# Foam Filtration Reflection Report 3

Foam Filtration Reflection Report


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AguaClara Reflection Report
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Abstract

The objecti ve of the foam filtrati on team is to design a foam filtrati on unit that can reliabl y treat the typical AguaC lara effluen t water with a turbidit y of about 5 NTU to a turbidit y of less than 1 NTU. To characterize the performance of 90 ppi polyurethane foam, certain variables were held constant while others were varied in order to find the optimal parameters for foam filtration. Previously, we have conduc ted experiments that varied the flow rates and depths of the filtration unit. An experiment utilizing aluminum hydroxide as a pre-treatment for the foam was also conducted. We propose to continue our perfor mance study of the foam by varying approach velocity, depth, and influent turbidity conditions.

## Introduction

The foam filtration team is currently conducting a performance study of the foam filter. **Our hypothesis is that it is possible to design a foam filtration unit that can reliably treat the typical AguaClara effluent water with a turbidity of about 5-10 NTU to a turbidity of less than 1 NTU or even less than 0.3 NTU (EPA standards); the filtration unit should also be able to achieve a pC* of 0.9, where pC* is a measure of the filters performance (logarithmic percent colloid removal).** Equation 1 shows how pC* is calculated for our experiments:

$$pC^* = -\log\left(\frac{ET}{IT}\right) \qquad (1)$$

where ET and IT stand for effluent and influent turbidity, respectively.

The performance study of our foam apparatus is designed to hold certain variables constant while varying others in order to determine the optimal parameters for foam filtration. Previously, we have varied flow rates and depths of the filtration unit while keeping other values – influent turbidity and alum presence – at a constant. Data for those experiments have been collected and analyzed using Excel and MathCAD. Inconsistencies have been found at specific data points and have prompted us to repeat certain experiments to ensure no mistakes have been made.

We will continue working on our performance analysis with variations in down flow filtration rates and foam depths, and eventually move on to experiments with variations in influent turbidity. Once our performance study is complete, we will determine the optimal parameters of foam filter operation (flow rate and filter depth that consistently deliver effluent water with turbidity  0.3 NTU).

## Materials and Methods

**Control of Parameters and Experimental Setup**

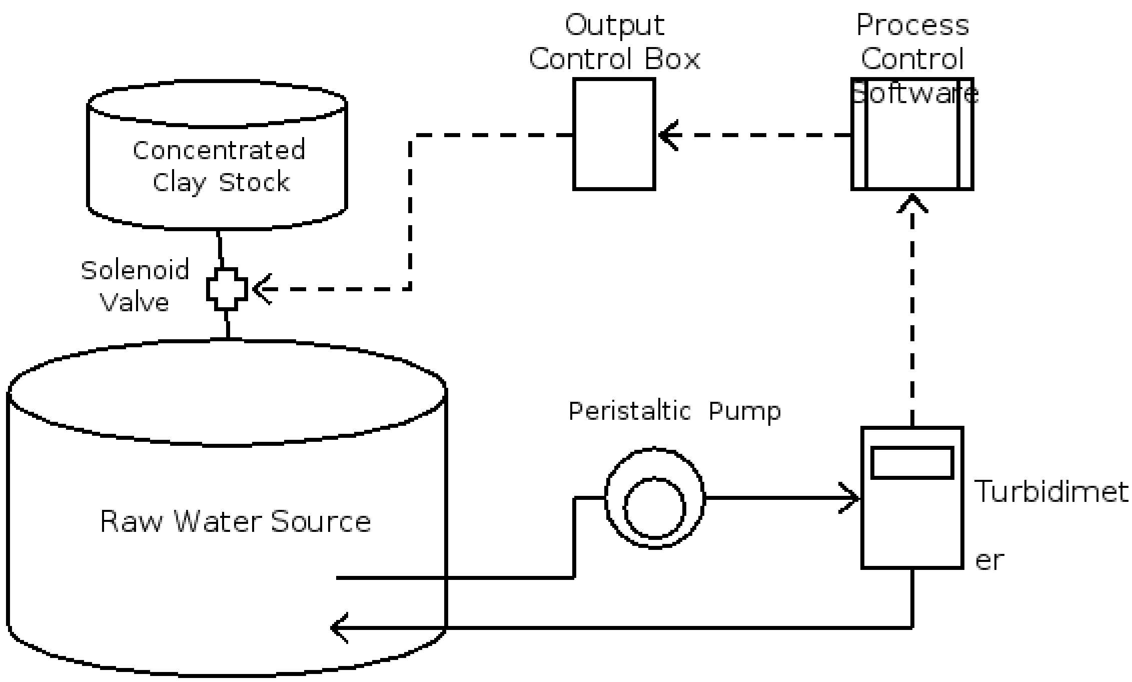


Figure 1. Schematic showing how influent turbidity is controlled using process

Conditions of constant input turbidity were created using a concentrated kaolin clay (R.T. Vanderbilt Company, Inc., CT) suspension diluted with temperature controlled, aerated tap water (Figure 1) to produce a raw water source for experimental trials.

Turbidity was controlled by process control software that compared turbidity readings to the specified target level. If the turbidity in the raw water source tank dropped below the target level, a signal to the output control box opened a solenoid valve allowing release of a small amount of the concentrated clay stock solution into the raw water source.

Raw water was pumped from the source tank to the experimental setup where the desired amount of alum coagulant was then introduce into the raw water line using a computer controlled digital peristaltic pump (Masterflex, Cole-Parmer, USA). The alum coagulant used the experiments was prepared and refilled daily for the duration of the experimental trial. Rapid mix was assumed to occur over the 5 cm length of 4.8 mm-I.D. (inner diameter) tubing (Figure 2).

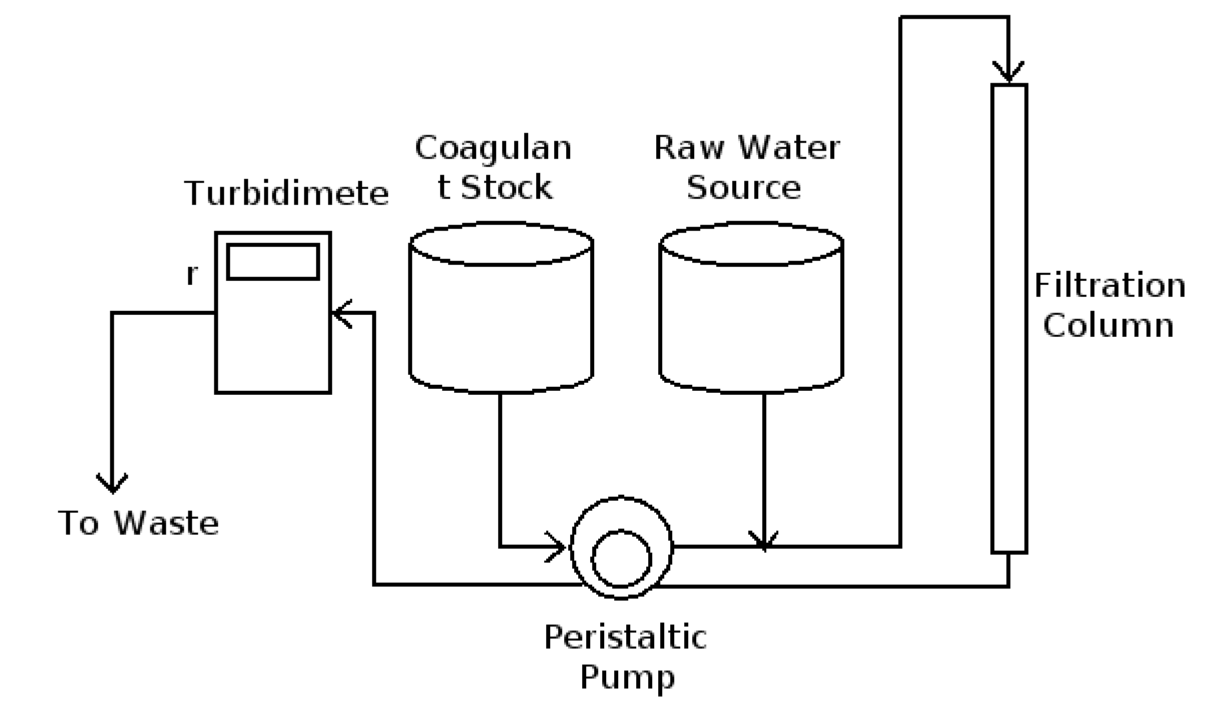


Figure 2. Schematic of flow through the laboratory scale filtration unit

Flow from the rapid mix segment of tube then entered the top of the 2.54 cm I.D. filtration column. The polyurethane foam material used as the filter media in this experiment was cut from 30.48 cm x 30.48 cm x 2.54 cm sheets into 2.54 cm diameter x 2.54 cm thick cylindrical layers using a band saw. It was necessary to cut the layers to fit exactly flush with the sides of the filtration column to avoid the development of preferential flow paths. From the top of the filter, the water pumped down through the filter media depth using the same pump as the alum control. The same pump was used to ensure the amount of alum delivered to the raw water source always remained proportional to the down flow rate through the filter.

Prior to the start of each experiment, the filter media was thoroughly cleaned by removing it from the filtration column, and rinsing and compressing the individual layers to release all of the trapped clay particles from the previous experiment. After the layers were thoroughly cleaned, they were replaced in the filtration column in the same order to maintain consistency in the experiments. Great care was taken to ensure air was not trapped in either the foam layers, or in the experimental apparatus itself as the trapped air bubbles would create inconsistency between experimental trials.

**Data Acquisition and Sampling**

Effluent turbidity was continuously sampled using a Micro TOL turbidimeter (HF Scientific Model 20053, Ft Myers , FL ), and recorded every 5 seconds for the duration of each experimental trial. Each experimental trial was allowed to run until filter failure occurred. For this experimental setup, filter failure is defined as the decrease in filter performance, or a buildup of particles causes excessive head loss throughout the filter which results in visible filter compression. Raw water turbidity was also recorded for comparison to the effluent data to determine the particle removal efficiency of the polyurethane foam filter.

**Performance Analysis**

Like any filter, a polyurethane foam filter is affected by a number of experimental parameters. In this study, we analyzed the effect of filtration velocity, filter media depth, influent turbidity, filter pore size, and the presence of a coagulant on filter performance.

In order to characterize and compare the performance of the polyurethane foam filter, the negative logarithm of the fraction of residual particles, pC* (equation 1) was employed. Log reduction is typically used to characterize the removal of biological pathogens; however, it is sometimes used to characterize the log removal of turbidity (Carlson, 2001). In this study, pC* (Equation 2) is used to indicate the log of the fraction of particles remaining after filtration.

$$pC^{*} = -\log\left(\frac{\text{Effluent Turbidity}}{\text{Influent Turbidity}}\right) \qquad (2)$$

For each parameter studied, a graph will be presented representing the maximum average pC* obtained for each trial, where the "maximum average pC*" is calculated as the average of the data +/- 50 hydraulic residence times from the maximum pC* value obtained.

For particularly impressive experimental trails, data is presented for the experiment for the entirety of the trial, with the exception of the first 5 hydraulic residence times (1-7 minutes, depending on the individual experimental flow rate and filter depth) at the beginning of each experimental trial since those data represent residual effluent from the previous experiment that is exiting into the effluent turbidimeter. In the graphical representation of the data, a smoothing function is employed, in which one graphical point represents the average of 10 data points. For these graphs, it will be important to note the lengths of time for which particular experiments performed below the U.S. EPA surface water treatment standard of 0.3 nephelometric turbidity units (NTU).

# Results and Discussion

Over the past two months, the Foam Filtration group has managed to run and obtain data for multiple experiments running with different velocities, foam depths, influent turbidity, and alloy coating.

Our recent test experiments have shown that the filtration performance (pC*) decreases with increasing velocity. This correlation between performance and flow velocity is important because it shows that the optima l velocit y throug h the foam filtrati on slices, at 90 pores per inch, is somew here around 3 mm /s. This water velocit y achiev ed the highest filtrati on perfor mance compa red to the other experi ments run with variabl e water velocit y. Theore tically, the data seems accurat e. If the velocit y throug h the foam filtrati on unit is extrem ely high, the water will be shootin g throug h the foam pores withou t allowing the foam any opportunity to collect the clay and dirt particles. At smaller velocities, the particles have time to rest and become captured by the foam material.

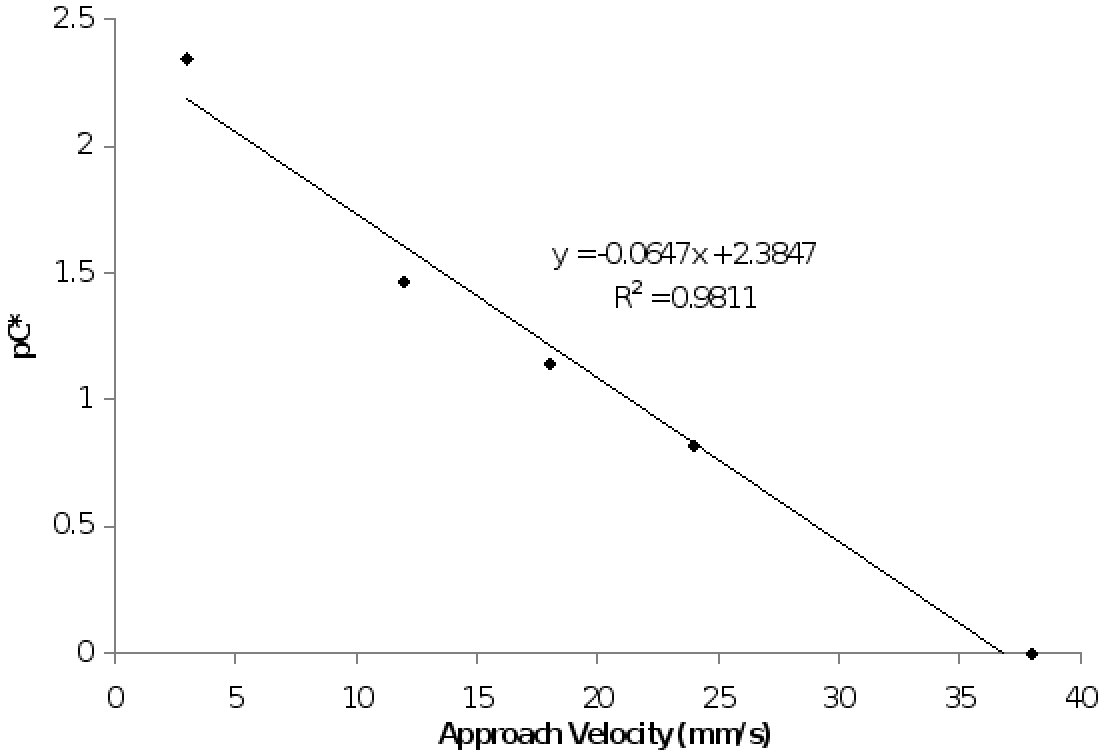


Figure 1 – Maximum average PC* versus water velocity

The data from the completed experiments also revealed that the effluent turbidity value is directly related to flow velocity – as velocity increases, turbidity of the filtered water increases. This trend is expected since we already know that as velocity increases, filtration performance decreases, and hence the turbidity of the filtered water should increase as fewer particles are trapped in the foam slices. In essence, based on the two comparisons between performance and turbidity with velocity, we can conclude that lower flow velocities achieve better filtration results, however, even at 12 mm/s, we are still able to achiev

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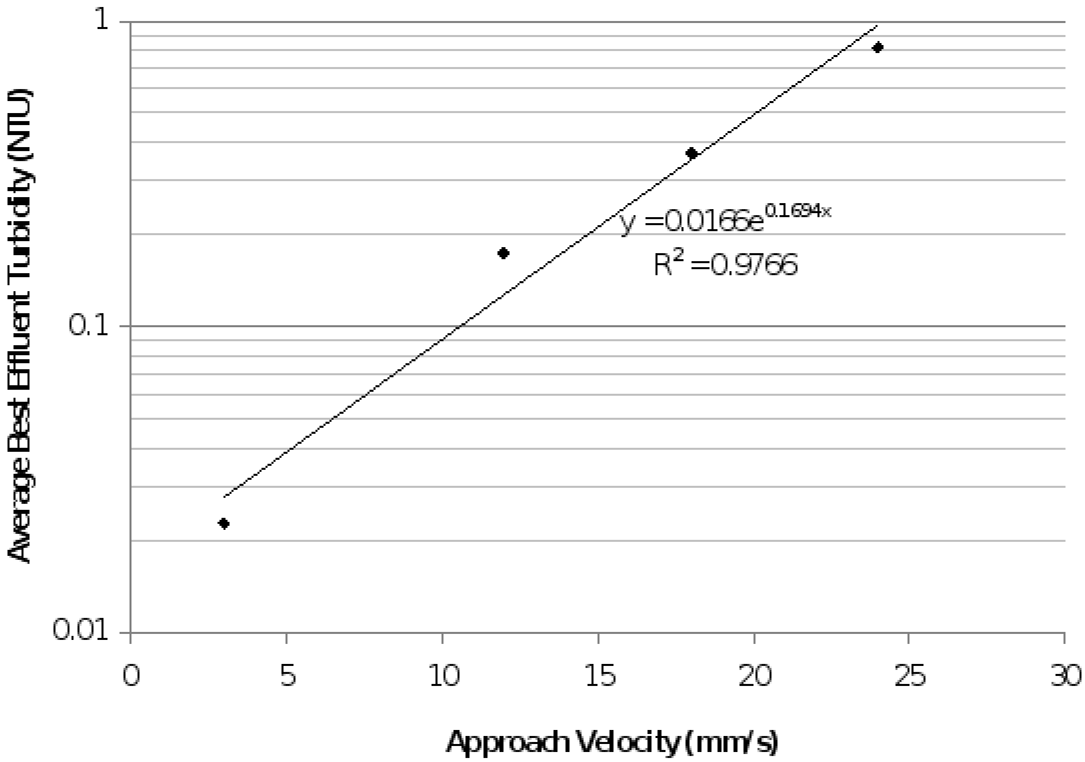



Figure 2 – Average effluent turbidity achieved versus velocity

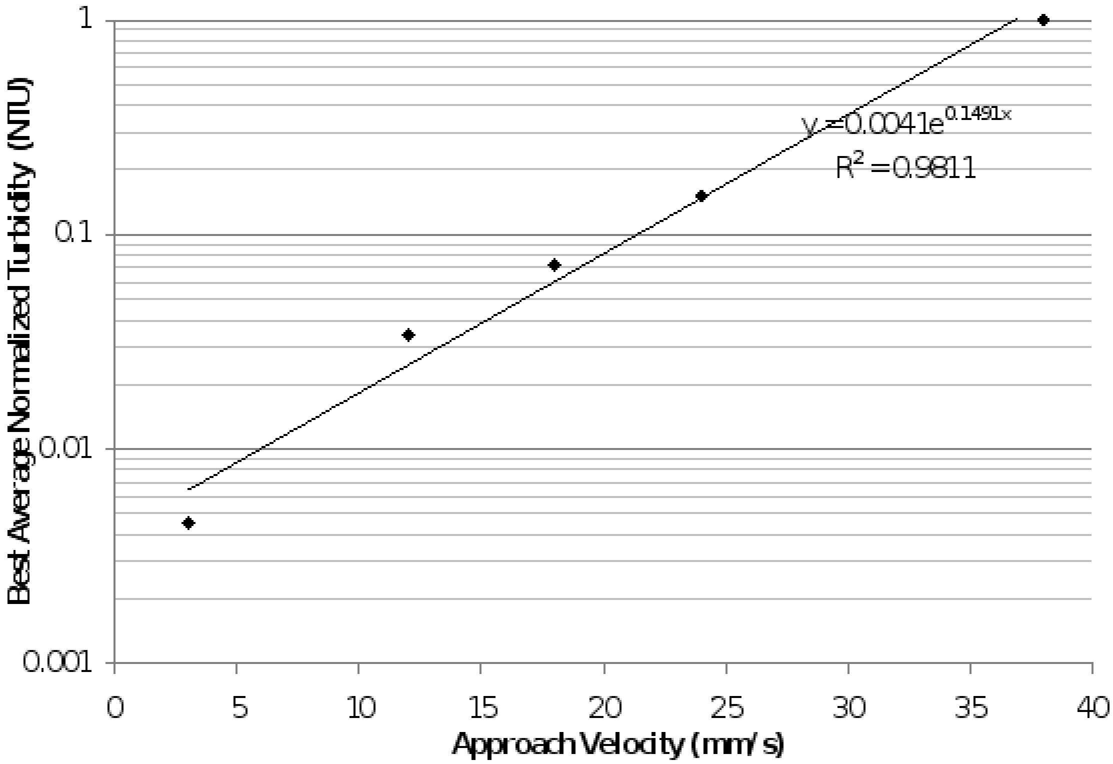
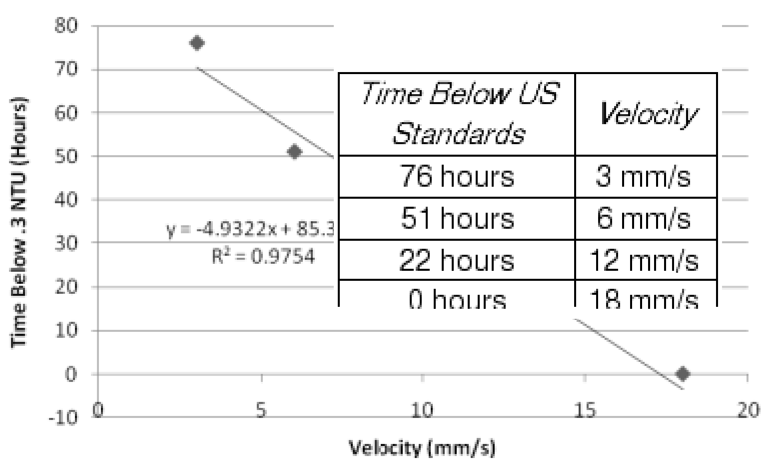



Figure 3 – Average normalized effluent turbidity achieved versus velocity

Note: ”Normalized” in above graph means best average effluent turbidity divided by average inf luent turbidity over same time interval.

The current US standard for drinking water remains at a maximum turbidity value of .3 NTU (Nephelometric Turbidity Units). For its filtration plants, AguaClara’s goal for effluent water turbidity is maintained at one

NTU. Becaus e the foam filter achiev ed its greates t perfor mance capacit y as well as the lowest effluen t turbidit y runnin g at 3 mm/s, it can be predete rmined that the experi ment at a flow velocit y of 3 mm/s will remain on par or better than US turbidity standards for the longest amount of time. (See graph below for confirmation)




| *Time Below US Standards* | *Velocity* |
|---|---|
| 76 hours | 3 mm/s |
| 51 hours | 6 mm/s |
| 22 hours | 12 mm/s |
| 0 hours | 18 mm/s |

Figure 4 – Approximate time below US turbidity standards versus velocity

Some of our experiments have experienced significant head loss. This large pressure causes the foam filtration pieces to compress greatly. Two experiments running with a foam depth of 10 inches once managed to

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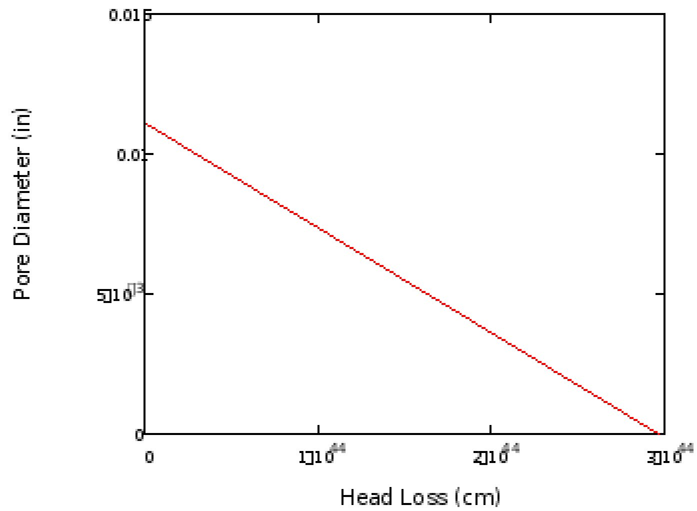
become clogged almost completely, and hence, the foam begins experiencing force and pressure from the water that is being pumped through the filter. As a result, the foam pieces become compressed.




The compression of our foam filter immediately terminates an experimental trial. Each foam layer is supposed to be 1 inch in depth throughout the entire experiment. The moment the foam material becomes compressed, the experiment changes and a variable, that should have been kept constant, (and was for all other experiments) changed.

Figure 8 – Head loss versus decreasing pore size

This compression has resulted in the depth study not yet being complete, as the 15 inch depth experiment was cut off half way through the experimental trial.

An experiment was also run to determine the effect of alum dose on the filter performance.  We surprisingly found that the filter performed extremely well under conditions of zero alum addition (Figure 9).  This experimental trial was cut short due to a failure in the water supply line, however, the data collected prior to the failure is very interesting.  Figure 9 shows that with no alum addition, the filter was able to perform at a pC* of more than 1 almost immediately.

Figure 9: pC* vs Time 6 mm/s, 10 inches, 5 NTU, without alum dose

The filter consistently achieved an effluent turbidity of less than 0.3 NTU for the duration of the trial (Figure 10). This experiment should be rerun to determine the run time for the filter, as well as to confirm these results.

Figure 10: Effluent Turbidity vs Time 6 mm/s, 10 inches, 5 NTU, without alum dose

It is possible that aluminum has chemical bonded to the filter, or that the filter has a residual coating of aluminum hydroxide from previous experimental trials. SEM images of unused and used foam (Figures 11 and 12) were taken, though it is difficult to discern if this is in fact true.

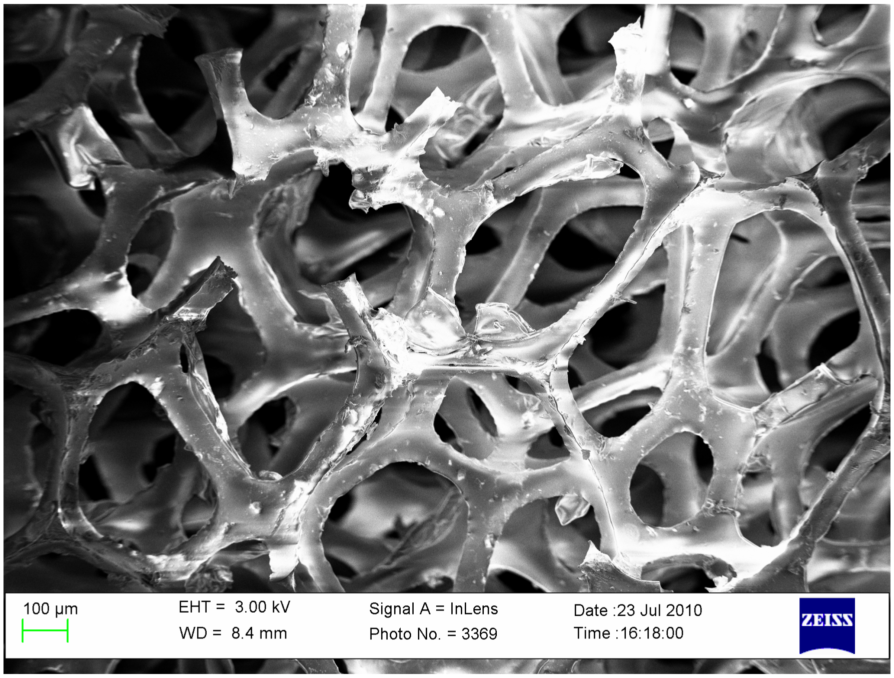



Figure 1 1 : SEM image of 90 ppi polyurethane foam, with no prior exposure to aluminum hydroxide

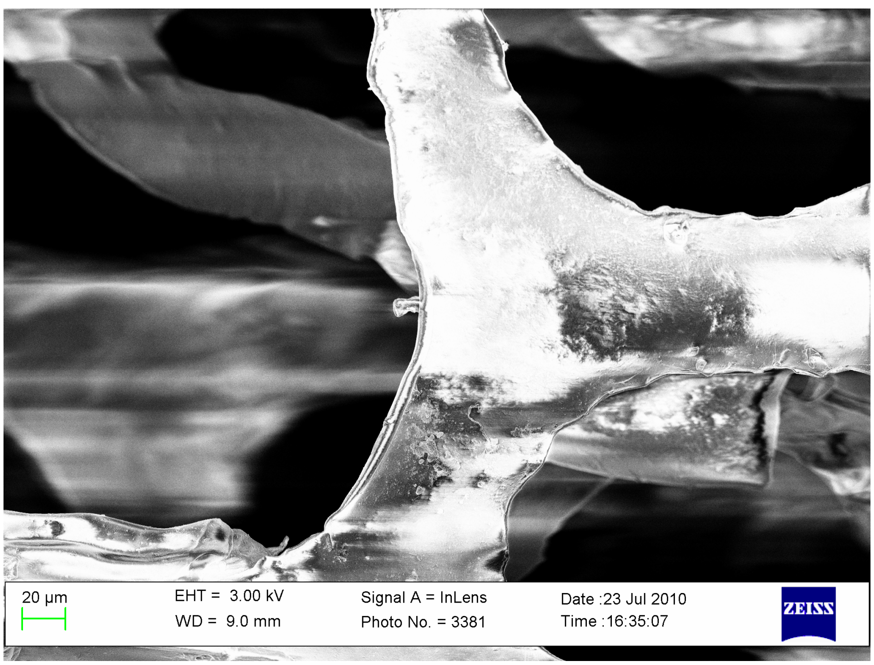



Figure 1 2 : SEM image of 90 ppi polyurethane foam, with extended exposure to aluminum hydroxide

Notice, that in Figure 12, a coating seems to exist on the surface of the polyurethane foam, though we can not say with certainty that this can be attributed to aluminum hydroxide coating. Images can be opened in another program, and expanded to view closer detail.

Calcul ations (Table 1) of velocit y based on porosit y were comple ted in order to mathe matical ly discuss the reason s that foam filtrati on can be run with such higher velocit ies as compa red to sand filtrati on. When compa ring the "active areas" for both sand and foam, it was found that the active area of foam is approximately 3 times the active area of sand. Hence, foam needs a filtration velocity 3 times greater than that of sand in order to achiev e the same velocit y per pore. This is why a foam filtrati on unit can run at faster velocit ies and still achiev e similar filtrati on perfor mance to sand units at lower velocit ies.

By calculating the Reynolds number at different velocities (Table 2) through foam of 90 ppi, our group found that viscosity is a dominating factor in our experiments, since each Reynolds number is signifi cantly less than 2100. Therefore, the pores can be modeled as cylindrical pipes running vertically along the depth of the foam. This approximation model was used in the previous calculations to determine the

2.77
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foam.

Table 1 : Calculation of approach velocity based on velocity per pore

| | |
|---|---|
| Active area of sand filter = porosity * sand volume<br>Active area of foam filter = porosity * volume<br><br>Compare active area in foam with active area in sand:<br>Active area of foam is approximately 3 times active area of sand  Need to increase filtration velocity to have same velocity per pore | |
| $Porosity_{sand} = .3$<br><br>$V_{sand} = 10 in \left(\frac{1}{2} in\right)^2$ | $Porosity_{foam} = .9$<br><br>$V_{foam} = V_{sand}$ |
| $Active_{AreaSand} = Porosity_{sand} V_{sand} = 0.045$ | $Active_{AreaFoam} = Porosity_{foam} V_{foam} = 0.125$ |
| $R_{activearea} = \frac{Active_{AreaFoam}}{Active_{AreaSand}} = 2.771$ | |
| $v_{sand} = 1.4 \frac{mm}{s}$ | $v_{foam} = R_{activearea} v_{sand} = 3.88 \frac{mm}{s}$ |

Table 2 : Calculation of Reynolds number in each pore to determine that viscosity dominates

$$V_{approach} := \begin{pmatrix} 3 \\ 6 \\ 12 \\ 18 \\ 24 \\ 38 \end{pmatrix} \frac{mm}{s}$$

$$D_{pore} := \frac{1in}{90}$$

$$A_{pore} := \left(\frac{D_{pore}}{2}\right)^2 \cdot \pi$$

$$A_{filter} := \left(\frac{1}{2} in\right)^2 \cdot \pi$$

$$n_{pore} := \frac{Porosity_{foam} \cdot A_{filter}}{A_{pore}} = 7.857 \times 10^3$$

$$Re(Q, D, \nu) := \frac{4Q}{\pi D \nu}$$

$$\nu_{water} := 1 \cdot 10^{-6} \frac{m^2}{s}$$

$$Re(Q_{pore}, D_{pore}, \nu_{water}) = \begin{pmatrix} 0.873 \\ 1.746 \\ 3.491 \\ 5.237 \\ 6.983 \\ 11.056 \end{pmatrix}$$

Future Work

Several experimental trials require us to rerun them in order to obtain accurate data, due to various forms of experimental failure (Team Reflections). Within the next few weeks, experiments will progress to changing the turbidity from 5 NTU to 10 and 15 NTU. Then, we hope to calculate the head loss within the column. If time permits towards the end of the semester, we will use different pore size filter foam (30 and 60 ppi) to determine filter performance according to pore size.

Team Reflections

In the past two weeks, a couple of issues have developed with our experimental setup. First, the foam seems to be experiencing fatigue. As head loss across the filter becomes greater and greater, it becomes increasingly difficult for the water to go through the filter media. As a result, this build up of head loss eventually causes the filter foam to collapse and compress. It seems that over time, as the filter is compressed on more and more occasions, it becomes increasingly more likely that the filter will compress at a lower levels of head loss. This observation is material fatigue, which indicates that the media is in fact deteriorating over time. However, if filter compression can be avoided to begin with, we might not experience filter media deterioration over time.

Data analysis indicated that one of our experimental trials was likely not accurate, due to a discrepancy in data fitting. It is necessary to run a replicate experiment to either confirm the trial results, or confirm that the data was inaccurate. The specific trial in question is the 6 mm/s approach velocity with 10 inch filter depth, with an alum dose of 1.5 mg/L and 5 NTU influent raw water. It is in question because the experimental trial with 12mm/s approach velocity, at the same influent and 10 inch filter depth conditions, outperformed the 6 mm/s trial. This does not make sense, as a filter with a flow rate twice as high should not perform better than a slower filter of the same depth, as the filter is more likely to capture more particles at the lower flow rate.

Additionally, we had a piece of ¼” plastic tubing that seemed to have experienced ageing as well, and developed a number of cracks in it which ultimately broke, and leaked water onto the lab space. This resulted in an influx of voltage being sent from the lab station to the server, and was necessary to disconnect the station from the server. We are currently waiting for it to dry out before another experiment can be run.