Foam Filtration

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Originally, the foam filtration system was designed to provide clean water to small-scale communities. The system was also designed to provide water in emergency situations such as a refugee camps. The system was ideally powered by gravity and the optimal filtration rate was made to be 3 L/min. For the Spring 2013 semester, the foam filtration team began fabricating a new system and recording the process of the new system. The previous filtration system was designed and shipped to Honduras in January 2013. The current design focuses on pieces readily acquired in-country. This allows feasible construction in Honduras and, potentially, other developing countries. Products such as 8020 steel, clear PVC piping and flexible tubing have been removed from the design because they cannot be easily found outside of the US. The foam filtration team this semester is also working on making the design more compact for easy transportation. Additionally, the foam filtration team designed a new compact stand of PVC piping to hold the filtration system. The team included a larger collection tank to allow for the incorporation of a linear dosing system.

Introduction & Background

The foam filtration system previously used for testing was designed to make data collection easier and research more feasible. Now that the parameters and design effecting the performance of the filter are better understood, the team is seeking to make a support frame and develop fabrication techniques so that the filter can be built and used in country. The previous foam filtration system was taken to Honduras during January 2013 to be field used and tested. This semester, the team was focused on the fabrication of a second foam filtration system with a support frame that could be built with locally available tools and materials. Pieces for this filter were ordered from McMaster-Carr and constructed and assembled in the AguaClara lab. Throughout the process, the team has been compiling a list of ordered pieces and a corresponding price list1. The new filter has gone through preliminary testing in the lab. An accurate list of necessary pieces to assemble a foam filter will exist along with documentation as to how the filter and frame were assembled.

The unit of measuring foam density is pores per inch (ppi). The higher the number of ppi, the more dense the foam is. The first foam filtration design consisted of a single column of 90 ppi foam. The design also utilized a peristaltic pump to transfer the water to the filter. The subsequent foam filtration teams have worked to understand how foam filters work to establish parameters that could be used for a better design. To avoid clogging the 90 ppi foam column when filtering extremely turbid water, the filter column has been divided into two processes: the roughing and finishing filtration. The water is first filtered by two 30 ppi foam columns to get rid of large particles and then sent through the 90 ppi foam column for filtration of finer particles. Up until the Fall 2012 semester, the filtration system has been reliant on a pump to move water from the tank through the filters.

This newly designed system features a larger entrance tank allowing for the addition of a linear chemical doser. This system required the creation of a new linear flow orifice meter (LFOM). The LFOM allows for a constant chemically dosed flow with respect to water input. This semi-automatic system requires minimal interaction to provide constant dosing. This process makes the system more independent and easier to manage. To keep the filters from building up head loss and effluent turbidity from exceeding standards, the foam filters have to be periodically cleaned. A "plunger" was made from a long PVC pole attached to a porous disc to clean the filter pieces. This "plunger" allows the foam to be compressed and force the dirty particles through the filter, similar to squeezing out a dirty sponge.

The foam filtration team has primarily been focused on the re-design and re-structuring of a foam filtration system. The greatest challenge thus far has been understanding which pieces will work in which location. Additionally, because there was little literature on the fabrication of the foam filtration system, designs have been created from scratch.

Challenges and Progress

FOAM FILTERS

For the foam filtration system there are two roughing filters and one finishing filter. These filters were cut in a $4\,inch$ ($10.16\,cm$) diameter circular shape and kept at the original height of $14.75\,inches$ ($37.5\,cm$). Past foam filtration teams determined that when using a $4\,inch$ ($10.16\,cm$) diameter filter, the approach velocity that produced the best removal efficiency was $6\,mm/s$. This corresponds to $3\,L/min$. Thus $4\,inch$ ($10.16\,cm$) Schedule 40 PVC pipes were ordered as holders for the foam filters.

For the filters, 2 roughing filters (30 ppi) and 1 refining filter (90 ppi) were used that were ordered from New England Foam by past foam filtration teams. 3These foam pieces have a height of 14.75 inches ($37.5\,cm$) and with a square face that is 4 in x 4 in. These pieces were cut as close to a 4 inch ($10.16\,cm$) circular diameter as possible using a band saw. In order to prevent preferential flow in the filter, which would reduce the removal efficiency, the foam needs to

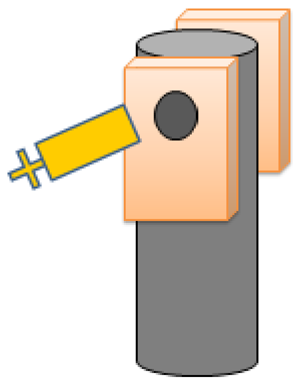

Figure 1: Method for puncturing foam filter to form a hole for threading the string that pulls the filter up after cleaning.

fit tightly against the wall of the PVC. Because it is difficult to cut the foam in a perfectly circular shape, filters resemble octagonal objects in shape.

Once the filters have been cut into their circular shape, a hole is punctured horizontally across the top of the filters using a corer. This is done by clamping the foam between two wood blocks, with a 0.5 inch (1.27 cm) hole drilled into one wood block, and puncturing the foam using the corer once the foam is secure as shown in Figure 1 below. This hole should be 0.5 inches (1.27 cm) in diameter. This hole will be used to thread the string through for cleaning and measuring purposes. A 0.5 inch (1.27 cm) diameter 4 inch (10.16 cm) long piece of flexible clear PVC was put into the hole of each filter to act as a barrier against the string, so it will not damage the filter as it is being pulled up after cleaning. A string with a plastic handle was threaded through the hole of the foam filter for foam removal. In order to remove the foam, handle bar is pulled up until the foam filter is free from the PVC piping. To insert the foam, the foam is pushed into PVC pipe as far as possible. To ensure the foam has reached its correct location, it is pulled back up by the string handle. On the string, there are markings which demonstrate that the foam is at the correct depth. These markings must be drawn on during construction. To create markings, thread the foam with string of ample length. Push the foam filter to the bottom of the pipe; check at bottom of PVC pipe to ensure foam is at bottom and fully expanded. Mark string length. Repeat for all filters. No specific height can be provided because string lengths vary based on the height of the PVC piping.

The 4 in diameter PVC pipes, used to support the foam pieces, needed to be cut into two segments; one for the roughing filters, one for the finishing filter. The roughing pipe must be at least the height of the two roughing filters. A

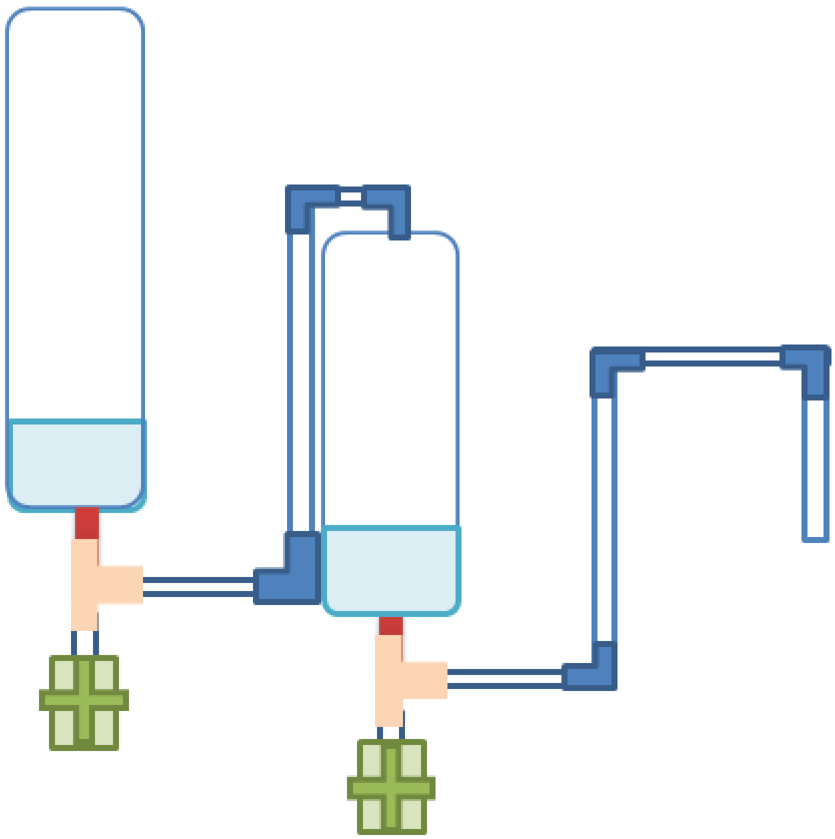

Figure 2: Schematic of connections, piping and joints of foam filtration system without stand.

10 $foot$ long, 4 $inch$ diameter Schedule 40 PVC pipe was ordered from McMaster Carr and cut into appropriate lengths.The roughing pipe is approximately 50 inches (142.25 cm). The refining pipe is approximately 31 $inches$ (78.75 cm). These heights are estimated, as final heights have not been decided. These pipes are connected to each other via $\frac{1}{2}$ in schedule 40 PVC pipe. The height of the connection piping should be at most, the height of the roughing filter. This is to ensure that the water will properly flow to the finishing filter. Below is a schematic of the connections, piping and joints.

STAND

The foam filtration team has redesigned the stand that will hold the foam filtration system. The previous foam filtration system was supported by a steel 8020 frame. Originally, the stand was to be made out of wood, but after consulting

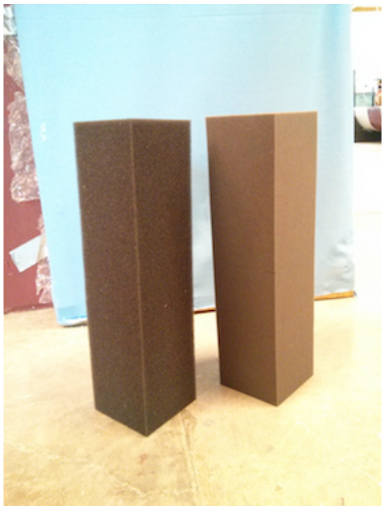

Figure 3: Uncut Roughing and Finishing Foam Filter.

Figure 4: Cut Roughing and Finishing Filter. Filters have been threaded with 1/2 inch hole and string.

the CEE shop, it was determined that PVC piping would be a more suitable material. Unlike wood, PVC will not warp from contact with water and it is more readily available in the Honduras. However, PVC does become more brittle when exposed to UV light. Since the foam filtration system will be located outside, we recommend that a shade for the foam filtration system be available. As a result, the foam filtration stand was redesigned to be built out of $1\frac{1}{2}\,in$ PVC piping connected with appropriate tees and elbows. Appropriate parts for the stand were ordered and consisted of 4 $1\frac{1}{2}\,in$ PVC pipe at a 10' length, 4 $1\frac{1}{2}\,inch$ 90 degree elbows, and 20 $1\frac{1}{2}\,inch$ tees. To prepare the construction of the filtration system, appropriate piping that connects the two filters was ordered as well. The parts consisted of 3 $\frac{1}{2}\,in$ tees, $8\frac{1}{2}\,in$ 90 degree elbows, 1 10' length $\frac{1}{2}\,in$ PVC pipe, 1 low-pressure $\frac{1}{2}\,in$ ball valve, $1\frac{1}{2}\,in$ standard-wall white PVC pipe fitting with a male adapter and a female socket, and a$\frac{1}{2}\,in$ diameter $3\,inch$ longthreaded nipple.

The stand design consists of 4 H-shaped rungs constructed out of $1\frac{1}{2}\,in$ PVC piping and tee fittings, with each rung rotated 90 degrees from the one below it. The rungs are attached and stacked upon one another through $1\frac{1}{2}\,in$ PVC piping and fittings. When determining the length of the stand piping, the diameter of the filters and connecting pipes were taken into consideration. This stand has been adapted to hold the entrance tank. The entrance tank rests on the leg which holds the roughing filter. The stand is not currently designed to hold the chemical stock tank. Space has been left on the highest rung to accommodate the chemical stock tank that will be added in the future.

Stock Tank

The goal of creating a larger stock tank is to provide enough space to implement the linear dosing system. With an increase in the size, the weight which controls the doser for coagulant will be able to fit more easily inside the stock tank. The stock tank was increased to be able to hold 3 liters of water and has a diameter of $15.3\,cm$ at the opening. The increase in diameter still allows for an linear flow orifice meter (LFOM) in the stock tank and also provides an opening for the coagulant doser weight to measure the height of the water. MathCad files were interpreted for optimization of new LFOM sizes and requirements for the linear dosing system. Because there has not been a linear dosing system designed for such a small operating system, this area requires more research. As the previous model did not use a linear chemical doser, we are currently working on new designs to incorporate this into the filter system.

The calculations for construction of the LFOM were completed and provided for by Casey Garland using MathCAD. The calculations were based off of a $1\,in$ diameter LFOM pipe with a max flow rate of $4\,\frac{L}{min}$. 9 rows of orifices were calculated. A $\frac{1}{8}\,in$ drill bit is to be used to drill 9 rows of orifices. The number of orifices per row is pictured below.

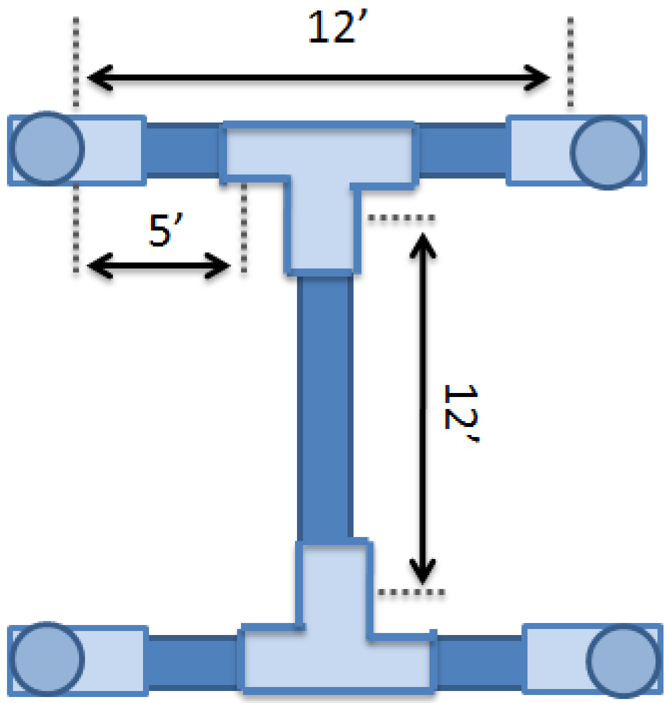

Figure 5: Schematic of a rung. The dark blue represents the PVC piping while the light blue represents the fittings. We decided to start off by cutting 5” long small pieces, and from that, we determined that the middle length needed to be cut at a 12” length to ensure that the rungs will fit on top of one another.

Figure 6: Assembled Stand.

Figure 7: Top of Stand. On the top of the stand, the entrance tank is connected to the leg holding the roughing filter.

$$A_{LfomOrificesTop}(Q_{Plant}, HL_{Lfom}) := Q_{Plant} \cdot \int_{HL_{Lfom} - fB_{LfomRows}(Q_{Plant}, HL_{Lfom})}^{HL_{Lfom}} W_{Stout}(HL_{Lfom}, z)\, dz$$

$$D_{LfomOrificesTopMax}(Q_{Plant}, HL_{Lfom}) := 2 \cdot \sqrt{\frac{A_{LfomOrificesTop}(Q_{Plant}, HL_{Lfom})}{\pi}}$$

```
FloorNearest(number, array) := | x ← number  if  number ≤ array_0
                               | x ← array_last(array)  if  number ≥ array_last(array)
                               | otherwise
                               |   | i ← 0
                               |   | while (number > array_i ∧ i < last(array))
                               |   |   i ← i + 1
                               |   | x ← array_(i−1)
                               | return x
```

$$fD_{LfomOrifices}(Q_{Plant}, HL_{Lfom}, D_{Drill}) := FloorNearest(min(fB_{LfomRows}(Q_{Plant}, HL_{Lfom}), D_{LfomOrificesTopMax}($$

$$fD_{LfomOrifices}(Q_{Plant}, HL_{Lfom}, D_{Drill}) = 0.117 \cdot in$$

$$A_{LfomOrifices}(Q_{Plant}, HL_{Lfom}, D_{Drill}) := \pi \cdot \left(\frac{fD_{LfomOrifices}(Q_{Plant}, HL_{Lfom}, D_{Drill})}{2}\right)^2$$

Figure 8: MathCAD Equations used to Calculate Orifice Positions

	0
0	0.149
1	0.649
2	1.149
3	1.649
4	2.149
5	2.649
6	3.149
7	3.649
8	4.149
9	4.649

·cm

	0
0	3
1	3
2	3
3	3
4	3
5	1
6	1
7	0
8	2
9	0

Number of orifice holes in each row

Figure 9: LFOM Orifice Spacing

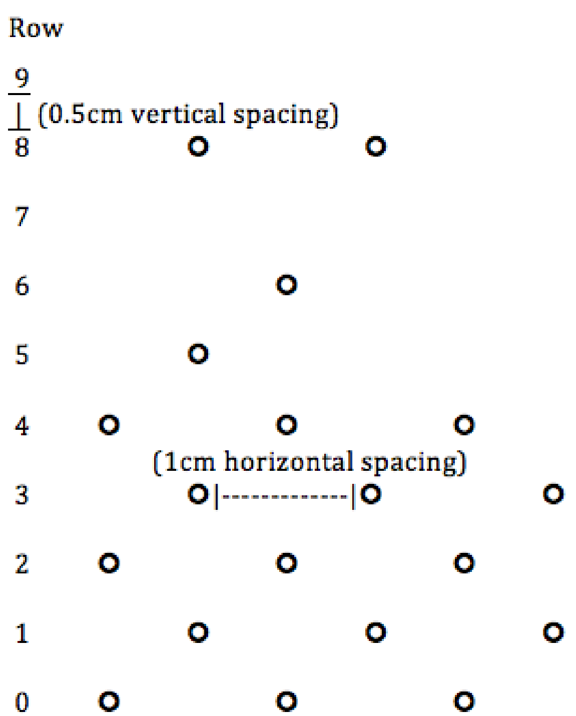

Figure 10: Layout of the orifices drilled in the LFOM of each row.

Material Sheet and Pricing

The following items were ordered from McMaster-Carr.

Conclusion

The piping for the stand has been cut into the appropriate sizes by the CEE shop located in Hollister Hall and assembled by the foam filtration team. The height of the finished stand is based on the raised heights of the roughing and finishing filter. The piping used to transport water between the filters and to the chlorine doser have also been cut and assembled. The LFOM and reservoir tank have been assembled and cut to the appropriate sizes. The piping used to hold the filters have been successfully attached to the stand using hose clamps with leftover foam acting as a padding between the foam holders and stand. Water was run through the system without filters to insure that the stand can support the filter system when in use and to gauge where leaks will occur so they can be sealed in the future. The stand turned out to be stronger and more stable than anticipated since water was successfully ran through the system without the stand tipping over.

In conclusion, the foam filtration team has successfully built a second system and stand for the system.

Future Work

A linear chemical doser for coagulant and chlorine dosing needs to be developed for the system. Originally, the Spring 2013 foam filtration team planned on completing this task but due to time constraints, were unable to do so. Experiments that involve running water at different turbidities need to be performed to determine the cleaning protocol, foam lifetime and filter cleaning requirements.

Item	Item Number	Description of Piece	
4" Sch 40 10' Length PVC Pipe	48925K18	White PVC with standard wall, unthreaded	
4" Sch 40 PVC Pipe Fitting, Cap	4880K58	Standard wall, 4" Sch 40 white PVC pipe fitting, female threading added	
3-7/8" Flange with 3/4" Pipe Fitting	4596K153	Thick wall, schedule 80, dark gray PVC, 3/4" female threading	
3/4" Sch 80 5' Length PVC Pipe	48855K22	Thick wall, dark gray PVC, male thread on one side	
1-1/2" Sch 40 10' Length PVC Pipe	48925K15	Standard-wall, white PVC, unthreaded	
1-1/2" Sch 40 PVC Fitting, Elbow	4880K25	90 degree elbow PVC pipe fitting, white	Attac
1-1/2" Sch 40 PVC Fitting, Tee	4880K45	PVC pipe fitting. white	Attac
1" Male Adapter, Female Socket x NPT Male	4880K63	Standard wall, Sch 40, female socket to male thread adapter	
1/2" Sch 40 PVC Pipe Fitting, Tee	4880K41	Standard wall, white PVC, unthreaded	Attachi
1/2" Sch 40 PVC Pipe Fitting, Elbow	4880K21	90 degree elbow PVC pipe fitting, unthreaded	Attachi
1/2" Sch 40 10' Length PVC Pipe	48925K11	White PVC with standard wall, unthreaded	Transport
PVC Ball Valve, 1/2" Female Threading	4876K11	Low-pressure ball valve, white	A
1/2" Male Adapter, NPT Male x Socket Female	4880K61	Standard wall, Sch 40, female socket to male thread adapter	Attaching
1/2" Sch 80 3" Length Threaded Pipe Nipple	9173K53	Short gray piping, with male threading on one side	Attach
Hose clamps		Metal hose clamps of various lengths found around the lab	Attaching

Table 1: Materials and Pricing (based on McMaster-Carr catalogue April 2013)