Tube Floc Final Report Fall 2010

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AguaClara Reflection Report
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Abstract

The Fall 2010 Tube Floc Team of aimed to better understand the development of rapid flocculation through a series of experiments and data analysis. In previous semesters, we had focused on the variation of flocculator length and alum dose. With the completion of these studies, we encountered more questions regarding the fundamental mechanisms involved in the process. As a result we chose to focus on characterizing the minimum coagulant dose needed to initiate rapid flocculation for two difference coagulants, alum and PAC. We hope to use this data in the future to develop a theoretical framework describing the onset of rapid flocculation. In order to accomplish this goal and to ensure the accuracy of our data we made a number of improvements and modifications to the FReTA apparatus this semester. We are currently in the process of collecting data and hope to complete our planned experiments by the end of the Fall 2010 semester.

Keywords: FReTA, Rapid Flocculation, Backwash, Pressure Sensor, Alum, PAC, Data Processor, Process Controller, Tube Flocculator

Introduction

In a water treatment plant, flocculation occurs when colloidal particles are forced to collide, attach, and grow. Through this process, particles that are previously small and light become heavier as they are now able to settle out in the sedimentation tank. Our research team focuses on studying the different properties that affect flocculation performance and tries to better understand them in order to improve the design and parameters used for the actual AguaClara plants.

There are several controllable properties that can be tested to change the performance of flocculation: water pH, flocculator length, and amount of coagulant agent used. In previous semesters, our team had studied the effects flocculator length and alum dose variations had on flocculation. From this study, we saw the necessity for a more focused and detailed understanding on each variable parameters. Therefore, for the fall 2010 semester, we chose to study the variation of coagulant dosage and the minimum dose required to initiate rapid flocculation for different influent turbidities. By studying the properties of different coagulant agents, we hoped to gain more knowledge on the degree of influence coagulant agent had on flocculation performance, how the dosage would vary according to the initial turbidity, and the possibility of exploring other coagulants, such as PAC.

Though it is too early to settle on a conclusion, we have seen promising results from the data collected so far. With our current results, we see that **a lower PAC dose can be used to achieve rapid flocculation compared to that of alum.** In addition, as expected, we see that **the minimum coagulant agent for rapid flocculation decreases with the increase of influent turbidity**. We hope to complete our planned experiments by the end of the fall 2010 semester.

Experimental Design

Detail how you conducted experiments or changes that were made to your experimental design. Connect the results from your experiment with what you anticipated to learn and what you did learn. (~500 words).

Apparatus Setup

There were some technical problems with FReTA and the tube flocculator apparatus that the team had been unable to fix in previous semesters. Therefore, before beginning any experiments, we aimed to resolve these issues. They included:

-Slipping and breaking of the glass settling column

-Elevated background turbidity

-Data would not fit properly due to turbidity spikes at the start of data collection caused by the effects of differential settling, a ledge collecting flocs near the ball valve, and data collection happening before flow in the settling column had completely stopped.

We were able to **lower the background turbidity significantly by replacing the settling column**; we suspected the high turbidity was caused by damages in the glass column. In addition, **we removed the ledge in the fitting** at the top of the settling column, which reduced the effects we had previously attributed to differential settling. Although we tried to find a replacement material for the settling column that would be sturdier, we were unable to find one with suitable optical properties. After several tests using an acrylic column, we concluded that it was best to **stay with the glass column**. Additionally, we added a lab jack to the apparatus to support the glass column and resolve the issues surrounding slipping of the column.

In order to handle the problems with the initial turbidity spikes, we modified the data collection protocols in Process Controller. Ideally, the sedimentation data should not be collected until flow in the settling column has completely stopped. Additionally, we would like the ramp down process to be gradual enough to ensure that flocs are not broken up as the flow is stopped and that the flow has fully stopped before the ball valve closes. Therefore, our team tried to find the optimal duration values of ramp down and ball valve close (the two parameters controlling the transition phase) in Process Controller. In order to do this we conducted experiments using the pressure sensor to determine the amount of time needed for oscillations in flocculator to damp out. The pressure sensor allowed us to infer when the flow stopped moving by measuring the head loss across the flocculator. This head loss is due to frictional losses, and is only present when the fluid is actually moving. After conducting several experiments, we found that the total ramp down duration could be calculated given the flocculator length according to a linear equation:

$$Ramp\ down\ duration = mX + b$$

with m being the proportionality constant determined through experiments, X being the number of flocculator lengths, and b being the time constant required for the pump to decelerate to 0 mL/s. **We determined the ramp down duration to best when the proportionality constant, m, to be 8, and b equal to 4, giving ramp down times of 11, 19, and 27 seconds for 28, 56 and 84 m flocculators respectively**.

Data Processor

Our team has been using Data Processor to analyze and observe flocculation performance through extracting necessary data and converting them to parameters we want to study (eg. extracting effluent turbidity at different alum doses and times and finding the corresponding sedimentation velocities). For the study of rapid flocculation, we had to readjust the program to find the minimum alum dose needed to achieve rapid flocculation. As can be seen in Reflection Report 4, our overall analysis process consisted of the following steps:

1. Find the mean sedimentation velocity for each dose of coagulant -the sedimentation velocity corresponding to normalized turbidity of 0.5 (Figure 1).

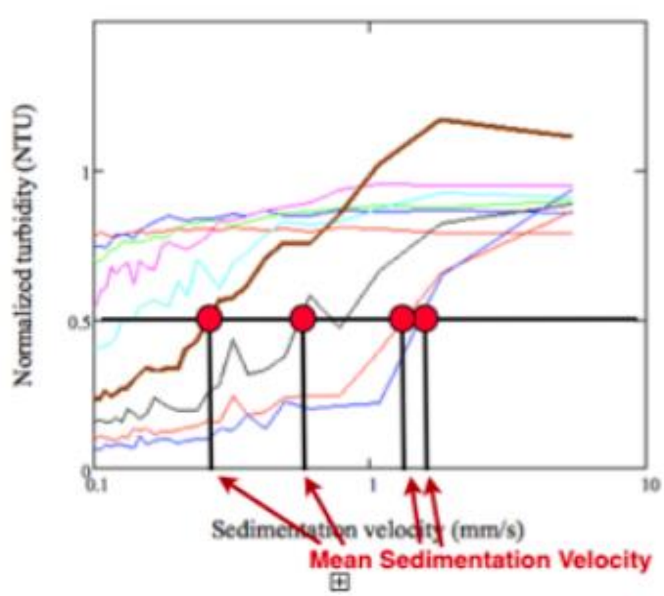


Figure 1. Normalized turbidity vs. Sedimentation velocity for influent turbidity of 50 NTU and flocculator length of 56 m. The sedimentation velocity corresponding to the normalized turbidity of 0.5 is estimated to be the mean sedimentation velocity.

2. Find the maximum point for plot of $\Delta v_s/\Delta$(coagulant dose) vs. coagulnt dose. The coagulant dose corresponding to this maximum point will be the minimum dosage required to induce rapid flocculation (Figure 2).

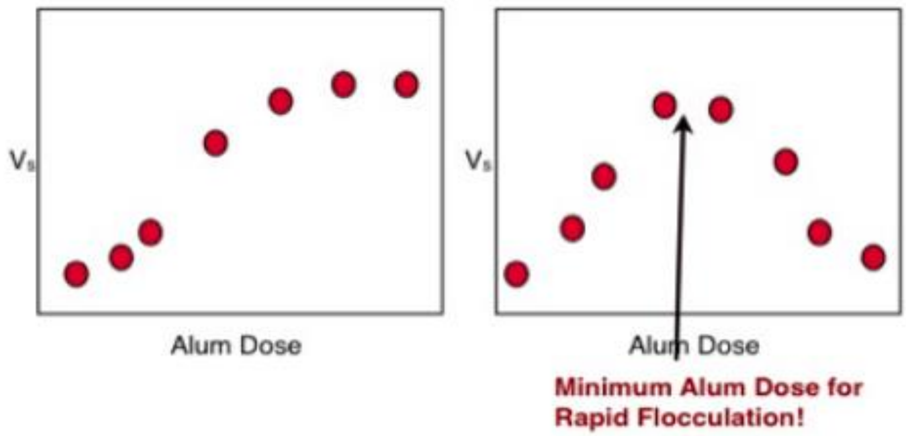


Figure 2. Rough estimate plots of mean sedimentation velocity against alum dose (left) and its derivate (right). The alum dose corresponding to the peak of the derivative plot will be the minimum alum dose we want to find.

In order for Data Processor to carry out this algorithm, we mainly used a MathCAD function called linterp. With linterp, we developed functions that would scan through the sedimentation velocities and find the point at which the velocity corresponds to 0.5 normalized turbidity (Figure 3).

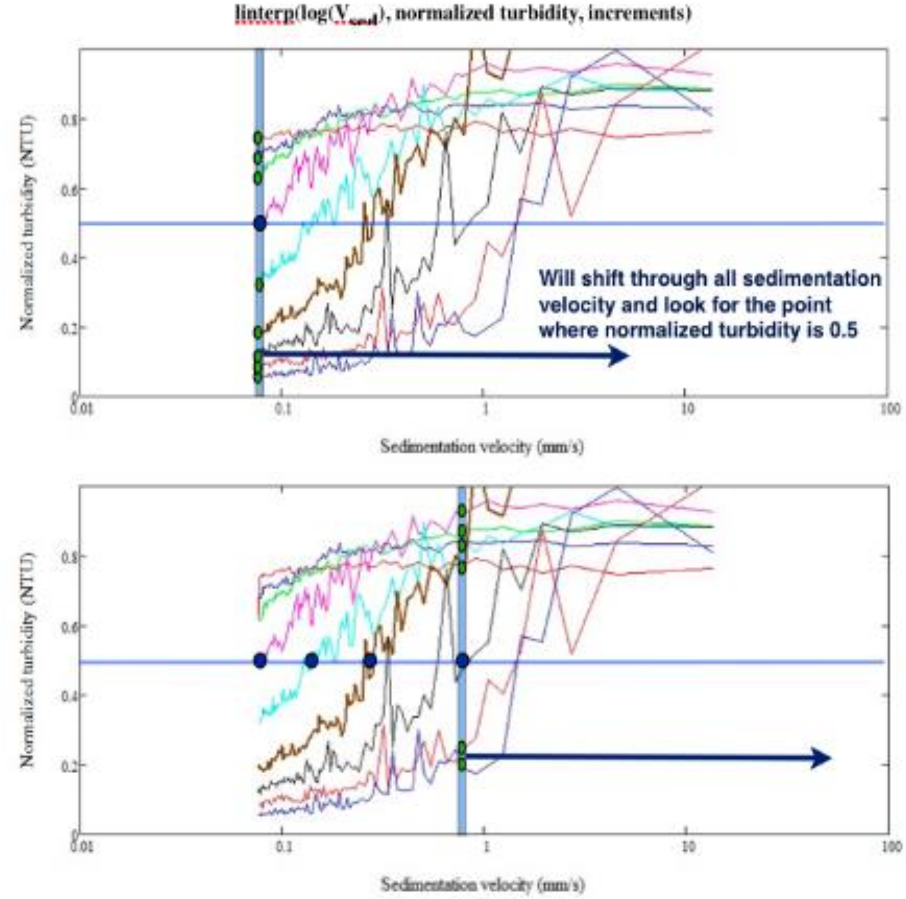


Figure 3. Plots of Normalized turbidity vs. log of sedimentation velocity at influent turbidity of 50 NTU. Linterp will shift through every sedimentation velocity value in small increments and output the correspdoning normalized turbidity value. Once the outputted normalized turbidity lands closest to 0.5 NTU, the sedimentation velocity at that point will be recorded.

Afterwards, Data Processor proceeds with our previously designed steps of getting the minimum coagulant dose through finding the maximum point for plot of $\Delta v_s/\Delta$(coagulant agent dose) vs. coagulnt agent dose (Figure 4).

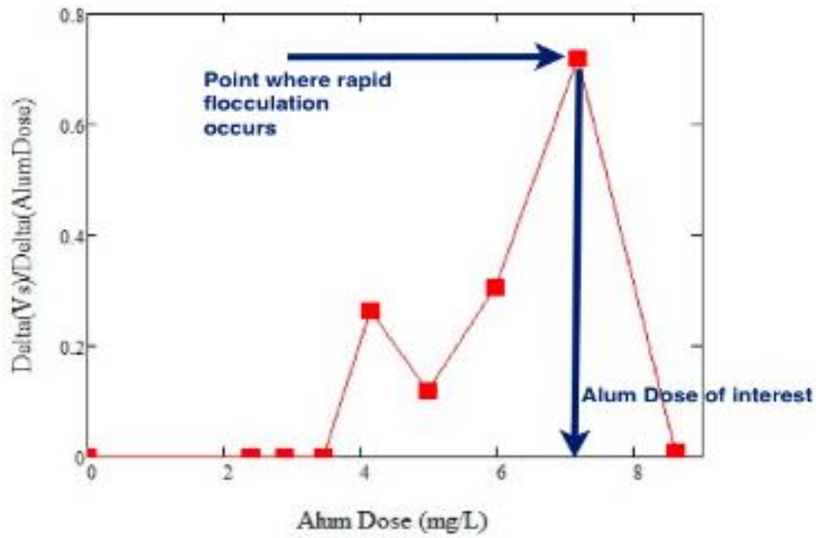


Figure 4. $\Delta V_s/\Delta$Alum Dose vs. Sedimentation Velocity for influent turbidity of 50 NTU. The alum dose corresponding to the highest point of this plot is the minimum alum dose needed for rapid flocculation to occur. In this plot, the minimum alum dose is 7.166 mg/L

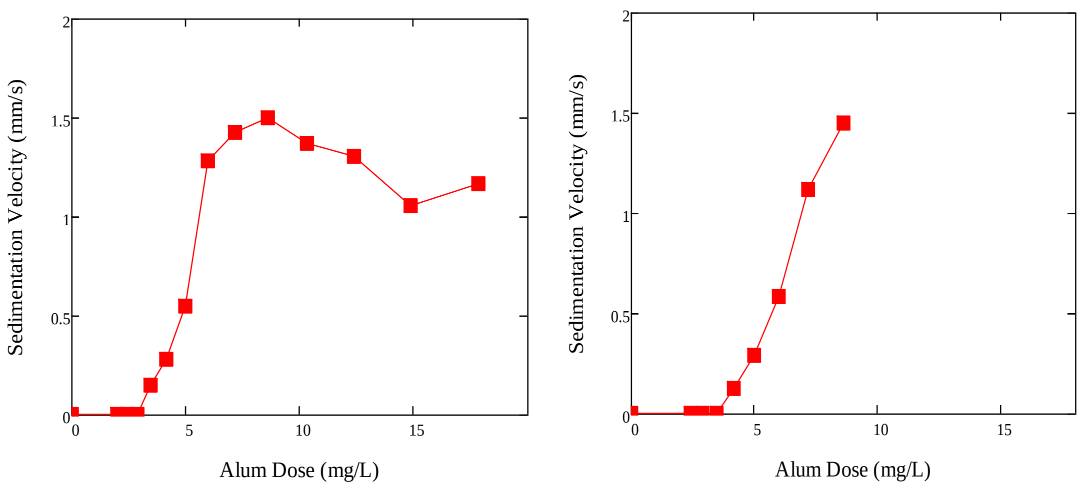
**More details on this process can be found in Reflection Report 5.

Results and Discussion

Data Processor

Data Processor has been running well and been outputting reliable results. Though we initially encountered some problems using linterp due to the fluctuations in the normalized turbidity data (see RR 4), after changing the inputs to this function, we created an overall robust method that would extract the minimum coagulant dose required for rapid flocculation (see RR5). We defined the minimum alum dose required for rapid flocculation as the alum dose that maximizes the change in sedimentation velocity at 0.5 normalized turbidity with increasing alum dose.

- For the alum experiments for influent turbidity of 50 NTU, we performed two replicates that showed the following results (Figures 5 and 6).



Trial 1 **Trial 2**

Figure 5. Sedimentation velocity at 0.5 normalized turbidity vs. alum dose for influent turbidity of 50 NTU and flocculator length of 56 m. Left plot is for the first trial and right plot is for the second trial for the experiments; the minimum alum doses are: 5.972 mg/L and 7.166 mg/L respectively.

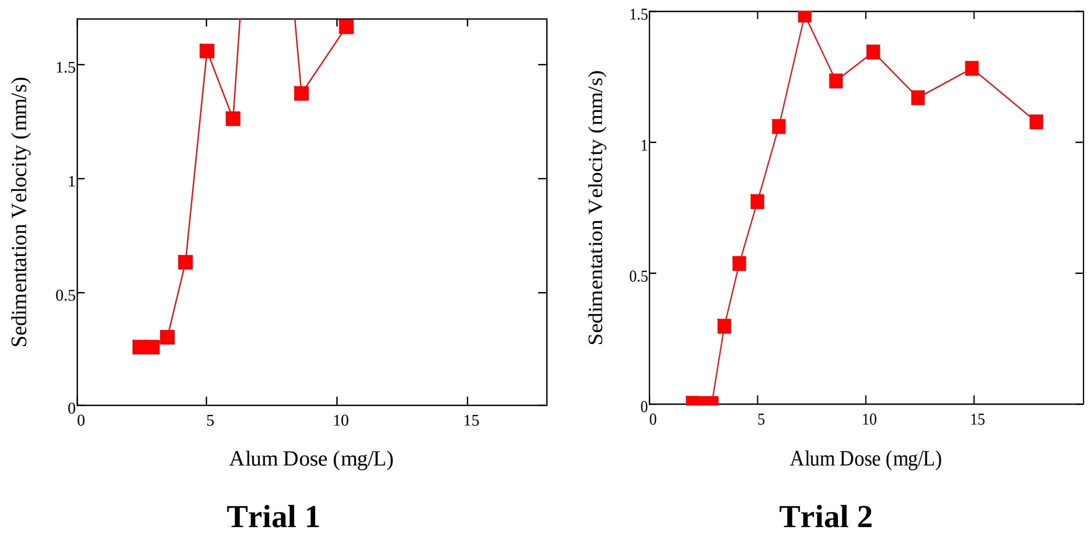


Figure 6. Sedimentation velocity at 0.5 normalized turbidity vs. alum dose for influent turbidity of 50 NTU and flocculator length of 82 m. Left plot is for the first trial and right plot is for the second trial for the experiments; the minimum alum doses are: 4.977 mg/L and 3.456 mg/L respectively.

Considering our experiments for the 56 m flocculator length and influent turbidity of 50 NTU (Figure 5), both our first and second trial experiments seemed to show good results. However, seeing that the second trial covered a longer range of alum dose, we concluded that the result for this experiment was more reliable.

For the experiments with flocculator length of 82 m and influent turbidity of 50 NTU (Figure 6), the first trial contained an outlier that gave an erroneous value of minimum alum dose due to an extreme outlier in the data. Therefore, we decided that to discount the outlier and select the data point showing the next largest change in sedimentation velocity with change in alum dose. The result obtained for the replicate justified this estimation as it was consistent with our first trial; in Figure 6, we could see that the change in sedimentation velocity of 0.5 normalized turbidity with increasing alum stayed relatively constant over the range of alum doses 3.5~7 mg/L and that any alum dose in this range could be the minimum alum dose needed for rapid flocculation. Therefore, we concluded that the dose of 4.98 mg/L was a good estimate of the average start result we desired to find.

In addition to our characterization of the minimum alum dose needed to induce flocculation, we began investigating PAC as a coagulant. In order to compare the two coagulants, we converted the minimum coagulant doses for rapid flocculation for both alum and PAC to a dose in terms of mg aluminum/L using simple stoichiometry. These comparisons can be seen in Figure 9 and Table 1.

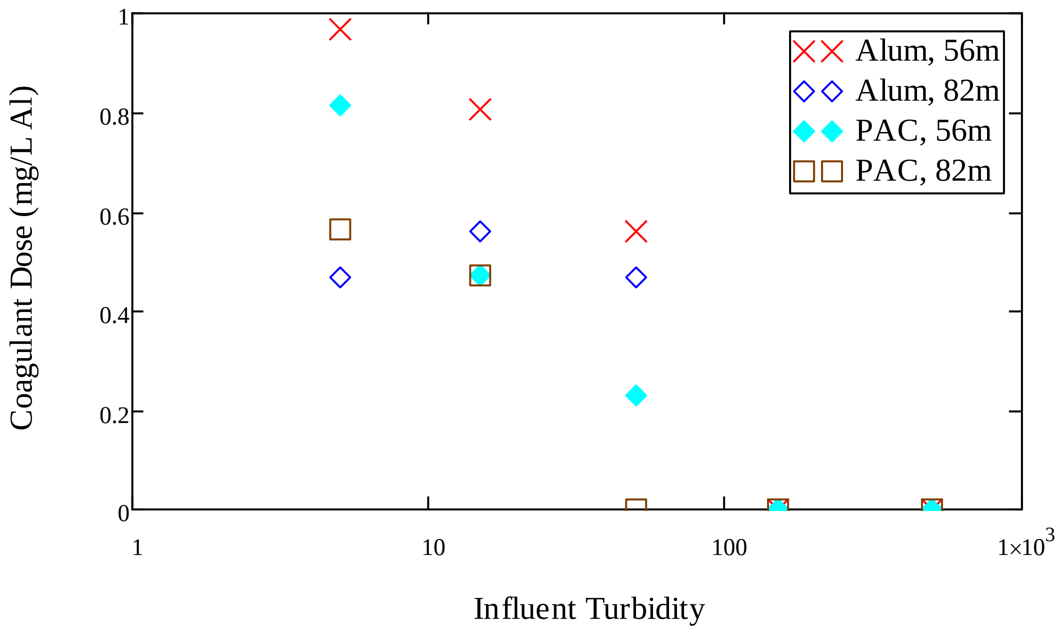


Figure 7. Minimum coagulant dose required to achieve rapid flocculation plotted against influent turbidity. We will be running experiments with higher influent turbidity in the future.

Table 1. Organized results of minimum aluminum doses for rapid flocculation for influent turbidities of 5, 15, and 50 NTU.

Influent Turbidity (NTU)	**Aluminum Dose for Alum (mg/L), Length 56 m**	**Aluminum Dose for Alum (mg/L), Length 84 m**	**Aluminum Dose for PAC (mg/L), Length 56 m**	**Aluminum Dose for PAC (mg/L), Length 84 m**
5	0.97	0.47	0.81	0.56
15	0.81	0.56	0.47	0.47
50	0.56	0.47	0.23	-

Looking at the results we have obtained so far, it is clear that in the 56 m flocculator, PAC consistently outperforms alum. For the 56 m flocculator tests, at 5 NTU PAC reduced the required aluminum dose by 16%, for the 15 NTU test PAC improved on alum by 42%, and on the 50 NTU test PAC required 60% less aluminum than alum to induce rapid flocculation. These results indicate that PAC outperforms alum even after their different aluminum contents are taken into account. However, when we look at the results for the 84 m flocculator, alum and PAC appear to perform quite similarly. It will be interesting to see if this trend continues as we gather more data. This suggests that although PAC initially out performs alum, the effect may be mitigated by increasing residence time in the flocculator. Given more time (longer flocculator), alum appears to be able to induce rapid flocculation with equivalent aluminum doses to PAC. This is an intriguing initial result, and we look forward to seeing if this trend continues as we gather more data.

Additionally, we observed that extending the flocculator in 15 NTU PAC tests did not reduce the minimum aluminum dose needed for flocculation. This suggests that for the different influent turbidities, there may be some limiting concentration of aluminum that must be present in the flocculator in order for rapid flocculation to occur. This combined with the previous observation regarding the performance of PAC and alum at different lengths, suggests that lengthening the flocculator may reduce the minimum alum dose needed to induce rapid flocculation to a certain extent, but there is some limiting minimum aluminum dose for the given influent turbidity that must be present for rapid flocculation to occur. We look forward to completing our study at higher NTU's and continuing to investigate the trends we have already observed in the upcoming semester.

Future Work

Over the course of this semester, we were able to make significant progress towards characterizing the development of rapid flocculation for both alum and PAC. We have been able to complete a large volume of experiments investigating the performance of the two coagulants over a sensitive region where behavior changes from little to no sedimentation and flocculation and covering the transition to rapid flocculation. These experiments have been completed in both alum and PAC for 5, 15 and 50 NTU water, providing a broad characterization of coagulant performance at low to moderate turbidity water. We have already uncovered a number of interesting trends regarding the development of rapid flocculation, and we look forward to investigating them further in the upcoming semester. We hope to complete similar experiments with high influent turbidities in order to see how these trends bear out.

Furthermore, this work will provide a baseline for evaluating how future experiments (such as changing the rapid mix) influence the development of rapid flocculation. We will be able to precisely evaluate how new concepts and designs for rapid mix impact performance by comparing results with the baselines established in our current experiments.

Team Reflections

The results we have obtained this semester have been very promising. We have been able to accomplish a large volume of experiments, particularly during the second half of the semester. We had a slow start due to difficulties with the apparatus; several weeks were spent working to improve the settling column to be easier to manage and developing protocols to avoid damage to the turbidimeter. Additionally, we spent several weeks conducting pressure sensor experiments in order to better understand the observed turbidity spikes at the start of settle state. By developing new data capture processes to focus in on sedimentation after the flow has completely stopped, as well as adding new modifications to the apparatus, we were able to minimize the appearance of turbidity spikes. Furthermore, we were able to justify our choice of beginning to record data after the initial spikes in settle state.

Despite the amount of time spent on maintenance work, we were still able to complete a large number of experiments. This reflects how our team was able to work well together and manage our time effectively in order to make up for the lost experimental time. The results we have obtained this semester have been very exciting. So far we have seen repeatedly that PAC outperforms alum as a coagulant even after accounting for the lower aluminum content of alum in shorter flocculators. Additionally, we have seen some evidence that there may be minimum aluminum doses needed to induce rapid flocculation, regardless of flocculator length or coagulant type. We look forward to investigating PAC further next semester, as well as designing new experiments to optimize rapid mix. It has been a very productive semester.