Stacked Rapid Sand Filter Theory, Fall 2014

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Abstract

The Stacked Rapid Sand Filter Theory team aims to create a mathematical model describing filter performance and head loss as a function of coagulant dosage and influent turbidity, given the filter media depth and media diameter. Hypotheses regarding colloid removal and particle interaction will be explored. The mathematical model will be constructed based on experimental data from a two-layer sand filter. The experimental apparatus will be assessed in its effectiveness of modeling stacked rapid sand filters to scale.

Table of Contents

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Introduction

The Stacked Rapid Sand Filter (StaRS) Theory Team hoped to develop a mathematical model that can provide more specific information about the StaRS filter, given a set of parameters. The goal for this model was to predict the mass of clay accumulated with respect to coagulant dosage concentration before particles can no longer attach to the filter media. The model would also predict pore storage volume and head loss as a function of coagulant dosage. From this model, one would then be able to calculate the theoretical filter run time before failure.

Over time, flocs build up along the sides of the sand pores, decreasing pore diameter and increasing shear force. Eventually, the flocs will be unable to attach to the sides of the sand pores, and dirty water will exit the filter because the flocs have not been removed, a condition known as breakthrough. At this point, the filter has failed. Once the filter fails, it must be cleaned through a process called backwashing before clean drinking water will be produced again. In order to optimize the water filtration process, the filter should be backwashed at the correct time. If the filter is backwashed too late, after the filter has already failed, dirty water will be distributed to the system. On the other hand, if the filter is backwashed too early, the filtration capacity would not have been reached and clean water would be used to clean the filter before necessary. This model will help determine the optimal time to backwash, ensuring water conservation and clean water distribution to the system.

The team planned to confirm and build off of the research from Spring 2014. Last semester, the subteam hypothesized that once the filter had failed, head loss would remain constant. However, the team proved that head loss continues to increase after filter failure. The team also proved that head loss is more dependent on the amount of coagulant added than the amount of clay added. The Spring 2014 team developed three new hypotheses that will be tested this semester:

1. By increasing the concentration of coagulant added to the system, the bond strengths between flocs are expected to increase. As a result, the flocs could adhere more tightly to the sides of the filter column. This adhesion could prevent lifting of the entire sand bed, causing an increase in head loss.

2. Flocs exhibit “fractal behavior”. When more coagulant is added to the system, flocs become larger, and as the size of a floc increases, the floc contains a higher percentage of water, and is therefore less dense. Accumulation would increase due to the higher water content, and head loss would also increase.

3. When the coagulant dosage increases, more mass accumulates in the pores, pore size decreases and head loss increases.

This team’s goal in experimentation will be to validate or reject these hypotheses in measuring head loss as a function of coagulant dosage.

Literature Review

Stacked Rapid Sand (StaRS) Filters are the last unit process in AguaClara water treatment. Another important step is called flocculation. When water enters the plant, colloids in the water are negatively charged and naturally repel each other. When the coagulant is added, the coagulant adheres to the colloids. This allows the oppositely charged particles to more easily approach each other. A hypothesis suggests that the polar bonds formed with coagulant cause the colloids to stick to each other and become large enough to settle to the bottom of the sedimentation tank (Weber-Shirk, 2014b). Thus, flocculation allows for much easier separation by sedimentation (Khan Academy). When water enters the Stacked Rapid Sand Filters, it contains the coagulant added from the flocculation step. The team will conduct experiments to determine how head loss, pore storage volume, and filter run time are affected by the coagulant dosage.

Generally, filters are not used to treat highly turbid water. A filter is most beneficial when it receives clean, pretreated water and further cleans it. The AguaClara Program uses coagulation, flocculation, and sedimentation for treatment prior to filtration.To optimize the performance of rapid sand filters, several variables should be considered, including sand diameter, layer height, and attachment efficiency (Weber-Shirk, 2014a). Last semester, team members had noticed that the sand particles were not of uniform size, and after backwash, the smaller diameter particles would make their way to the top of the column, with the larger diameter particles settling towards the bottom. The team addressed this issue by obtaining sand with a more uniform diameter (Ðuriš et al., 2013). In order to improve rapid sand filter performance, coagulant must be added to make particles stickier and thus have more successful collisions leading to flocculation to make them into larger flocs that are more easily filtered (Weber-Shirk, 2014a).

Two categories of filtration include depth filtration and surface filtration. In surface filtration, the particles to be removed are larger than the size of the pores. As a result, pores clog rapidly, large pressure drops occur, and more energy is required. On the other hand, the particles in depth filtration are smaller than the size of the pores. These filters can handle larger amounts of solids before excessive head loss occurs. In depth filtration, it is required that the particles attach to one another (Weber-Shirk, 2014a). This semester’s team set out to explore the pore storage volume in the sand filter and how this value is related to the amount of coagulant added.

In order to understand what makes AguaClara Stacked Rapid Sand Filters so unique, two other types of depth filtration sand filters were examined: slow sand filters and traditional rapid sand filters. In slow sand filtration, water is filtered through a biofilm layer that grows naturally on the surface of the sand before the water enters the porous media. However, the biofilm layer grows thicker and becomes saturated with entering contaminants, clogging the pores. Filter performance decreases as a result. Eventually, the top of this layer must be scraped off in order for a clean layer to develop. Another cleaning option is to lower the water level in the filter and stir so that particles and organisms in this biofilm layer become suspended in the water, and then sent to waste. In traditional rapid sand filters, water with added coagulant flows through a single-layer sand bed (compared to AguaClara StaRS filters, which use multiple stacked layers), and flocs become trapped in the sand. Rapid sand filters can handle high flow rates and use less land area and sand compared to slow sand filters. However, maintenance for rapid sand filters is costly, because rapid sand filters need to be cleaned often (di Bernardo).

At a minimum suspended particle size of approximately one μm, removal efficiency of a sand filter reaches a minimum. At sizes larger than one μm, removal efficiency increases rapidly with particle size. In these cases, the larger particles are removed by sedimentation or interception. Interception occurs when larger particles are trapped by media because of the large sizes of the particles relative to the pores. Sedimentation occurs when particles with densities larger than the density of water settle downward because of differing densities. These particles also have different trajectories, which are determined by the buoyant, gravitational, and drag forces on the particles. For suspended particles with sizes smaller than one μm, removal efficiency increases with decreasing particle size. These smaller particles often include viruses, bacteria, clays, and organic colloids found in raw and biologically treated water. Most particles in water are one μm or smaller in diameter, and these small particles are often removed by diffusion, in which the particles move from areas with higher concentrations toward areas with lower concentrations, where the particles adsorb to the sand. In general, to enhance attachment, traditional filters must provide larger pores (Habibian, et al., 1971).

StaRS filters are more advantageous than traditional rapid sand filters, because StaRS filters self-backwash, have smaller required filter area in plan view, and backwash using single-valve control. During backwash, a ball valve is used to initialize and terminate a siphon that backwashes the filter. However, StaRS filters also have a few design constraints: the inlet slotted pipe spacing must be kept small to uniformly distribute flow, the filter should be able to be backwashed at the beginning of the cycle, and the kinetic energy in the manifolds should be less than or equal to ten percent of the clean bed head loss in order to achieve uniform flow distribution in the sand bed. (Weber-Shirk, 2014a)

StaRS filters are also beneficial, because by stacking the filters, the same water used to clean one layer can be used to clean every layer. Additionally, the same flow rate can be used for filtration and backwash, since the flow that would be input into each of the layers during filtration is diverted through the bottom of the filter to fluidize the bed. AguaClara also uses settled water instead of filtered water for backwashing without any noticeable or substantial negative effects. The filter is kept clean because, unlike traditional rapid sand filters, the backwashed water does not pass through the sand bed (Weber-Shirk, 2014a). The goal of this semester's team was to further improve the backwashing process by creating a mathematical model to predict when the sand filter will fail, therefore predicting when backwashing should take place.

In order to obtain more uniform sand, the sand can be sieved with a shaker. Sieves are categorized by sieve numbers. The table below shows the responding opening size with the sieve numbers (Engineering Toolbox).

Table 1. Sieve Size and Number

Sieve Number	Sieve Size (mm)
20	0.841
30	0.595
40	0.400
50	0.30

Previous Work

In Fall 2013, the StaRS Theory team redesigned the experimental apparatus so that the filter would best model stacked rapid sand filters in AguaClara plants. They also wrote a Process Controller method file to run experiments and collect data with this new apparatus. They ran experiments varying coagulant dosage measuring effluent turbidity and head loss in order to analyze filter performance.

These experiments were carried on in Spring 2014. PACl dosages were varied between tests and some different hypotheses were proposed in order to explain the collected data. These hypotheses remained to be tested.

Methods

Stacked Rapid Sand Filter Lab Apparatus

The team reassembled the model stacked rapid sand filter, which is a two-layer sand filter. The first of several pilot experiments was run with the apparatus design of previous semesters. The subteam hoped that these experiments would confirm the data trends found in Spring 2014.

The team hypothesized that the mesh covering the openings in which water flows in and out of the filter to prevent sand from exiting the filter bed may have lead to an unexpectedly high head loss that is much higher than the change in height of the water flow. To test for this head loss, the team removed the sand from the filter in order to later measure the head loss across the mesh. If the head loss was significant, then the team would have to reassess using the mesh in the apparatus and come up with a new design. As discussed later on, the subteam determined that head loss was significant in the mesh compared to the rest of the filter column, having an initial head loss value that increases over time.

One issue was that the sand in the filter column was visibly of non-uniform size. The sand needed to be roughly a uniform diameter throughout the filter column. Stacked rapid sand filters used in the field are not entirely uniform, but segregation throughout the entire bed makes the individual layers more uniform than the layers in the current StaRS Theory filter. The major reason for this is that field filters are much deeper and therefore allow for easier segregation of the individual filter layers.To achieve this uniformity in StaRS Theory filters, the sand must be sieved at the desired diameter and then replaced in the column.

A review of the relevant literature revealed the following statement: “segregation occurs when the ratio between the largest and smallest diameters of sand particles is greater than 1.5...” (Đuriš, 2013). Taking this into account, the StaRS Filter Theory team used the sieves in the Geotech Lab to collect sand between sieve sizes 30 and 40. As can be seen in Table 1, sieve sizes 30 and 40 correspond to particle diameters of 0.595 mm and 0.400 mm, respectively, obtaining a ratio of 1.48, which is less than 1.5. Thus, sieving will prevent segregation in the column. After running tests without the sand, the sand will be replaced in the column.

For this subteam’s experiments, the influent turbidity should have been a constant 5 NTU. However, as can be seen in Figure 10, the influent turbidity varied widely during the first several tests. The subteam’s first guess for this was that the stock concentration of the clay was too large. When the influent turbidity drops below 5 NTU, PID adjusts by adding more clay. If the clay concentration were very large, adding even a small amount of clay to the water could cause the large increases in influent turbidity that were seen. To fix this, the team attempted to dilute the clay, which was of unknown concentration, by adding more water to the clay solution. However, this did not have much of an effect, so the team removed the old clay solution and measured a new solution with a concentration of 2.0 mg clay/L. After this, a definite improvement in influent turbidity was seen, but the value was still not close enough to 5 NTU. In an attempt to correct this, approximately 1 L of water was added to the clay solution. Additionally, for PID control, the P value was set to 1.0, and the I value was set to 0.25. This appeared to fix the problem, and Influent turbidity will continue to be recorded for each experiment to determine if future action is needed.

For the experimental conditions, this subteam wanted to test a range of coagulant dosages while also having an influent turbidity that is similar to what an AguaClara filter in the field would intake.

Experimental conditions:

- Coagulant: polyaluminum chloride (PACl) at concentrations of 0.2 mg PACl/L, 0.65 mg PACl/L, 1.55 mg PACl/L, and 2 mg PACl/L.
- Raw water: a mixture of kaolinite clay and water at ambient temperature with a turbidity of 5 NTU.

Description of Experimental Apparatus Setup

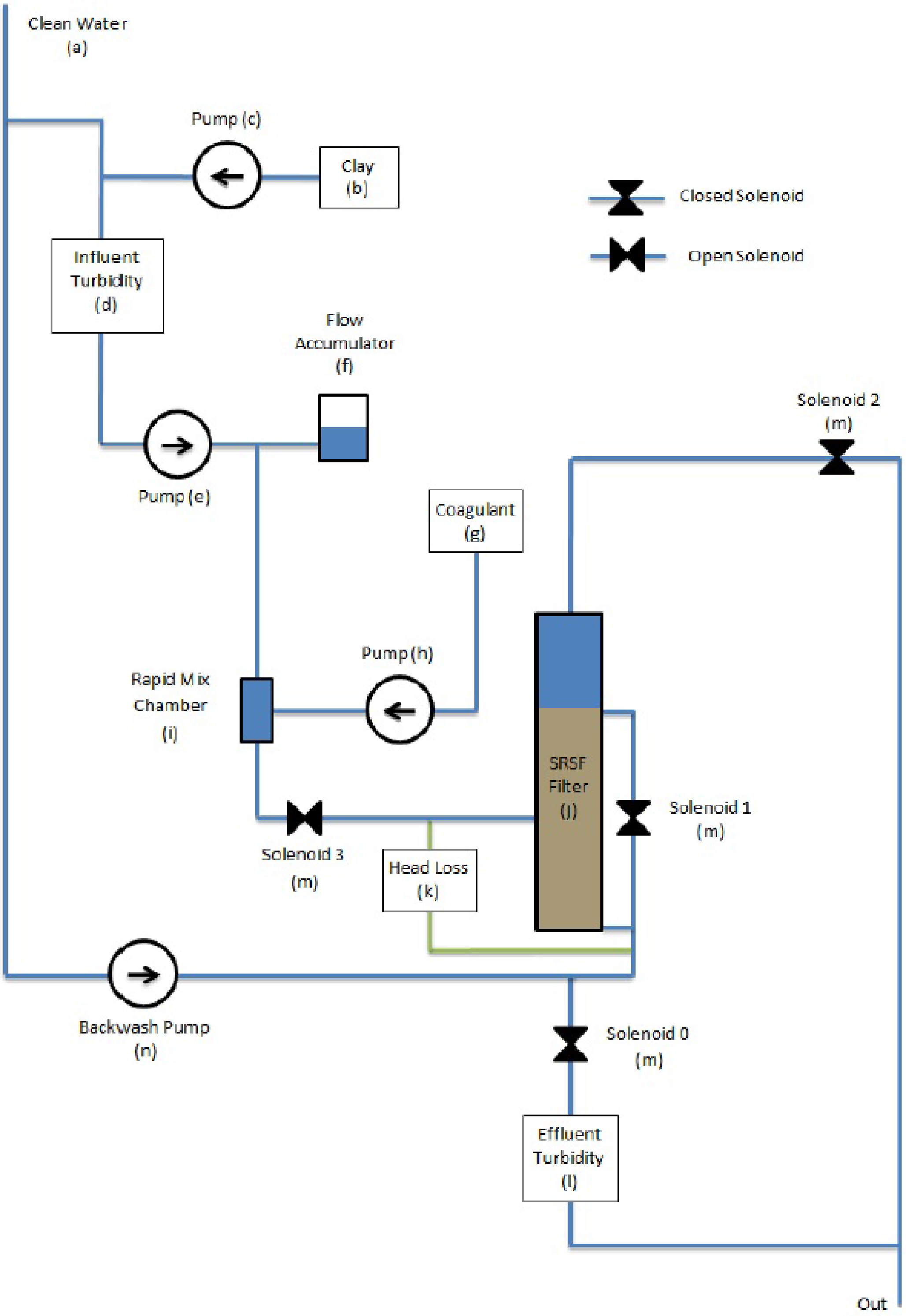

Figure 1. Schematic of Experimental Design in Filter State

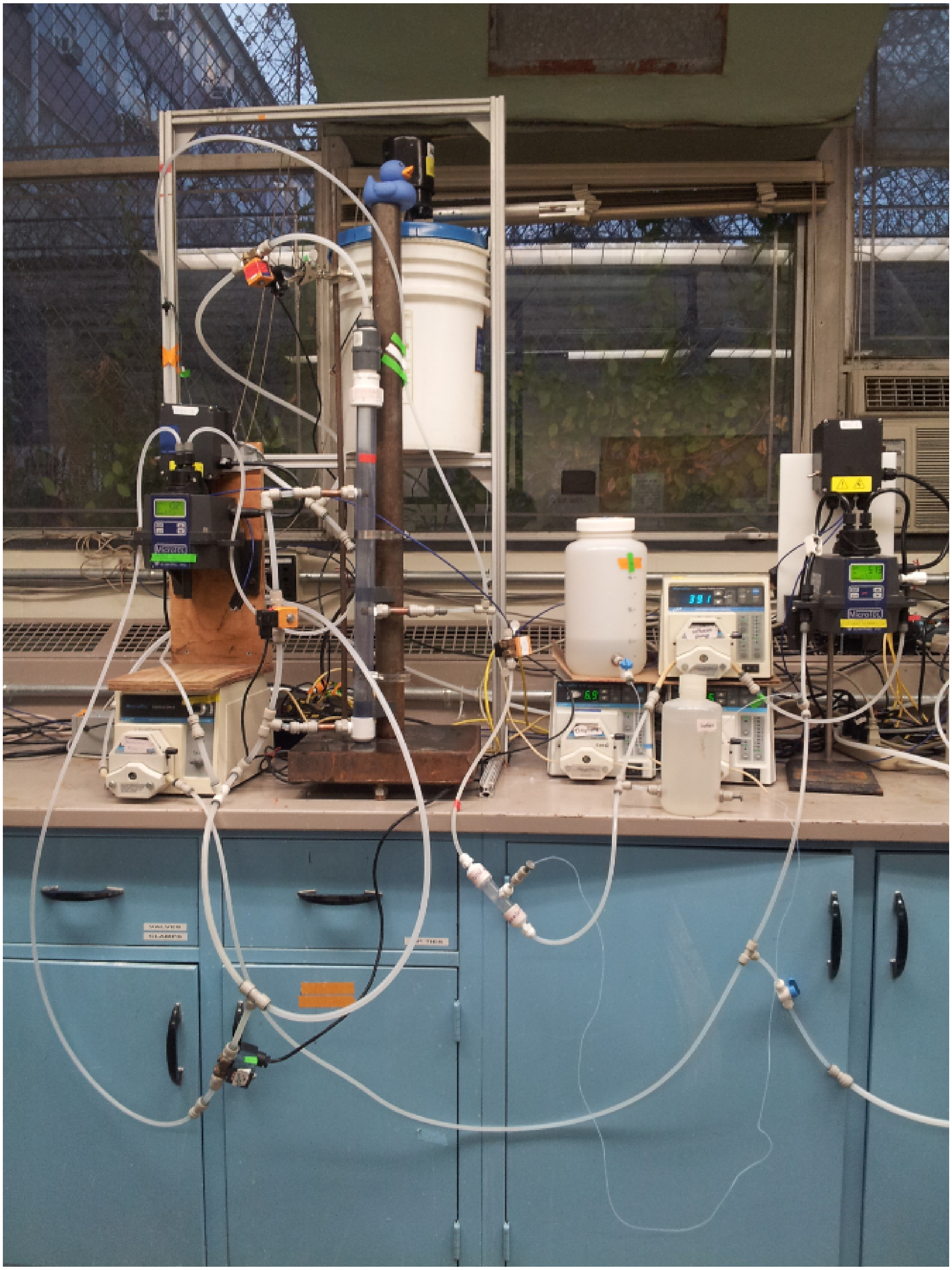

Figure 2. Photograph of Apparatus in Hollister B60 Lab

a) Clean water is stored in an aerated water supply tank in HLS B60.
b) Water is mixed with clay and stored in a stock tank. The turbidity of the clay stock is kept constant with the help of an electric mixer. The turbidity of the clay stock will be kept constant at 5 NTU.
c) Water mixed with PAC coagulant is stored in a stock tank. The mixture is constantly stirred by an electric mixer to maintain constant concentration throughout the mixture. The coagulant dosage was varied in our experiments.
d) Two peristaltic pumps were utilized to pump the clay stock and the coagulant stock from their separate tanks to the influent water tubing. The speed of each of the pumps is controlled by process controller and varies depending on the desired dosage of each. PID control adjusts the clay pump speed based on the influent turbidity reading (f).
e) A contact chamber mixes the coagulant solution with the clay water solution. The water that exits the chamber is high turbulence water and is uniform solution of the two solutions that entered the chamber. There are most likely small flocs within the solution.
f) An influent turbidimeter measures the turbidity of the solution before it passes through the SRSF filter.
g) A flow accumulator is utilized to ensure a smooth water flow from the peristaltic pump.
h) The SRSF filter contains two 20 cm sand beds that filter out flocs and reduce the turbidity of the influent water.
i) A pressure sensor is installed across the sand column. The sensor measures the difference in head between the top and the bottom of the sand column. The sensor is zeroed before every test when there is no water flowing through the pipe.
j) A solenoid valve controls the flow out of the column. The solenoid valve opens during filtration and closes during backwash.
k) A turbidimeter measures the turbidity of the water leaving the StaRS filter.
l) A peristaltic pump is utilized to backwash the filter in between tests. Water is pumped through the sand beds to fluidize the beds and remove the deposited clay from the previous test.
m) A solenoid valve controls the flow of the water out of the filter during backwash. It is open during backwash and closed during filtration.

Mathematical Model

The following data from experiments are collected: influent turbidity, effluent turbidity, and head loss. These data will then be manipulated to obtain values for pC* and mass of clay accumulated over time, assuming that 1.7 mg/L clay is equal to 1 NTU. The mass of coagulant accumulated over time will be calculated based on the PACl dosage. Performance curves of pC* and head loss trends will be generated and compared for various coagulant dosages. Both head loss and pC* will be plotted against time, coagulant dosage, and mass of clay accumulated.

Filter failure can be described with the following definitions:

1. The effluent water does not meet the turbidity standards (0.3 NTU in the USA).
2. Head loss is so high that water cannot flow through the filter.
3. The ratio of effluent turbidity to influent turbidity is greater than or equal to 0.5.

Using these definitions, significant changes in filter performance can be used to judge whether the filter has failed. These conditions ultimately signify that completely treated water is no longer exiting the treatment plant.

Process Controller Method File

The Process Controller method file contains the following:

States:

- Off: All pumps are off, all solenoids are closed.
- Pre-Filter: Clay pump and filter pump are on; coagulant pump and backwash pump are off. All solenoids are closed. Prepare for Filter mode.
- Filter: Clay pump, coagulant pump, and filter pump are on; backwash pump is off. Solenoids 0, 1, and 3 are open; solenoid 2 is closed.
- Backwash (0 and 1): Backwash pump is on; clay pump, coagulant pump, and filter pump are off. Solenoid 2 is open; solenoids 0, 1, and 3 are closed. Allows for cleaning.
- Transition: Filter pump is on; clay pump, coagulant pump, and backwash pump are off. Solenoids 0, 1, and 3 are open; solenoid 2 is closed. Essentially the same as Filter state, sans clay and coagulant. Flushes remaining particles out of the filter.
- Calibrate Pumps: Set pump speed to 5% or 95% of total pump speed as necessary to calibrate the peristaltic pumps.
- Toggle Solenoid Valves: Set solenoids to turn on and off every 0.5 seconds to check if solenoids are working properly.

Setpoints:

Each state includes a series of setpoints, some of which include:

- Off/On: Correspond to boolean 0/1, respectively. Can be used to turn pumps off/on, switch solenoid valves from closed/open, or switch pump direction between clockwise/counterclockwise.
- Turbidimeters: Includes an ID number (necessary for sorting the information gathered from each one)
- Pumps: Flow Rates and corresponding fractions (of maximum RPM) to dictate the speed at which each pump is run
- Runtime: Determines the length of time to run a certain state before switching to the next state (this set point is only used when in automatic mode)

Starting an Experiment

The following procedure was used in experiments to clean the filter column out from the previous experiment and set it up for each new experiment. Around 20 minutes should be allotted for this process.

1. Change state to Backwash State in Automatic Operation. The following states will be run.

(a) Backwash State - 5 minutes. Tilt the column to fluidize the filter bed as necessary. After this is complete, the filter column should be re-leveled (set parallel to the ring stand support). This is important because if the filter column is not level, the sand will segregate and no longer be uniform in the column.

(b) Transition State - 1 minute.

2. Clean all cuvettes.

(a) Dump the water in the turbidimeter cuvette and wipe the inside and outside with a Kimwipe.

3. Clean the flow accumulator.

(a) Dump the water from the flow accumulator bottle. Rinse if necessary.

4. Check all PACl concentrations, already established and mixed in the laboratory.

5. Check if all pumps are switched on.

6. Check if the correct manual valves are open.

7. Zero the pressure sensor(s) in Process Controller.

8. Change state to Pre-Filter on Automatic Operation (to fill flow accumulator).

After 5 minutes, the state will switch to Filter for the new experiment.

Results and Discussion

Analysis of Spring 2014 Data

The team has written MATLAB code to analyze data from the Spring 2014 semester. Some experiments from Spring 2014 showed slopes of nearly zero for head loss as a function of time. After speaking with Monroe, the team determined that leaving these experiments out of the calculations would result in the most accurate representation of the data. The team used a cutoff value for the slope of the best fit line of head loss as a function of time. If this slope was less than one for a single experiment, that experiment would not be considered in the calculations. This cutoff was applied in Figure 3.

In the bar graphs (Figures 1 and 4) below, the error bars represent the maximum and minimum slopes from all experiments that were considered at various concentrations. Experiments without error bars were either run only one time (as was true for PACl concentration 0.8 mg/mL), or only had one experiment where the slope of the head loss versus time best fit line was greater than 1 (as was true for PACL concentration 1.55 mg/mL).

As can be seen in Figure 1, with the exception of the 1.1 mg/L coagulant dosage, head loss increased with time as coagulant dosage increased. In Figure 4, for each coagulant dosage concentration, the average line of best fit was found from all experiments that were considered.

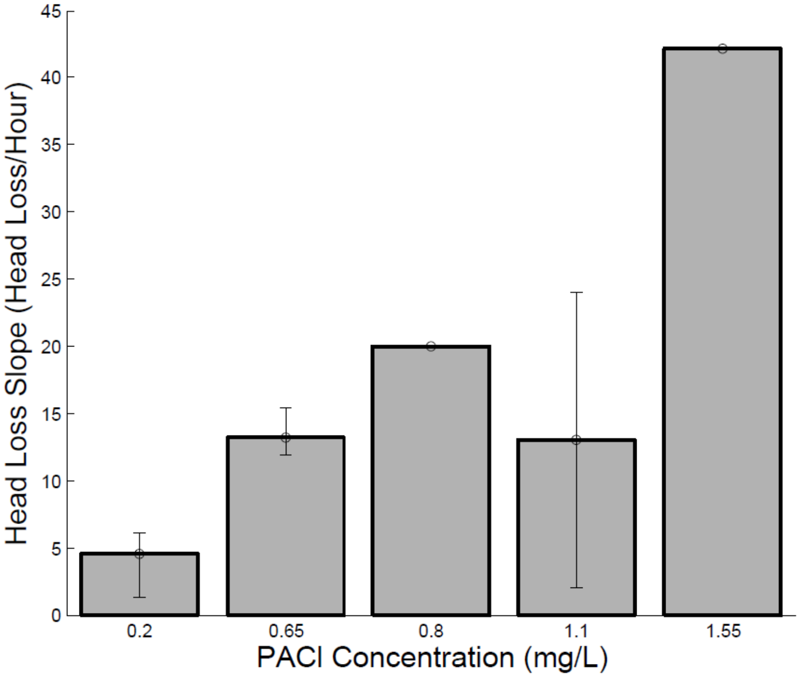

Figure 3. Head Loss slope versus PACl dosage concentration

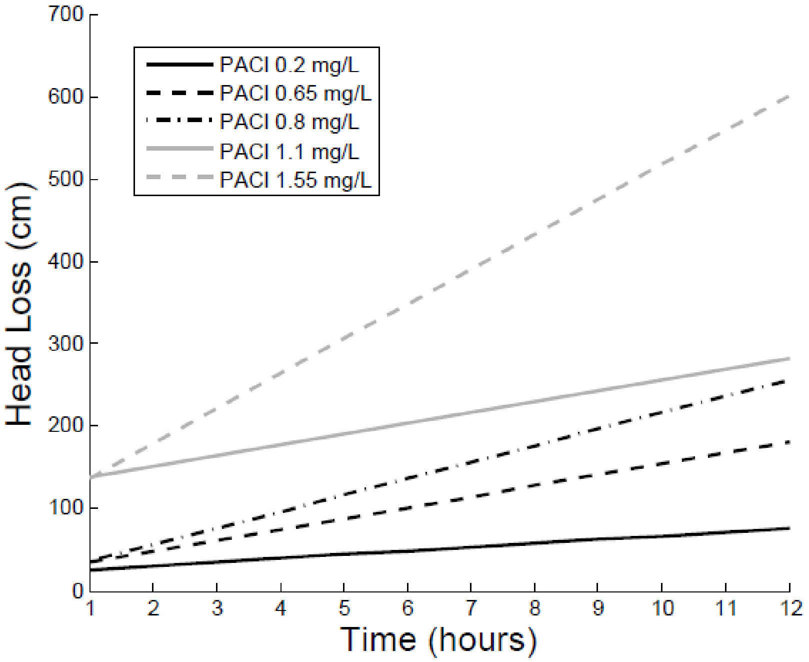

Figure 4. Head Loss versus time

Figure 5 demonstrates how multiple experiments were performed in Spring 2014 and analyzed for the 0.2 mg PACl/L coagulant dosage. Multiple experiments were conducted for most, but not all, coagulant dosages in Spring 2014, and these other dosages will be analyzed if necessary. In Figure 5, the dosage was 0.2 mg PACl/L, and nine experiments were performed, with several experiments overlapping towards the bottom of the graph (head loss ≈ 0). In Figure 6, with the exception of the 1.1 mg PACl/L concentration, pC* decreases as coagulant dosage increases. In essence, this seems to indicate that as coagulant dosage increased, filter performance decreased.

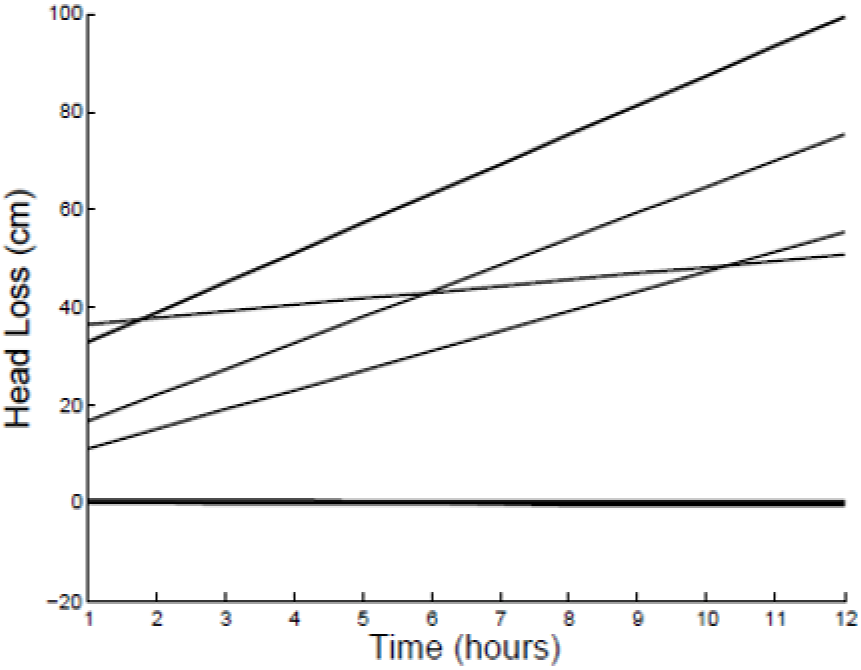

Figure 5. Head Loss versus time, PACl dosage concentration: 0.2 mg PACl /L

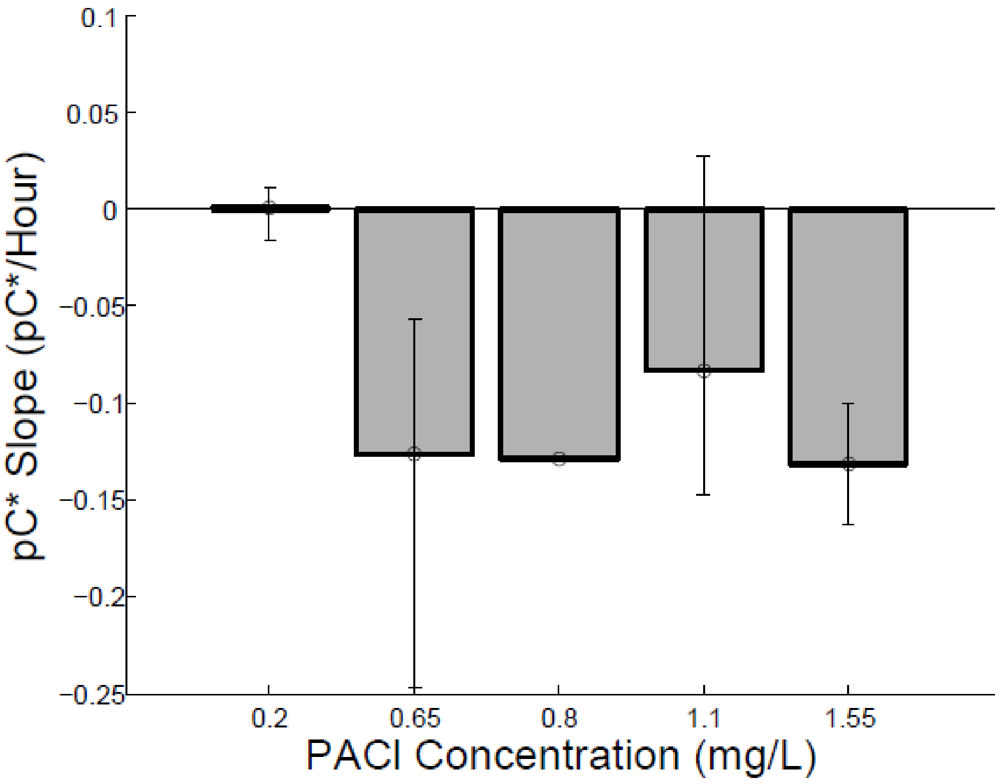

Figure 6. pC* slope versus PACl dosage concentration: 0.2 mg/L

Figure 7 represents the average lines of best fit for each coagulant dosage, and Figure 8 shows the lines of best fit for all experiments at a coagulant dosage of 0.2 mg PACl/L, the dose at which the most experiments were conducted.

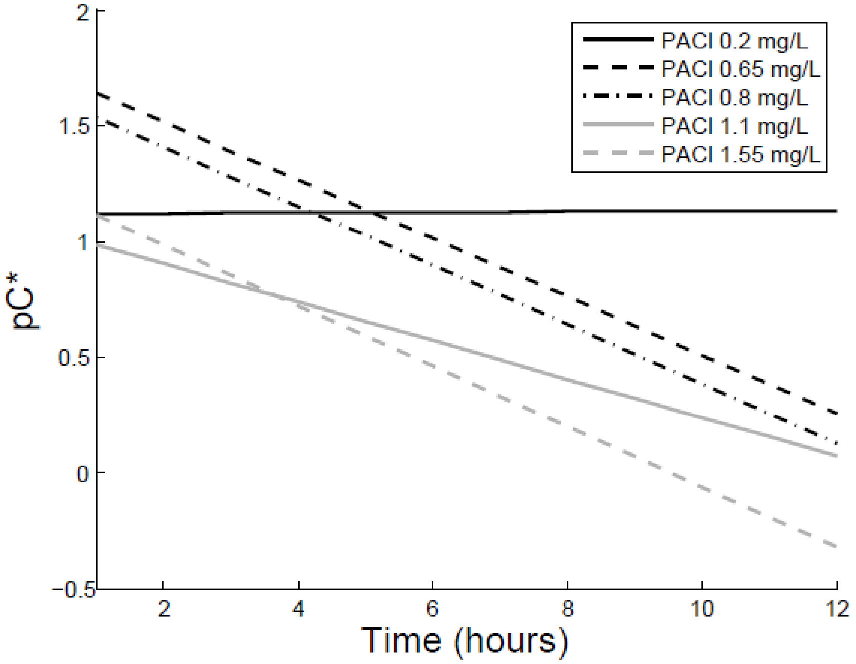

Figure 7. pC* versus time

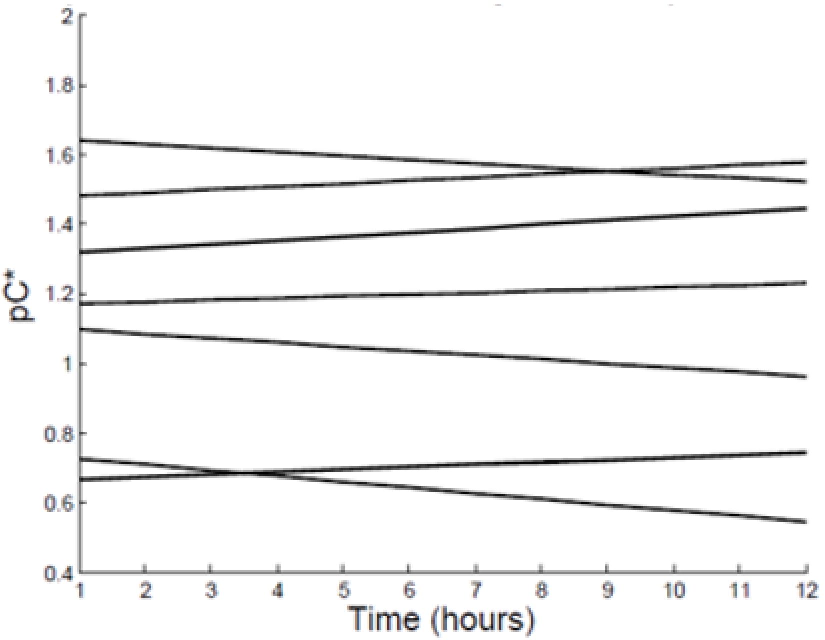

Figure 8. pC* versus time, PACl dosage concentration: 0.2 mg/L

Given the variability among the experiments from Spring 2014, the team will further analyze Spring 2014 data if deemed necessary.

PID Control and Influent Turbidity

The influent turbidity to the filter needed to remain constant over time so that the data could be isolated from the effects of changes in influent turbidity with the least variability between experiments. The leftover clay-water mixture from the previous semester was used to run the first few experiments with no sand. As seen below in Figure 9, the influent turbidity was very variable.

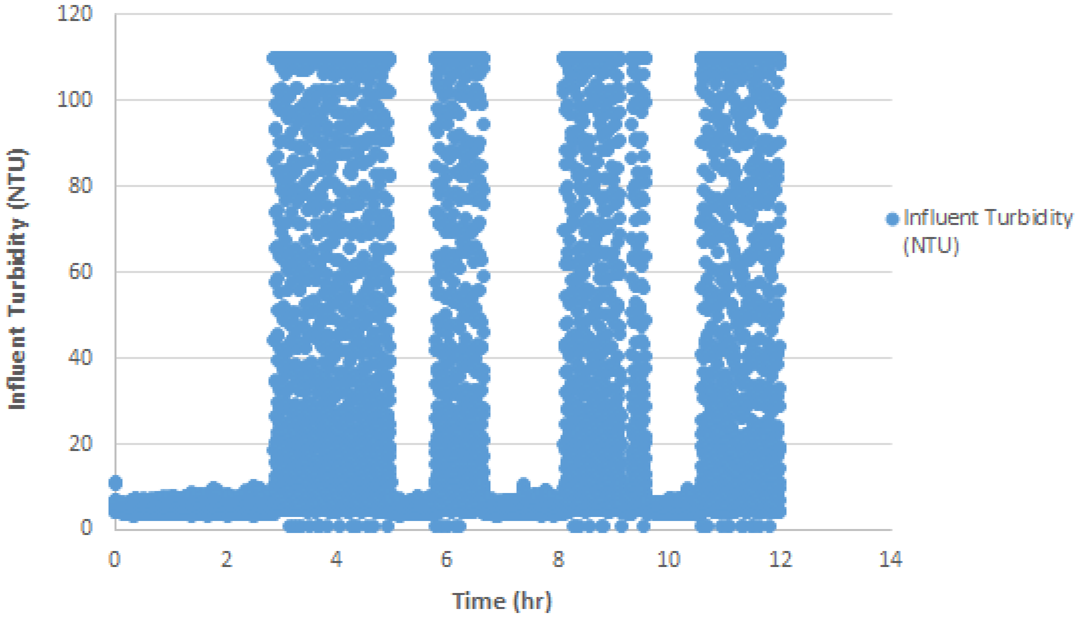

Figure 9. Influent Turbidity over Time

Once PID control was modified so that P = 1, I = 0.25, D = 0, and the clay-water mixture was changed to a more dilute concentration, another experiment was run. The below graph, Figure 10, shows the influent turbidity over 12 hours. The turbidity remained constant at around 5 NTU for almost the entire run time.

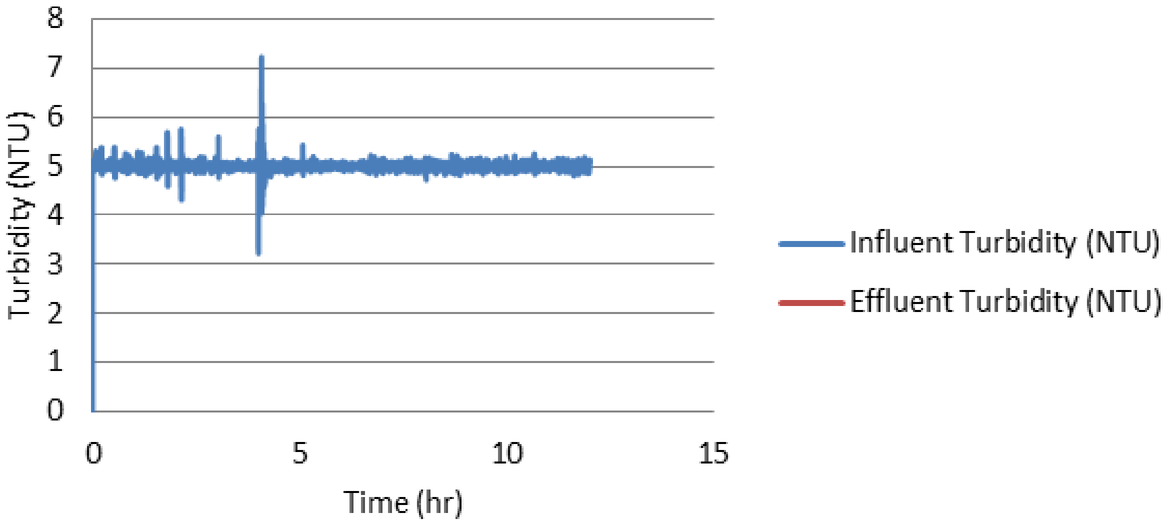

Figure 10. Influent Turbidity over Time with Working PID Control

The pump speed value that was calculated by PID control for this experiment with constant influent turbidity is shown below in Figure 11. At these settings, the clay pump was able to maintain a constant running speed so that the pump did not have to constantly start and stop in order to maintain constant turbidity.

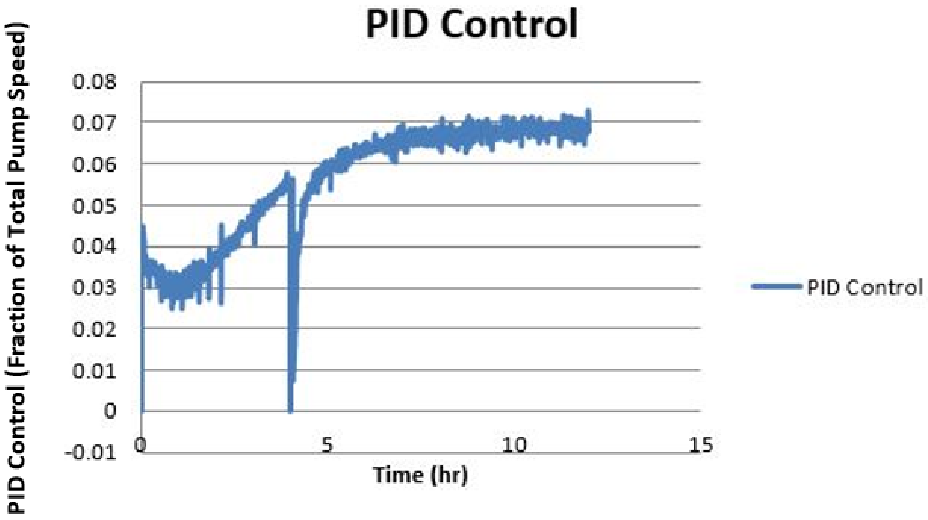

Figure 11. PID Control: Calculated Pump Speed Fraction versus time

Head Loss Across the Mesh

The team ran experiments with the apparatus design of previous semesters. However, unlike previous semesters, the filter column contained no sand.

The following graph, Figure 12, shows the head loss for three experiments with no sand in the filter column. The PACl dosage was 2 mg PACl/L. The influent turbidity was supposed to remain constant at 5 NTU, but the turbidity varied greatly. As expected, the head loss was shown to have low values and never rose above 5 cm over 12 hours.

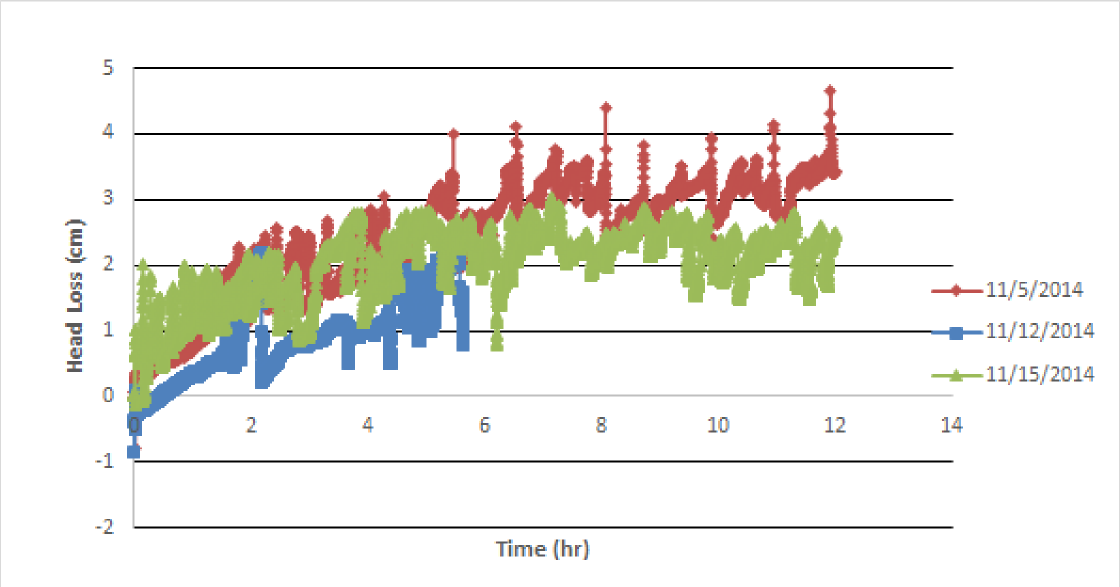

Figure 12. Head Loss Across the Mesh; Influent Turbidity: Varying; PACl Dosage: 2 mg/L

Experiments run without sand show that the head loss due to the mesh has a negligible value. While the the sand produces a head loss with values between 50 and 200 cm (Figure 4), head loss produced by the mesh (Figure 12) reaches a maximum value of 4 cm.

In a second set of experiments, the PID control and the clay-water mixture were modified so that influent turbidity remained constant at 5 NTU. The resulting head loss over time is plotted below in Figure 13. Rather than the usual low head loss values, however, the head loss reached over 30 cm over 12 hours for two out of three experiments. One of the experiments, however, reached a head loss of 5 cm over approximately 10 hours. Data was not shown for this experiment for the whole 12 hours, because Process Controller did not record the data for unknown reasons. However, as seen by the slopes shown below, the experiment with 5 cm of head loss had a smaller slope than the other two experiments and was unlikely to reach head loss values as high as 30 cm.

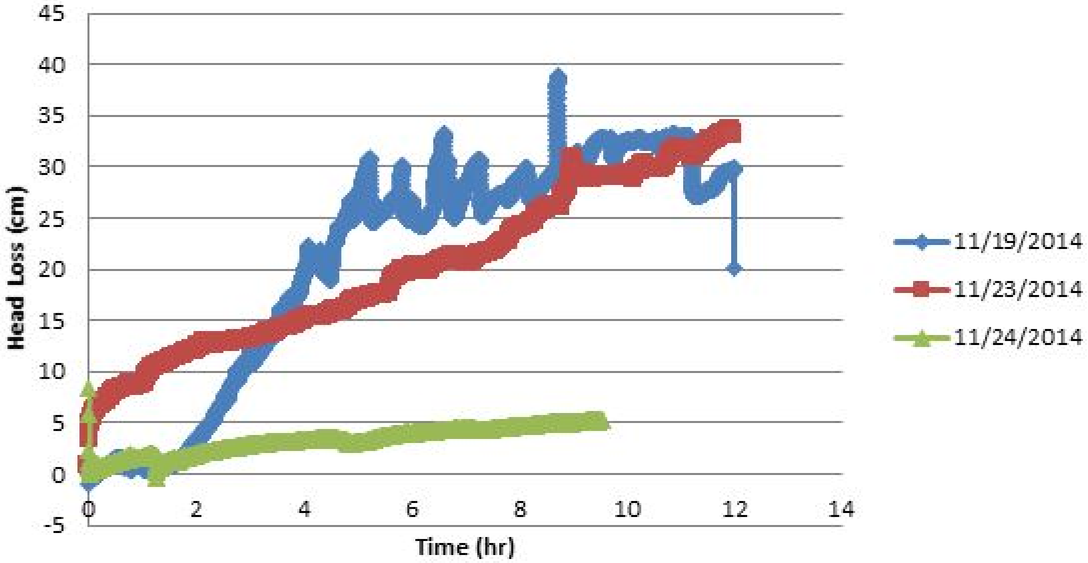

Figure 13. Head Loss Across the Mesh; Influent Turbidity: 5 NTU; PACl Dosage: 2 mg/L

Experiments were then run with lower values of PACl dosage because it was suspected that the high ratio of coagulant to clay actually caused clogging to occur at the mesh. A lower PACl dosage would then result in a lower head loss. The copper tubing was removed and then scrubbed and soaked in vinegar to clean the tubing of residual flocs and coagulant. The graphs below for 1.1 mg PACl/L and 0.2 mg PACl/L are shown in Figure 14 and Figure 15, respectively.

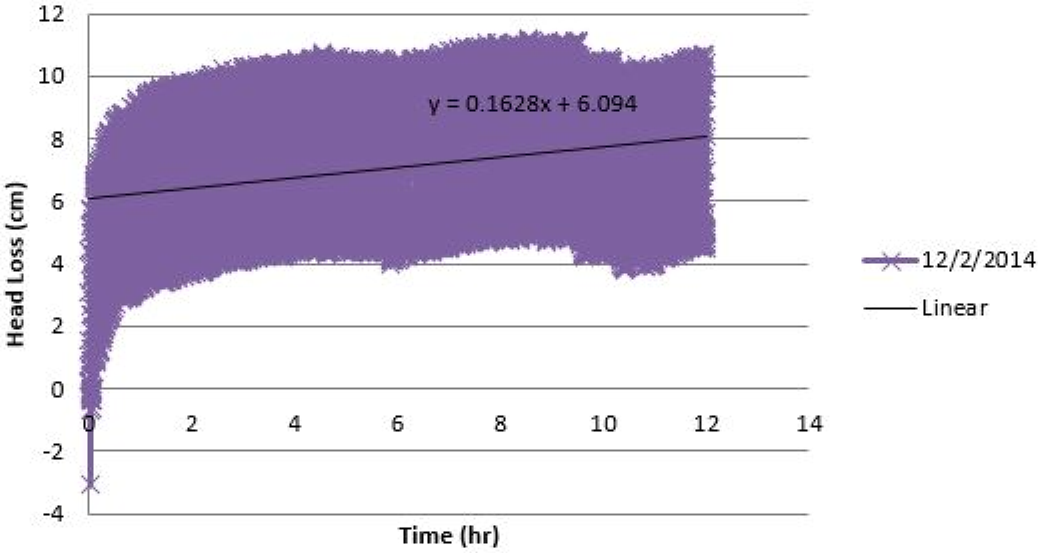

Figure 14. Head Loss Across the Mesh; Influent Turbidity: 5 NTU; PACl Dosage: 1.1 mg/L

The experiment with 1.1 mg PACl/L, shown above in Figure 14, reached a maximum head loss of 11 cm over 12 hours. There was evidently a lot of noise in the data as the head loss varies greatly, but there was a slight upward trend. After the initial increase in head loss, the slope leveled off and there was only a slight increase in head loss over time, which was about 0.16 cm per hour, according to the trendline. This head loss graph showed that with clean inlet and outlet tubing, there was not a significant amount of head loss throughout the column.

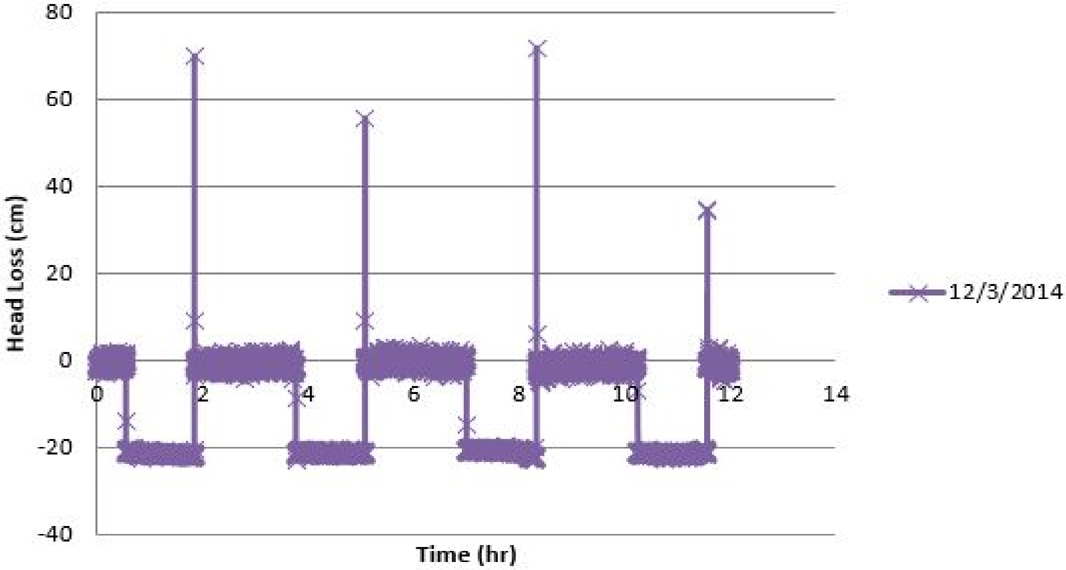

Figure 15. Head Loss Across the Mesh; Influent Turbidity: 5 NTU; PACl Dosage: 0.2 mg/L

The above graph, Figure 15, is a plot of the head loss for the PACl dosage of 0.2 mg/L. The trend looked similar to a square wave and was not expected for head loss, which should have increased linearly over time. This trend demonstrated that there is likely an issue with the pressure sensor. This plot was most likely not a representative trend of the head loss for this PACl dosage, especially since there were several negative head loss values, which were not physically possible because the water will not gain pressure as it travels through the filter.

Discussion

The data collected last semester showed that there was a relation between head loss and coagulant dosage. Some possible hypotheses, as previously mentioned, were proposed in order to explain this behavior. However, it was clear that some experiments were not reliable and had large variances, the causes of which are unknown. This semester, the team worked to confirm or disprove the trends seen in previous data. This subteam's goal was to run more experiments varying the PACl dosage in order to confirm or deny any of these hypotheses. Due to the large variability in the Spring 2014 data, the Spring 2014 data analysis was be put on hold unless further deemed insightful.

The data from three experiments showed that head loss across the mesh after 12 hours was only up to 4 cm. As expected head loss values across the sand filter after 12 hours are typically around 40 cm, the head loss across the mesh was insignificant.

However, in the second set of experiments, where a constant influent turbidity of 5 NTU was finally achieved, the head loss over 12 hours rose to over 30 cm in two cases. These head loss values were large and unexpected. The team has not been able to find a reason why head loss would increase so rapidly, but the mesh at the inlet tubing is a possible explanation for the head loss. Since one of the experiments with 2 mg PACl/L still had a low head loss value, there is no current explanation for how different head losses were achieved for the same experimental conditions. The lower coagulant dosage of 1.1 mg PACl/L also had a low head loss value after 12 hours, which shows either that the lower coagulant-clay ratio reduced clogging at the mesh, or shows that the mesh does not add to the head loss. The head loss for the 0.2 mg PACl/L graph is inconclusive and this experiment should be performed again.

The team must run more experiments to analyze whether the mesh actually adds significantly to the head loss. If the mesh does add to head loss significantly, then these experiments also prove that head loss in the slotted pipes in AguaClara treatment plants is an issue.

Sand has been sieved between the sieve numbers 30 and 40. With the future addition of the sieved sand, the experimental apparatus is otherwise almost ready to test the hypotheses for PACl dosages.

Future Work

The future subteam should consider switching the current copper mesh to a copper mesh with smaller openings. The opening size of the current mesh, 0.23 mm, is much smaller than the diameter of the sieved sand particles, which are between 0.400 mm and 0.595 mm. The subteam hypothesizes that if the mesh openings were larger, fewer clay particles would be trapped in the mesh, reducing head loss and clogging. However, when the filter's inlet pipes were removed this semester in order to clean the mesh, the subteam did notice some corrosion of the copper mesh. Switching the mesh to a different, less corrosive material, will also be considered.

In the future, the subteam can continue to run tests with different coagulant to clay ratios to test head loss across the copper mesh. These experiments are important because if results continue to show large head loss across the mesh, there is most likely head loss across the slotted pipes currently used in AguaClara filters. In this case, a new design will need to be implemented to replace the slotted pipes, and the mesh in the apparatus.

Head loss throughout the sand filter could also be measured more precisely. More pressure sensors could be added throughout the filter column in order to measure the pressure differences at various points in the filter. Although the hypotheses are built on the assumption that head loss is uniform throughout the filter, this assumption may not be true, which may have implications for filter performance over time. However, perforating the filter column is a difficult process, and the head loss across the filter is not a priority issue, so the subteam will leave this method for later.

If possible, the subteam should communicate with previous subteam members to discuss the large variation in the Spring and Fall 2014 results.

Assuming that the experimental apparatus will not need significant modification, the sieved sand can be added to the filter. A suggestion for a future set of experiments is to vary PACl dosages between 0.2 mg PACl/L and 2 mg PACl/L and then analyze the head loss and effluent turbidity data.

Another possibility to test is how filter performance is related to influent turbidity. By varying only the influent turbidity, the subteam will be able to tell if the filter column performance is more closely related to that of filtration or sedimentation. In traditional filters, performance decreases as influent turbidity increases because the particles cause clogging of the filter. However, with sedimentation, large flocs can form in water with a higher influent turbidity, increasing filter performance.

Both of these relationships are very important in creating a mathematical model describing filter performance.

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