Foam Filter Cleaning, Fall 2015

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Abstract

The AguaClara foam filters are a relatively new technology. The primary goal of the foam filter is to have a low cost, locally sourced, easy to operate water filtration option for smaller villages that do not require a whole AguaClara plant. Previous Foam Filtration subteams performed experiments on the 4” small scaled pipe filter, designed in Fall 2014 that modeled the full scale filter implemented in El Carpintero, Honduras. The Foam Filter Cleaning subteam this semester focused on constructing a new testing apparatus and optimizing the cleaning efficiency of the 30 ppi and 60 ppi foam. The 90 ppi foam was not tested because it cannot be sufficiently cleaned according to field tests. The team designed and assembled a new, apparatus to test the cleaning efficiency with two turbidimeters. The team ran experiments with a combination of the 30 ppi and 60 ppi pore sizes and an uniform pore size of 60 ppi. The forward velocities were varied while keeping backwash velocity constant in order to determine optimal parameters for cleaning efficiency.

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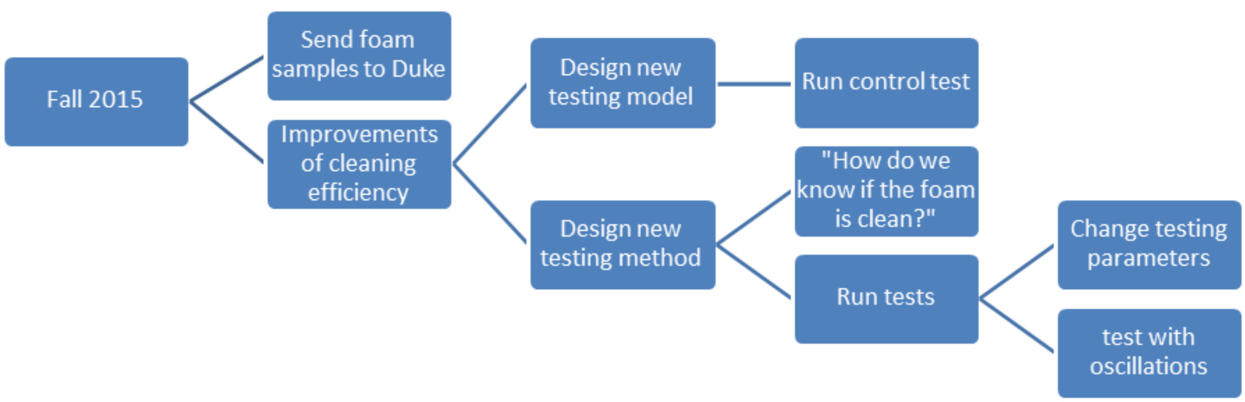
Task Map



Task Details

- Send foam samples to Duke - all - by September 18th
    - complete submission process (http://foam.pratt.duke.edu/how-submit-sample)
    - figure out chemical composition of the foam and the materials that could be leaked out into the water
- Design new testing model - all - before October 30th

    - taking new lab space into account (2 meter headloss)
    - sizes of foam being used
    - size and type of instrument
- Design testing method - all - before October 30th
    - figure out control parameters
    - previous foam team reports and scientific reports
    - decide between two potential methods of determining cleaning efficiency
        - timed
        - measured NTU
- Run Tests!!! - all - end of semester
    - change parameters that limit cleaning efficiency
        - temperature
        - flow rate
        - foam pore size and depth
        - change flow rate settings (high vs low)
    - with oscillation
        - does it help with the cleaning efficiency?

Introduction

The Foam Filter Cleaning subteam this semester aimed to examine and better understand the cleaning efficiency. This research will not only help AguaClara continue to improve the current foam filter model, but also help resolve foam cleaning problems occurring at the Honduras pilot plant. The research is crucial to the improvement of cleaning efficiency in the team's existing foam filter model in El Carpintero, Honduras and to the possibility of the foam filter's expansion into other communities. The subteam worked, in particular, to better understand the relationship between cleaning efficiency and loading flow rate.

Previous Work

Foam filtration is an emerging technology and the cleaning mechanism of it is even less researched than the filtration technology itself. Therefore, there is not much published literature available to review. However, past works of foam filtration subteams within AguaClara have been reviewed. The information they have gathered in the past about foam filter cleaning is detailed below.

Spring 2015

Foam Filtration Spring 2015 subteam mainly prepared for the EPA P3 Phase II competition. However, they also conducted backwash cleaning efficiency experiments with the 4" small scaled pipe filter designed by Fall 2014 subteam. Figure 1 shows the schematic of the apparatus. Water was pumped through the foam layers rather than plunging the foam to clean it. Manually pushing foam through water for backwash created many variables, especially when force applied was not constant. Pumping water through the foam allowed the isolation of a very important variable, water velocity through the pore sizes. The major problem the team ran into was that the turbidity of the effluent water of the backwash was too high for the turbidimeter. Dilution is essential to get accurate readings from the turbidimeter. The team concluded that the foam pores may act as sedimentation tanks for the flocs to settle rather than the initial hypotheses of flocs getting stuck in the pores. The results also indicated that finer foam may be harder to clean than coarser foam.

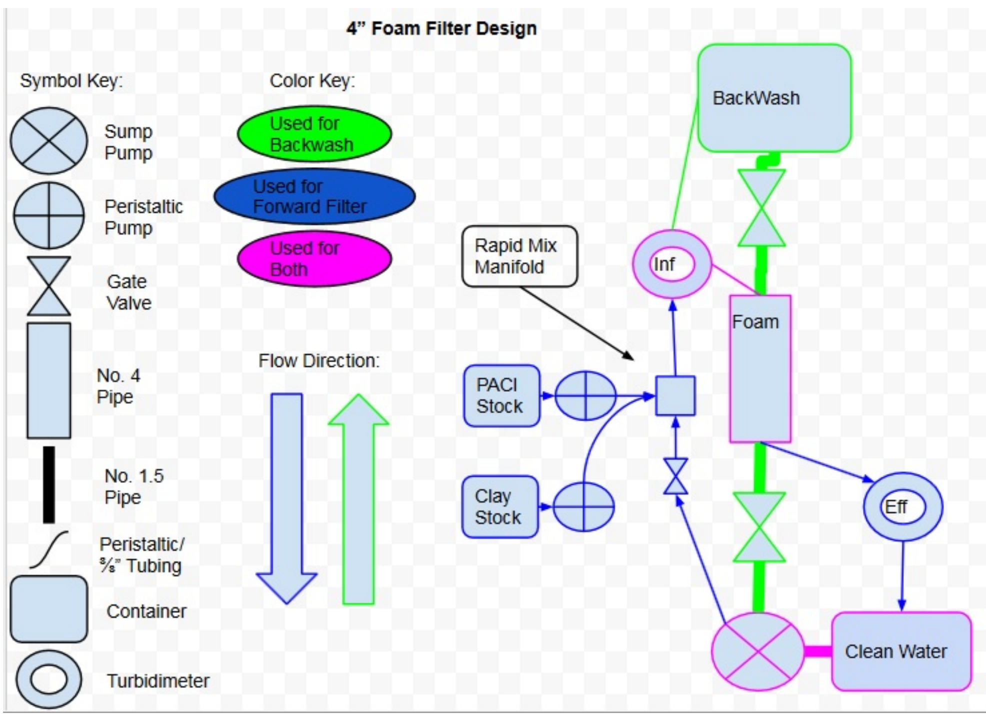


Figure 1: Schematic of the small 4" pipe filter that was designed by the Fall 2014 subteam.

Fall 2014

The Foam Filtration subteam of Fall 2014 designed the new apparatus shown in figure 1, the 4" Pipe Small Scale Filter. The subteam's main goal was to determine an empirical relationship between backwash pore velocity and the percent mass removal during the cleaning cycle. The team started with the backwashing method of plunging the foam through water. The intention was to create high pore velocities that would shear flocs free from the foam. Backwashing the foam proved to be more efficient than compression in both cleaning efficiency and the force required to wash the foam. Mass spectrometry tests were run to figure out if any chemicals were being released from the foam. The assumption was the amount of leaching did not depend on the type of foam. The tests confirmed there were chemicals leaching from the foam, with a significant amount of the chemicals being the esters that the high and low PPI (10, 20, 60, 80, 90 PPI) foams they tested were made of. The potential danger the Fall 2014 team was concerned with ester leaching was that reactions between esters and water could lead to the formation of acids which could be harmful. They were also concerned whether the ether-based medium PPI (20, 30, 40, 50 PPI) foams would leach either because it could potentially react with halides, most probably the chlorine used to disinfect drinking water. Literature reviews were done regarding chemical leaching and potential risks. Some potential risks in the leaching include the decomposition of urethane, a common material for a variety of filtration systems, when in contact with urea and the flame retardant added by manufacturers. However, none of these potential risks were confirmed. Some variables the team suggested that may affect cleaning efficiency included coagulant dosage, total foam width, and backwashing with turbid water versus backwashing with tap water.

Summer 2014

The Summer 2014 subteam worked to build a new linear flow orifice meter (LFOM), improve the chemical dose controller (CDC), and remodel the foam cleaning system of the old plant design. The team developed a flexible siphon to help drain dirty water from any height. After switching into the lever arm design, the flexible siphon was changed back to side valve because varying water level was no longer an issue. A velocity of 181 millimeters per second or more is required to clean out the foam after one plunge, but to compress the foam with enough force was difficult with the old design of the filter. The team worked to build a new system that was centered around effective compression so that not as much force would be needed to clean the foam.

Methods

Information from Honduras

The pilot project site in El Carpintero, Honduras has confirmed that the 280 micrometer, 90 ppi pores are not being properly cleaned. Figure 2 shows the bottom of a foam disc after five backwash cycles, and figure 3 shows the sludge that is still trapped inside the foam. Even after many backwash cycles these pores are not adequately cleaned. Concentric rings were added to the original plunger cross frame on top of the foam to create a better seal at the edge of the foam during backwash. However, this reduced the maximum plunge velocity from 68 millimeter per second with the 280 micrometer pores to 20 millimeter per second, which is insufficient to clean the small pores. Due to the inability to clean the small pores, the team will be focusing on 60 ppi and 30 ppi foams. The parameters the team will be testing are influent turbidity, forward flow rate, coagulant dose, and foam pore size. Experiments will be designed to vary either different parameters while keeping the same backwash velocity or varying the backwash velocity while keeping the parameter constant.

Figure 2: The bottom of most 90 ppi foam discs after five backwash cycles.

Figure 3: The sludge that is still trapped inside the filter after five backwashing cycles.

New Apparatus

The Fall 2015 Foam Filter Cleaning subteam built a new apparatus that would focus mainly on the backwashing cycle with the loading phase solely to prep the foam for back washing. The sketch diagram of the apparatus is shown in figure 4 with the water paths of loading phase and backwashing phase indicated.

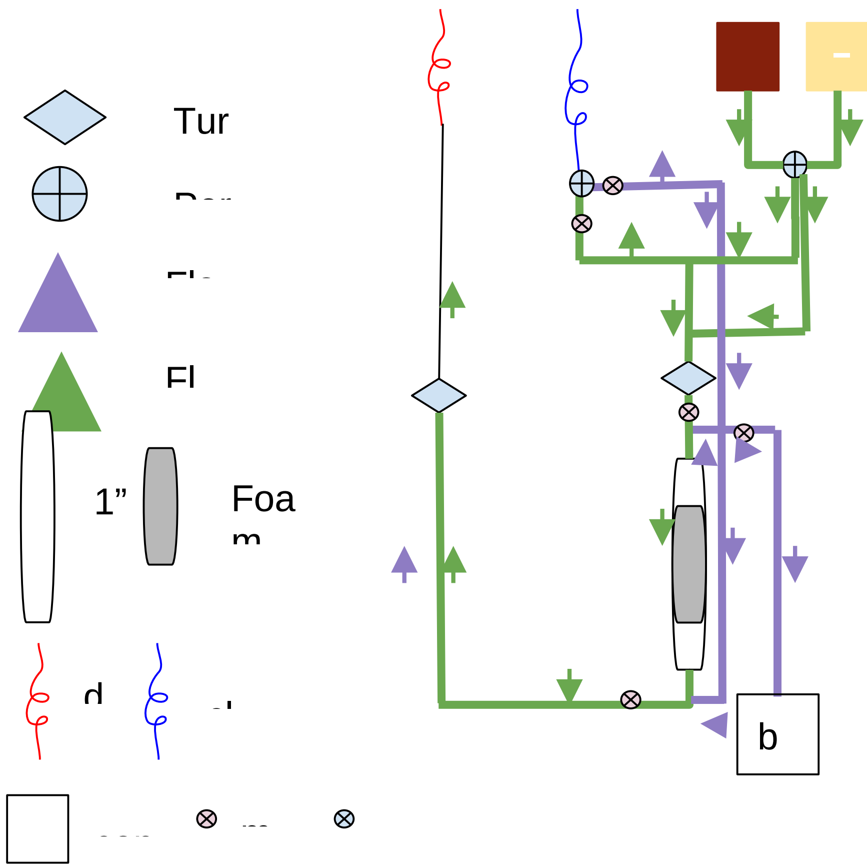


Figure 4: The sketch diagram of apparatus.

During the loading phase, clean water will be mixed with the clay stock to dilute the influent NTU so the turbidimeter can record the reading. Before the solution passes the influent turbidimeter, coagulant will combine with the clay water. Because the clay water and the coagulant use the same pump, the coagulant concentration is proportional to the turbidity of the clay water. The clay stock is made with 4 grams of clay per 1 liter of water. The team decided to use a coagulant concentration of 15 milligram per liter for coating the clay particles in the clay stock. Total filtration flow rate, Q_{filter}, is calculated by adding all the individual flow rates,

$Q_{filter} = Q_{Coagulant} + Q_{Clay} + Q_{water}$. The $Q_{Coagulant}$ is the flow rate of the coagulant stock, Q_{Clay} is the flow rate of the clay stock, and Q_{water} is the flow rate of the clean water. Using mass conservation, concentration of the coagulant during loading phase, $Concentration_{Coag}$, is calculated with $Concentration_{Coag} = Q_{filter} \times \frac{C_{dose}}{Q_{Coagulant}}$, where C_{dose} is the coagulant concentration for 15 milligram per liter that the team set. The original coagulant concentration, $C_{CoagStock}$, is 69.4 grams per liter. The volume of the original coagulant needed to make the stock, $V_{CoagStock}$, is calculated by $V_{CoagStock} = \frac{Concentration_{Coag} \times 1L}{C_{CoagStock}}$.

A T-connector acts as a rapid mix in this system for the diluted clay solution and the coagulant stock. A 100 rpm peristaltic pump with tubing 13 is used to drive the clay stock and coagulant stock. A 600 RPM pump is used for pumping water. Water will then flows through the 1" PVC pipe from the top. Due to the different flow rate needed for loading phase and backwash phase, tube 16 is used for loading phase of target flow rate ranging from 0.91 to 1.66 milliliter per second and tube 18 is used for backwash phase for flow rate of 8.61 to 15.7 milliliter per second. When the water flows out of the foam, it is read by the effluent turbidimeter. The loading phase will be stopped when the effluent turbidimeter reaches above 5 NTU and when the pC* is equal to 1. This is because water with a turbidity higher than 5 NTU will be above the maximum NTU for safe drinking water and is no longer suitable for consumption. The differences between the two meters will be taken and plotted onto a graph. The integral of the graph will allow the team to calculate the amount of clay particles loaded inside the foam.

For the backwash phase, the water's path will reverse. After the pumping tube has been changed, clean water will be pumped in from the bottom of the filter. Backwashing phase will proceed for a pre-set amount of time.The dirty effluent water will be collected in a bucket till the backwash phase ends. The team will then take a sample of the water inside the bucket and measure its turbidity. This will become the average turbidity of the backwash effluent.

The different parameters, influent turbidity, forward flow rate, coagulant dose, and pore sizes, will be changed to determine their effect on cleaning efficiency. The team will calculate the cleaning efficiency of the process by this equation: $Cleaning\ Efficiency = \frac{NTU_{Backwash} * V_{Backwash}}{(NTU_{LoadingINAvg} - NTU_{LoadingOUTAvg}) * V_{Loading}}$. $NTU_{Backwash}$ is the average backwash effluent turbidity. $NTU_{LoadingINAvg}$ is the average influent turbidity of the loading phase and the $NTU_{LoadingOUTAvg}$ is the average effluent turbidity of the loading phase. $V_{Backwash}$ is the volume of water used to backwash while $V_{Loading}$ is the volume of water used to load the foam. They can be calculated by multiplying the flow rate by time.

Before changing the parameters, influent turbidity, forward flow rate, coagulant dose, and pore sizes, the team first determined the optimal velocity for backwashing by changing the backwash velocities. From these initial experiments, it was concluded that the optimal velocities for using current calibration of the 600 RPM pump and the size 18 tubing for backwashing should be between 17 mm/s and 31 mm/s (or 8.61 to 15.7 milliliter per second as previously stated above). Between these two backwash velocities, the relationship between the coefficient inputted into the ProCoDa software used on the computer and the flow rate is linear, as seen in figure 5. Using this data, the team then calculated the filtration velocities needed to mimic the El Carpintero plant's ratio of backwash velocity to filtration velocity of around 10:1. The filtration velocities the team is using are between 1.8 mm/s and 3.3 mm/s (or 0.91 to 1.66 milliliter per second as previously stated above).

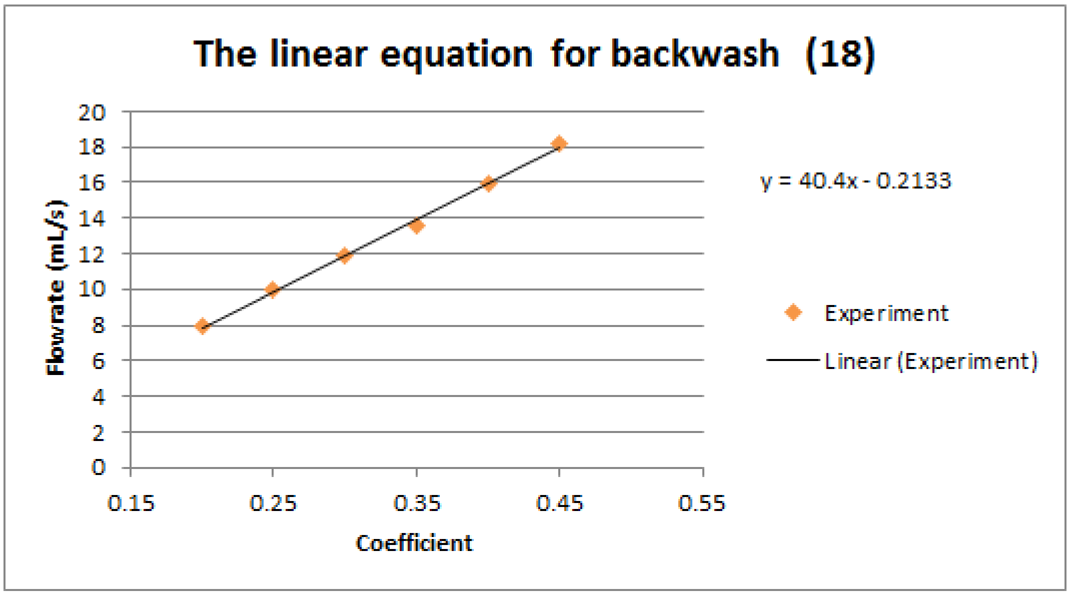


Figure 5: The graph showing the linear relationship and the equation for 600 pump coefficient, which controls the pump speed between 10 and 600 RPM, and flow rate of size 18 tube.

A similar experiment was run to find the linear region of flow rate in mL/s versus pump coefficient for tube size 16, which is used during the loading phase. Figure 6 shows the linear relationship between pump coefficient and the flow rate and the line's equation. The team will use this equation to calculate pump coefficient and control the water flow rate during loading.

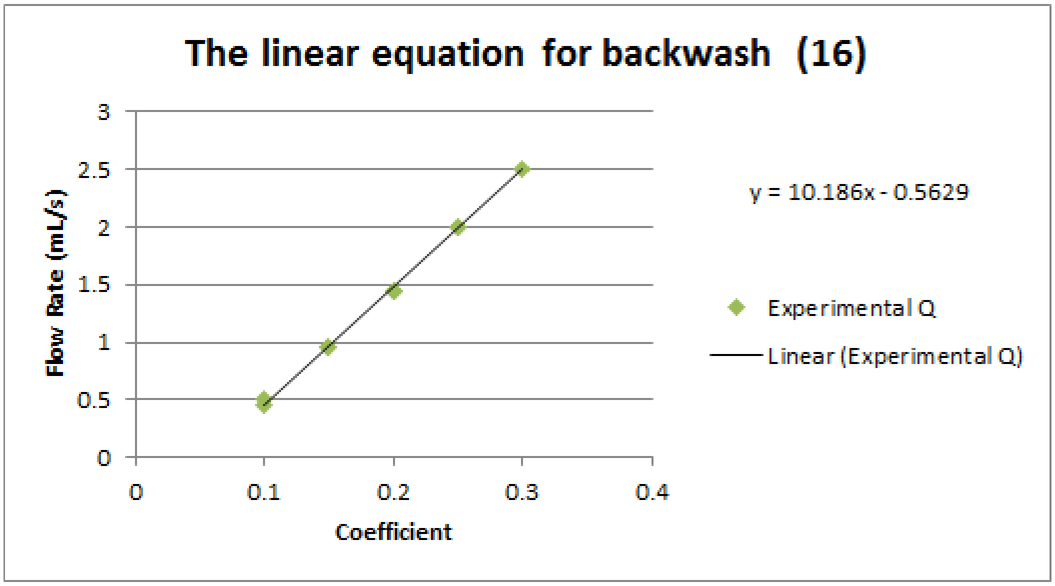


Figure 6: The graph showing the linear relationship and the equation for 600 pump coefficient, which controls the pump speed between 10 and 600 RPM, and flow rate of size 16 tube.

Filtration Flow Rate versus Backwash Efficiency

The first experiments conducted looked at the relationship between filtrating flow rate and and backwash efficiency.A clean water loading flow rate between 2.5 mL/s and 1.0 mL/s with increments of 0.25 mL/s were used . The team used the calibrated equation for the 600 RPM pump and tube size 16, y = 10.186 x - 0.5629, and solved for the pump coefficient that controls the pump speed between 10 RPM and 600 RPM. The y in the equation is the flow rate in mL/s and the x is the 600 RPM coefficient. The total flow rate through the system is calculated by $Q_{filter} = Q_{Coagulant} + Q_{Clay} + Q_{water}$.The$Q_{Coagulant}$is the flow rate of the coagulant stock, $Q_{Clay}$is the flow rate of the clay stock, and $Q_{water}$is the flow rate of the clean water. The volume of original coagulant added to one liter of water to make the stock is based on the maximum filtration flow rate, 3.607 mL/s. With this flow rate, a volume of 1.5 mL of original coagulant is needed for 1 liter of water, calculated with equations described above.

PC* is a measurement of turbidity removal, and it is equal to $-log(\frac{Effluent\ Turbidity}{Influent\ Turbidity})$. The team considered using pC* as an indicator of when to stop the loading phase. When pC* is equal to 1 then the effluent turbidity is 10 times smaller than the influent turbidity. Using the pC* as a guide and keeping in mind that any turbidity value above 5 NTU indicates unsafe drinking water to determine the appropriate time to end the loading phase, the team then uses the data collected by ProCoDa to calculate filtration time, average influent turbidity, and average effluent turbidity.

The backwash velocity and duration of the experiment were kept constant, at 21.3 mL/s for 300 seconds. The flow rate of the clay stock and coagulant stock are also constant, at 0.538 mL/s. A bucket is used to collect the effluent water for the 300 seconds of backwash phase. The team then took a sample and measured its turbidity manually with a hand turbidimeter. This would be the average effluent turbidity. Figure 7 shows the plot of filtration flow rate versus cleaning efficiency percentage. As the filtration flow rate increases, the percentage of cleaning efficiency also increases.

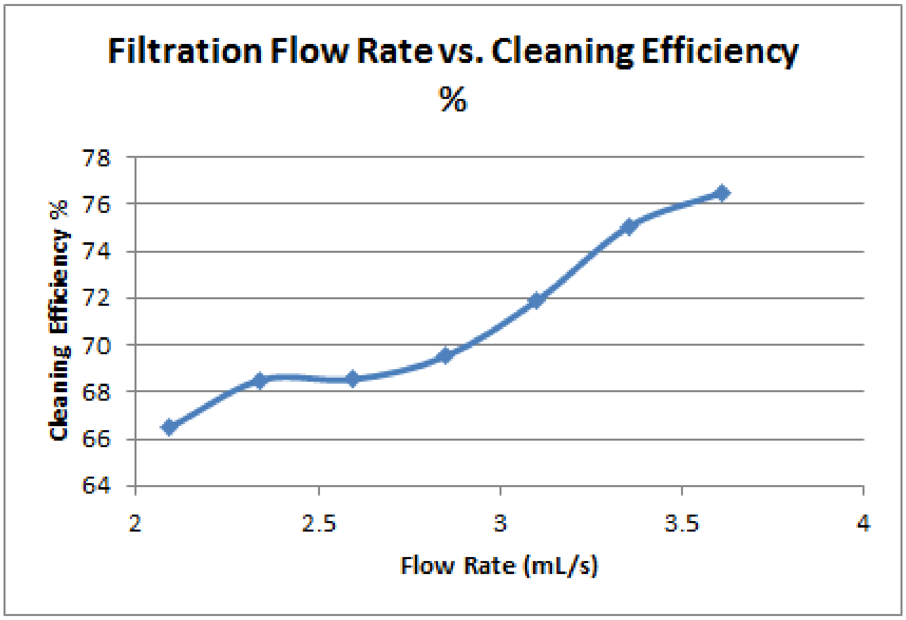


Figure 7: The graph showing that when the filtration flow rate increases, the backwash efficiency also increase.

Analysis

The team finished constructing and making sure everything is water-tight in the new apparatus. Coagulant stock and clay stock was made with calculated concentrations to run a control test. Although data has been collected, the process has not been running smoothly. One major problem the team ran into is using process control to vary loading and backwash flow rates. As seen in figure 6, the backwash flow rate does not vary linearly with the coefficient. Thus the team chose to use only the velocity within the linear region. The team thinks that this nonlinear relationship is due to the high range of flow rates of the pump.

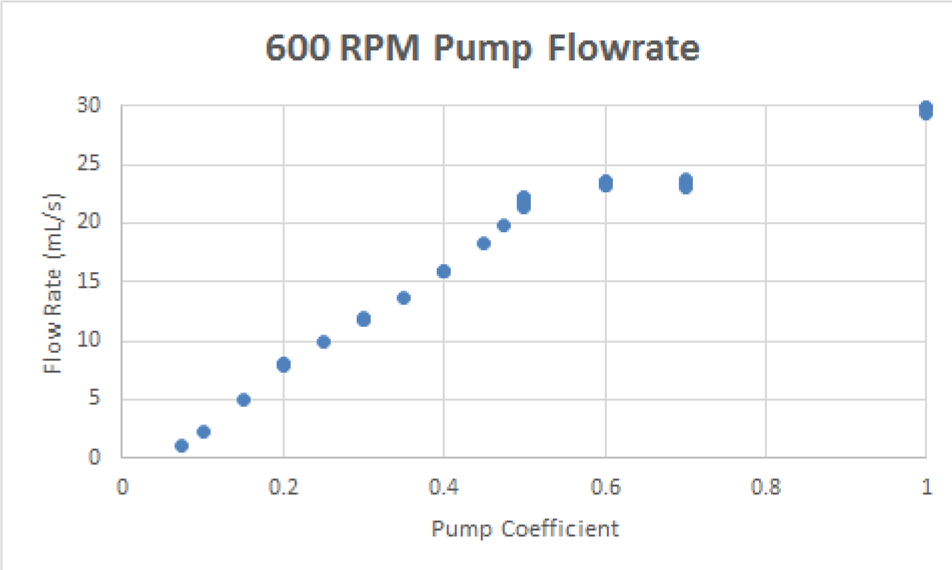


Figure 8: Graph of flow rate versus the 600 rpm pump coefficient.

In the first experiment "Filtration Flow Rate versus Backwash Efficiency," the result show that the backwash efficiency increases when the filtration flow rate increases. The team speculates that this is due to the energy dissipation rate of the process. The energy dissipation rate is calculated by $\frac{g*headloss}{filter\ residence\ time}$ and the filter residence time is dependent on the height of the filter and the velocity of filtration, $filter\ residence\ time = \frac{Height\ of\ filter}{Filtration\ velocity}$. When the filtration flow rate increases, the energy dissipation rate becomes larger. The high energy dissipation rate causes floc break up, and the foam is loaded by smaller flocs. The team thinks that the small flocs in the foam are much easier to backwash out of the foam than larger flocs, because larger flocs get stuck in the foam pores more easily according the data of average effluent turbidity. In consequence, it is easier to backwash and the backwash efficiency becomes higher.

In the field, the plunge method, instead of the compression method, is the method mainly used to clean the foam because it requires less manual force. Instead of displacing the foam in the water to create a high pore velocity, water will be shot through the foam with a high velocity to imitate the plunging method. The team mainly worked with foams of 30 ppi and 60 ppi sized pores because the team in El Carpintero has confirmed that 90 ppi foam cannot be sufficiently cleaned with the backwash method utilized in the field.

Challenges

Some of the major challenges the team faced this semester include problems with apparatus design, backwash efficiency calculation methods, water, clay stock and coagulant stock flow rates control, and process control with the ProCoDa box.

The team ran into several problems when designing the new apparatus and calculation methods due to the complexity of the problem. The team originally wanted the whole apparatus to be automated, changing between phases with the process control. This was not achieved due to the maximum reading level of the turbidimeter and time constraint. There are multiple ways to indicate the end of the phases and to calculate the backwash efficiency, picking one that provides the most amount of information turned out to be challenging.

As mentioned above, pump flow rate does not vary linearly with the coefficient set in process control. This limits the maximum and minimum flow rates that can be controlled during experiments. Future teams should take this limitation into consideration when designing test flow rates.

The most difficult challenge the team faced this semester is trouble shoot the ProCoDa box. The ProCoDa box has stopped working three times this semester, the first two times were due to a blown fuse while the cause for the third time is unknown. Paul suggested that this problem may be caused by the solenoid valves the team were using. However, even after changing all the valves into manual ones, the ProCoDa box ceased to work again. Currently, the box is only connected to the two pumps, a 100 rpm pump and a 600 rpm pump. Although Paul has suggested that valves do not contribute much to the electric current inside the ProCoDa box. The team has not come up with a reason to why the box keeps on malfunctioning.

Future Work

The team conducted experiments that compares the different backwash velocities with backwashing efficiency when the ProCoDa box stopped working. Future teams should figure out the reason why the ProCoDa box kept breaking before continuing with the experiment.

Other experiments that relates influent turbidity, pore size, and coagulant dose to backwashing efficiency should also be conducted. Influent turbidity can be varied by changing the ratio of water to clay in the clay stock container.The foam pore sizes and thickness should be changed to determine the minimum pore size and maximum thickness that can be effectively cleaned. Additionally, the flow rate of loading as well as the coagulant dosage should also be altered by changing the ratio of coagulant dose to water in the coagulant stock container.

Equations solving for the amount of coagulant needed to add in one liter of water have already been made in MathCAD and can be used by future teams. Future teams should also try to work with the 90 ppi foam to determine if it can be efficiently cleaned at all.

Changes coagulant and clay stock concentration, foam pore size, and other parameters future teams identify will need to be documented. Similar calculations for backwash efficiency and methods to identify the start and end of phases are needed to better compare and analyze the relationship between the different parameters and backwash efficiency. Since a working apparatus has already been built, future teams will be able to start right away to test the relationship between cleaning efficiency and other indicated parameters. If the backwash flow rate is found to be too small, future teams can look into having multiple heads on the pump as a way to increase the flow rate.