EStaRS Filter, Fall 2016

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Abstract

The EStaRS team's goals for this semester were to design a new EStaRS filter that was compatible with the recently built 1 L/s plant. The 1 L/s plant's sedimentation exit elevation provided a height constraint of 6 feet and required a scaled-down version of the existing EStaRS filter. The team first worked to gain a complete understanding of EStaRS filter design and operation using experiences and observations recorded by previous teams. MathCAD calculations from the AguaClara design server were adjusted for the new design and AutoCAD drawings were created to provide a completed design that was ready for fabrication.

Introduction

Design and construction of a 1 L/s plant contributed to AguaClara's mission of providing safe drinking water to communities that were too small for the existing water treatment plant designs. These smaller communities in both rural India and Honduras needed plants with low flow rates, which challenged AguaClara to design low flow versions of the entire treatment train. Filtration was deemed a necessary component of the low flow plant to catch any sediment or contaminants that escaped flocculation and sedimentation. The Enclosed Stacked Rapid Sand Filters (EStaRS) was created by AguaClara as a way to significantly reduce the amount of space required for filtration and has undergone testing since 2012. The existing EStaRS filter, however, was too large for the 1 L/s plant and therefore needed to be scaled-down. The Fall 2016 EStaRS team built upon previous research by examining what did and did not work in the existing design, exploring different options for fabrication, and seeing how the EStaRS filter could be constructed within the height constraint provided by the 1 L/s plant.

Literature Review

In contrast to traditional sand filters, the EStaRS filter operates through multiple layers of stacked sand with embedded inlet and outlet manifolds (Weber-Shirk, 2016). As shown in Figure 1 from the Fall 2012 report, water flows into the inlet pipes during filtration and either flows upward or downward into the nearest outlet pipe (Gupta et al., 2012). The slotted pipes are designed to allow water to enter while keeping sand out. As particles from the influent water get trapped in the layers of sand, the efficiency of the filter decreases and it is necessary to backwash the filter by opening only the bottom inlet, which has a larger diameter to accommodate the higher flow. As the filter fills with water from the bottom inlet, pressure builds up and the bed fluidizes, allowing water to be siphoned out through the backwash outlet near the top of the filter.

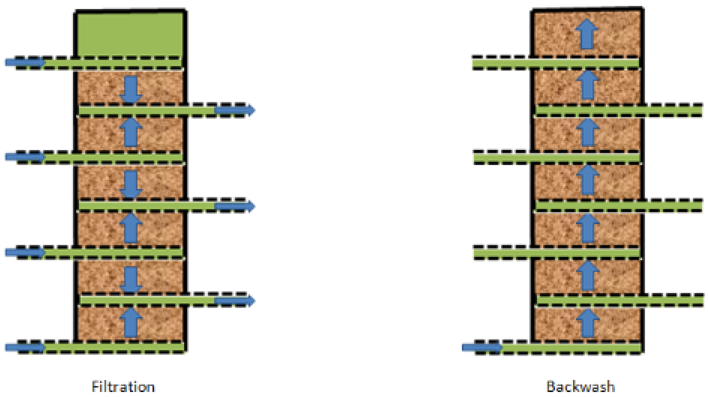

Figure 1: Flow Through the Filtration and Backwash Modes

EStaRS filters offer not only an inexpensive and electricity-free means to remove particles, but also an efficient means to backwash the filter by creating an upwards flow to fluidize the sand, starting from the bottom layer upward. This method of backwash also requires less water than traditional methods. The EStaRS filters are designed to operate at flow rates lower than 6 L/s, usually around 0.8 L/s.

Previous Work

The EStaRS design team was created in Fall 2012 and their report provided the basic information about filter design and operation (Gupta et al., 2012). Prior to fabricating the EStaRS filter, the 2012 team first needed to model it and make several important calculations. Using MathCAD, four conditions were modeled: filtration and backwash, both with and without sand. The system was first modeled and tested without sand, which allowed for straightforward modifications without the complication of sand. Using the calculations and corresponding dimensions obtained in the MathCAD model, the team was then able to create a model of the design in AutoCAD, shown in Figure 2.

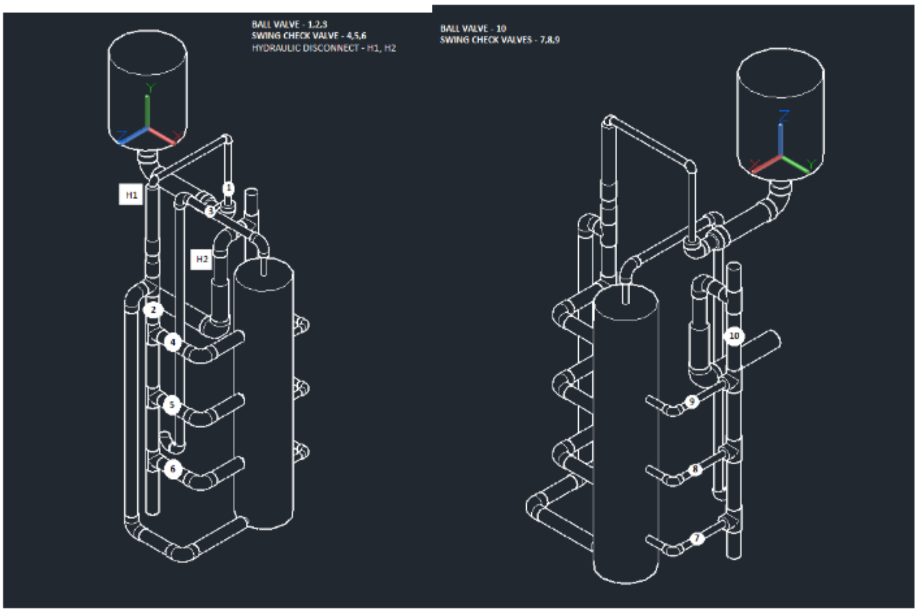

Figure 2: Southeast (left) and Northeast (right) isometric view of the existing Low Flow Enclosed Rapid Sand Filter

Initial models determined head loss through the system without sand in filtration and backwash modes. The system needed to be able to handle the corresponding flows without backing up at the outlets. To determine minor and major head loss through one flow (assuming all six paths are equal) the team calculated the height difference between the water level in the entrance tank and the outlet pipes. During filtration, the head loss without sand was calculated to be 39.68 cm. The following equations were useful for modeling this, with (1) and (2) corresponding to filtration and backwash, respectively.

$$Q_{Total} = \sum Q_{ParallelPath} \tag{1}$$

$$Q_{Total} = Q_{Filtration} * 6 \tag{2}$$

To model the system more realistically, the team also needed to calculate the head losses in a system with sand. In filtration, head loss, which was predicted to be 14.28 cm, was calculated as the distance between the bottom of the filter and the second outlet. In backwash, head loss was calculated as the distance between the bottom of the filter to the water level of the backwash pipe outlet. Some other equations that were useful are the major and minor loss equations used for modeling fluids:

$$h_f = f * \frac{L}{D} + \frac{V^2}{2g} \tag{3}$$

$$h_e = K_e * \frac{V^2}{2g} \tag{4}$$

The Fall 2012 team that designed and fabricated the original EStaRS filter included specific information about some components of the filter (Gupta et al., 2012). These components were either redesigned due to issues during fabrication or are additional components that assist with testing and verification.

The backwash pipe was reconstructed in order to reduce the amount of head loss. The diameter was first expanded from 1 inch to 1.5 inches. The o-ring diameter and thickness were also both increased and holes were cut to allow the o-ring to fit over protruding bolts. In addition, an NPT fitting and flexible tube were attached to alleviate air bubbles building up in the system. The team also changed the type of valves used from spring valves to swing valves, which resulted in lower minor losses.

To assist with testing, the previous EStaRS fabrication team recommended that a pitot tube be installed inside the filter. The pitot tube should be located at the first outlet pipe for the set-up without sand and at the bottom inlet pipe for the set-up with sand. Verification of the fluidization process had also been a concern for past teams and is discussed in a later section. The original EStaRS team installed a small diameter PVC pipe inside the filter that stretched through its entire length and out the top (about 5 feet long). If the filter was fluidizing properly, the pipe would be loose and could be moved by the operators. The usefulness of this addition was inconclusive at the time, leaving it as a potential option to re-explore.

One of the problems that previous EStaRS teams had was figuring out how to check if the filter bed was fluidized during backwash operation. The manometer system that was installed, shown in Figure 3, proved to be unreliable during operation, so the addition of a clear PVC window was considered. The main concern with this idea was the potential cost and the availability of clear PVC (Mottl et al., 2016).

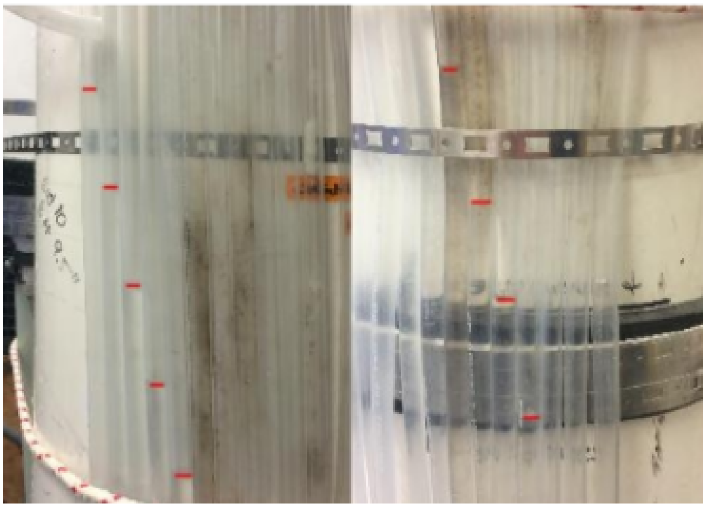

Figure 3: Manometer Setup from Spring 2016

Also during the backwash process, another problem was the introduction of air bubbles in the filter. This produced additional head loss, according to manometer measurements, so it was necessary to find a way to make the filter air-tight.

In addition, it was required to compute and coordinate times for backwash and forward filtration: maximum possible filtration until backwash is needed, and necessary backwash to continue with the filtration operations. During the transition between the two processes, backwards flow can occur. That has to be avoided as much as possible, because this causes reverse flow into the inlets. One solution to the sand blockage was to add ball valves to the inlets so they could be closed off during the backwash process.

Methods

The work of past years was very helpful for acquiring additional data and insights, particularly the existing MathCAD calculations, found on the AguaClara Design Server. In addition to past reports, the AguaClara Source Code for the EStaRS filter (StackedRapidSandFilterLow) was the team's main tool in the creation of the new filter design. A greater understanding of the system as a whole was achieved by analyzing the parts that are currently being used for the EStaRS filter and why they were being used. To do this, the team took apart the non-functional laboratory prototype built by previous teams. As shown in Figure 4, sketches of the different filter components were drawn according to the current measurements. These sketches gave the team insight into the proportions of different components that needed to be scaled down as well as the constraints created by interactions between various parts.

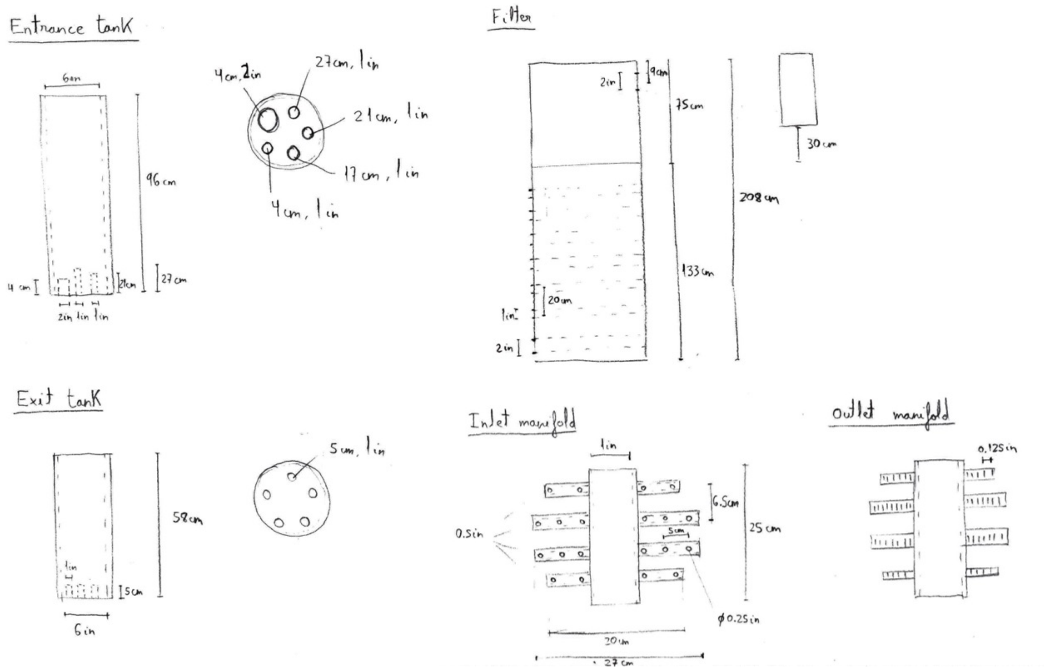

Figure 4: Sketches of Previous EStaRS Geometry

Understanding the MathCAD code and accessing the necessary formulas to complete it allowed the team to determine the design parameters that were needed for fabrication of the filter. The main limiting parameter was the height of the sedimentation tank outlet manifold on the 1 L/s plant, which feeds into the filter's entrance tank. This was measured on the 1 L/s plant built in the lab as 6 feet, shown in Figure 5. Additionally, the head loss through the 1 L/s plant was reported as 25-30 cm.

Figure 5: Sedimentation Outlet of 1 L/s Plant

While initially the team had planned to reduce the filter height by reducing the height of the filtration layers, it seemed unlikely that the filter would operate at high enough efficiency if the layers were reduced from 20 cm to 10 cm of sand. Another idea for reducing the total filter height was to split the flow from the 1 L/s plant into two filters that act side-by-side, each with four 20 cm sand layers. This plan added the challenge of being able to backwash at a high enough velocity to fluidize the bed in each filter. A possible solution was to attach valves to the pipes going into the entrance tank that would allow all the water to flow into one filter for higher velocity backwash.

Upon further investigation of the reduced filter layer height option, the team determined that one filter could be constructed to meet the height constraint of

6 feet if the filter layers were 15 cm. This was chosen as the preferred alternative since it was less complicated than the two filter design. In addition, having only one filter would assist with the goal of making the 1 L/s plant modular (one of each component in the treatment train) and therefore easier to construct. While the team believed that 15 cm would be an adequate amount of sand for successful filtration, fabrication and subsequent testing will determine if this is actually the case.

Once the one filter design was selected, the team split into pairs to focus efforts on certain areas of the filter. One pair was devoted to the inlet and outlet designs, including developing the manifold systems and brainstorming techniques to fabricate the inlets and outlets with rigid PVC pipe rather than flexible tubing. The second pair was dedicated to filter body design, focusing determining the sizes of filter components that were needed for fabrication. The team created diagrams with AutoCAD to determine the viability of each idea and used MathCAD to guide the dimensions of the filter.

Results and Analysis

The results produced by this semester's EStaRS team consist of MathCAD calculations and AutoCAD drawings detailing the new filter design for the 1 L/s plant. The heights, elevations, and diameters of the filter, inlets, outlets, siphon, entrance tank, and exit tank were determined based on the calculations performed in MathCAD and modeled in AutoCAD. Additional information can be found in the associated files.

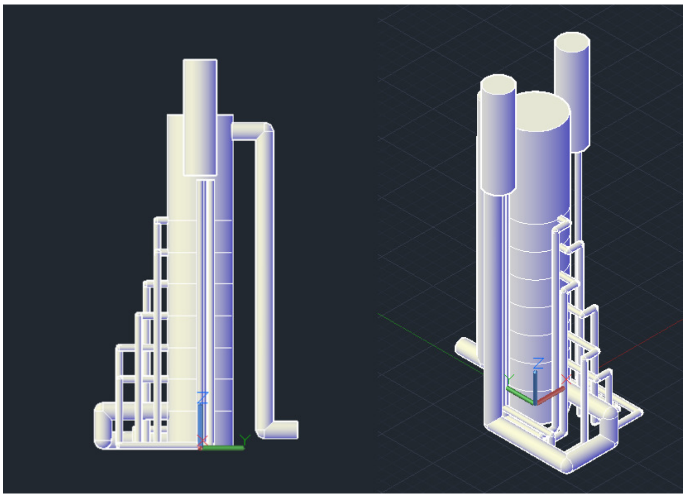

Figure 6: New EStaRS Geometry - Filter Profiles

The new filter body, shown in Figure 6 was designed with the same main components as the original filter. 12 inch diameter, white PVC pipe was selected again for the body since this is one of the largest available sizes of PVC piping. 6 layers of 15 cm sand were needed for adequate filtration, which therefore required four inlet pipes (including one for backwash) and three outlet pipes.

The inlet manifolds distribute water evenly throughout the sand layer where it is filtered before entering the outlet manifolds. The team used observations of the existing filter's manifolds and decided to continue using four branches on each manifold. The minimum trunk and branch diameters were changed in the MathCAD file from 2 and 1 inch, respectively, to match the existing manifold diameters of 1 inch for trunk and 0.5 inches for branches. Since the filter body pipe diameter was not changed from the existing filter and the manifolds aim to cover as much of the cross-sectional area as possible, the new manifold dimensions are similar to those found in the existing filter.

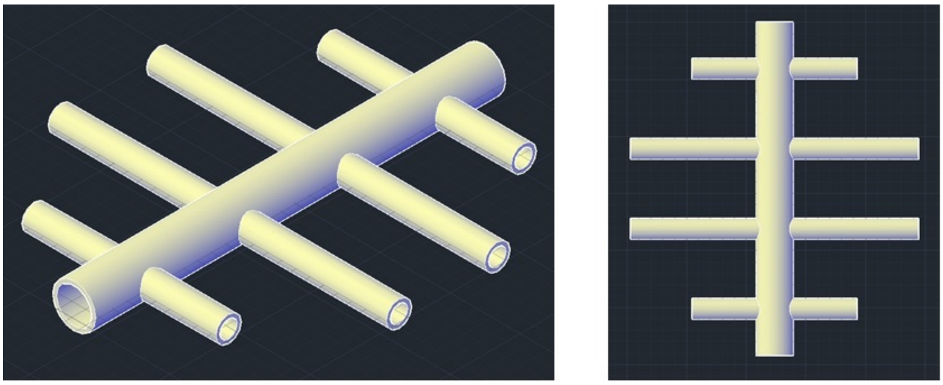

Figure 7: New EStaRS Geometry - Forward Filtration Manifold

The new forward filtration manifold design, shown in Figure 7, had a trunk diameter of 1 inch and branch diameters of 0.5 inches. The trunk length was approximately 29 cm with the first and fourth branches extending out 7 cm on either side and the second and third branches extending out 12 cm. Spacing between the branches was calculated as 7 cm.

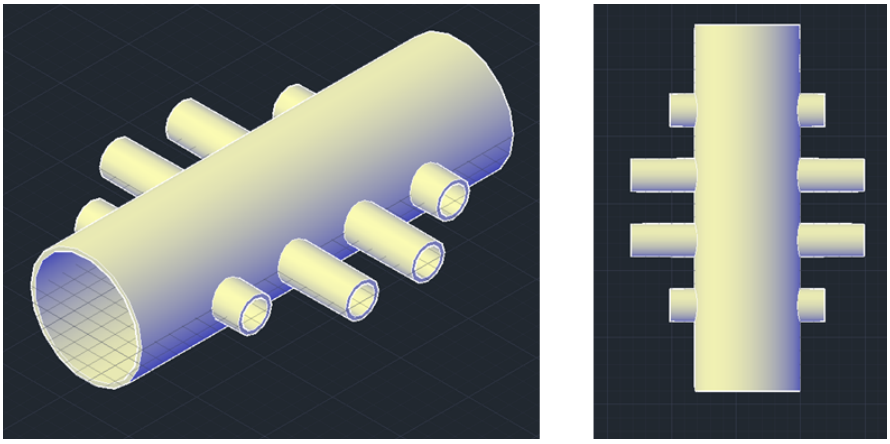

Figure 8: New EStaRS Geometry - Backwash Manifold

The new backwash manifold design, shown in Figure 8, had a trunk diameter of 3 inch and branch diameters of 0.75 inches. The trunk length was approximately 27 cm with the first and fourth branches extending out 6 cm on either side and the second and third branches extending out 9 cm. Spacing between the branches was calculated as 4.9 cm.

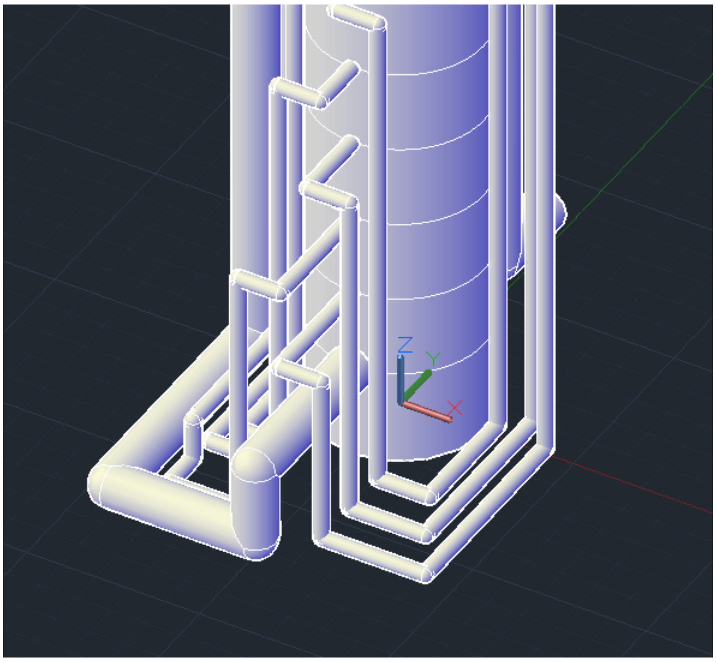

Figure 9: New EStaRS Geometry - Pipework Detail

The inlet and outlet pipes were designed to have the same diameter as their associated manifolds to allow water to pass evenly into the sand layers. The layout of these pipes presented the main challenge for creating the AutoCAD drawings. One of this semester's challenges was to design the filter with non-flexible PVC pipes instead of flexible tubing, a transition that required a more careful design of the pipe layouts. Each pipe must reach ground-level before entering the filter in order to avoid suctioning air into the filter. Figures 6 and 9 show the design of the new filter in profile and a close-up view on how the pipe are overlaid. The pipes were designed to be a minimum of a quarter inch distance apart in order to account for error. Most pipes are at least half an inch apart.

The configuration of the entrance tank, exit tank, and siphon were rearranged from the original EStaRS design as shown in Figure 6, allowing more room for the non-flexible tubing. The entrance and exit tank diameters were not changed and set as 6 inches for the new design. The entrance tank height was calculated as 54 cm.

Fabrication Specs for 1 L/s Plant:

$Z_{FiEntWeir} = 1.873\,m$	$Z_{FiInlet1} = 1.075\,m$
$Z_{FiInletDrain} = 1.843\,m$	$Z_{FiOutlet1} = 0.925\,m$
$Z_{FiOverflowWeir} = 1.833\,m$	$Z_{FiInlet2} = 0.775\,m$
$Z_{FiEntTank} = 1.291\,m$	$Z_{FiOutlet2} = 0.625\,m$
$Z_{FiEntChannel} = 1.291\,m$	$Z_{FiInlet3} = 0.475\,m$
$Z_{FiExitTank} = 1.291\,m$	$Z_{FiOutlet3} = 0.325\,m$
$Z_{FiTop} = 1.572\,m$	$Z_{FiInlet4} = 0.175\,m$
$Z_{FiBwPipe} = 1.459\,m$	$Z_{FiBottom} = 0 \cdot cm$
$Z_{FiSiphonOutlet} = 0.95 \cdot cm$	

Figure 10: New EStaRS Geometry - Elevations

Given that the goal of the new EStaRS design was to reduce the total height to under 6 feet, the elevations section of the MathCAD file was heavily used. The exact specifications of the new filter elevations are provided in Figure 10. The team hypothesized that the elevation of water in the entrance tank during steady state backwash must be greater than the elevation of the siphon entrance in the filter body. This design passes this requirement, calculated below.

$$ZW_{FiEntBwSS} - Z_{FiBwPipe} > 0$$
$$1.491m - 1.459m = 0.032m$$

Elevations of entrance components were calculated by starting with the height constraint and working down the filter. The entrance tank and exit tank were different heights but had the same bottom elevation of 1.291 m. The siphon outlet was also calculated top down to ensure that there would be adequate head loss during steady state backwash without discharging water below ground level (Z=0).

The main filter body elevations were calculated from the bottom (ground level) upwards to the top of the filter. Necessary fabrication components were factored in at the top and bottom of the filter. The inlet and outlet layers were calculated 15 cm apart due to the size of each sand layer. An additional 30 percent of total sand depth was added as space for fluidization during backwash. This led to a total filter body height of 1.572 m from the ground.

Conclusions

The Fall 2016 EStaRS team was tasked with determining if AguaClara's existing filter design could be modified to conform with the height requirements of the newly fabricated 1 L/s plant. After thoroughly researching the work of previous teams, a filter design featuring six 15 cm layers of sand was created. Fabrication and testing will determine if this design performs as well as the larger version, but the team's results indicate that it is possible to scale down an EStaRS for a 1 L/s flow rate.

The completion of the MathCAD document specifies the design parameters that will allow fabrication of the filter to begin. In addition, it was possible to transition from flexible to PVC pipe tubing. The viability of an EStaRS filter that is compatible with the 1 L/s plant allows for smaller communities in Honduras to have access to clean water. Previously used exclusively in India, the filter can now be used in Honduras as well.

Future Work

Next semester's team should be focused on completing the fabrication of the filter and performing preliminary tests to discern how well the filter removes turbidity when connected to the 1 L/s plant. The design and dimensions for the filter can be found in the MathCAD and AutoCAD files uploaded to the Fall 2016 EStaRS Google Drive folder and should assist with the fabrication process.

Future teams should continue to address fabrication challenges that were not investigated this semester. This includes finding a way to visually verify fluidization of the sand bed during backwash, potentially by adding glass sights to the filter body. Also, efforts should be devoted to addressing problems from past semesters, such as experimenting with less tedious ways to fabricate manifold slots while still preventing sand from entering. See the Fall 2016 Challenges document for more issues that past teams have had with fabrication, which will be relevant next semester.

References

Gupta, M., LaPan, K., and Proske, R. (2012). Enclosed Stacked Rapid Sand Filtration - AguaClara - Dashboard.

Mottl, N., Bowen, M., Mendoza, L., and Marroquin, E. (2016). Enclosed Stacked Rapid Sand Filtration - AguaClara - Dashboard.

Weber-Shirk, M. (2016). Filtration Theory - Filtration.pdf.

Semester Schedule

Task Map

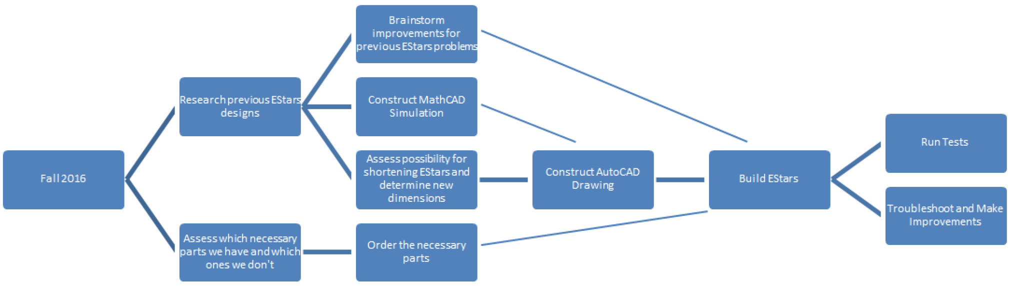

Figure 11: Task Map Fall 2016

Task List

1. **September 9:** Completed Detailed Task List and Update Wiki Page (individual and team)
2. **September 14:** Complete research of previous Estars designs and assessment of necessary parts.
3. **September 16:** Complete Literature Review.
4. **September 19:** Order the filter body
5. **September 23:** Complete Research Report 1 and Progress Report.
6. **October 21:** Complete Research Report 2 and Progress Report.
7. **October 24:** Complete presentation for symposium.
8. **October 28:** Complete midterm peer evaluation. Update Individual Contribution Page.
9. **November 2:** Complete MathCAD simulation.
10. **November 11:** Complete Research Report 3.
11. **November 28:** Complete AutoCAD drawing
12. **December 2:** Complete Final Report Draft.
13. **December 11:** Complete Final Report, Final Presentations and peer evaluations.
14. **December 11:** Upload Final Presentation and Final Report on team wiki page.