High Rate Sedimentation, Summer 2017

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Abstract

The High Rate Sedimentation team designed, fabricated, and experimented on various sedimentation designs with an upflow velocity of 3 mm/s while maintaining a efficient effluent turbidity and reducing cost and space. Working off where the Spring 2017 team left off, the HRS team continued to research the effects of floc blanket height, tube settler length, varying geometries, and the size-driven floc blanket formation hypothesis. The HRS team concluded that the height of floc blanket may not provide better performance, as originally thought. Also, it has been concluded that the Trapezoidal geometry is not necessary, but provided insight on the behavior of floc on bends.

Introduction

Sedimentation is a very important process in many water treatment plants. It is the process in which coagulated masses of minerals, dirt, clay, and particles are settled out by gravity and removed from the water. These masses settle into a "floc" or "sludge" blanket - a fluidized bed of suspended flocs colliding in a bottom zone of the tank. The particles start off very light and small, but as coagulant dosage persists and particles continue to collide, the particles clump together into heavier floc that will drop back into the basin of the recirculator. This process permits clearer water to continue up the plate settler while keeping the NTU (Nephelometric Turbidity Unit) of the effluent low.

AguaClara's sedimentation tank design includes inclined parallel plates called plate settlers. The purpose of these plates is to catch small particles and return them to the developing floc blanket at the basin of the apparatus. In the AguaClara lab, a sedimentation tank and its respective plate settlers are simulated by tubing. The tube that simulates a pathway of fluid in the tank basin is known by the the High Rate Sedimentation team as the "recirculator" and the slanted tube that simulates a plate settler is referred to as the "tube settler." See Figure 1 for a visual representation of this concept. The plate settlers increase the amount of horizontal area for the flocs to settle out. Due to their sticky nature, these flocs aggregate; growing in size as they slide down the plate settler and back into the basin.

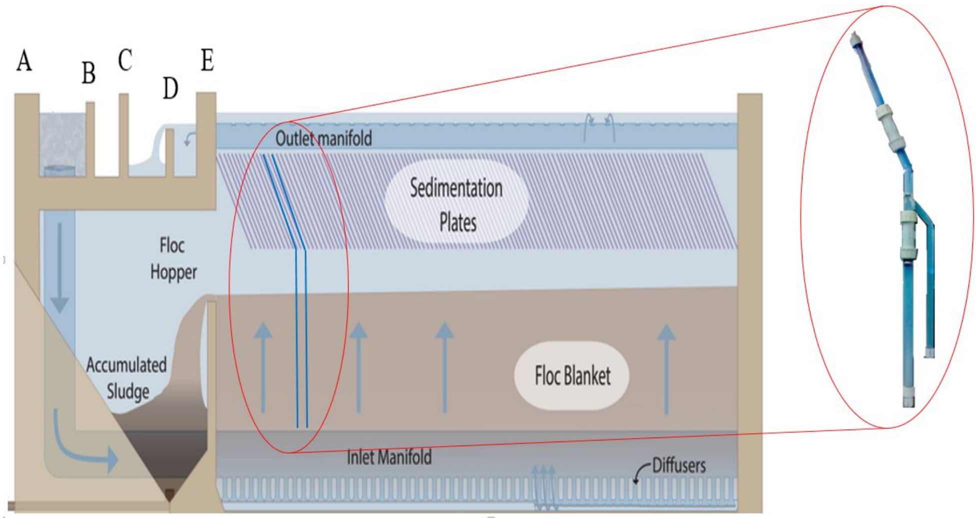

Figure 1: The recirculator and tube settler simulate the sedimentation tank basin and plate settlers respectively. Since the behavior of a section of fluid is characteristic of the entire tank, tubing can be used to simulate a simple pathway in the reactor. This allows for a practical form of experimentation that is small scale, easy to manipulate, and representative of the respective tank design.

"Capture velocity" describes the slowest velocity for flocs to be captured by the plate settler. If the flocs downward terminal velocity is slower than the capture velocity, the flocs will be end up in the effluent water.

AguaClara designed a vertical sedimentation tank, which has the water flow from the bottom of the tank to the top. The flow velocity that maintains the floc blanket is known as overflow rate or upflow velocity. Flow rate (Q), upflow velocity (V), and tank surface area (A) are related to the continuity equation:

$$Q = VA, \tag{1}$$

The AguaClara High Rate Sedimentation (HRS) team hopes to design a tank that will yield an effluent of .3 NTU or lower. While the World Health Organization has a standard of at most 1 NTU for drinking water, the EPA standard is .3 NTU.

The Fall 2016 team focused on the effects of of effluent turbidity by changing the floc blanket height and tube settler length while the Spring 2017 team focused on the design and geometry of the recirculator to see if it affected the turbidity of the effluent. Designs such as the "Trapezoidal" and "Zigzag" recirculators have been tested with 100 NTU influent water and coagulant dosages from .5-3.2 PAC-Al/L.

The Summer 2017 team has continued research from the past semester by understanding the Trapezoidal design and what about its geometry yields the exceptional performance observed by the Spring 2017 team. The team's goal is to limit the amount of bends, while keeping efficiency high.

The results of past experimentations indicated that modifying the recirculation zone of the sedimentation tank enabled increased upflow velocity and flow rate, without compromising the water quality. A high rate sedimentation tank can be designed that could have the capability of producing the same quality and quantity of water, but in a more compact size. This will save time, money, space, and materials required to construct this section of a standard AguaClara plant.

Literature Review

The following is the literature review done by the Spring 2017 HRS team.

Swetland (2014) illustrated in a model study that one main purpose of flocculation research was to increase the performance of the flocculator as well as the following steps (e.g. sedimentation and filtration) while minimizing overall construction and operation costs. As flocs formed, they would sediment due to their higher density compared to water. The flocs must settle faster than the upflow velocity. As the flocs concentrated and fell down to the bottom of the tank, a floc blanket formed.

Hurst (2010) stated that the presence of the floc blanket would enhance the removal of turbidity. Hydraulic residence time indicates the amount of time that drop of water or particle spends in the system, measured from the minute the drop enters a system to the minute it leaves. With hydraulic residence time of the particles in the floc blanket decreasing, fewer collisions would take place and the overall performance would decrease. However, the upflow velocity of 3 mm/s was not tested by Hurst (2010). The 2016 Fall team and the 2017 Spring team used an upflow velocity of 3 mm/s, triple the typical AguaClara upflow velocity of 1 mm/s.

Balwan (2016), a researcher from the International Journal of Innovative Research in Advanced Engineering (IJIRAE), explored the effect of the length of tube settler on effluent turbidity. As indicated in his report, increasing the length of tube settlers increased the percentage of turbidity removed (defined as percentage change between influent and effluent turbidity). With tube settlers in 45 degrees inclination angle and 60 cm length, turbidity removal was measured to be 80 percent. However, his experiments only had three length variables (40cm, 50cm, 60cm) and the effluent of longer tube settlers were unknown.

Culp et al. (1968) used tubes to figure out the optimal slope of the tube settlers. Under laboratory conditions, a 60 degree angle with respect to the horizontal provided continuous sludge removal while showing effective sedimentation performance. Future experiments could be based on Culp's 2016 optimal result, and other aspects such as changing length.

Previous Work

In Fall 2016, the HRS team decided to build another flocculator design that is more suitable to the new specifications. The flocculator must be able to accommodate the same flow as the model sedimentation tank. AguaClara's traditional flocculator design is for a $G\theta$ of 40,000, where a higher $G\theta$ indicates better flocculated water flowing into the sedimentation tank. With an upflow velocity of 3mm/s and a nominal diameter of 0.824", the flow for the tube model is 1.032 mL/s. The given velocity and $G\theta$ value, the equation below chose a flocculator with a diameter of 1/8" and length of 9.2m.

$$L_{Floc} = \theta_{goal} \times \frac{4 * Q_{Reactor}}{\phi * D_{Floc}^2}, \tag{2}$$

The Fall 2016 team used a cardboard tube with a diameter of 3" and a length of 32" to coil the flocculator around. The entire flocculator apparatus is hung from the workspace to save space. The pipe cannot be too small or too big because the flocs will get stuck or use an excessive amount of space, respectively.

In Spring 2017, the HRS team experimented with the effectiveness of various geometric recirculator designs with an upflow velocity of 1 mm/s and 3 mm/s. They tested two main reactors, the Trapezoidal (Figure 3) and Zigzag (Figure 2) recirculators, both of which were geometric variances of the 1 m, vertical recirculator. What generated interest in these designs was the characteristic of the "pinch puddle," or the subtle floc blanket that forms at the transition from the recirculator to the tube settler only at 3 mm/s upflow velocity. Given that this anomaly occurred at the bend, the Spring 2017 team decided to incorporate these bends into recirculator design to mimic flow patterns and floc blanket density.

Figure 2: The zigzag recirculator produced lower effluent turbidity than the straight recirculator, but higher effluent turbidity than the trapezoidal recirculator.

Figure 3: The trapezoidal recirculator outperformed both the straight and zigzag recirculators, raising more questions on floc blanket formation at, and below, pinch puddles.

After experimentation, the design that stood out the most to the Spring 2017 team was the Trapezoidal recirculator, whose performance at a 3.2 mg/L PAC dose was a third of the Fall 2016 team's best case (Figure 4).

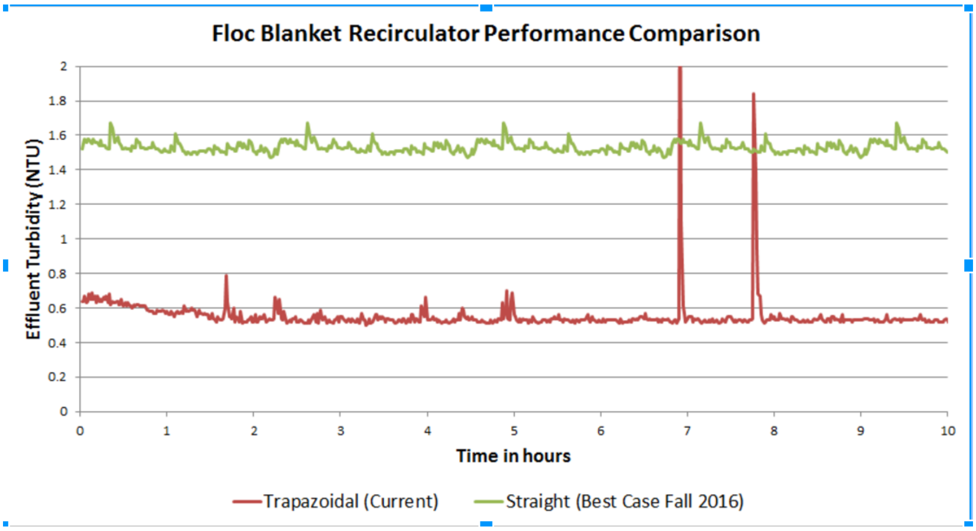

Figure 4: The trapezoidal recirculator produced effluent turbidity over three times lower than the straight 1m recirculator. The 2016 experiment only lasted about 2 hours, and has been extrapolated out for comparison to the trapezoidal results (cite spring 2017).

Additionally, the Spring 2017 team did further research about the effectiveness of the different types of bends on the connection between the recirculator and tube settler. The two bends are the dimple bend (Figure 6) and the smooth bend (Figure 5). To their surprise, there was virtually no difference in the performance of the two. Therefore, it seems that simply having the bend has an effect on floc blanket development rather than the type of bend implemented.

Figure 5: The model with a smooth bend.

Figure 6: The model with a dimpled bend.

1 Lab Bench Setup

The overall lab bench set up of the HRS team is composed of several parts (Figure 7). They are the pumps, the stocks, the flocculator, and the turbidimeters.

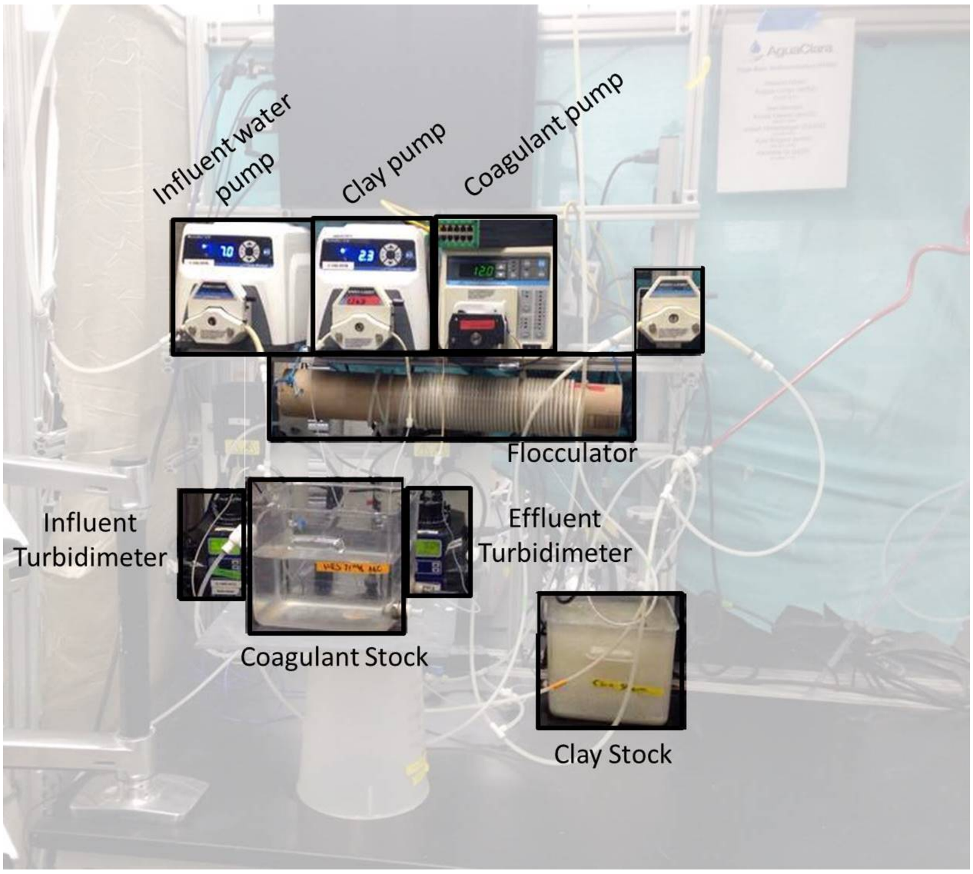

Figure 7: The HRS lab bench setup is composed of the turbidimeters, stocks, pumps, and flocculator. This allows the team to simulate non-potable water and its treatment through high rate sedimentation while keeping track of performance via NTU.

The influent and effluent turbidimeters are what tell the team how well the system is performing at any given time. In order to run experiments, tap water is contaminated with clay from the Clay stock. This contaminated water is known as the influent and is kept at a constant NTU of 100 through ProCoDA by utilizing PID control. For more on Clay dosing, see Manual.

Once the influent passes through the turbidimeter, it moves toward the flocculator. Upon entering the flocculator, the untreated water is dosed with Poly-Aluminum-Chloride (PAC), which is the coagulant Aguaclara utilizes. The Coagulant pump is manually set up to control how much of the Coagulant stock enters the system. When a dose is chosen (generally between .5-3.2 mg/L PAC), the team uses a MathCAD doc (see MathCAD) to determine the stock concentration and required RPM of the pump. For more on Coagulant dosing, see

Manual. The treated water then passes through the coiled tube that is the flocculator, forming flocs. The end of the flocculator then enters the bottom of the recirculator where upflow begins.

The effluent that exits through the top of the tube settler then flows through the effluent turbidimeter. This is where the turbidity of the effluent is determined; the goal is to reach an NTU of .3 or lower. After the effluent turbidimeter, the wastewater flows out towards the wastewater drainage.

2 Troubleshooting

Throughout the Summer, the HRS team experienced multiple issues that set back progress and produced unreliable data. This section serves to prevent this from occurring in the future. The Manual (see Manual section) further walks through the steps to set up an experiment, run it, and clean up after testing.

Working with Coagulant

The Summer 2017 team experienced a significant amount of trouble understanding how to correctly dose the various reactors with coagulant. This was due to the use of an out-dated MathCAD document that assumed different pump tubing was being utilized. As a result, more coagulant than originally thought was pumped into the system, causing inaccurate data and, in some cases, an un-fluidized floc blanket. For future teams, it is important to be wary of up-to-date documents and the current status of the lab bench setup so that experimentation can go as smoothly as possible.

Dosing and Tubing

A major problem that the Summer 2017 team faced was accurately translating a calculated coagulant dose on MathCAD into its respective RPM and Coagulant stock concentration for experimentation. For the majority of the summer, the team had been using a MathCAD document that calculated dosing with the assumption that the tubing used in the coagulant pump was size 13. This, however, was not the case. The Spring 2017 team was using yellow-blue marked tubing which has a diameter much larger than that of size 13 tubing (Figure 8).

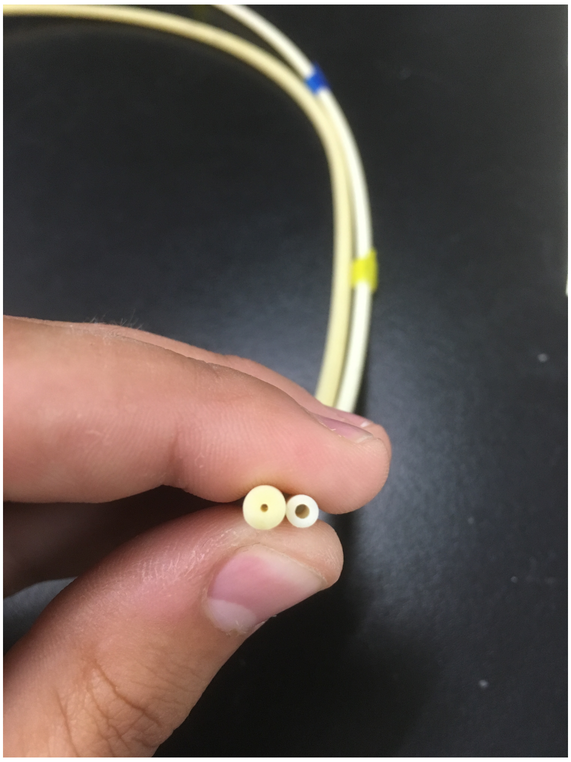

Figure 8: On the left is size 13 tubing and on the right is blue-yellow tubing. Notice how the size 13 tubing has a much smaller inner diameter. Calculations on MathCAD were done with the assumption that the size 13 tubing was being used, not the blue-yellow. This resulted in the dosing to be very inaccurate by pumping more coagulant into the system than intended.

As a result, when the team calculated a .7 mg/L dose to be a 344.175 mg/L stock concentration being drained at 2.1 RPM, it was actually a much stronger dose. Therefore, these values cannot be compared to the constants that are established in the Developing a Constant Section.

Knowing a Fluidized Floc Blanket

An important aspect of HRS experiments, of course, is the floc blanket. Although not much is known about floc blankets and what influences performance, they must always be "fluidized." This means that the particles flowing upward that make up the blanket must take on the characteristic of a fluid in motion. A fluidized floc blanket is necessary because it allows flocs to collide into each other and recirculate successfully in the basin as well as undergo settling at bends (such as at the pinch puddle).

A good indicator that the floc blanket will not be fluidized is the presence of large flocs. As seen in Figure 9, the flocs are not fine particles and have conglomerated into sizable flakes.

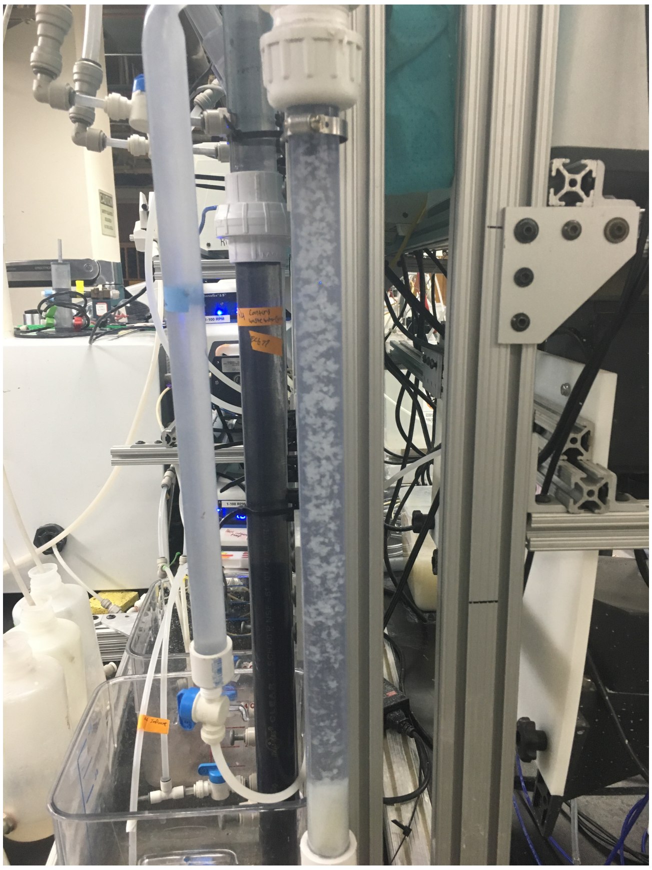

Figure 9: Large flocs such as these is a possible indication that the blanket will become a dense pile of sludge rather than a fluidized floc blanket.

The main sign that the floc blanket is sludge rather than a fluidized is if it comparable to curdled milk. It is a dense chain of flocs that has taken on a shape. At points, the sludge will break apart and form clogs in the reactor which can be clearly seen in Figure 10.

Figure 10: Pieces of the non-fludized sludge blanket break off from the main mass and travel upwards in the reactor. This causes clogging and a failed experiment.

The reason for a non-fluidized floc blanket may be because of a coagulant dose that is too high or premature precipitation of the coagulant in the stock. Using deionized water in the coagulant stock prevents this occurrence.

3 Developing a Constant

The Summer 2017 team decided that in order to accurately analyze and interpret results, it was necessary to observe how the current AguaClara design of sedimentation is influenced by varying upflow velocities, and record their respective turbidities. This way, a performance curve can then be constructed. The current AguaClara plant measurements include a 1 m deep sedimentation tank basin and 60 cm long plate settlers. Although the Spring 2017 team compared trapezoidal performance to the Fall 2016 design (see Fall 2016 report), they did not compare performance to what AguaClara plants actually yield.

Methods

To simulate the AguaClara plant, a 1 m recirculator and 60 cm tube settler were utilized. As for coagulant, a dose of .7 mg/L PAC was used. This dose was attained by adding 1.175 mL of 70.9 g/L PAC stock to 5 L of deionized water (a calculated quantity using MathCAD). Insight from Professor Monroe Weber-Shirk helped the team decide that a lower coagulant dose would be a better choice since varying geometries will produce a more observable effect on performance. This is because with a lower coagulant dose, performance is lower in general. Therefore, there is a greater observable effect on effluent turbidity. If dosage was higher, performance would always be exceptional and harder to distinguish effects on NTU. This will be important for later experiments.

Figure 11: The reactor that simulates the current design in AguaClara plants. A sedimentation tank basin (recirculator) that is 1 m deep and a plate (tube) settler that is 60 cm long.

The AguaClara simulation was tested at three different upflow velocities: 1 mm/s, 3 mm/s, and 5 mm/s. To obtain these upflow velocities, the flow rate (mL/s) of the pump necessary was calculated using the following equation

$$V_{floc} = \frac{Q_{floc}}{(\frac{D_{pipe}^2}{4}) * \pi}, \tag{3}$$

where the inner diameter of the pipe is 3/4 in. The RPM of the water pump was set to 5.7 RPM, 16.4 RPM, and 29.6 RPM for calculated flow rates of .35 mL/s, 1.04 mL/s, and 1.72 mL/s. The necessary RPM was obtained experimentally through a trial and error stop watch method.

Table 1: The parameters for upflow velocities of 1, 3, and 5 mm/s. Notice the difference in G values for these three variables.

Upflow	Flow Rate	Res. Conc.	RPM	G
1 mm/s	.35 mL/s	17 mg/L	5.7	79.591 s^{-1}
3 mm/s	1.04 mL/s	17 mg/L	18.8	266.430 s^{-1}
5 mm/s	1.72 mL/s	17 mg/L	31.1	476.265 s^{-1}

Since the length of the tube settler remained at a constant 60 cm, the capture velocity would be worse due to increased upflow velocities. As a result, the capture velocities for 1, 3 and, and 5 mm/s are .059, .177, and .296 mm/s respectively. Capture velocity was calculated using the following equation

$$V_c = \frac{SV_\alpha sin\alpha}{Lsin\alpha cos\alpha + S}, \tag{4}$$

where α is the angle of the tube settler, V_α is the upflow velocity, L is the length of the tube settler, and S is the diameter of the tubing.

Results and Analysis

At steady state, the 1 mm/s upflow produced the best performance with an approximate .17 NTU while 3 mm/s and 5 mm/s produced .2 and .23 NTU respectively. However, the manner in which these three velocities approached their steady values is complexing.

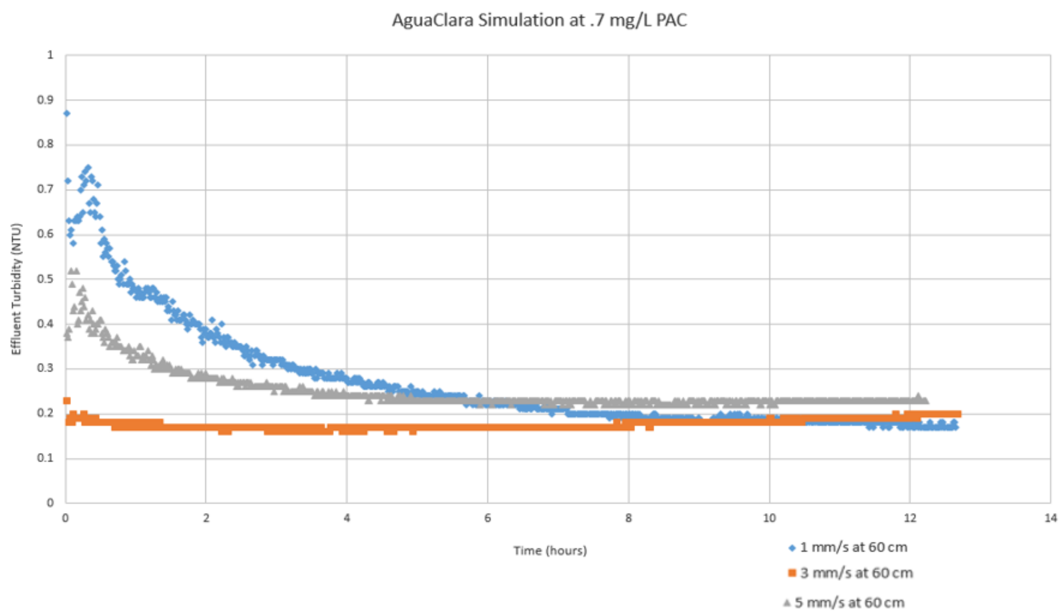

Figure 12: A standard AguaClara sedimentation tank response to upflow velocities of 1, 3, and 5 mm/s at a .7 mg/L PAC dose.

As seen in Figure 1, the 3 mm/s upflow sustained a very low NTU for hours before slowly deviating. Although the initial NTU is not relevant due to the disruption in the effluent turbidimeter upon opening the valve, the residence time is minimal. Professor Monroe Weber-Shirk informed that team that a section of water in an AguaClara plant sedimentation tank, which runs at a 1 mm/s upflow velocity, takes about a half hour to complete its course. Therefore, 3 mm/s has a residence time of about 10 minutes and 5 mm/s has a residence time of about 6 minutes.

If one looks at the one hour mark in Figure 1, 3 mm/s is still performing best way after treated, 100 NTU water has been in the reactor. This lead the team and Professor Monroe Weber-Shirk to theorize that perhaps big flocs, which are produced during more prolonged flocculation (1 mm/s), are not as efficient at interacting with clay particles as small flocs are. This is because a floc is more effective at sticking to another clay particle the closer they are in size. If one particle is larger than the other, the greater shear that is innate to the larger particle ends up repelling the smaller particle, causing it to be less sticky.

This data is important because it makes the team question whether performance is not linear, but rather parabolic where 1 mm/s is too slow, 5 mm/s is too fast, and 3 mm/s is somewhere in the middle and possibly producing flocs closest to the diameter of the standard clay particle. Due to the lack of time the team had, multiple trials at each upflow could not be performed.

4 Revisiting Trapezoidal Design

Now that they had a constant to compare performance, the Summer 2017 decided to revisit the Trapezoidal recirculator that the Spring 2017 team found to be more successful than the Fall 2016 best case.

Methods

The trapezoidal design for the recirculator is formed from a 110 cm piece of PVC piping with 60° bends throughout. The Summer 2017 team used the same recirculator that the Spring 2017 did for their experiments. To produce bends in the PVC, the Spring 2017 team created the method of filling the tubing with sand and exposing it to high temperature through a PVC welder. By using a large protractor, the tubing could then be accurately bent into place before cooling with water. The Summer 2017 adopted this method for later experiments.

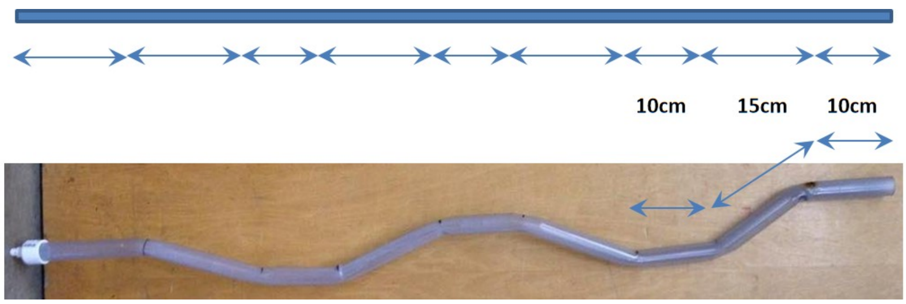

Figure 13: The trapezoidal recirculator started as a 110cm PVC pipe and was bent (reference spring 2017 report).

The coagulant dose remained at .7 mg/L and was administered in the same way as the 3 mm/s upflow in Table 1. In order to be consistent with the constant, the tube settler was kept at the 60 cm length instead of 53 inch tube settler used by the Spring 2017 team. This means the capture velocity in the tube settler was .177 mm/s.

Results and Analysis

The Summer 2017 team's trial of the trapezoidal experiment revealed some interesting findings. For one thing, the floc blanket was very well established, much more than that of any of the upflow velocities tested in the AguaClara simulation. Not only was it dense, it had also climbed significantly, reaching the weir towards the end of experimentation.

Figure 14: Trapezoidal recirculator design with a formed floc blanket. Although initially yielding effluent turbidity around .14, performance decreased as the floc blanket climbed.

Clearly, the bends in this recirculator design are responsible for this type of floc blanket formation. However, its performance seems to decrease significantly as the floc blanket climbs. Figure 14 represents this occurrence. Initially, the NTU of the water is exceptional, producing better water than 3 mm/s upflow in a traditional AguaClara plant design. Yet, after 10 hours of experimentation, effluent turbidity drastically shifts.

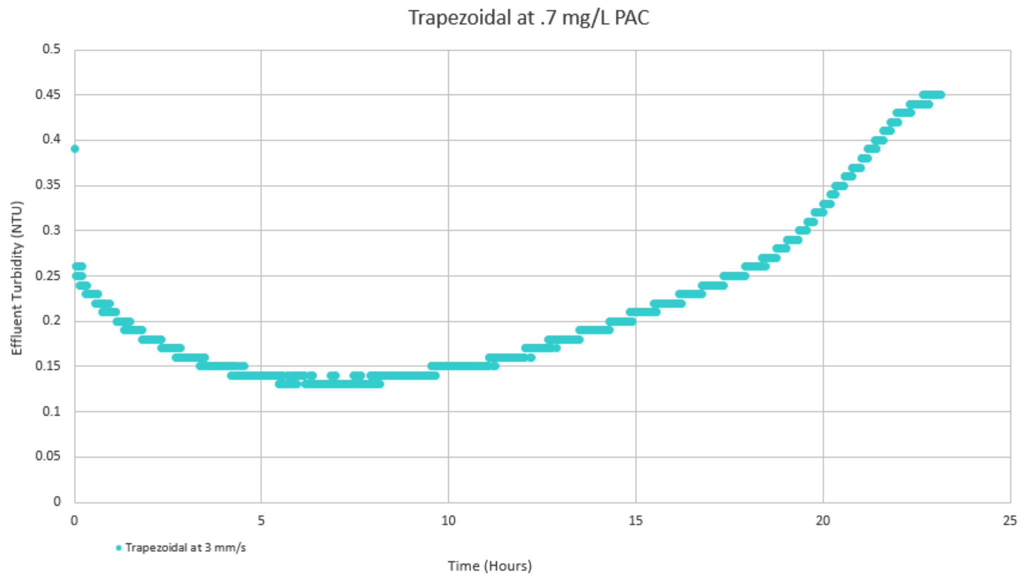

Figure 15: Trapezoidal recirculator performance at 3 mm/s with a 60 cm tube settler. As the floc blanket became more established and grew in height, performance greatly decreased.

The Summer 2017 team hypothesized that the number of bends is to blame. A "straight then bend" geometry promotes flocs to be captured and recirculate into the basin below. A traditional AguaClara incorporates this method only once and it only occurs at the transition from the recirculator to the tube settler. In turn, the floc blanket is kept low and a majority of the basin remains a field of thin, less thick conglomeration of particles. The trapezoidal recirculator, on the other hand, makes use of this mechanism five times (including the recirculator/tube settler transition). As a result, it acts as a ladder for the floc blanket to densify and scale the length of the recirculator unlike other geometries.

The issue this phenomenon brings up is the effectiveness of floc blankets and how they may hurt sedimentation rather than assist it. Does height matter? How dense is too dense? In order to investigate these questions further, another recirculator was fabricated that made use of the floc capture mechanism only twice.

5 Understanding the Bend

In an attempt to solve the floc blanket predicament, the team designed a new recirculator that incorporates a bend at the beginning of the recirculator. The team believed that by implementing only one bend rather than four like the trapezoidal, the floc blanket would be kept low and performance would improve.

Methods

This new recirculator was referred to as the "Low Bend" recirculator and was 1 m in length. The bottom half was a "straight then bend" mechanism and the top half was a straight section. A .7 mg/L dose was used at a 3 mm/s upflow velocity. Figure 16 shows the overall shape of the recirculator.

Figure 16: Captions go beneath figures.

Results and Analysis

The Low Bend recirculator design yielded a lower effluent turbidity overall and did not deviate from steady state as drastically as the Trapezoidal geometry did (Figure 17).

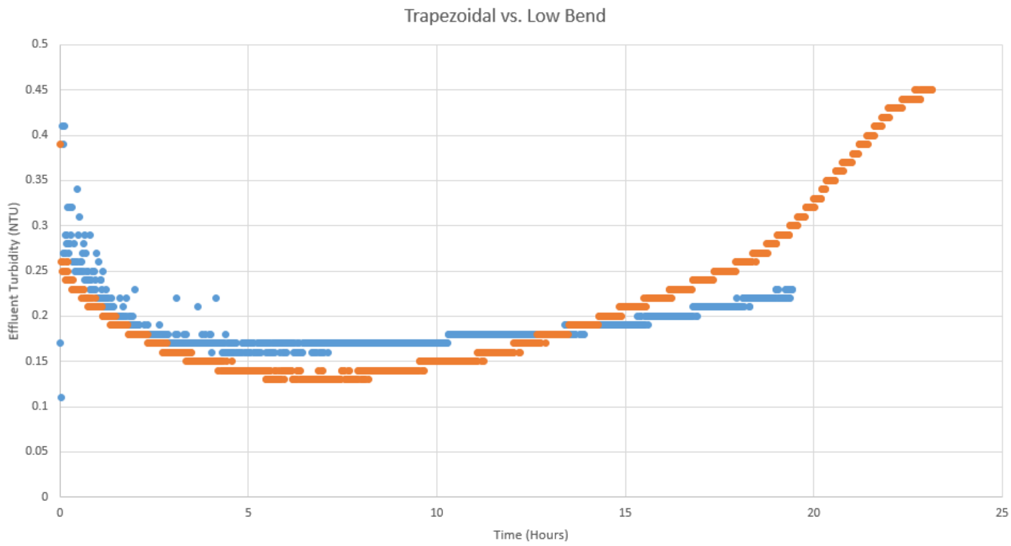

Figure 17: The Trapezoidal (Orange) and Low Bend (Blue) design performances. Although the Trapezoidal geometry was able to attain a lower NTU, the Low Bend recirculator produced a similar NTU, maintained performance longer, and did not deviate as dramatically from steady state conditions.

From these results, it is clear that the Trapezoidal recirculator is better at achieving a low NTU, but not maintaining it. Although the design was able to attain an effluent turbidity of .14 NTU rather quickly, it was short lived. On the other hand, the Summer 2017 team was able to bring water quality to about .17 with only one bend and maintain performance with only slight deviation from steady state. Even though the Low Bend experiment was cut short (due to a time crunch), it is clear that water quality was worsening more gradually than the Trapezoidal experiment.

The explanation for movement from steady state may be found in floc blanket development. As stated earlier, the Trapezoidal design inhibits a climbing floc blanket that densifies quickly and remains closer to the tube settler. Figure 18 depicts the floc blanket created by the Low Bend recirculator. The floc blanket was much lower than the Trapezoidal, which raises the question of how much of the sedimentation basin is necessary and if the floc blanket has much of an effect on performance after a certain height.

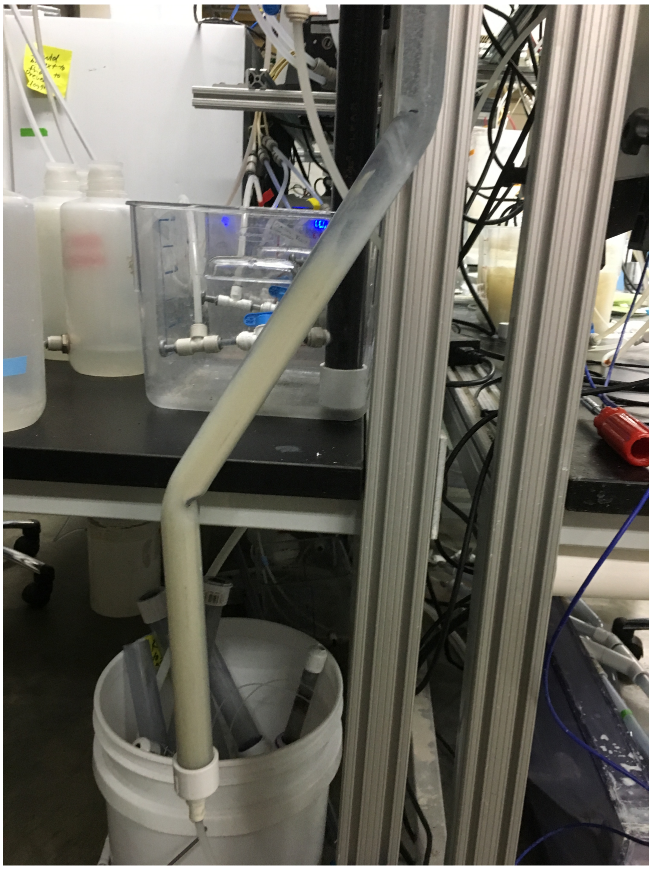

Figure 18: The floc blanket produced by the Low Bend recirculator. This floc blanket was not only dense, but shorter than the floc blanket produced by the Trapezoidal recirculator.

Despite the fact that the dense floc blanket gradually hurts effluent water quality, it is clear that the Trapezoidal geometry is excessive. To investigate floc blanket effects on performance, further modification of the Low Bend design should be incorporated (See the Future Work section).

Conclusions

This summer, the HRS team investigated the Trapezoidal design created by the Spring 2017 team and worked towards developing constants for experimental comparison with respect to performance. It was found that the bend is important for floc blanket development, an observation that the Spring 2017 team confirmed as well. However, if the standard AguaClara simulation already performs better at 3 mm/s, the question of whether bends in the recirculator are necessary still remains. Although bends promote floc blanket development, it was found that they do not necessarily keep water quality low for extended periods of time. At least this is true for a .7 mg/L coagulant dose.

The Spring 2017 team showed that the Trapezoidal design performs well with multiple bends. The Summer 2017 team found that this many bends is unnecessary and may actually harm performance. This finding is significant because it means the extensive geometry that the Trapezoidal design implicates can be greatly simplified; saving money, space, and materials.

Due to the time crunch near the end of the summer, the HRS team did not have the time to run experiments multiple times and solidify findings. Future replication of these experiments is needed in order to establish consistency in these conclusions.

Future Work

The future focus for the HRS subteam is multifaceted. For one thing, more should be investigated on how flow rate affects flocculation, floc blanket, and sedimentation. The 3 mm/s upflow performed better than the 1 mm/s experiment which shouldn't be occurring. The hypothesis is that performance is parabolic rather than linear as one increases upflow velocity, where an upflow velocity in between 1 mm/s and 5 mm/s is producing flocs most similar in size to clay particles.

In addition, more testing should be done with the Low Bend recirculator and floc blanket effects. Since it is believed that flocs are climbing and decreasing performance as they stray from the dense floc blanket, perhaps implementing a weir within the low bend itself rather than before the tube settler could provide insight on more efficient sedimentation tank design. Figure 19 below provides a rough graphic on this new reactor design.

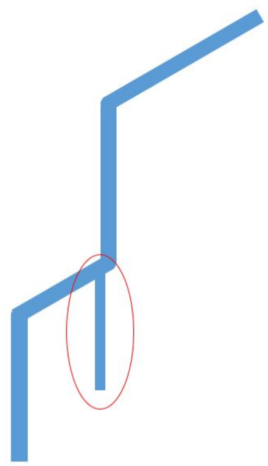

Figure 19: This new reactor design incorporates a floc weir on the low bend rather than before the tube settler. The team expects this design to not only keep the floc blanket low, but also to capture flocs that may be escaping into the tube settler and harming performance

Since there were many difficulties with coagulant dosage, the HRS believes it would be best if the coagulant stock was placed on a scale and mass was kept track of through ProCoDA. This way, the team can make note of the theoretical dosage calculated through MathCAD as well as the dosage that the system is actually experiencing. This may be done by recording the mass lost over time to calculate the flow rate of coagulant and then comparing this to the concentration of the reservior and the calculated amount of volume leaving over time. This is represented by the equation below:

$$\frac{Mass_{leaving}}{time} = C_{stock} V_{leaving}, \tag{5}$$

This will help us measure our dosage correctly and accurately. This will also help future HRS teams to experiment with the different levels of dosage, while easily being able to compare to other experiments.

MathCAD

The Summer 2017 team established that the two MathCAD files necessary for experimentation are ”G value calculation” and ”PAC Dosing.” These two files may be found on the High Rate Sedimentation Google Drive. However, for the documentation purposes, images of the files themselves have been provided below. It’s important to note that the PAC Dosing MathCAD file calculates dosing with the assumption that blue-yellow tubing is being used.

$$Q_{Plant} := \left(1.04 \frac{mL}{s}\right) \quad ID_{Tube} := \frac{1}{8} in \quad R_{Coil} := 1.5 in \quad T := 23\,°C$$

$$G_{Straight}(Q_{Plant}, ID_{Tube}) := \frac{64 \cdot Q_{Plant}}{3 \cdot \pi \cdot ID_{Tube}^{3}}$$

$$Re_{Rm}(Q_{Plant}, ID_{Tube}, T) := \frac{4 \cdot Q_{Plant}}{\pi \cdot ID_{Tube} \cdot 1 \cdot 10^{-6} \frac{m^2}{s}}$$

$$De(Q_{Plant}, ID_{Tube}, R_{Coil}, T) := Re_{Rm}(Q_{Plant}, ID_{Tube}, T) \cdot \left(\frac{ID_{Tube}}{2R_{Coil}}\right)^{\frac{1}{2}}$$

$$G_{Coil}(Q_{Plant}, ID_{Tube}, R_{Coil}, T) := G_{Straight}(Q_{Plant}, ID_{Tube}) \cdot \left[1 + 0.033\left(\log\left(De(Q_{Plant}, ID_{Tube}, R_{Coil}, T)\right)\right)^{4}\right]^{\frac{1}{2}}$$

$$G_{Straight}(Q_{Plant}, ID_{Tube}) = 220.654 \frac{1}{s}$$

$$G_{Coil}(Q_{Plant}, ID_{Tube}, R_{Coil}, T) = 266.43 \frac{1}{s}$$

Figure 20: G value calculation

SYSTEM is the final concentration of coagulant in the water running through the apparatus

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$Conc_{Sys} := 0.7 \frac{mg}{L}$ The desired final concentration of coagulant in the system in mg PAC per L of water in the system. (0.5-2.5 mg/L is standard)

$Q_{System} := 1.04 \frac{mL}{s}$ Flow Rate of System

$MassFlow_{coag} := Q_{System} \cdot Conc_{Sys} = 7.28 \times 10^{-4} \cdot \frac{mg}{s}$ Required Mass Flow rate of PAC to meet concentration requirement

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$k_{dilution} := .235 \frac{mL}{L}$ How many mL of the Lab concentration are added per L into the Reservoir

$Conc_{Lab} := 70.9 \frac{gm}{L}$ Conentration in grams per L of lab solution

$Conc_{Reservoir} := Conc_{Lab} \cdot k_{dilution} = 0.017 \cdot \frac{gm}{L}$ Uses above to calculate Reservoir concentration in grams per L of Reservior solution

$Q_{reservoir} := \frac{MassFlow_{coag}}{Conc_{Reservoir}} = 0.044 \cdot \frac{mL}{s}$ Volumetric Flow Rate of solution leaving the reservior and entering the system to achieve desired final concentration.

$V_{reservoir} := 5L$

$V_{Lab} := \frac{V_{reservoir} \cdot Conc_{Reservoir}}{Conc_{Lab}} = 1.175 \times 10^{-3} L$

$Q_{perRPM} := 0.002324 \frac{mL}{s}$ Experimentally determined flow rate for type of tubing used. (.0025mL/s is theoretical value for blue/yellow tube, but we should use what we actually observe) WE OBSERVED 0.002324 mL/s at 11.3RPM

$RPM_{Desired} := \frac{Q_{reservoir}}{Q_{perRPM}} = 18.8$ RPM to use on pump to get desired concentration of PAC in system

Figure 21: PAC Dosing

Semester Schedule

Task Map

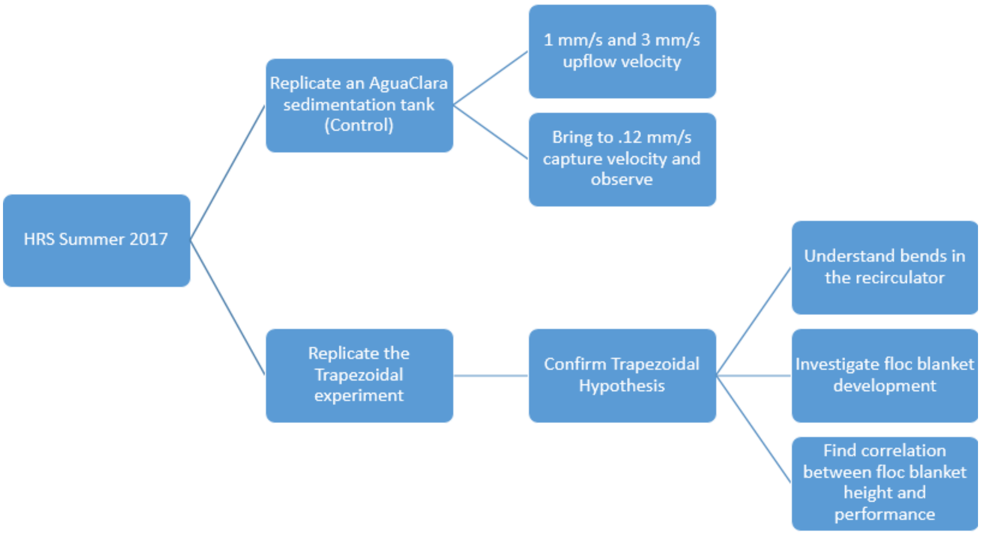

Figure 22: High Rate Sedimentation Summer 2017 Task Map

Manual

PID Control

The following is taken directly from the Calibrating PID Control on the AguaClara Confluence website:

To establish constants for PID control in ProCoDA, follow the procedure shown at this link. The steps will be summarized below

1. After you have loaded the proper PID control function and have created the appropriate set points in your method file, set the P, I, and D set points to zero
2. Set P to a small value and change the target value to provoke a response from the PID control
3. Observe the graph of the variable being controlled for this value of P. If the result is an oscillation that becomes damped (decreasing amplitude), increase the value of P incrementally and repeat the process. If the result is an oscillation that becomes amplified (increasing amplitude), lower the value of P and repeat the process.
4. The objective is to find a value of P for which there is a periodic oscillation of the value with a constant amplitude. Once the correct P value (Ku) has

been found, write it down and also record the period of the wave (time between two consecutive crests of the oscillation - Pu - in minutes).

5. AguaClara researchers typically use PI control (the value of D is set to zero). To find the value of P required, use the equation: P = Ku/2.2. To find the value of I required, use the equation: I = Pu/1.2. This should result in a value in minutes, which is the correct unit for I.

6. Change your set points (P and I) to the new values. Ensure that there is less than 10 percent variation in your variable, and fine tune if necessary.

This calibration method may result in oscillatory behavior. To reduce variability in the output, consider reducing P to damp the oscillations. This will reduce the responsiveness of the algorithm and will increase the stability.

Set up

1. Make sure the set up is throughly cleaned out and the stocks are replenished. Open the valves for the water supply as well as the wastewater tube. Fill the recirculator and tube settler with water by turning on the water pump, but keep the effluent turbidimeter closed. To speed up the process of filling up the apparatus with water, bring the RPM of the water pump to 25.

2. Once the apparatus is filled, pause the water pump, close the valve to the wastewater, and use a push pin to replace the influent turbidimeter outflow tube on the connection between the flocculator and influent turbidimeter.

3. Turn on the water pump to 16.4 RPM for 3mm/s flow rate or 5.7 RPM for 1mm/s flow rate. Be sure to put the outflow tube of the influent turbidimeter in a container to collect the water that will be flowing through the influent turbidimeter.

4. Turn on ProCoDA by going to process operations and select ON, make sure the clay pump stabilizes and does not constantly stay at 100 RPM. The clay pump must be set on EXT and going clockwise. Also, make sure that the "1 rpm pump" and "on off switch" are both OFF. See ProCoDA section below on how to turn those off.

5. Wait until the the influent turbidimeter stabilizes to 100 NTU.

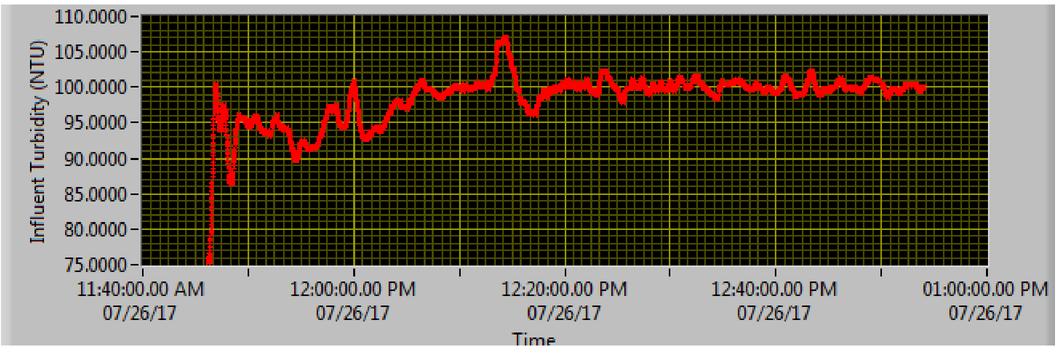

Figure 23: Once the P and i values are established, the pump will correct itself in order to oscillate the NTU around the target turbidity. Above is a graphical representation of this adjustment. For High Rate Sedimentation experiments, the target NTU is 100.

6. Start recording/ logging data on ProCoDA. Save the recording with a specific name of the experiment and date into the correct folder (high rate sedimentation folder/ correct semester and year folder).

7. Once stabilized, replace the push pin in Step 2 with the outflow tubing of influent turbidimeter back into the connection with the flocculator.

8. IMMEDIATELY open the wastewater valve

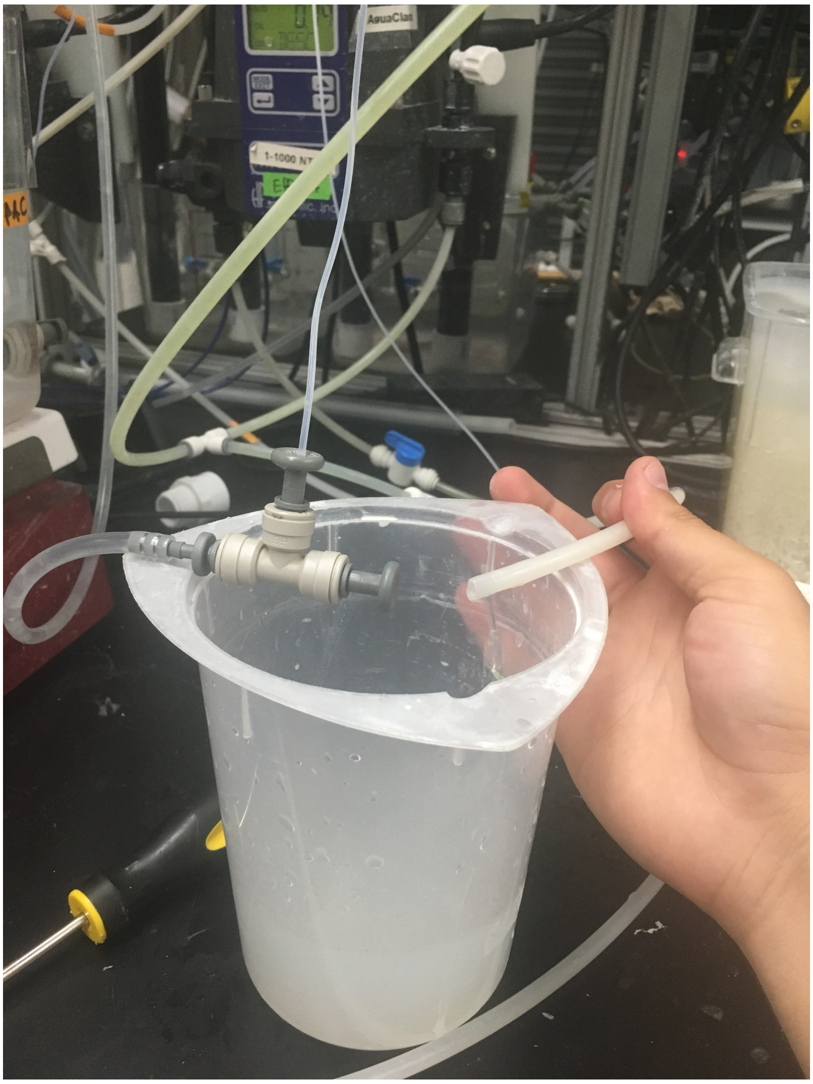

Figure 24: In order to prime the influent turbidimeter to 100 NTU without contaminating the reactor and flocculator with too much or too little clay, the team plugged the pathway that leads to the beginning of the flocculator (left) and allowed the influent outflow tube (right) to empty into a container. The clay pump is turned on through ProCoDA and the water moves through at its respective velocity for the experiment. When the NTU stabilizes at 100 NTU, the two tubes may be reconnected and the experiment can begin.

9. Turn on coagulant pump and record that on ProCoDA by clicking on the text log next to the green box on the configuration tab.

10. Open the effluent turbidimeter valve, wait a couple seconds, unpinch the outflow, wait a couple seconds, the bypass valve can be closed or open. Log that effluent is open on ProCoDA by clicking on the text log.

11. ProCoDA: turn on the "1 rpm pump" and "on off switch" on configura-

tion/edit rules. Open the weir valve.

12. Make sure everything is running properly

Cleaning

1. Turn off all applications and apparatus
2. ProCoDA: Off for Operator Selected State
3. Close the red wastewater valve
4. Place bucket under recirculator, then unplug the inlet tube from the bottom of recirculator, and unplug the connection between the top of the tube settler to the inlet tube for the effluent turbidimeter
5. Drain out the floc weir
6. Remove entire apparatus from wall (recirculator & tube settler) and throughly wash it out, then reattach it back to the wall
7. Wash out the Flocculator by unplugging the connection between the the outflow tube from the influent turbidimeter and the flocculator, and plug in tubing from the nearby sink to wash out the flocculator. Make sure there is a bucket at the end of the flocculator that will collect the water.
8. Clean the influent and effluent turbidimeter. Make sure to turn on the Bypass channel first! First, open the bypass valve. Second, pinch the black outflow tube. Third, close the inflow valve.
9. Remove and wash out the vials from both turbidimeters. Refill the vials with clean water, then put back into the turbidimeters.Use Kim wipes to clean the glass throughly.
10. Turn off water to the flocculator and detach the tubing. Hook up the influent turbidimeter back into flocculator then re-open the influent turbidimeter BUT keep the effluent turbidimeter closed. Turn on the water pump to clean out the influent turbidimeter as well as the flocculator.
11. Pour out the coagulant reservoir into a different bucket and rinse reservoir with deionized water to make sure all residue is washed out. Take out the push pin then wash out the coagulant reservoir throughly. Replenish reservoir with 5L (or less) of deionized water. Use MathCAD to determine how much 70.9mg/L PAC coagulant needed to use to get the desired results for the experiment.
12. Replenish the Clay stock. Generally add 2 grams of clay for every 1 Liter of water added. However, this can change depending on how your clay pump is dosing and NTU response.

ProCoDA

Ending Experiment

1. Click on the green box to stop recording the experiment.
2. Click on the configuration tab
3. Click on edit rules
4. Go to Rules & Output tab
5. Click on the "On" State list
6. Click on the Outputs tab
7. Select "OFF" for both the "1 rpm pump" and "On/off" switch