Fall 2010 Foam Filtration Final Report

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AguaClara Reflection Report

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Abstract

The objective of the foam filtration team is to develop a point-of-use foam filter that can reduce water turbidity to meet EPA standards. The team has focused a lot of its efforts, especially during the beginning of the semester, on designing different aspects of the filter, considering different scenarios where the filter can be used (see Reflection Reports #2 and 3). This semester, the team is submitting an application to the EPA P3 competition; the application is currently being edited and should be completed by the end of the Fall 2010 semester.

Once the experimental apparatus was assembled, the team began gathering physical data on the performance of foam in the filter. Initial head loss measurements through the foam have been completed (see Reflection Report #3), but the head loss over time and the measured head loss that causes compression are in the process of being determined. As for future work, we will layer foam of varying porosities to achieve a more uniform particle removal over the depth of the filter since clay particles are currently being trapped in the uppermost layers of the foam. The foam will also be tested under varying influent turbidities to determine the range of turbidities that the material can effectively filter.

Introduction

After foam filtration was ruled out as a possible filtration method for an AguaClara plant, research was directed towards designing a small scale, point of use filter utilizing polyurethane foam. Our work for the semester has consisted of both design and experimentation. First, the foam filtration team has been working to design a point of use filter that will be constructed in future semesters. Many modifications to the design have been made over the course of the semester in order to make the design more user-friendly. Additionally, the team conducted several

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g to get the best filter performance. **With this greater understanding of how foam filtration works through experimentation, our team will be able to design an optimized point of use foam filtration unit.**

Experimental Design

Over the course of the semester, several experiments were conducted. Each used the same experimental apparatus, some with slight modifications. The first experiment we conducted determined the head loss through the foam with clean water running through it. While most of our experimental data is collected using process controller, we decided not to use the computer for this experiment. Previous work had indicated that head loss through the foam was almost insignificant, meaning that the noise from a pressure sensor reading would be significant compared to the head loss measurement. We therefore decided to measure the head loss visually (see Reflection Report #3). This was done by setting the outlet height at a specific point and marking the equilibrium point of water in the foam column. The pump was then turned on and provided a constant flow velocity of 4 mm/s. When the water height came to equilibrium, the difference between the original and new water height corresponded to the head loss in the foam and filter column. The same experiment was conducted with no foam in the column and the two values were subtracted to determine the head loss in the foam. This test was run with both 60 and 90 ppi foam. 'Ppi' stands for pores per inch and repesents the porosity of the foam. Lower ppi foam will have a higher porosity.

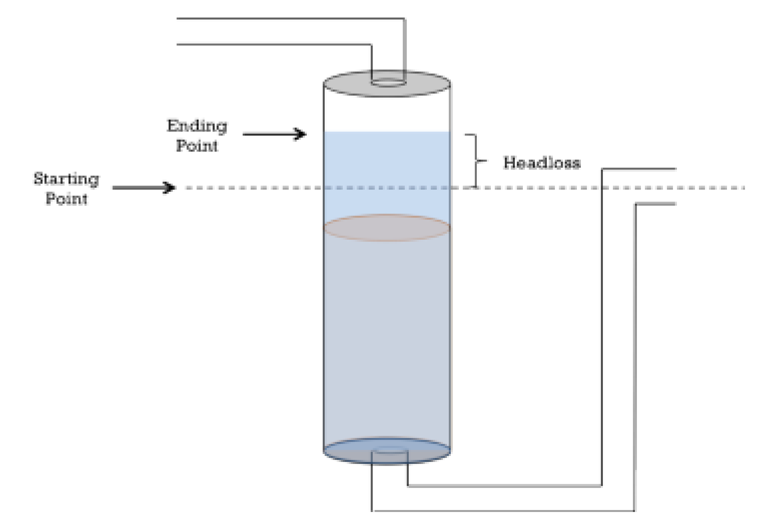

Figure 1: Head Loss through Foam

The second round of experiments utilized the full experimental apparatus (see Reflection Report #1). Temperature controlled water was dosed with kaolin clay to provide a specific influent turbidity (5 NTU). The influent water was then dosed with alum and then pumped into the filter column at a flow velocity of 4 mm/s. Because we are using a peristaltic pump, it is necessary to use a flow accumulator to lessen the pulsing effect of the pump and provide a more constant flow rate to the filter. The experimental appar a tus is a downflow filter which is representative of what the actual point of use filter will be. A one inch foam column is used and foam depth for all experiments was 10 inches ;- t his was achieved by using 10- 1 inch foam slices. Effluent turbidity was mon i t o red along with the pressure difference across the foam column.

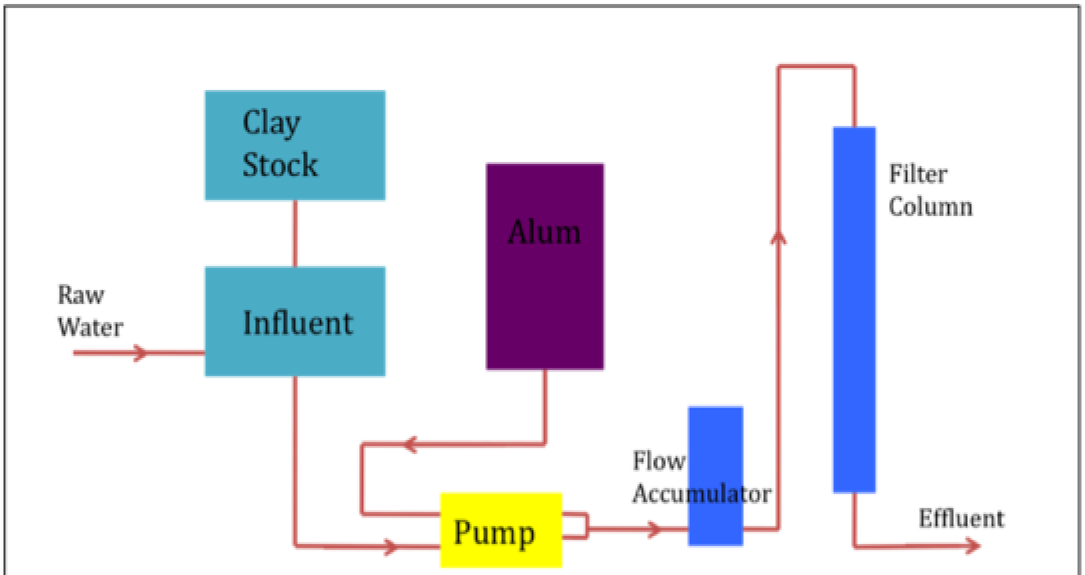

Figure 2: Foam Filtration Experimental

The first set of experiments run using this experimental set up was to monitor the head loss across the foam filter (see Reflection Report #5). At failure, the foam collapses and we wanted to measure the head loss as a function of run time until collapse occurred. It was important that no air bubbles were in the system to get an accurate pressure reading, which was difficult due to dissolved air in the water as the weather got colder . Tests were run using both 60 and 90 ppi foam, however the foam never collapsed because air bubble buildup occurred in all experiments. Because of the air bubble build up, these experiments must be rerun in order to obtain accurate results.

The second set of experiments considered the layering of foam porosity. We hope that by doing this we can improve filter performance by either lowerin g effluent turbidity or by extending the time the filter can run and produce effluent turbidities below 0.3 NTU. The first test that was run consisted of

3 inches of 90 ppi foam on the bottom, then 5 inches of 60 ppi foam and 2 inches of 30 ppi foam. Based on results from this test, discussed in the *Results and Dis*

cussion section below, the layering was slightly altered in order to find the optimal layering, if such a layering exists.

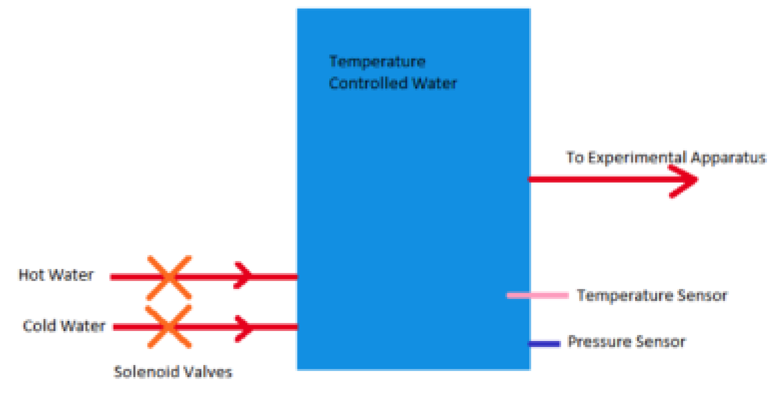

Figure 3: Temperature Controlled Water

All experiments utilized temperature controlled water that is stored in a distribution tank separate from the experimental apparatus. Temperature controlled water ensured that differences in temperature would not affect our results.

Results and Discussion

The Foam Filtration team has spent much time designing a point-of-use filtration unit. The unit is designed so that the dimensions can be linearly scaled up or down to successfully filter enough water for a given amount of people. Our group has documented the five different cases for which our point-of-use can be used (see Table 1).

Table 1. Different cases for point-of-use filtration unit design

Case	Family Unit with Water Distribution System	Family Unit without Water Distribution System	Apartment Building with Water Distribution System	Business / School with Water Distribution System (without shower)	Small Village without Water Distribution System (only drinking)

Number of Expected People Using the Filter	7 people	7 people	50 people	50 people	200 people
Average Water Consumption per Person per Day	120 L/day	50 L/day	120 L/day	40-45 L/day	3 L/day

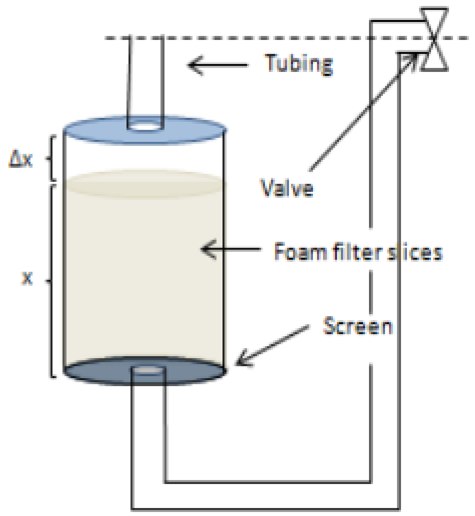

Figure 1. Sample sketch of current filter column

For the cases with a water distrib ution system , the filtrati on unit will be directl y connec ted to a tap, while for these cases withou t water distrib ution system s, a holdin g tank will be necess ary and the filter unit can then be attache d by plastic tubing. The filter colum n itself will consist of one inch stacked layers of foam to produce a foam depth of ten inches total. Two-inch spacing in the column above the foam is anticipated (see Figure 1) as this is expected to give the influent water a sufficient amount of volume to distribute itself evenly over the foam layers and to avoid a concentration of flow though the center of the foam, as would happen if there was zero spacing. For more information, see Reflection Report 2.

We recently changed the design of our unit in that we are now going to use the exit tubing height as a method of both combating the head loss that will occur though the filter as well as to control the approach velocity within the unit so that it remains a constant 4 mm/s.

If large amounts of head loss occur, the foam layer in the filter column will collapse and performance of our filtration unit will suffer. After water flows through the filtration column, chlorination dosing will occur at . 1125 mg/L. This chlorination dose is based on calculations that downscaled the dosing that currently occurs in AguaClara plants to fit our point-of-use unit design. See Reflection Report 1 for more information and further explanation. Mixing will take place by inserting elbows into the tubing, and the treated water should flow into a holdin g, distribution tank (see Figures 2 and

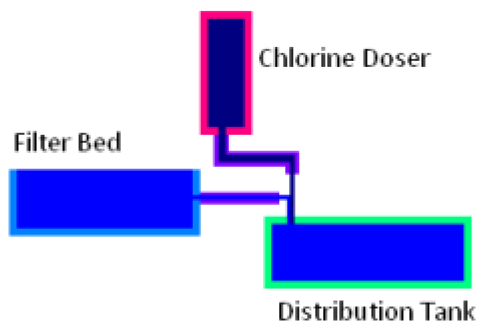

Figure 2. Overall schematic if water distribution system is available.

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Our group created a MathCAD file takes user input of approach velocity, number of people expected to use the filter, as well as amount of water used per person per day and outputs the required filter column diameter (and corresponding foam diameter) needed to achiev e filtrati on of the spe cified amoun t of water. The progra m then iterates throug h tube diamet ers availab le for purcha se and outputs the nearest larger diamet er that will actuall y be needed . O rifi ce sizing for inlet and exit tubing is then calcula ted as well. For exampl e, a small village of 200 people using 3 L /day will require a column diameter of 2 inches and orifice sizing of 2.6 mm.

The first experiment completed this semester was a head loss experiment. We were able to determine the head loss through our filter column (see Table 2).

Table 2. Head loss through 10 inches of foam at 4 mm/s

	Experiment One	Experiment Two
60 ppi	2.1 cm	1.9 cm
90 ppi	2.8 cm	2.6 cm

We were also able to create another MathCAD file that could calculate theoretical head loss through any filter unit design given filter column diameter and length as well as tubing diameter and length (including the number of 90 degree elbows). The algorithm supports our experimental results.

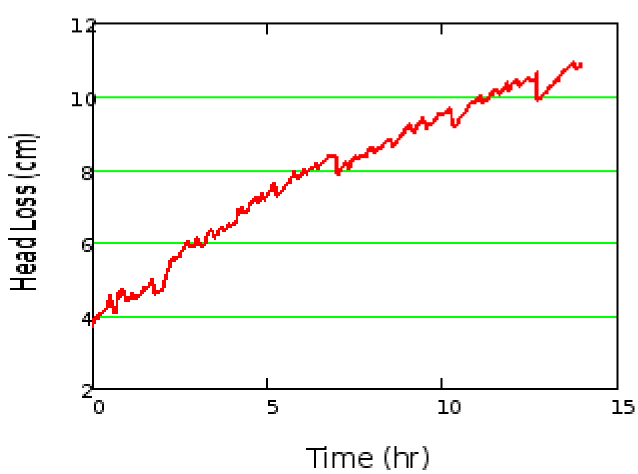

Figure 4. 60 ppi foam at 10 inch depth with incorrect alum

After the head loss experiment was successfully administered and all of the glitches within our experimental system were eliminated, we began running experiments to determine filtration performance using a 4 mm/s approach velocity. First we experimented with 60 ppi (pores per inch) foam to determine head loss at failure. Most of our experiments were ruined because of the introduction of air pockets in our column. Apparently, experimentation during winter months is extremely hard due to dissolved air within the water. Hence, we were never able to determine the head loss at failure, but instead were able to get sufficient data showing the correlation between head loss over time (see Figure 4). The data shows an apparent linear relationship between the time that the experiment is running and head loss accumulation. This trend will be helpful in determining an estimate for how long our experiments can successfully run before failure.

However, these experiments with 60 ppi foam cannot be compared to previously obtained results over the summer because we discovered that the alum dose we were using had not been adjusted correctly. Over the past summer, we ran experiments using an alum dose of 1.5 g/L with 6 mm/s water velocity. For our first few experiments this semester, we used the same alum stock concentration, but with a lower flow rate, which resulted in a higher alum dose. This is what lead to the lower effluent turbidities. This error was fixed so that results from summer 2010 could be compared with those from the fall.

We have not yet run an experiment with the correct alum dose with 60 ppi foam. However, we were able to run one experiment using the correct alum dose that was targeted toward discovering layering effects with different pore per inch foam. We layered the foam using two one-inch thick slices of 30 ppi foam at the top, five one-inch thick slices of 60 ppi foam in the middle, and three one-inch thick 90 ppi foam at the bottom. From experience, we know that larger pore sizes should be located at the top of the filter and smaller pore sizes should be located at the bottom of the filter to avoid clogging and ensure depth filtration occurs .

The layered experiment shows promising results (see Figure 5). The effluent turbidity remained under 0 .3 NTU for approximately one day and could have possibly remained under EPA standards for a longer period of time. Unfortunately, our experiment was cut short due to a mass power-outage on Cornell campus. Therefore, we can not compare these results to the summer's 90 ppi trials as of yet. Nevertheless, the use of both 60 ppi foam and layered foam show great potential to be successful within our designed filtration unit.

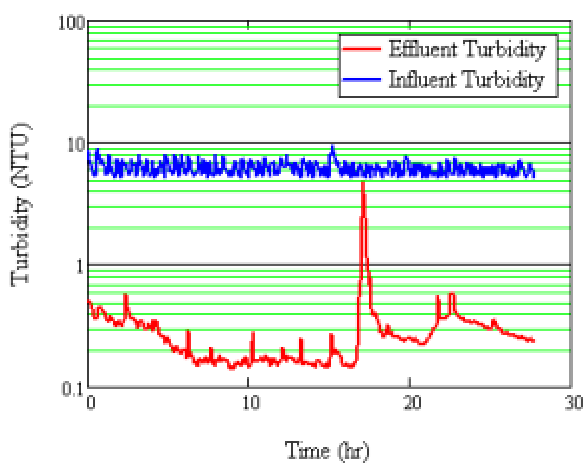

Figure 5. Layered foam at 10 inch depth with correct alum

Future Work

Next semester, the foam filtration team will need to continue running experiments. Due to experimental apparatus issues throughout the semester, we were not able to run all of the experiments we planned. First, the team will need to run an experiment until collapse occurs and get a head loss reading. The team had trouble completing this experiment because dissolved air in the water would build up over the course of the experiment (60 hours). This will not be an issue in warmer weather, and the experiment can be more easily completed in the spring of 2011.

Another set of experiments that must be run is the layering of different pore sizes of foam. We hope that by varying pore size between 60, 90, and 30 ppi, we can lower effluent turbidities and increase run times. Smaller pore sizes (larger porosities) would be on the top and the larger pore sizes will be on the bottom. The optimal depth of each pore size is what must be determined. Since effluent turbidities are extremely low and turbidimeter readings are only accurate above 0.2 NTU, the main way we will compare layering alternatives will be to compare the length of the run time in which effluent turbidities are below a set level (1 NTU or 0.3 NTU).

Additionally, the foam filtration team will need to investigate the effects of varying the influent turbidity. Previous work was conducted using 5 NTU water, which corresponds to the effluent for an AguaClara plant. However, now that the team is focusing on designing a point of use system, it will be important to know the range of turbidities for which the filter can produce clean water. This will be necessary for providing instructions for people using the filter. Experiments will gradually increase influent turbidities and we will see at which influent turbidity the foam filter can no longer produce an effluent turbidity less than 0.3 NTU or the run time is less than 24 hours. With turbidities at this failure level, the filter will no longer function in a way that is convenient or safe for the user.

In addition to experimentation, the team will also need to continue work on the design of the point of use filtration unit. Preliminary designs have been developed, but they need to be improved. Additionally, we want to build a prototype and run tests on that to ensure that the unit is running properly. Important things to consider in the design are delivering a constant flow rate through the foam and that the unit is easy to operate and clean.

Team Reflections

At the beginning of this semester, our team had trouble with assembling the experimental apparatus from scratch. We also faced several problems with writing the process control file needed to automate our experiments (see Reflection Report #2). Because of the initial problems we faced with the experimental apparatus, our team decided to focus our efforts on the design aspects of the project, as well as applying for project funding through the EPA's P3 competition. Although we were initially unable to gather physical data, a lot had been accomplished in our design work, allowing us to further develop our ideas for the project.

During the assembly of our experimental apparatus, we faced minor technical challenges, including problems from Process Controller, computer wiring and communication, and turbidimeters (see Reflection Reports #2 and 3). Despite this, we were still able to perform head loss experiments and run initial trials with the apparatus. Ever since the experimental apparatus had been finalized, the team became very focused on experimental work. Our team was able to collect a large amount of data on head loss through the foam over time, but we cannot be entirel y confident in the data because of problems experienced with the experimental apparatus. We found that the experiments were interrupted due to the closing of water valves during run time and also due to air entering the filter column as a result of dissolved air within the water source (see Reflection Report #5). Though we have obtained useful data, much more work needs to be done next semester. We are hopeful that the time and effort spent in finalizing our experimental apparatus will pay off in future semesters, allowing us to collect experimental data without any persistent problems.