolds to 1/4", the largest they can be. From there the team calculated the diameter of the orifices in the top manifold using the total area of all the orifices, the area of the middle manifold orifices, and the number of orifices per manifold. The orifices in the top manifold are 11/64" diameter. The backwash orifice diameters were calculated using the total area of all the orifices, since the entire flow through the filter has to go through the backwash orifices. The backwash orifices are 25/64" in diameter.

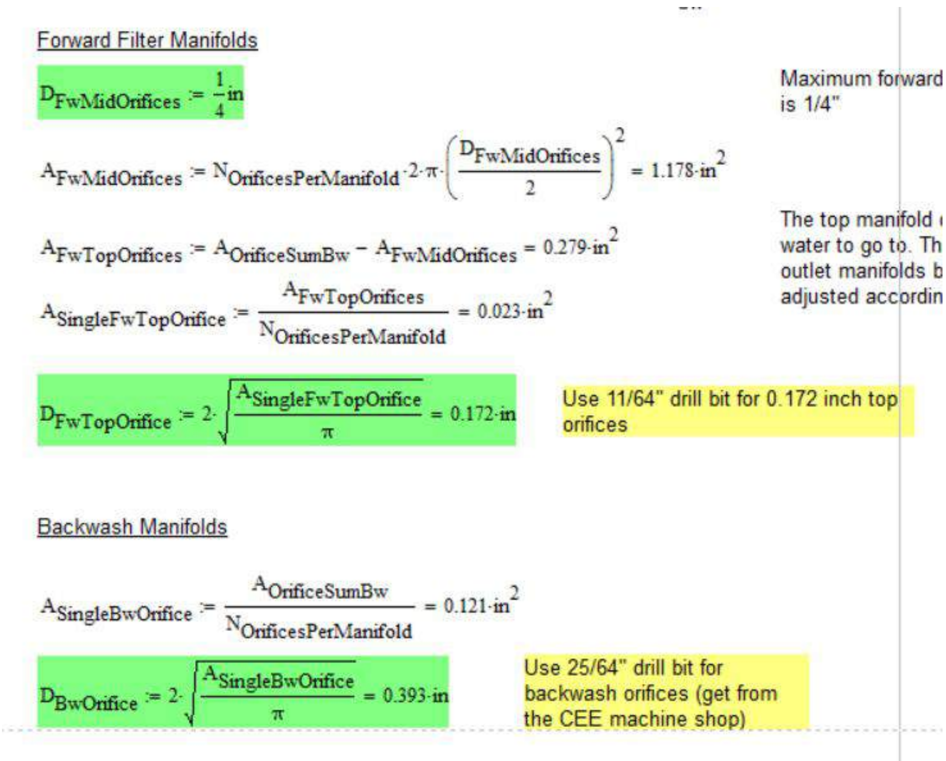

Figure 19: The Mathcad code used to calculate the diameter of the orifices in the top manifold. The number of orifices in each manifold was set to twelve, and the diameter of the orifices in the middle manifolds was set to 1/4".

After calculating the orifice sizes, the team calculated the spacing between the orifices. For each forward filter manifold, there are two long branches and two short branches. Each long branch has two orifices on either side of the trunk, and each short branch had one orifice on either side of the trunk, for a total of twelve orifices. The lengths of each branch do not include the diameter of the manifold trunk. To calculate the spacing between orifices, the team first divided the branch lengths (not including the diameter of the trunk) by two. That value was then divided by the number of orifices per branch divided by two plus one. Since the number of spaces on each half branch had to be one more than the number of orifices, the team divided the length of half of each branch by the number of spaces on each branch. This ensured that one could measure the space to the first orifice from either the trunk or the end of the branch, and the locations of the orifices would stay the same.

Finding distance between orifices

Forward Filter Manifolds

$D_{FwTrunk} := 1.5\text{in}$

$$L_{FiBranchFw} := \begin{pmatrix} 18.368 \\ 26.632 \\ 26.632 \\ 18.368 \end{pmatrix} \text{cm} - D_{FwTrunk}$$

$$S_{OrificeSpacingFw} := \frac{\frac{L_{FiBranchFw}}{2}}{\frac{N_{OrificePerBranch}}{2} + 1} = \begin{pmatrix} 3.639 \\ 3.804 \\ 3.804 \\ 3.639 \end{pmatrix} \cdot \text{cm}$$

Orifice spacing for just one half of the branch, or one side of the manifold

Spacing can be measured either from the ends of the branches inward or from the trunk outward.

Backwash Manifold

$D_{BwTrunk} := 3\text{in} = 7.62 \cdot \text{cm}$

$$L_{FiBranchBw} := \begin{pmatrix} 20.358 \\ 25.751 \\ 25.751 \\ 20.358 \end{pmatrix} \text{cm} - D_{BwTrunk}$$

$$S_{OrificeSpacingBw} := \frac{\frac{L_{FiBranchBw}}{2}}{\frac{N_{OrificePerBranch}}{2} + 1} = \begin{pmatrix} 3.185 \\ 3.022 \\ 3.022 \\ 3.185 \end{pmatrix} \cdot \text{cm}$$

Figure 20: The Mathcad code used to calculate the spacing between the orifices in the forward filter manifolds.

Due to head loss through the orifices, either the diameters of the orifices may have to be increased or the number of orifices on each branch may have to be increased. Additionally, the spacing may be changed.

Finally, the branches were inserted in respective trunks, the pipe caps were placed on both ends of each branch and one end of each trunk, and everything was glued together. This was to ensure that the branches and caps were watertight.

Figure 21: The final manifolds were tested for sizing in the trunk and glued to close any gaps.

SJM: [Probably want some kind of header here. Also why is the font size in table 2 twice as large as in table 1?]

Manifold Specifications and Materials

Table 1: Manifold Specifications

Manifold Type	Component	Quantity	Inner Diameter (in)	Length (cm)
Forward Filter	Trunk	6	1.5	26.7
	Long Branch	12	0.5	26.632
	Short Branch	12	0.5	18.368
Backwash	Trunk	1	3	24.5
	Long Branch	2	0.75	25.751
	Short Branch	2	0.75	20.358

Table 2: Materials Used in Manifold Fabrication

Part Description	Item Number	Quantity	Price per Unit
1.5” Rigid PVC Pipe	48925K95	5 ft	\$7.20
0.5” Rigid PVC Pipe	48925K91	5 ft	\$2.88
0.5” Slotted PVC Pipe			
3” Rigid PVC Pipe	48925K97	5 ft	\$19.70
0.5” PVC Pipe Cap	4880K51	30	\$0.27
0.75” PVC Pipe Cap	4880K52	10	\$0.32
1.5” PVC Pipe Cap	4880K55	6	\$0.78
3” PVC PVC Pipe Cap		2	
13/16” Hole Saw	4066A15	1	\$5.25
1 1/16” Hole Saw	4066A19	1	\$5.47
Average Total Costs			\$41.28

Manifold Pipe Stubs and Ferncos

Pipe stubs were fabricated to be glue into the column. They were designed to have 1.6 cm on the sticking out on the inner side and 4.9 cm sticking out on the outer side. The thickness of pipe is 1 cm so the total length of each pipes stub is 7.5 cm. 6 were fabricated, one for each manifold, excluding the backwash pipe.

Regular size ferncos were used on the outer side to connect the pipe stub to the plumbing.However, on the inner side smaller ferncos were made so compensate for the smaller amount of space allowed in the column. They were fabricated by cutting off the outer lip with a bandsaw and cutting 2.8 cm above the previous cut. Each regular sized fernco can make 2 smaller ferncos.

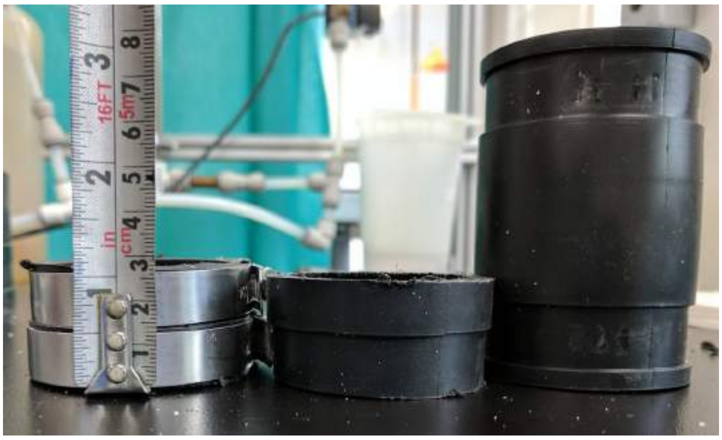

Figure 22:

The backwash pipe stub is 8.5 cm and requires a different fernco that is 2.7 cm, just long enough for two hose clamps. It is a smaller than previous ferncos because the larger diameter makes it harder to stay flat against the ESTaRS curved walls.

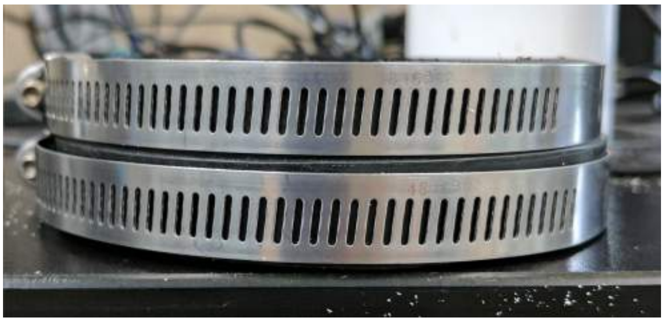

Figure 23:

Entrance Tank, Exit Tank, and Plumbing

Entrance and Exit Tanks

The entrance and exit tanks from the previous iteration of the EStaRS, the LFSRSF, worked very well and provided no issues upon operation of the filter, so their design was replicated this semester. The two components required for each tank were the walls, just large diameter PVC pipe, and the base, a 0.5 inch thick PVC sheet (see Figure 3 for the LFSRSF entrance tank).

The pipe size used for the wall for each tank was determined by the number and size of connecting pipes that must be attached to it. The connections to the LFSRSF's entrance tank included three 1 inch pipes that fed into the filter trunk, one 2 inch pipe that both fed into the trunk and also supported all the backwash flow, and a single 1 inch pipe that delivered water from the source (a pump in the case of the LFSRSF) to the entrance tank. The Fall 2013 team determined that these five pipes (four 1 inch, one 2 inch) could all fit within a 6 inch pipe, and therefore decided to use 6 inch pipe as the wall of their entrance tank. The LFSRSF's exit tank required five 1 inch connections: three pipes coming out from the filter, one to carry the filtered water out of the filter module, and one to carry away backwash water. These five 1 inch pipes also fit within a 6 inch pipe, and the Fall 2013 team decided once again to use 6 inch pipe for their exit tank. This semester, the EStaRS team determined that the plumbing pipe size of the LFSRSF (1 inch pipe), caused problems in flow distribution between manifolds (discussed above in the Filter Trunk section, as a result of switching from flexible tubing to rigid piping). Therefore, the plumbing pipe size was increased to 1.5 inch, which resulted in an 8 inch entrance tank (see Figure 24).

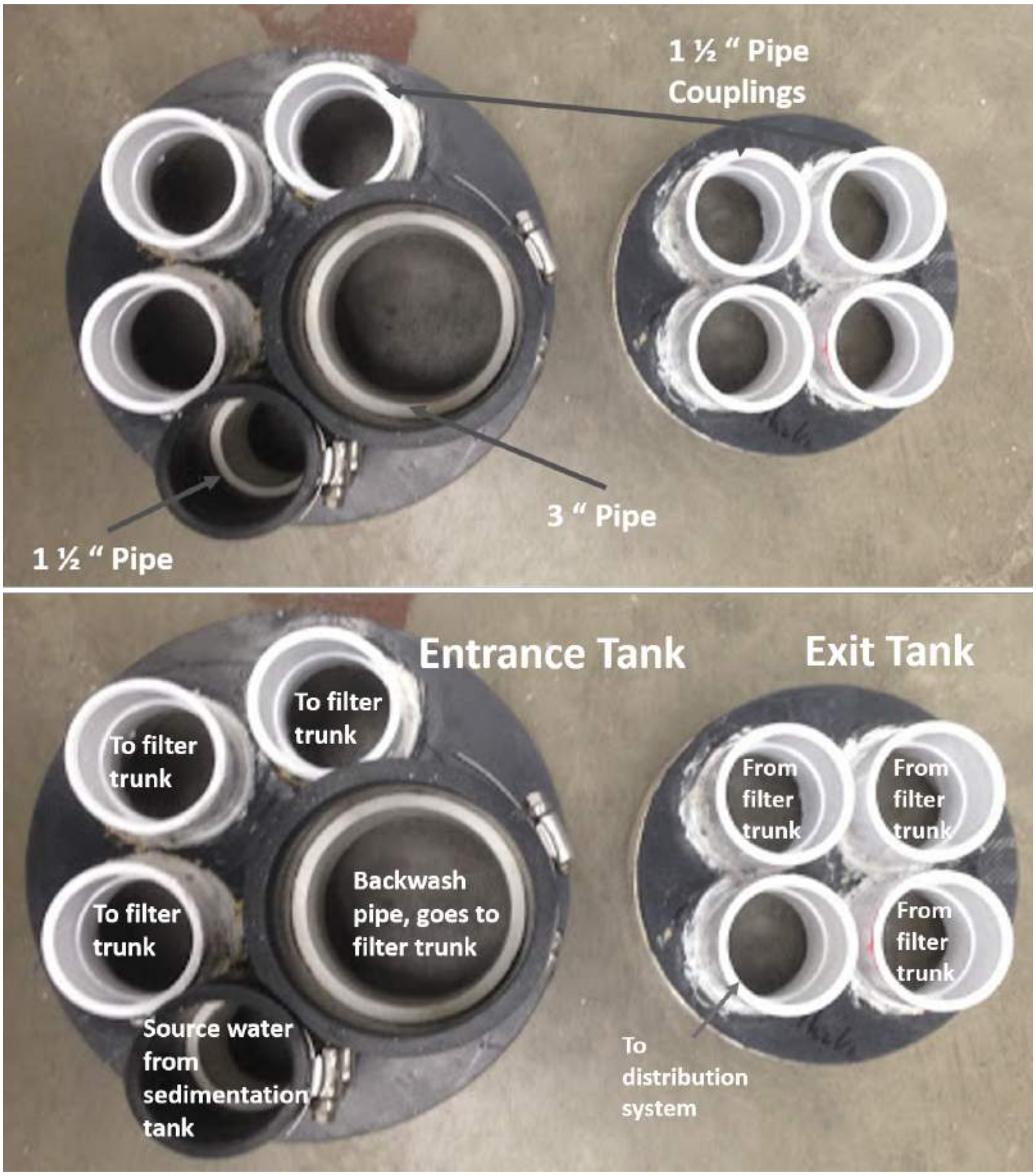

Figure 24: These are the current bases for the EStaRS entrance (left) and exit (right) tanks. The entrance tank is larger than it was in the LFSRSF (8 inch as opposed to 6 inch) since the plumbing pipe size had to be increased from 1 inch to 1.5 inch, and the backwash trunk size went from 2 inch to 3 inch for reasons explained above in the 'Filter Trunk' section. Due to this size increase, the plumbing pipes no longer fit within a 6 inch PVC pipe, so the team used an 8 inch pipe instead.

Tank Walls

Fabricating the entrance tank of the EStaRS filter system first required the team to size and cut 8 inch pipe. After calculating the difference between the maximum head loss during backwash (110 cm) and the height of the effluent pipe of the 1 LPS plant's sedimentation tank (183 cm), it was determined that the length of the entrance tank would be 73 cm. This length represents the maximum possible length of the entrance tank, as it needs to be at least 110 cm above the ground to provide the head necessary for backwash, and the water level in the tank can never exceed the height of the sedimentation tank's exit launder. After marking the pipe with the method shown in Figure 9, a small hole was drilled along the marked line to make an entrance for the jigsaw blade to begin the cut. A flexible rubber coupling (fernco) was placed a distance of 3.5 cm away from the hole onto the pipe to guide the path of the jigsaw while cutting (see Figure 25).

Figure 25: The pipe was marked 73 cm from one end and a fernco was placed 69.5 cm from the end to serve as a guide for the jigsaw. This 3.5 cm difference is to account for the distance between the blade and the outer wall of the jigsaw.

The team paid special attention while using the jigsaw, but did not realize that the blade was being bent off course during the cut. Almost a quarter of the way through the cut, the blade's path began tilting towards the fernco, and if the team had continued in this manner, the finished cut would have been very crooked. Thus, the blade was swapped for a far stiffer one (Figure 26) and cutting began in the opposite direction from the initial, soft-bladed cut. Using the new blade, the cut lined up properly. Fabrication with the jigsaw in the future should always go slowly, stopping incrementally to see if the cut is straight.

The 6 inch PVC pipe that was the LFSRSF's exit tank was reused as the EStaRS exit tank, so no fabrication was required to create it.

Figure 26: The smaller blade used initially (right) became slightly bent over the course of the cut. This slight bend dramatically changed the trajectory of the cut, despite the use of the fernco as a guide. The new, blade (left) proved stiff enough to resist bending and yielded a pure cut.

Tank Bases

The other component to the entrance and exit tanks was a PVC sheet-based bottom. PVC sheets come from suppliers as rectangles, so the team requested the help of Tim Brock of the CEEMS to turn rectangular, 0.5 inch thick PVC sheets into two circles whose diameter was the same as the outer diameter of the 6 and 8 inch pipe. This was done on a lathe. In addition to simply turning the circles, a 0.125 inch deep incision was made along the thickness of the outer diameter of the circle (new thickness of 0.375 inch). The length of this incision went from the circle's outer diameter to the inner diameter of the PVC pipe that the circle would rest on (the incision can be seen in the right hand side of Figure 27. The purpose of this was to allow the circle that would become the base to fit more tightly into the entrance tank.

After the sheets were turned, circles were drawn to outline where the holes were going to be (the size and amount of holes in each tank are shown in Figure 24). Notice that some of the holes in Figure 24 have couplings and some are just PVC pipe. The holes that have couplings are intended to have pipe within the entrance tank. By virtue of having couplings, the flexibility of the design is increased. If the pipes within the entrance tank are the incorrect size, they can merely be taken out, cut the the correct size, and replaced. The two holes in the entrance tank that are simply pipe are for backwash and the influent water. There is no need for these paths to have pipe in the interior of the entrance tank, so couplings were not used. Figure 27 shows the entrance tank base after cutting all 5 holes, in addition to the drill press and setup used to make them.

Figure 27: The drill press and setup used to clamp the entrance tank base (left) and the base once all holes were cut (right). The single hole labeled 1 was cut with a 1.875 inch hole saw. The three holes labeled 2 (in addition to all four holes in the exit tank) were cut with a 2.25 inch hole saw, and the hole that will fit the backwash piping, labeled 3, was made with a 3.5 inch hole saw.

Finally, two inches were cut off of both the entrance and exit tanks and welded onto their respective bases. This is because the mechanism by which the base was to be connected to the walls (the rubber gaskets shown in Figure 1) was incredibly difficult to make watertight with such a small surface area to clamp. By adding the two inches of pipe wall to the bottom of the base, it became far easier to create a watertight seal with the gasket, as the hose clamp had much more surface area on which to clamp. A clear picture of the two inches of pipe welded onto the base is shown in Figure 28.

Figure 28: The entrance and exit tanks were cut a few inches short in order to weld those few inches onto the base. This allows for a much improved watertight seal with the gasket method.

Spacers

The last step to finishing the entrance and exit tanks was fabrication of the PVC spacers that would connect the tanks to the main filter trunk (shown in Figure 4 for the LFSRSF). With the purpose of maximizing efficiency, the team re-used the top section of the LFSRSF filter trunk, which already had the spacers for the 6 inch exit tank fabricated and attached (Figure 29).

Thus, only the two spacers for the entrance tank were fabricated. 0.5 inch thick PVC sheets were used, as 0.5 inches was the thickness of the LFSRSF's spacers, and was deemed strong enough to support the tanks without buckling.

Figure 29: This is the top half of the LFSRSF, cut to the size needed by this semester's EStaRS team. It has two gray PVC frames, referred to as spacers, glued onto it. The purpose of these spacers is to allow for the entrance and exit tanks to be secured onto the main filter trunk. The team decided to reuse the 6 inch spacers (and therefore the whole top half of the trunk) since they are difficult to fabricate.

The two spacers for the entrance tank were made with two 1 foot by 1 foot by 0.5 inch PVC sheets. Two partial circles were drawn onto each sheet, one for the 12 inch filter trunk and one for the 8 inch entrance tank. To mark the semicircles, each pipe was placed on top of the sheet and the outer diameter was drawn directly onto the sheet (Figure 30). One third of the diameter of the circles was the arc length chosen based on the LFSRSF's spacers.

Figure 30: A spacer before being cut (shown left). Partial circles are drawn to fit be able to fit the 12 inch filter trunk and the 8 inch entrance tank. Once the spacer is cut on the band saw, the drum sander (shown right) is mounted on the drill press and used to smooth the cut and ensure a tight fit between the spacer and the two pipes it will space.

Once the first spacer was cut on the band saw and perfected with the drum sander, it was used as a template for the second spacer, which followed the same fabrication procedure. The two spacers are shown in figure 31.

Figure 31: The two spacers overlayed on top of each other.

Next, the completed entrance tank spacers were welded onto the filter trunk at the same height as the already-attached exit tank spacers. They were placed such that the entrance and exit tanks would be exactly opposite each other along the filter trunk. Figure 32 goes into more detail as to how the spacers were welded.

Figure 32: The first spacer was welded by securing it to the filter trunk with hose clamps (shown left). Once it was secured, a level was placed on top of it to ensure that it was secured perfectly perpendicular to the trunk. The second spacer was secured by clamping it to the entrance tank to guarantee that the entrance tank would line up with both spacers (shown right).

Finally, both tanks were placed on the spacers and secured to each other and the filter trunk with two hose clamps. The completed filter (without the manifolds in the interior or plumbing) is shown in Figure 33.

Figure 33: The EStaRS without the manifolds or the connective plumbing.

Connective Plumbing

The connective plumbing for the EStaRS filter system requires 4 elbows for the highest inlet, 5 elbows for the middle inlet, and 6 for the lowest non-backwash inlet. Because EStaRS plumbing pipe sizes increased from the previous iteration, the orientation in which the plumbing was connected deviates slightly from the AutoCAD drawing. The middle inlet sticks out and turns closest to the tank wall so that it is almost being hidden by the plumbing of the highest inlet. The lowest inlet sticks out the furthest and uses 5 elbows before running alongside the backwash plumbing.

The outlet plumbing was changed from the original CAD drawing to save space and material. The fist outlet sticks out so that it is in the middle of where the second an dhird outlet plumbing leads. The second outlet runs the furthest from the filter column and the third outlet runs the closest. Unlike the inlet plumbing, the oulet plumbing is constructed with pipes that are angled as opposed to those that are just orthogonal to each other. This was done so that there would be less turns, saving elbows.

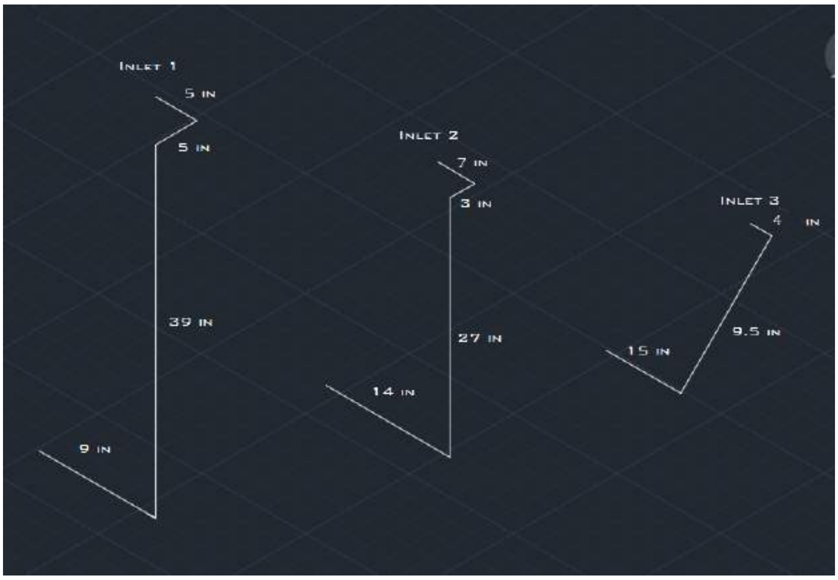

Figure 34: An AutoCAD image with all the dimensions of the 1.5 inch pipe needed to construct the plumbing. This does not show the change the angle of the 3rd and 4th elbow of the middle inlet's plumbing.

Figure 35: EStaRs with it's inlet plumbing installed. The top inlet is the same as in Figure 36 with 4 elbows except it goes into a diferent inlet. The middle inlet plumbing turns left before turning down to avoid contact with the bottom inlet's plumbing using 4 elbows and sits below the backwash pipe. The bottom inlet, using 3 elbows, slopes down until it sits on top of the backwash pipe

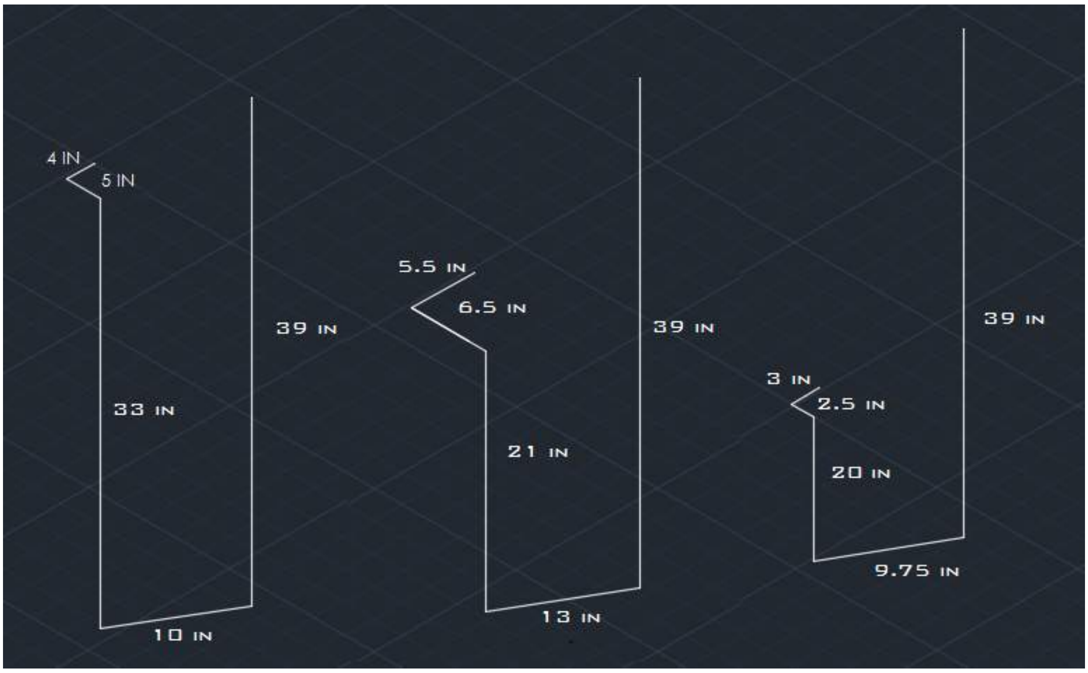

Figure 36: An AutoCAD image with all the dimensions of the 1.5 inch pipe needed to construct the outlet plumbing. This shows the approximately 30 degree bend away from the column each of the paths take.

Figure 37: EStaRs with it's outlet installed. Each of the outlet paths only require four elbows and is wrapped as tightly as possible to save space and piping.

Future Work

The manifold design was recently updated to include bigger orifices intended to lower the headloss, as previously calculation for orifice size was found to be incorrect. However, due to time constraints, the manifold orifices will only be redesigned if a backwash test fails as a result of the orifices.

Manifold orifices aside, only the exit tank plumbing and manifold insertion into the trunk are required to complete the EStaRS. Once it is complete, it will be connected to the 1 L/s plant in the AguaClara lab and used to conduct research. Having an entire, complete, and functional water treatment plant opens up many avenues for potential research interests.

References

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Task Map

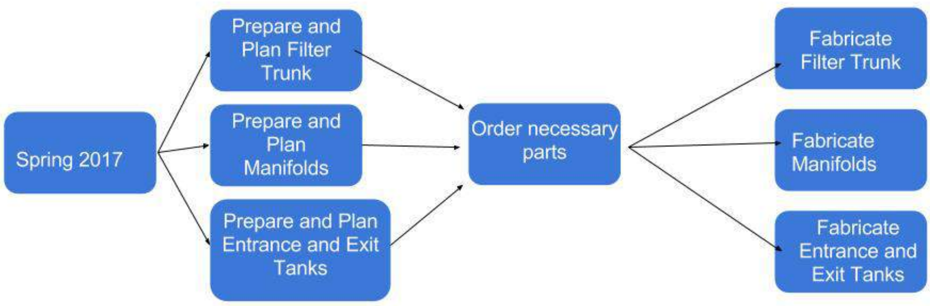

Figure 38: EStaRS Task Map Spring 2017

Semester Schedule

Task List

Team 1 - Anna and Lilly

1. Finalize manifold dimensions. (February 17) - Anna and Lilly. The team will finalize the dimensions of the pipes needed to construct the inlet, outlet, and backwash manifolds.

2. Order parts (February 25) - Anna and Lilly. The team will order the pipes necessary to build the manifolds.

3. Fabricate (March) - Anna and Lilly. Throughout March the team will work on fabricating the inlet, outlet, and backwash manifolds.

Team 2 - Felix and Juan

1. Finalize trunk dimensions and connecting pipe sizes (February 22) - Felix and Juan. Ensure functionality of the spatial geometry of the trunk and connective piping (from entrance box to filter and filter to exit box). Mark locations along trunk where manifolds will be inserted.

2. Order parts and piping (February 25) - Felix and Juan. The team will carefully consider each component necessary to create the connective piping and the joint between the connective piping and the manifolds.

3. Fabricate (early March) - Felix and Juan.

Full Team

1. Prepare and plan entrance and exit boxes (mid March) - Full team. Determine external geometry, internal piping structure, and method of connection to the filter trunk.

2. Order Parts (late March) - Full team. Order parts for both boxes and for how to fix them to the filter trunk.

3. Fabricate (early April) - Full team. Finish filter fabrication.