Foam Filtration Reflection Report 1

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Date Submitted: 25/06/2010

Abstract

Currently, after undergoing filtration and sedimentation, an AguaClara plant can produce effluent water with a turbidity of approximately five NTU (Nephelometric Turbidity Units). By adding foam filtration to the plants, the group hopes to reduce this effluent turbidity to below one NTU.

Last semester, the foam filtration team tested the filtering capacity of foam using a shallow filter (3 inch depth) and flow rates comparable to a rapid sand filter (1-3mm/s). While acceptable performance could be achieved under the right conditions (alum dose, low flow rate), it was found the filter could not be run with a horizontal flow direction. This inability to manipulate the geometry of the filter resulted in a large required plan area, and it became necessary to test for different filtering conditions.

This semester, it was decided to manipulate the geometry of the foam filter by increasing both the down flow velocity and filter depth. Research over the last two weeks has proven this to be an effective method, and a performance study will be conducted throughout the summer to determine the parameters under which effective performance can be achieved.

Introduction

The filtration team's objective is to design a filtration unit that can reliably treat the current effluent water with a turbidity of about 5 NTU to a turbidity of less than 1 NTU. Most of the current filtration systems use sand as the porous media, and very little information is present regarding foam filtration. Rather than using the traditional method of sand filtration, our research will focus on the filtering capacity of polyurethane foam material.

Members of a previous foam filtration team have tested the filtering capacity of foam under worst-case scenarios, which involved filtering water with un-flocculated clay particles. To simulate conditions that more resemble those of an AguaClara plant, an alum dosing system and rapid mix tube were added to the experimental apparatus. The first experiment, which used an alum dose of 25 mg/L (a very high and unrealistic alum dose), resulted in effluent turbidities of less than 1 and pC* of .9 when flow rates of 2 mm/s or less were used. This demonstrated that filter performance declined with increased flow rates. This was explained by the idea that at lower flow rates, the foam was able to capture even the smallest particles that would have been made sticky by alum, but as flow rates increased, it became increasingly difficult for the foam to capture smaller particles. The next experiment used an alum dose of 1.5 mg/L, a value chosen based on the assumption that 5% of the particles remained when originally exposed to a 30 mg/L alum dose. The minimum turbidities achieved were not as low as that achieved with a higher alum dose. This can be attributed to the fact that with lower alum dose, not as many of the smaller particles are made larger from contact with alum. Subsequent experiments compared performance from 3-in. to 1-in. foam depth, and demonstrated that foam filtration acted as a function of depth, rather than surface area.

The feasibility of horizontal filtration, in which raw water would flow horizontally through a vertically placed filter, was tested. It was shown that horizontal filtration could not provide the standards of achieving a .9 pC* within a reasonable timeframe (pC* of .7 after 20 hrs). Rotation of the column in a subsequent experiment showed that a turbidity gradient had developed over the depth of the filter, with very turbid water going through the bottom and less turbid water going through the top. This turbidity gradient is likely to contribute to the observed decrease in performance when compared to vertical filtration.

A number of experiments utilizing foam with different pore sizes and flow rates were conducted. The first experimental set-up utilized 60-ppi foam, while the second used 90-ppi foam. With 60-ppi foam, a significant level of colloid removal was achieved with a pC* of .6 at 1.15 mm/s and pC* of .4 at 2.31 mm/s. It would be optimal to achieve a pC* of .9, so consequently, foam with a higher ppi was investigated. Using flow rates varying from .57 to 2.89 mm/s, an effluent turbidity of 1.5 NTU and pC* of .55 were found, which is similar to that of the 60-ppi foam. Despite varying flow rates, pC* remained constant, suggesting that the filtering ability of foam is dependent on the size of the particles, regardless of the influent turbidity.

Since horizontal filtration proved infeasible, it was decided to manipulate the required plan area geometry by instead increasing the down flow rate through the filter. Previous research showed it was also necessary to increase the filter depth in order to achieve effective performance.

Literature Review

Polyurethane foam filter/PAC adsorber

A foam filter consisting of small cubes of polyurethane foam is used to remove turbidity with three different foams at different degrees of compression, while monitoring the filter's clean bed head loss. Experiments demonstrated that the foam filter is capable of removing turbidity with results similar to that of sand and anthracite filters. Turbidity removal improved with an increase in foam compression and decrease in ppi. The run time increased with decreased compression and decreased ppi. The head loss for 15-ppi foam compressed 29% was 0.025 ft/ft, much less than the calculated sand head loss of 2 ft/ft. Powdered activated carbon (PAC) loaded in the filter acted as a fixed-bed adsorber and helped to reduce the levels of organic chemicals in water. These results are not directly applicable to our research, as we are using foam sheets, which utilize the porosity of the foam itself, rather than using foam cubes and compression to manipulate the porosity of the material. The loading of PAC into our filter to remove natural organic matter could be applicable to our design.

Coated Sand Filtration - An Emerging Technology for Water Treatment

Filtration media can be modified by using oxide coated sand in order to improve their ability to remove heavy metals and other impurities from water. Studies found that “the iron and manganese oxides alone are not suitable as a filter medium because of their low hydraulic conductivity.” Hence, recent research has focused on sorptive sand filtration using iron, aluminum, and manganese coasted sand. Ferric nitrate is best used as the source of iron if exposure to mild abrasion is possible due to back-washing. Many pollutants and microorganisms can be removed from drinking water by utilizing oxide coated sand. Lukasik experienced a removal of “greater than 99% of

E. coli, Vibrio cholerae poliovirus and coliphage MS-2 from dechlorinated tap water.” In addition, aluminum and iron were both undetected in the effluent water after treatment, revealing that the metallic hydroxide coating is insoluble. The metal-loaded sand can be disposed of as cemetitious solidification, the “best demonstrated availabl

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Open-Cell Polyurethane Foam (As a Filter Medium)

This article focused on using Polyurethane Foam as a filter medium for air. Though AguaClara is investigating using foam as a filter for water rather than air, the author, Collings, provides a strong background for us to build upon. Collings researched in great detail the process of manufacturing foam, calculating foam resistivity and permeability -information that our team can apply to our foam selection and calculations. Variables in Collings' experiment such as temperature, concentration, contact time and fluid velocity will probably effect our experiment as well. Similar to our current experiment, Collings mentions a big downfall in foam filtration is finding a method of cleaning the foam without execution downtime. Unfortunately he did not go into detail as to how this could be solved.

Potential of Silver Nanoparticle-Coated Polyurethane Foam as an Antibacterial Water Filter

Silver and other such metal ions have shown signs of having antibacterial properties without causing excessive harm to humans. For communities without access to major water purification plants, silver nanoparticles can be an effective alternative (Jain 63). Another major upside to using silver nanoparticles is their resilience to washing cycles. According to the article, “There was no loss of nanoparticles after several washing and drying operations and after keeping it for several months in a closed environment” (Jain 62). Most importantly however, the silver nanoparticles greatly enhance the efficiency of the polyurethane foam by successfully eliminating any residual pathogens (Jain 62). By using similar methods in soaking the AguaClara foam filters in aluminum hydroxide and sodium carbonate mix, the Foam Filtration Team hopes to meet similar success in eliminating all bacterial contaminants.

Detailed Task List

1. Perform a Performance Study of the 90 ppi polyurethane foam:
In order to characterize the performance of the foam, we will vary different variables while holding the others constant to find the optimal parameters to use for designing a foam filtration unit, and under what varied conditions the filter will still perform well. The variables we will study are Down flow Velocity(6, 12, 24 mm/s), Filter Depth (5, 10, 15 in), Turbidity(5, 10, 15 NTU), and Alum Dose(No or Yes).

	Velocity(mm/s)	Turbidity(NTU)	Depth(in)	Alum Dose		
	6	5	5	0		
	12	10	10	1		
	24	15	15			
	1.2					
Vary Flow:					Done?	Started
Experiment 1	6	5	10	1	YES	10-Jun
Experiment 2	12	5	10	1	YES	14-Jun
Experiment 3	24	5	10	1	Too High	
Vary Depth						
Experiment 4	6	5	15	1	YES	22-Jun
Experiment 5	6	5	10	1		
Experiment 6	6	5	5	1		
Experiment 7	12	5	15	1		
Vary Turbidity						
Experiment 8	6	10	10	1		
Experiment 9	6	15	10	1		
Vary Alum						
Experiment 10	6	5	10	0		
Headloss						
Experiment 11	Empty Column - No Filter					

2. Calculate the head loss through the filter using a pressure sensor:
We have calculated the head loss through the filter using the Hagen-Poiseuille equation, which models the filter as a number of long thin pipes, but this does not seem correct. This may be due to an underestimation of the pore size used. Given the high porosity of the foam material, it is likely that the pore diameter should be larger than the value of 1/90 inch used in the calculation. Therefore, we will use pressure sensors to measure the headloss across the filter, as well as measure the head loss through an empty filter column(to calculate how much of the head loss is due to the flow through the fittings and tube) and subtract the two, resulting in the head loss across the filter. We will also measure head loss over time, to determine how long a filter can effectively be used for, before head loss is too great.

3. Determine the effectiveness of adding an Aluminum Hydroxide filter wash to the cleaning method:
We may be able to achieve even greater filter performance by rinsing the filter in aluminum hydroxide prior to reinstallation in the filter column. Please see experimental methods section for preparation details. Additionally, it will be important to monitor the amount of residual alluminum in the effluent from the filter. This is an important parameter due to the potenially toxic effects of aluminum. The EPA secondary standard maximum contaminate level for aluminum is .05-.2 mg/L.

4. Determine the effect of Natural Organic Matter on the foam material, and its changed performance:
Our experiments in the lab do not account for natural organic matter that will be in the water in AguaClara plants. Therefore, before we are able to implement any designs, we need to understand and account for the effects that the natural organic matter will have on the foam's filtering capacity, and associated method of cleaning.

5. Determine an efficient cleaning method for the filter:
It is necessary to detail a cleaning method for the foam material. This method should effectively remove particles and any bio matter, and simultaneously be easy for an operator to perform within a reasonable time frame.

6. Design a Foam Filtration Unit
This filtration unit design should be optimized according to the required surface area and filtration velocity parameters determined through previous laboratory experiments. In addition, it should minimize the required plan area, as well as maximize the ease of maintenance for the operator.

Experimental Design

Polyurethane foam has proven to be a potentially effective means of filtration due to its small pore size, yet very high porosity(. 969). The small pore size enables clay particles to be captured in the foam, while the high porosity yields minimal head loss across the filter. These parameters allow a foam filter to achieve a high particle removal, even when run at very high flow rate. This high flow rate results in a reduced required plan area for a filtration unit.

In our experiment we are currently using 90 pores per inch (ppi) foam in a 1 inch diameter graduated cylinder. One inch thick foam boards are cut using a band saw to fit the exact circumference of the cylinder. Cutting the foam accurately is a crucial part of the experiment. The foam must fit flush to the graduated cylinde r to prevent prefere ntial flow around the foam through the cylinde r. A tight seal with all edges will force the water through the pores of the foam. Togeth er, the foam and graduat ed cylinde r act as our filter.

This summer, the first variable that the Foam Filtration team will test is foam thickness. We will test thicknesses 5, 10 and 15 inches. When placing the foam inside the graduated cylinder, two things are crucial: consistency in experiment, and prevention of air bubbles. To maintain consistency, each 1 inch foam piece is number ed in order of placement in the filter, and replaced in the same order each run. Great care is also taken in the placement of the individual filter layers. If the layers are pressed too close together, the filter may become compressed, thus changing the pore size of the filter, and making the data inconsistent with other experimental trials. Dislodged air bubbles can create inconsistency in data measurement and interfere with the filtration process.

The second variable we are analyzing is the effectiveness of adding an Aluminum Hydroxide /Sodium Carbonate filter wash to the cleaning method. The solution must be prepared at the time of use to prevent the formation of complex polymers in the solution. Our solution pH is maintained at roughly 7.0, the same pH as distilled water. The solution needs to be saturated with Aluminum Hydroxide, but not so much that the precipitate clogs our filter. The solution is prepared by adding 5 mL of a 20 g/L Sodium Carbonate solution to 50 mL of a 30 g /L Aluminum Hydroxide solution. The first foam layer will not be soaked since it already captures the majority of particles going through it—this layer does not need the extra filtering power. The last layer will not be soaked to reduce aluminum seepage into the effluent.

Before the experiment begins, the Process Controller must be set up to control our third and forth variables: turbidity and downward water velocity. The method controls the addition of clay solution to our influent ‘raw water’, as well as the pump that pulls water through our filter. The raw water simulates the effluent from an

AguaClara plant. We will test our filter at influent concentrations of 5, 10 and 15 NTU, and down flow velocities of 6, 12 and 24 mm /s.

After the foam layers have been placed in the cylinder, the entire filter is secured into a clamp, joining it with the rest of the apparatus. The addition of Alum is the fifth tested variable. Currently, in active AguaClara plants, Alum is always added to the raw water supply. To determine the role that Alum plays in achieving effectiv e performance in the foam filter, Alum will not be added to the raw water in some tests.

When connecting our experiment, we must ensure air is removed from both the filter column and all connected tubing. Air bubbles in the water supply can cause spikes in the pressure sensor and also result in inaccurate NTU readings. To remove these air bubbles, raw water must be sent into the filter from the opposite direction: in from the bottom of the filter and out through the top. Meanwhile, tubing of the raw water and the filtered water are connected to a pressure sensor to monitor head loss, the amount of energy required by the water to go through the foam.

When all air is removed, the tubing is then connected in the proper direction. Alum will be added to the raw water prior to the filter by means of alum stock tank, where the amount added is determined by the filter down flow rate. The alum is connected to the same pump as the effluent water, so an increase in filter flow rate results in a corresp onding increas e in alum. The raw water with alum is sent to the top of the filter, and flows through the foam before being pumped out through the bottom of the filter. This effluent filtered water is sent to a turbidi meter.

Both NTU and pressure values are recorded by Process Controller every five seconds for both the raw and filtered water. Through these experiments, the Foam Filtration team hopes to validate the filtering effectiveness of foam, while achieving performance comparable to conventional methods, yet requiring less planned area.

Future Work

Over the next two weeks, our team will conduct a variety of foam filtration experiments while varying a specific parameter for each trial. By changing one variable and holding others constant, our group can determine the optimal parameters for designing a foam filtration unit. Parameters that will be varied include down flow velocity, filter depth, turbidity, and alum dose. The foam currently being used is set at 90 ppi (pores per inch) polyurethane foam.

Please refer to the “Detailed Task List” section for more information on further experiments scheduled to be completed by the end of this summer.

All of these tasks and experiments will be able to help us design the most favorable and feasible foam filtration unit for AguaClara plants. Based on our research, we will be able to better understand the process of foam filtration and hopefully be able to implement the unit

easily
into
later
plants.

Team Roles and Expectations

Team Expectations:

- Come to meetings when you can
- Remember Lab Safety
- Do your share of the work
- Complete work in a timely fashion (by the deadline..)

We will have a team meeting on Wednesdays at 5:00 pm in Hollister 150. In addition, we will meet up as a team to conduct experimental work as needed. Since the experiment run time varies for each experiment, it is difficult to say exact days and times when the experiment will be finished, and a new one can be set up to run. We will likely meet weekdays after 5, or in the afternoon depending on availability.

Team Roles: These roles will be rotated among team members with each experimental trial

- Experimental Setup – This will entail cleaning out the filter from the previous experiment, replacing the filters in the filter column, and setting up the experiment to run again. Will also involve checking that the process control file is operating for the right flow rate and experiment time, and the data is being saved in the proper location.

- Experimental Maintenance/Operation – This task will involve preparing an aluminum hydroxide sodium carbonate mixture to wash the filters in, refilling alum and clay stock tanks when necessary, and checking in on the experiment to ensure there are no leaks/failures in the system.

- Data Analysis – After an experiment is complete, this task will entail compiling all of the data for the duration of the experiment from the datalog files into one text file, resolving any issues in it (replacing 0's and -999's) and loading the file into the Simple Data Analysis file in MathCAD.

- Wiki Editor – After the data is analyzed for an experiment, it will be necessary to document the results and the implications on the Wiki so others will be able to easily find and understand the results.

- Team Leader (Sarah Stodter) – Responsible for managing the team and experiments run, and ensuring assignments are completed on time, and the work load is evenly distributed amongst team members. Ensure that all team members understand the experimental set up, and reasoning, help troubleshoot problems, and provide guidance for the experiment.

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