Stacked Rapid Sand Filter Theory

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Abstract

The overarching goal of the Stacked Rapid Sand Filter Theory team is to develop a model for filter performance. An experimental apparatus was designed to model a stacked rapid sand filter. Experiments with constant turbidity and varying coagulant dosages were run and analyzed. From the analyzed data the team began graphing a group of performances curves to create a model that will be able to predict the expected head loss of a given SRSF filter if the coagulant dosage and amount of solids already accumulated in the filter are known.

Literature Review

The Stacked Rapid Sand Filter (SRSF) is an AguaClara innovation that uses subsurface sand filtration by injecting water into the sand. The water is injected evenly throughout the layers of sand in the filter and then flows both up and down through the sand and out through pipes leading out of the filter. Particulate matter in the water is then caught in the sand due to particle size, charge, coagulant addition, and settling due to gravity. Previous teams established that backwashing is much more efficient and faster in subsurface filtration than surface filtration. The reason for the higher efficiency is that in subsurface filtration, the clay is caught in the depths of the sand and does not build up to large floc particles, while in surface filtration, a layer of schmutzdecke or clay buildup forms on the surface of the sand. In conventional surface filters, the schmutzdecke is usually scraped off, but given the design of the sand filters, this cleaning process could not be performed on AguaClara plants or the lab-scale filter plant. The stacked rapid sand filter has been found to remove clay from water of very high levels of turbidity (~100 NTU) and lower turbidity to about 5 NTU. Clogging occurs much more quickly at high influent turbidity, high coagulant dosages, and high flow rates, or a mix of any of the three conditions. Head loss generally occurs linearly but then follows an exponential trend once clogging occurs. Effluent turbidity also increases after clogging. It was found that the subsurface sand filter often had lower effluent turbidities than the surface sand filter until the subsurface sand filter clogged. The subsurface sand filter clogged more quickly than surface.

Backwashing is the method used to clean the filter by running clean water backwards through the system. When backwashing, the velocity of the water through the filter should not be run at full speed immediately. The backwash velocity should start slowly, which allows the filter media to fluidize. If there is air in the filter, starting backwash too quickly may force the air through the filter and damage it. After starting at a slower backwash speed, the velocity can then be increased to the maximum desired backwash speed. [2]

In the lab-scale bench setup, influent turbidity levels and coagulant dosages have been difficult to keep constant. The smaller the tube diameter, the lower the fraction of coagulant on the clay. Much of the coagulant is lost to the filtration system, whether in the rapid mix chamber or on the sides of the tubes. Possible solutions to reducing coagulant loss is having a larger contact chamber or adding the coagulant to the clay stock and recirculating the raw water so that floc particles do not settle. The coagulant loss is not as significant in actual AguaClara plants simply because the piping is larger and the clay and coagulant are mixed better before filtration. Influent turbidity can be kept at a more constant level using a PID feedback control on the clay pump. Turbidity should be within 10% of the target value; if turbidities of 5 NTU are desired, the error should not be greater than +/- 0.5 NTU.

Proportional Integral Derivative (PID) control is a feedback system which helps keep a measured variable in range of the target value. The proportional value, P, is how much in proportion of the target value the system should respond to a high or low variable reading. The integrative value, I, is the integral of the function of the variable over time and is proportional to the amount of time error exists. The derivative value, D, is proportional to the amount of change in the variable over time. These values are used in PID control to properly respond to a discrepancy in the variable and the target value. [3]

Introduction

The Stacked Rapid Sand Filtration (SRSF) Theory subteam is a new team this semester that aims to develop a more thorough understanding of the theory of subsurface rapid sand filtration. A previous subteam, Subsurface vs. Surface Sand Filtration concluded that subsurface filtration is indeed more adept at filtering than a traditional surface filter [1]. The subsurface filter was able to capture more particles during filtration and was less likely to become clogged to the point of requiring hours of backwash, therefore making the subsurface filter is a more appropriate option in filter performance. The ultimate goal of the SRSF Theory subteam is to be able to develop a model that will be able to predict the head loss of a filter as a function of the coagulant dose and the mass of the solids already accumulated in the filter. This model should prove beneficial to the AguaClara plant operators.

Methods

Experimental Apparatus Design and Construction

With the set up of the previous team's apparatus in mind, the experimental apparatus was designed to test stacked rapid sand filter performance. The former apparatus was used to test surface vs. subsurface filtration. The SRSF Theory team focused only on stacked rapid sand filters (SRSF), which use subsurface filtration. A new filter column, therefore, was designed to model two layers of a SRSF. Water was injected in the middle of the sand bed and exits the filter at the top and bottom of the sand layer. A schematic was first created for the design of the new apparatus, but the schematic may be modified in the future to solve issues of turbidity and coagulant loss.

The new filter column was constructed from 1 inch clear PVC. The column height of the filter was calculated. The two filtration layers were 20 cm in height, therefore the total height of the sand bed was 40 cm. Considering that an extra 30% space was needed in the pipe when the filter is fluidized during backwash, the height of the new pipe was calculated. The height of the sand was multiplied by 0.30 to account for the space needed during backwash and determined that the height of the column should be roughly 52 cm. Since the lower outlet pipe would not be exactly at 0 cm and extra backwash space would be needed, the final filter column height was 60 cm.

A model of the filter column is shown below in Figure 1. The PVC pipe was cut and a cap was glued on to one end in order to seal it. Holes were drilled in the PVC pipe at the appropriate places for inlet and outlet systems. The upper end of the PVC pipe will be connected into the system for backwash. All extraneous pumps, turbidimeters, and tubing were removed from the testing area.

The velocity of the inlet and outlet systems and through the sand filter should model the respective velocities. The SRSF Theory team met with the design team to discuss how to find values for the area of the inlet tube and the velocity in the inlet/outlet tubes. The design team gave the team access to the design files and these values were then calculated. Given that the velocity through the filter is 1.8 mm/s, the flow rate through the filter column, which has an inner diameter of 1 inch, is calculated to be about 0.93 mL/s. Since there are two filter beds, the flow rate was doubled to approximately 1.86 mL/s so the correct velocity of water is through each layer. After utilizing the design code and finding that the ratio of the area of the inlet to the cross-sectional area of the filter is 0.04 (m^2 inlet/m^2filter), the area of the inlet could then be calculated. This area and equivalent flow rate then gave the necessary velocity through the inlet and outlet systems.

Mesh on entrances to the filter was necessary so that water could flow through the filter while sand could not exit the filter. Either copper or brass could be used for the mesh on the inlet and outlet pipes, because these are the only materials that could be welded to the copper pipe. Copper was chosen because it was the material used in the last apparatus and was cheaper than brass. Based on these parameters, the following materials were used for the inlet and outlet pipes: multipurpose copper tubing with an inner diameter of 9.4 mm (0.37 in.) and copper mesh with openings of 0.23 mm (0.009 in) and a porosity of 30%. As in the AguaClara plants, the velocity through the filter is 1.8 mm/s. Given the area ratio, the velocity through the inlet pipe is 90 mm/s.

The filter column was constructed as specified. The proper inlet and outlet holes were drilled and threaded into the PVC pipe according to the values calculated in the analysis section. Currently, the filter column has the push-to-connect fittings in the inlet and outlet holes. The copper pipe was cut into three pieces and the copper mesh was soldered onto one end of each segment. The pipes were inserted through the push-to-connect fittings to the middle of the PVC pipe. Push-to-connect fittings were also put on the open end of the copper pipe to allow connections for hard tubing. In order to test that the column was watertight, water was run through the column with plugs in the openings. The fittings from the previous team's columns will be reused on the top of this filter column since those fittings already have the mesh attached to the opening.

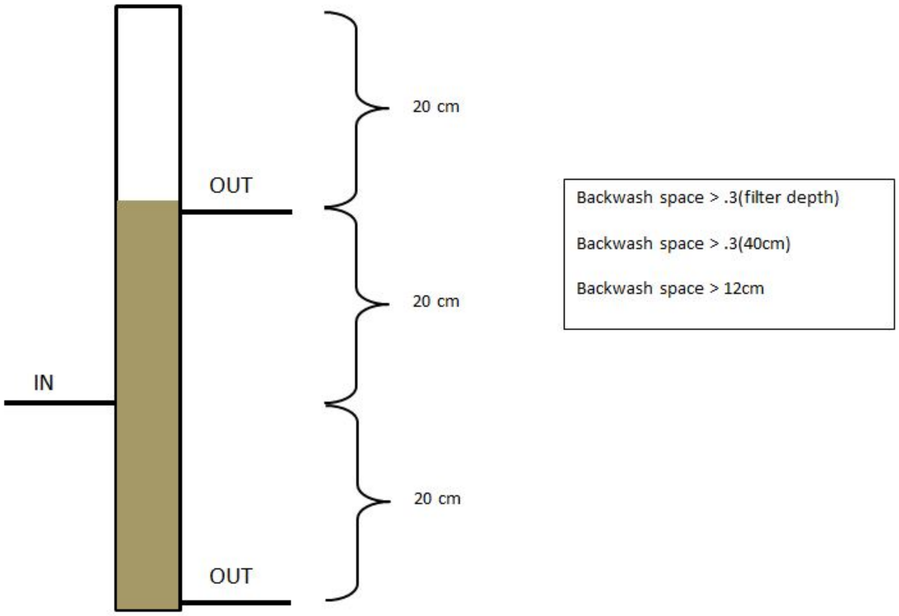

Figure 1: Filter Column

Description of Experimental Apparatus Setup

A schematic of our design and the lab setup can be viewed below (Figures2).

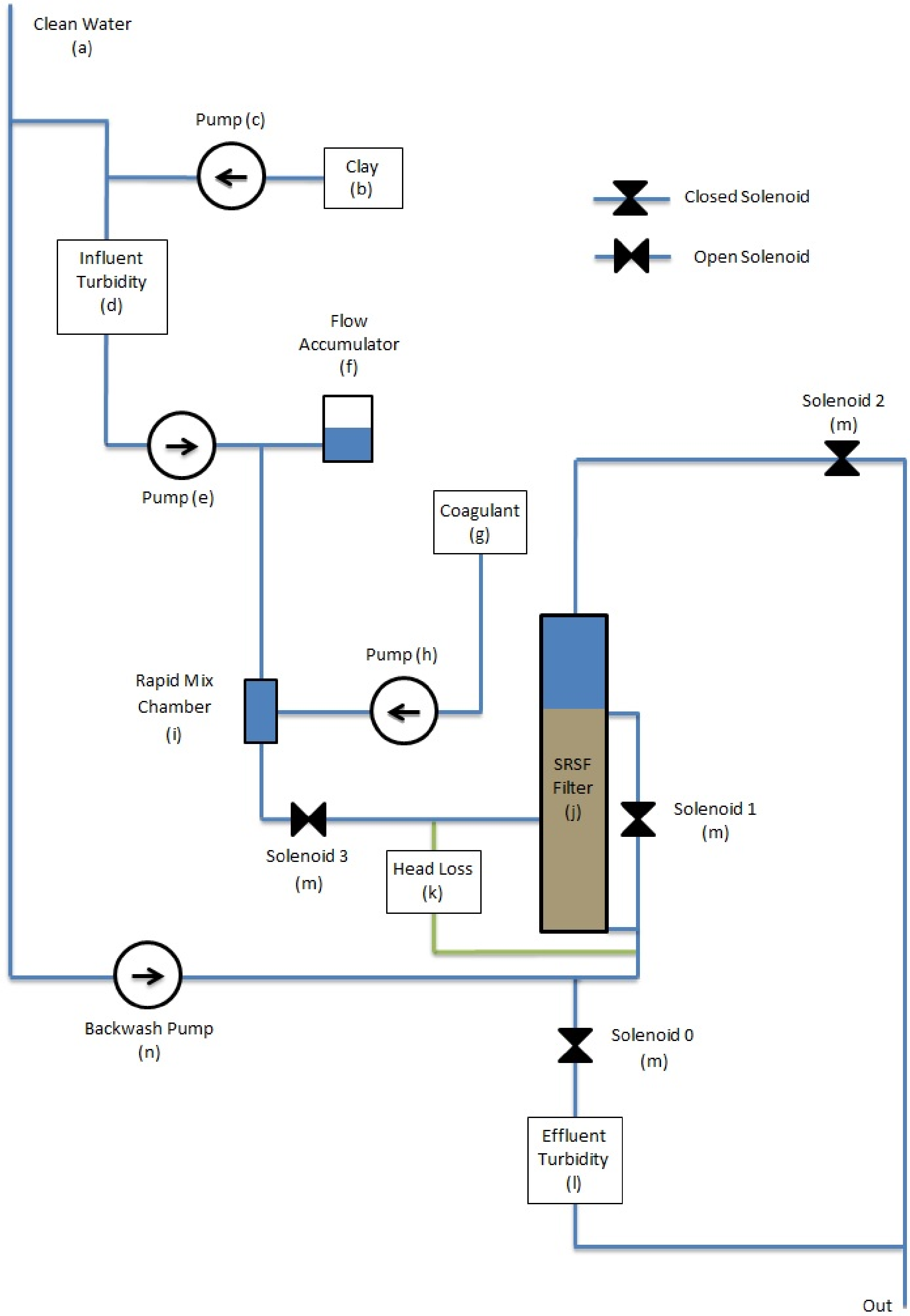

Figure 2: Schematic of Experimental Apparatus in Filter State

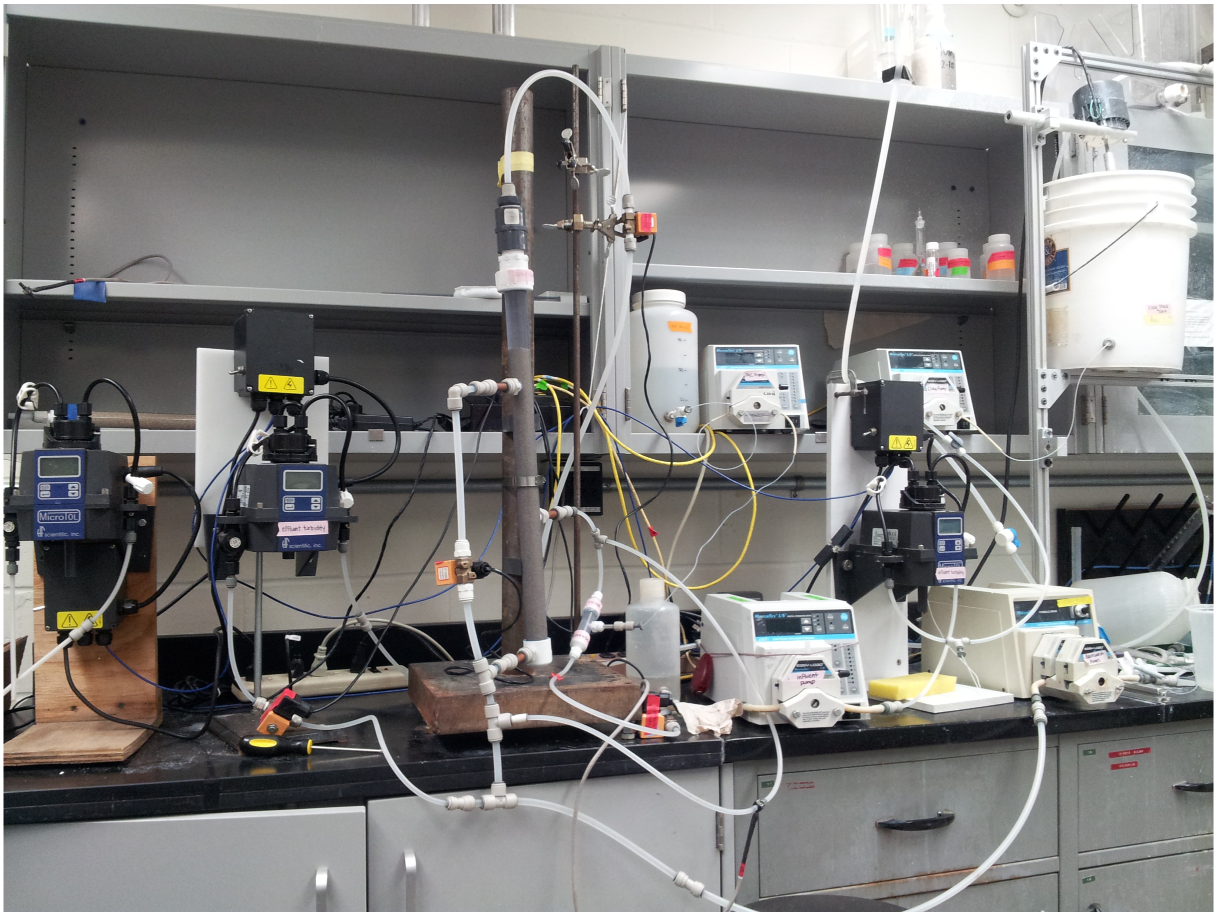

Figure 3: Lab Setup of Experimental Apparatus

1. Clean water (a) is stored in a temperature controlled (20º C) and aerated water supply tank in HLS 160.

2. Water is mixed with clay and stored in a stock tank (b); the concentration of the clay and water mixture can be varied based on the desired turbidity. An electric mixer keeps the stock tank at a consistent turbidity.

3. The clay and water mixture is pumped into the influent water. The speed of the clay pump (c) is set using Process Controller and PID control in order to achieve a relatively constant influent turbidity.

4. A turbidimeter (d) measures the turbidity of the water before the water enters the column and before coagulant is added.

5. The water passes through a peristaltic pump (e) and then through the flow accumulator (f) which decreases irregularities in the flow of the pump.

6. Coagulant (PAC) is stored in a stock tank (g) and is pumped into the

rapid mix chamber (i) where it mixes with influent water. The speed of the PAC pump (h) is altered to achieve desired PAC dosages.

7. The water, with clay and coagulant added, passes through the filter column, which contains 40 cm of sand. The water enters the filter column 20 cm from the bottom and from there must travel 20 cm up or down through the sand before leaving the filter. As a result, the filter effectively contains two 20 cm sand beds, which trap the suspended clay and reduce the water's turbidity.

8. A pressure sensor (k) is installed across the sand column. The sensor measures the difference in head between the influent and effluent water. The sensor is zeroed before every test when there is no water flowing through the pipe.

9. A turbidimeter (l) measures the effluent turbidity (the turbidity of the water after it has passed through the column).

10. During backwash, a pump (n) is used to fluidize the the filter bed between tests and remove the deposited clay and coagulant. Four solenoids (m) are used to control the flow through the apparatus. During backwash, solenoids 0, 1, and 3 are closed and solenoid 2 is opened. These settings are reversed during filtration.

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: Set pump speed to 5% or 95% of total pump speed as necessary to calibrate the peristaltic pumps.
- Toggle: Set solenoids to the Toggle setpoint 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 or switch solenoid valves from closed/open.
- Turbidimeters: Includes an ID number (necessary for sorting the information gathered from each one)
- Pumps: Fractions and Flow Rates 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)

Purpose of Pre-Filter State

The Pre-Filter state was added so that more useful data would be collected in the Filter state. By starting the clay and filter pump without water flowing into the filter, raw water enters the system. The influent turbidimeter is allowed to fill with raw water and PID control can then adjust the clay pump to the necessary speed. Since the cuvette is initially filled with clean water, the time in Pre-Filter state allows PID control enough time to even out the clay pump speed so that there aren't a lot of jumps in turbidity at the beginning of filtration. The flow accumulator is filled above the entrance with raw water so that when water passes by in filtration state, the flow accumulator can still smooth out the flow without adding air to the system. Before the Pre-Filter state was added, there would only be an empty flow accumulator that allowed for air to enter the filtration column. The flow accumulator could not be filled with tap water or any other water because the volume of water would change the concentration of the clay running through the filter. The runtime for Pre-Filter is set at 3 minutes for this transition to occur smoothly.

Backwash States

In order to allow the sand in the filter column to fluidize more easily, an intermediate backwash speed was added to the backwashing process. The backwash pump runs at about half the final speed for a minute and then switches to the higher backwash speed to achieve the backwash velocity of 11 mm/s in the filter column. The state Backwash 0 was added so that this switch may be done automatically. Backwash starts with Backwash 0 at the lower speed, and then switches to Backwash 1 at 11 mm/s.

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 the new experiment. Around 20 minutes should be allotted for this process.

1. Change state to Backwash State on in Automatic Operation. The following states will be run.
   (a) Backwash State - 5 minutes. Tilt the column to fluidize the filter bed as necessary.
   (b) Transition State - 1 minute.
2. Clean all cuvettes.
   (a) Dump the water in the cuvette and wipe the outside with a Kimwipe.
3. Clean the flow accumulator.
   (a) Dump the water from the flow accumulator bottle. Rinse if necessary.
4. Check all concentrations.
5. Check if all pumps are switched on.
6. Check if the correct manual valves are open.
7. Zero Pressure Sensor in Process Controller.
8. Change state to Pre-Filter on Automatic Operation (to fill flow accumulator). After 3 minutes, the state will switch to Filter for the new experiment.

Calibrating the Peristaltic Pumps

For the experimental data to be accurate, the peristaltic pumps had to be calibrated so that a) the pump speeds in Process Controller matched the actual pump speeds and b) the pump flow rates in Process Controller matched the actual pump flow rates. Part a) of the calibration involved sending each pump two pump speeds (5% and 95% of the pump's total speed) through Process Controller and then recording the average pump speed displayed on the pump. These values were then put into the Process Controller calibration tool. Part b) of the calibration involved sending each pump two different flow rates. For each of these flow rates, the actual flow rate was measured using a graduated cylinder and a stop watch. As with part a), these values were then put into the Process Controller calibration tool.

Experiment Parameters

Influent turbidity was kept constant at 5 NTU. The plant flow rate was kept constant at 1.83 mL/s, which corresponded to a filtration velocity of 1.8 mm/s through both layers. The coagulant dosage was varied within the range of 0.2 mg/L to 2 mg/L, with five different dosages being used. The five dosages were evenly spaced through the range of interest, so the interval between dosages was 0.45 mg/L. Therefore the five dosages, in mg/L, were 0.2, 0.65, 1.1, 1.55, and 2. The filter runtime was 12.5 hours, and a minimum of two tests were run at each dosage level.

Plant Flow

To visualize the flow of water through the filter column, red dye was pumped into the filter column using what is normally the coagulant pump. A short pulse of the dye was sent through the filter, and the progression of the dye through the filter and effluent tubing was observed and recorded using a camera.

To gain a quantative understanding of water flow through the filter, the flow rates through the top layer (upflow) and bottom layer (downflow) were measured. This was done by detaching the two outflow tubes from the T-connection which normally connects them, putting the system in filter state, and using graduated cylinders and a stopwatch to measure the individual flow rates.

Maintaining Constant Influent Turbidity

In order to have useful data that effectively compares influent turbidity to effluent turbidity, the influent turbidity must remain constant. Based on previous teams' experiences, it was known that influent turbidity may not remain constant using the previous setup. This setup uses a peristaltic pump to draw turbid water from a clay stock tank and into the system to be mixed with coagulant and clean water. Three experiments were run to determine whether or not the influent turbidity could be kept constant over time. Only the water supply, clay stock tank, clay pump, and influent water pump were connected in order to test the variability of influent turbidity. Graphs of these experiments may be seen below in the Analysis section. It was concluded that a method for keeping the influent turbidity constant must be devised. The clay stock should be diluted from the current stock concentration of 5 g/L in order to obtain the desired influent turbidity. In order to prevent clay from settling out in the larger tubing, the length of the tubing and the unplanned drops in height between influent water and throughout the system will be reduced as much as possible.

Proportional Integrative Derivative (PID) control was implemented as the most accurate and reliable method to keep influent turbidity constant. Although the turbidimeter measures the turbidity, the turbidimeter does not register as a sensor reading, which is what the code uses, because the turbidity value is a setpoint in Process Controller. The code to convert a setpoint into a sensor reading was written so that the PID method file can be used. The code for PID control reads the influent turbidity, evaluates the value relative to the target value of 5 NTU, and then changes the peristaltic pump speed as necessary to achieve the target value. The clay pump control is then set as the PID control instead of the calculation based off of flow rate, tubing size, and desired turbidity value.

PID control changes the clay pump speed so that the clay pump only pumps as much clay mix as needed. If the turbidimeter reads values that are too high, then PID control sends the value 0 to the pump so that the pump stops running. If the turbidimeter reads values that are too low, then PID control sends a value to the pump so that the pump will start running to reach a higher turbidity. There are values assigned for P, I, and D to set the magnitude and rate of response. Although there are methods to fine tune PID control such that the PID values work best to keep influent turbidity constant, the values at which PID control is optimized have been found through trial and error.

The proportional value, P, is how much in proportion the pump should respond to a high or low turbidity reading. The higher the P value, the more responsive the PID control is to the change in turbidity. The P value is dependent on clay stock concentration. The more dilute the clay stock is, then the more responsive the pump and the higher the P value needs to be. The clay stock concentration that works with these PID control values to achieve constant turbidity has also been found through trial and error. There is probably a range for the clay stock concentration at which PID control will work effectively, but these bounds have not been found definitively. If a graph of influent turbidity cycles through a large range of turbidities, then it means that PID control is overshooting and the P value should be lowered. The P value was set to 1. The integrative value, I, is proportional to how great the error has been over time. Process Controller stores data of the turbidity values to correct for the error. The lower the I value is, the fewer number of previous points from memory areused. There is less averaging in the value and thus more instantaneous change in the pump. The I value was set to 0.25. The derivative value, D, is proportional to the rate of change of the error and has been set to 0.

In order to use PID control most effectively, small changes were made to the apparatus so that the response of the clay pump would correspond to the turbidity almost instantaneously. Tubing which was run originally from the clay pump has been extended to go through the system and ends just before the cuvette in the turbidimeter. The tubing is set up in this way so that clay immediately enters the turbidimeter when the clay pump starts running and the turbidimeter values correspond more accurately to the current clay pump speed. This setup also ensures that clay does not settle out in the larger tubing of influent water. The turbidimeter settings were changed such that it read turbidity at the fastest response time and gives PID control the most updated turbidity for that clay pump speed.

PAC Stock Tank Preparation

The concentration of the PAC stock tank must be calculated in relation to the required range of PAC dosages (0.2 to 2 mg/L) and the pump speed limitations. Then the PAC stock tank must be prepared and connected to the apparatus. The PAC stock tank has a maximum volume of 3 L. At higher PAC dosages, the coagulant pump speed would be higher. However, the volume of PAC stock may not be enough to last an entire experiment, so a higher PAC concentration should be used so that the PAC stock tank does not have to be refilled during an experiment. The PAC stock tank should be covered to ensure that no significant amount of evaporation occurs, which would change the concentration.

Accounting For Error

It is important to note that although the experimental process has been refined and streamlined as much as possible, there were still areas for error in experimentation. Process Controller will sometimes switch to the Off state without reason for a short period of time (about 1 second). The peristaltic pumps may also lose the original calibration setting as the experiment continues over long periods of time. Also, after long filtration times there is some air in PVC pipe. The system should be closed and it is unknown how the air enters the system. It is also desirable for the system to be water tight. When a connection begins to leak it must be replaced. Continual fittings were changed for the connection to the rapid mix chamber. Eventually caulk was applied to the edge of the fitting to insure water would not leak through.

Analysis

Influent Turbidity Tests

Five experiments were run using the original setup of a clay stock tank and mixer to test the variability of the influent turbidity. Any change in turbidity must be within 10% of the desired value to be acceptable for running future experiments to properly test filter performance. The percent difference between the maximum and minimum influent turbidity was calculated. During these experiments the influent turbidity either rose or fell by more than 10% of the desired value. The influent turbidity also did not reach 5 NTU. Of the first three trials that were run, the first differed by 54.0%, the second by 39.1% and the third by 30.9%. The average change in turbidity was 41.3%. These results show that the apparatus must be improved to collect more accurate data.

Figure 4 shows turbidity over time for two experiments - one with PID control and one without PID control.

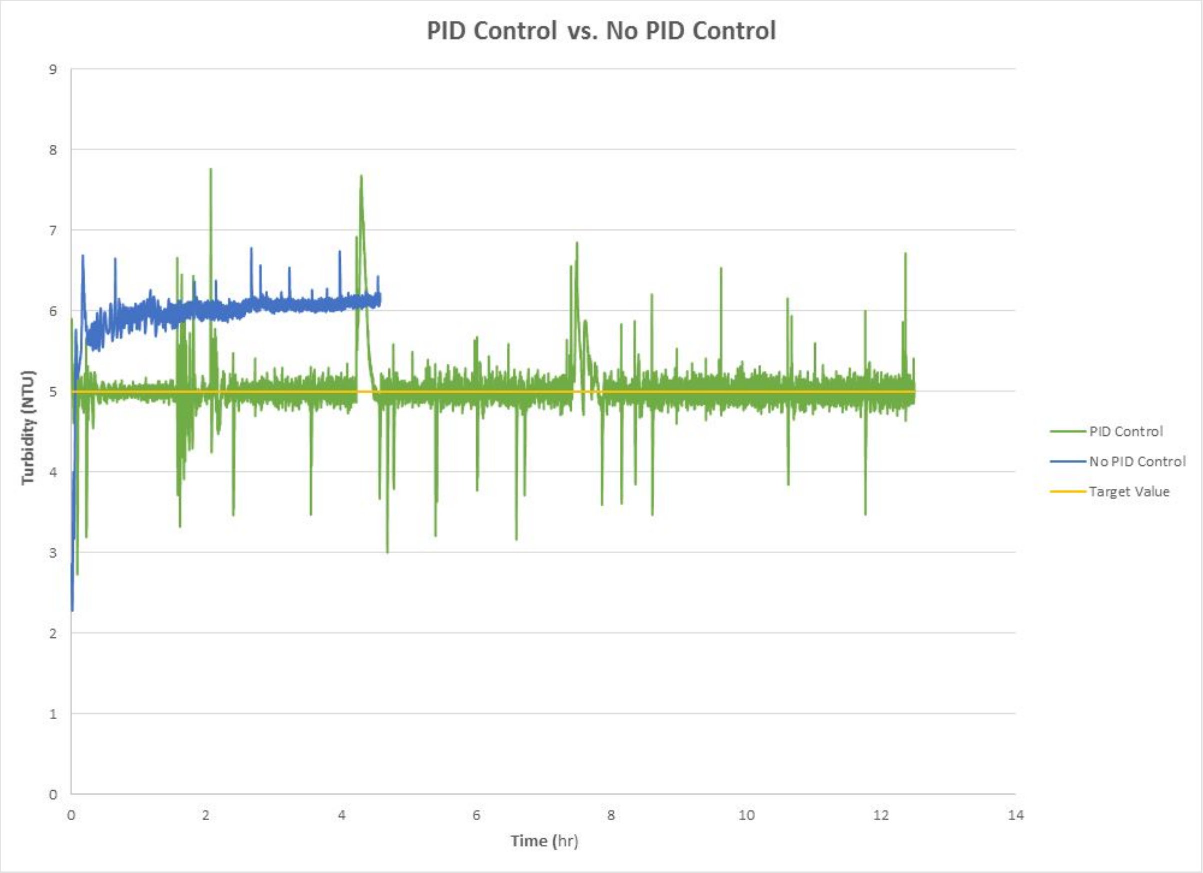

Figure 4: Influent Turbidity with and without PID Control

The experiment shown above without PID control achieved a much more consistent turbidity value than other experiments without PID control, but after starting at 5 NTU, the turbidity increased to 6 NTU and seemed to follow an increasing trend in turbidity. The influent turbidity with PID control was much more consistent with the target value of 5 NTU and does not show any sign of changing over the long term. Despite the spikes in turbidity, the influent turbidity is shown to be held constant at around 5 NTU. The spikes in turbidity might have occured because when the clay pump turned on after being off for a period of time, clay was sent into the cuvette when the turbidity was being read and passes in front of the light. There are also certain increases in turbidity that lasted for more than a few seconds, which may imply that PID control was being too responsive.

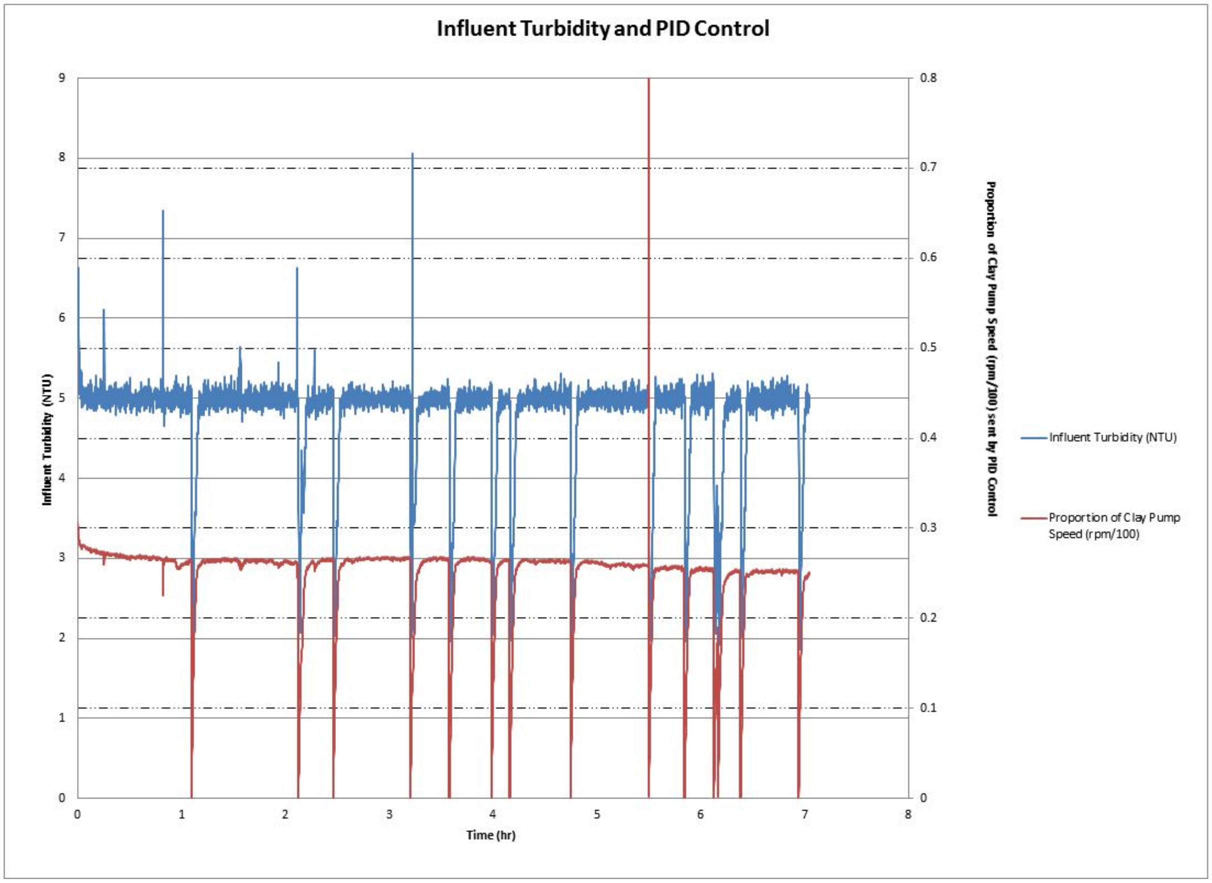

Figure 5: Influent Turbidity and PID Control

As seen in Figure 5 above, there have been slight issues in achieving constant turbidity. When this experiment was run, the clay stock tank had a concentration of 0.2 mg/L, the P-value was 1, and the I-value was 0.25. Process Controller would sometimes shut down automatically for about a second, causing PID control to send a value of 0 to the clay pump. The turbidity would thus drop, and PID control would have to compensate. However, PID control did not respond to the error quickly enough so the turbidity would stay out of range for several minutes at a time in order to return to the pump speed at which the target value of 5 NTU was reached.

Plant Flow

Qualitative observations of the dye test revealed that the dye passed through the lower layer of the filter faster than it passed through the upper layer. This observation showed that the flow rate of the water downwards is likely significantly higher than the flow rate of the water upwards. In order to reinforce the qualitative observations with quantitative data, the flow rates through the separate layers of the filter were measured as described in methods. For both layers, the duration of the test was 2 minutes. For this test, the flow rate through the system was 0.93 mL/s (which is half the usual test flow rate). During those two minutes, 50 mL of water came from the upper layer and 60 mL of water came from the lower layer. These measurements, when converted to flow rates, resulted in a flow rate of 0.417 mL/s through the upper layer and a flow rate of 0.5 mL/s through the lower layer. The calculations are shown below.

Upper layer flow rate $= \frac{50mL}{120s} = 0.417\frac{mL}{s}$
Lower layer flow rate $= \frac{60mL}{120s} = 0.5\frac{mL}{s}$

The percent difference between the upper and lower flow rates is approximately 20%. This difference is significant, but the effluent water from the two layers is combined after leaving the filter and before the effluent turbidities are measured, so any differences in performance between the layers will almost certainly average out. The flow rate for both columns should be tested in future experiments, at the proper flow rate of 1.83 mL/s.

Effluent Turbidity

The following graphs (Figure 6 and 7) demonstrate the filter performance for PAC dosages of 0.2 mg/L and 0.65 mg/L and a flow rate of 0.93 mL/s.

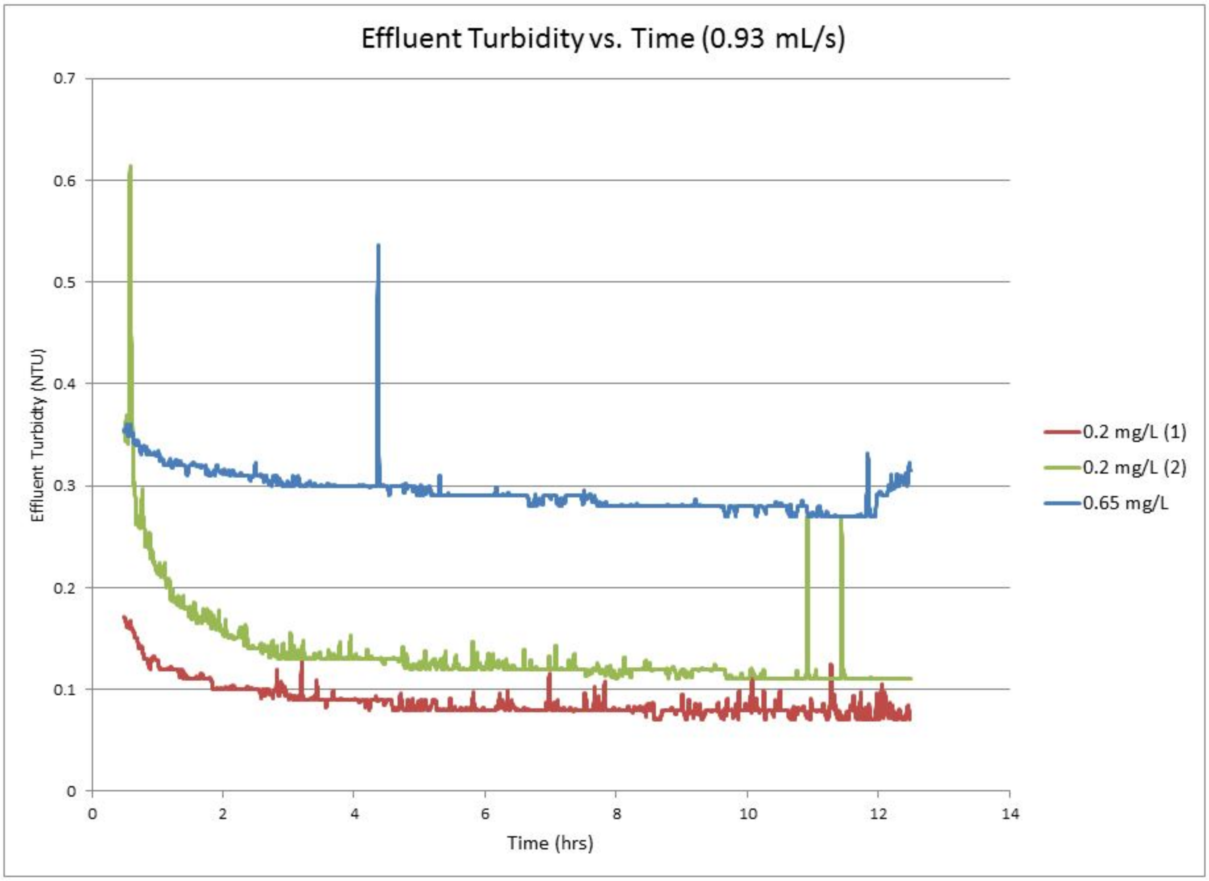

Figure 6: PAC Dosages: 0.2 mg/L, 0.65 mg/L; Flow Rate: 0.93 mL/s

As seen in 6, the filter sucessfully reduced the turbidity of the influent water by a large amount; the effluent turbidity was almost always below 0.3 NTU and was below 0.1 NTU for the first trial with a PAC dosage of 0.2 mg/L. The two trials at dosages of 0.2 mg/L produced comparable results. However, the trial using the 0.65 mg/L dosage resulted in significantly higher effluent turbidities. This result was unexpected, as sand filters normally achieve better performance with higher coagualant dosages. It must also be noted that all three of these tests were run at a flow rate of 0.93 mL/s, which produces filtration velocities that are half of the velocities found in AguaClara plants. Future tests will be run at higher flow rates to achieve the correct filtration velocities, though the trends will possibly be similar.

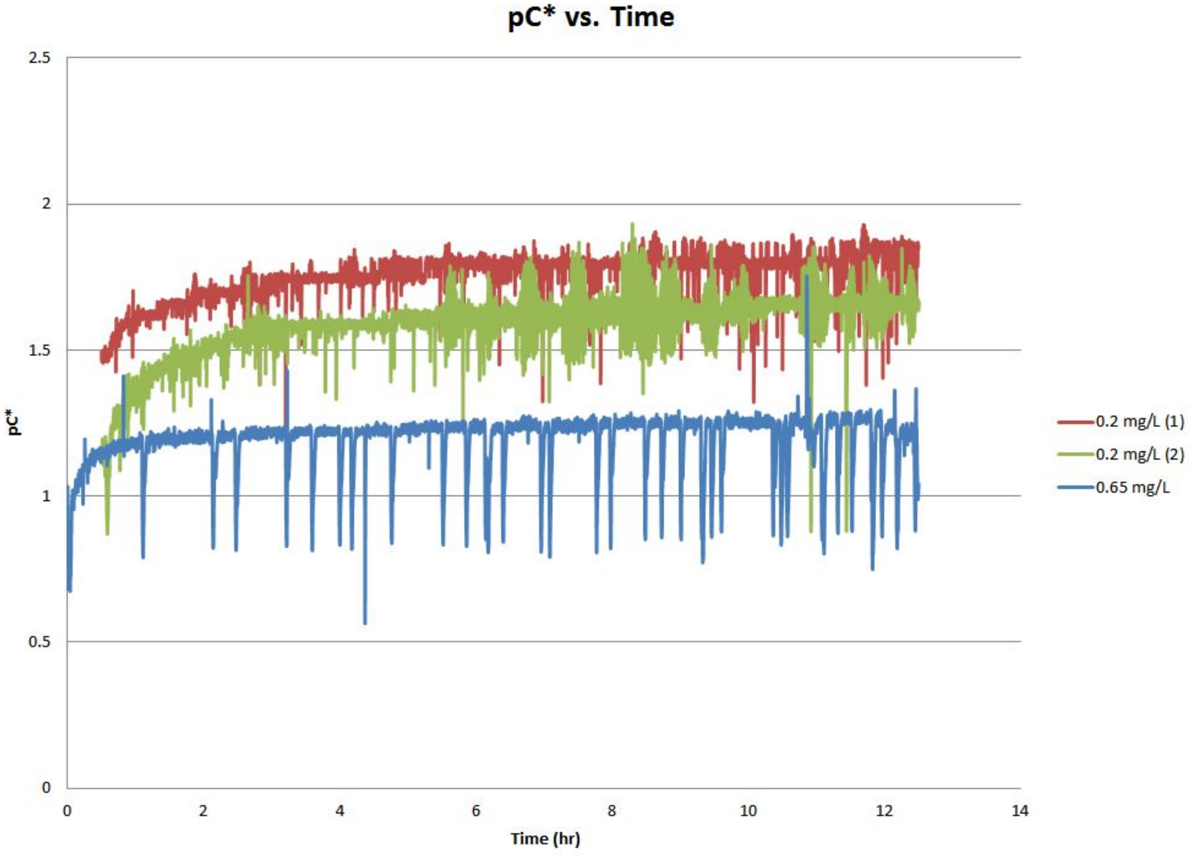

Figure 7: PAC Dosages: 0.2 mg/L, 0.65 mg/L; Flow Rate: 0.93 mL/s

To more accurately quantify filter performance, pC* graphs were produced for the three trials, as seen in 7. The quantity pC* is defined as $pC* = -log(\frac{effluent}{influent})$, where effluent and influent are effluent and influent turbidities, respectively. It may be observed that the pC* curves for all three tests are inversely related to the curves of effluent turbidity vs. time. This relationship exists because the influent turbidity was kept relatively constant for all three tests. The first trial at the 0.2 mg/L dosage has the lowest effluent turbidity curve and the highest pC* curve, both of which show that the filter was performing best during this trial. The following graph (Figure 8) demonstrates filter performance for a PAC Dosage of 0.0 mg/L and a flow rate of 1.83 mL/s.

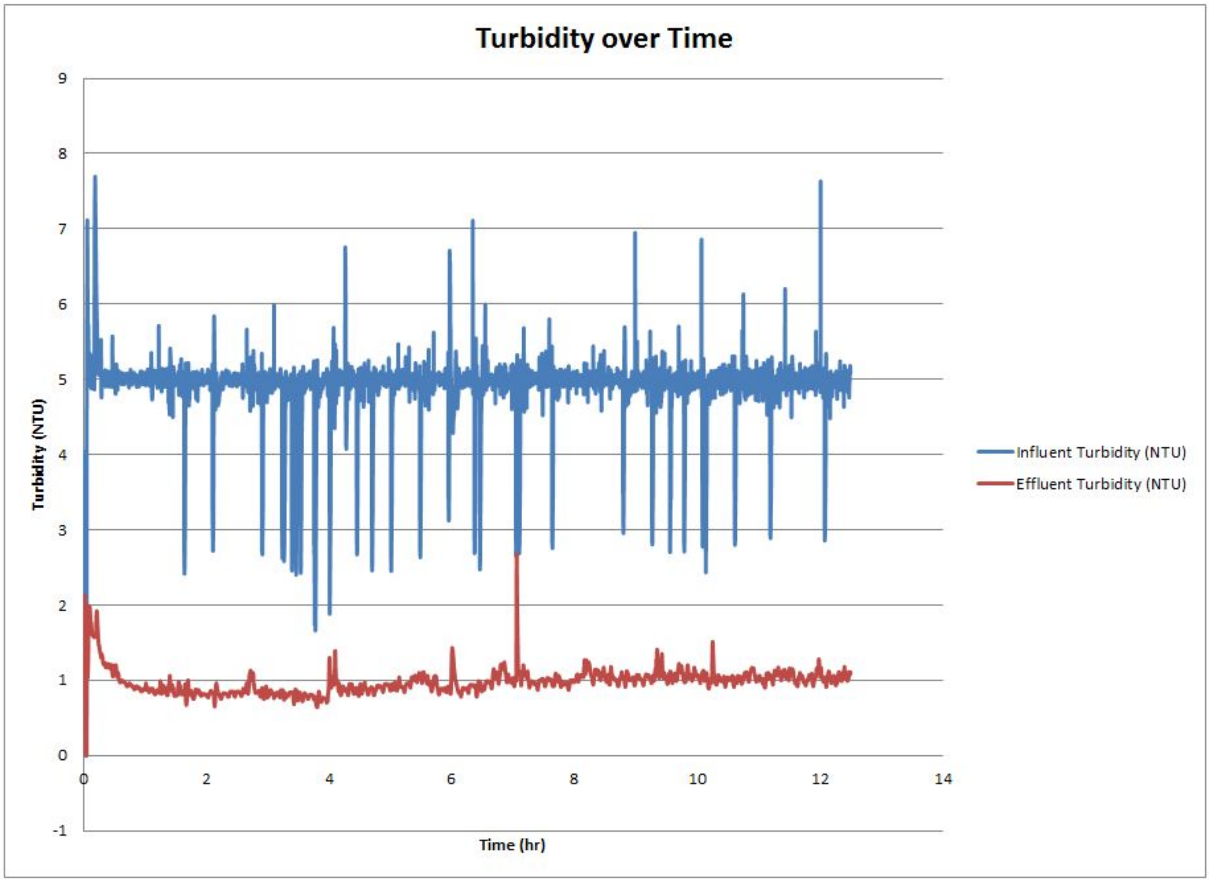

Figure 8: PAC Dosage: 0.0 mg/L; Flow Rate: 1.83 mL/s

Unsurprisingly, the filter's worst performance thus far occurred during the trial with a PAC dosage of 0.0 mg/L. To compare, the three trials with coagulant produced effluent turbidities below 0.3 NTU for the majority of the filter runtime, while the trial without coagulant produced effluent turbidities of approximately 1 NTU. This drop in performance was most likely due to two major factors. First, the filter was run without coagulant. Without coagulant, the filter could not trap particles as effectively. When the coagulant was added, the coagulant joined the particles, making them more easily removable in the filter. Second, the flow rate for this trial (1.86 mL/s) was twice that of the flow rate for the first three trials (0.93 mL/s). A higher flow rate results in higher filtration velocities, and as a result the water spends less time in the filter. These two factors in combination caused the filter performance to drop significantly during this trial.

Three experiments were run at the proper flow rate of 1.86 mL/s. The following graph shows the effluent turbidity for each experiment. These experiments correspond to the head loss data shown below.

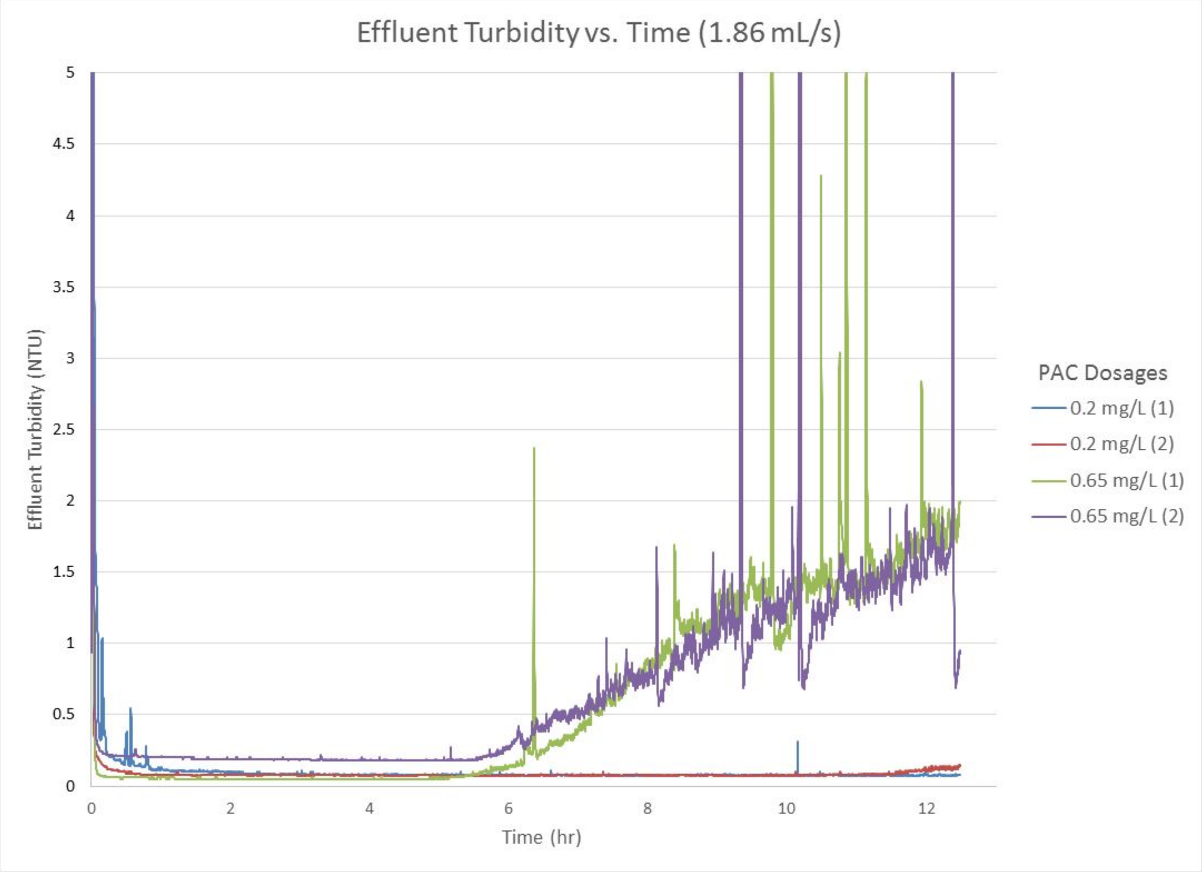

Figure 9: PAC Dosages: 0.2 mg/L, 0.65 mg/L; Flow Rate: 1.86 mL/s

The effluent turbidity for the experiments where the PAC dosage was 0.2 mg/L were relatively similar and achieved low effluent turbidity of about 0.08 NTU. There was a slight increase in turbidity towards the end of the experiment, showing that filter performances decreases after a period of 12 hours. The effluent turbidity for the experiments ran with 0.65 mg/L of PAC steadily increased after about 6 hours. However, one of the experiments with 0.65 mg/L of PAC achieved a lower turbidity level of about 0.05 NTU than the experiments with 0.2 mg/L of PAC during the first few hours. It is normally expected that filters will run better at higher coagulant dosages, up to a point, so this result is quite abnormal. In addition, the transition that occured near the time of 6 hours was a very distinct transition, which could indicate that the filter experienced a malfunction of some kind which caused the filter performance to decrease. Another possible explanation for the decrease in filter performance after 6 hours is that the higher coagulant dosage clogged the filter, causing turbidity breakthrough to occur and for effluent turbidity to increase. Further tests will show whether or not this behavior is normal

Head Loss

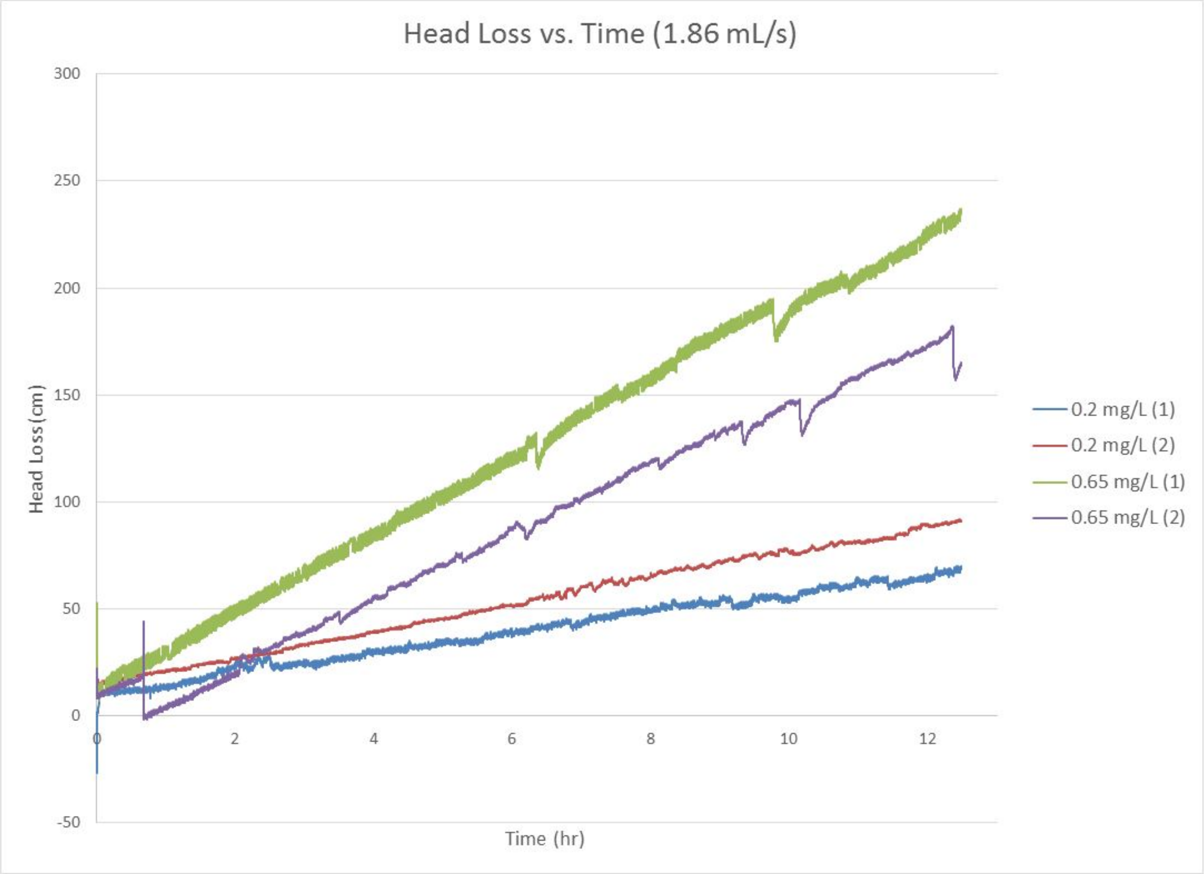

Figure 10: PAC Dosages: 0.2 mg/L, 0.65 mg/L; Flow Rate: 1.86 mL/s

The above graph (Figure 10) shows three representative head loss curves at two PAC dosages of 0.2 mg/L and 0.65 mg/L. The scale of the head loss height is suspected to be measured incorrectlythe column is only 60 cm long, so having head loss of up to 200 cm is probably unrealistic. In addition, the code used to measure head loss linearly interpolates the pressure reading based on voltage readings from Data Acquisition, and then scales the reading to a range of 0 to 70 kPa. Any readings outside of this range are thus inaccurate.However, the overall trends shown are most likely representative of the head loss in the filter, as they show that head loss is increasing linearly. The head loss curves for the system during experiments run at 0.2 mg/L of PAC also have the same slope, so the trend is consistent. The slope of the head loss for the experiment with 0.65 mg/L of PAC is steeper than the head loss in experiments at 0.2 mg/L of PAC, showing that there is more head loss with more coagulant added. Based off of this set of data, it cannot be detected from head loss graphs as to when clogging in the filter occurs.

Conclusions

When setting up the clay stock tank, it was found that there was significant loss in water after a day. The level of the water was above the mixer and not used, but after a day, the level of the water was below the mixer. It is unclear how there was so much water loss because loss due evaporation should not be significant and the clay stock tank will need to be tested again. This issue has seemed to resolved itself and evaporation does not seem to be a problem. The water level should be observed in future experiments to note that water loss is not significant, but there is no immediate change to the system that should be made. In addition, now that PID control is being used, the clay pump speed will change to compensate for any changes in the concentration of the clay stock.

The implementation of PID control has led to significant improvements in influent turbidity; the average turbidities for nearly every test run with PID control in place are within 10% of the desired target turbidity. PID control alllows more room for human error in measuring out a clay stock concentration and means that there is no longer any guesswork about how fast the clay pump should run for the duration of the experiment. However, significant spikes in turbidity are still occurring several times per test. One cause of the shorter spikes may be a larger portion of clay passing in front of the light when turbidity is being measured. In order to improve the constancy of the influent turbidity, the clay stock tank should be diluted more from the original 1 mg/L stock concentration. With a more dilute clay stock, PID control does not have to correct so much for every change in turbidity. Although the concentration of the clay stock does not need to be an exact value due to PID control, the concentration should be at a range where the clay pump must run continuously to keep influent turbidity constant. It is better for the clay pump to be running continuously than periodically stopping and starting at high speeds because the range in speeds can cause influent turbidity to also cycle through high and low turbidities. After evaluating the influent turbidity of the system over long experiment times it was concluded that the PID system provided sufficient stability to the turbidity. Although the clay pump occasionally turned off for brief periods of time causing influent turbidity shocks, severe influxes of clay stock due to the turbidimeter reading spontaneous low values, the average value of the influent turbidity during the test was still close to 5 NTU.

From our initial experiments run with varying coagulant doses and half the flow rate the filter performance appears to increase over time. This might be explained by the pores in the filter getting smaller and collecting larger particles. As of now, not enough experiments have been run to conclude that this is a trend, so more experiments must be run to reinforce this possible trend. Even after 12.5 hours of runtime, the effluent turbidity continues to decrease slightly. The AguaClara plants in Honduras have comparable runtime lengths, so the data confirms that the filter can perform well for this length of time and that the filters do not have to be backwashed earlier.

The recent tests at the full flow rate through the filter showed that filter performance is decreasing over time. As the filter begins to clog, more particles are being released with the effluent water. The experiments run with 0.2 mg/L of PAC added seem to be rather consistent. It was expected that adding slightly more PAC to the system would decrease effluent turbidity; however, using a higher PAC dosage resulted in a dramatic decrease in filter performance, as shown by the experiment with 0.65 mg/L of PAC. More experiments should be run in order to collect more conclusive data, as no definite trends have been shown in the data collected thus far. Although the numbers on the head loss graphs do not seem to be accurate, head loss does follow a linear trend over time. These graphs show that no conclusions about filter performance can be made from the head loss graphs alone.

Given the two different results of filter performance for these two flow rates of 0.93 mL/s and 1.86 mL/s , it may be suggested that the lower flow rate allowed for better filtration. This increasing performance might be explained by the fact that the slower speed through the filter allowed particles to collect throughout the sand and particles were not forced through the filter and into the effluent water, as might have occurred in the normal flow rate of 1.86 mL/s.

Future Work

The future team should continue to collect and analyze data on effluent turbidity and head loss at various coagulant dosage values and a constant influent turbidity. As it has been established that the PID control can keep influent turbidity at a constant value, the team will no longer need to actively make changes to the variables of influent turbidity, such as clay stock concentration and PID control values. However, the resulting influent turbidity should be constantly monitored and recorded to ensure that the values are around 5 NTU.

Running all of these experiments will result in a large amount of data to be processed and analyzed. The code to process data directly from Process Controller's datalog files will be written so that data from only the Filter state will be graphed automatically. A Meta File should be written to organize the experiments run and send the necessary information to the code to process the data. With the Meta File and code, processing data should be much more efficient and display the results of experiments more easily. The data for these experiments will be analyzed and should illuminate where the SRSF Theory team should go next in experimentation and how to begin creating the model of filter performance. The ultimate goal of these experiments is to develop a model for the mass of clay that will be able to fill a pore in the filter before the flow path through the pore has a small diameter. The model should be able to predict the level of head loss as a function of the coagulant dose and the mass of the solids already accumulated in the filter.

Team Reflections

Our team worked well together and had good communication with our team leader. The majority of our time was spent redesigning the apparatus and improving the constancy of the influent turbidity. As each team member had been on an older version of this subteam in a previous session, previous experience helped facilitate experimentation.

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