High Rate Sedimentation, Fall 2017

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January 30, 2018

Abstract

Past high rate sedimentation teams have tested the effectiveness of varied sedimentation basin geometries. The goal of the current team is to test whether these geometries could be simplified and shortened while maintaining an acceptable effluent turbidity. However, the results of this semester raise more questions than they answer. Although the team begins with a clear direction, investigation of the flocculator dominates the majority of research. Future work needs to be done on exactly what is causing floc blanket deterioration. The Fall 2017 team theorizes that the flocculator itself is to blame. By diagnosing this experimental issue, the team will become one step closer toward providing high quality water in a fraction of the time.

1 Introduction

Sedimentation is a critical process for water treatment plants. It is the process by which coagulated minerals, dirt, clay, and other particles are removed from the water via gravitational settling. The particles settle into a "floc" - a fluidized bed of suspended solids colliding in a bottom zone of the tank. The particles are initially light and small, but as coagulant dosage persists and particles continue to collide, the particles clump together into heavier floc that will settle into the basin of the recirculator. This process permits clearer water to continue up the plate settler, resulting in a lower effluent NTU (Nephelometric Turbidity Unit, a measure of clarity).

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 floc blanket developing in the base of the tank. 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 is referred to as the "recirculator" by the High Rate Sedimentation (HRS) team. The slanted tube that simulates a plate settler is designated 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.

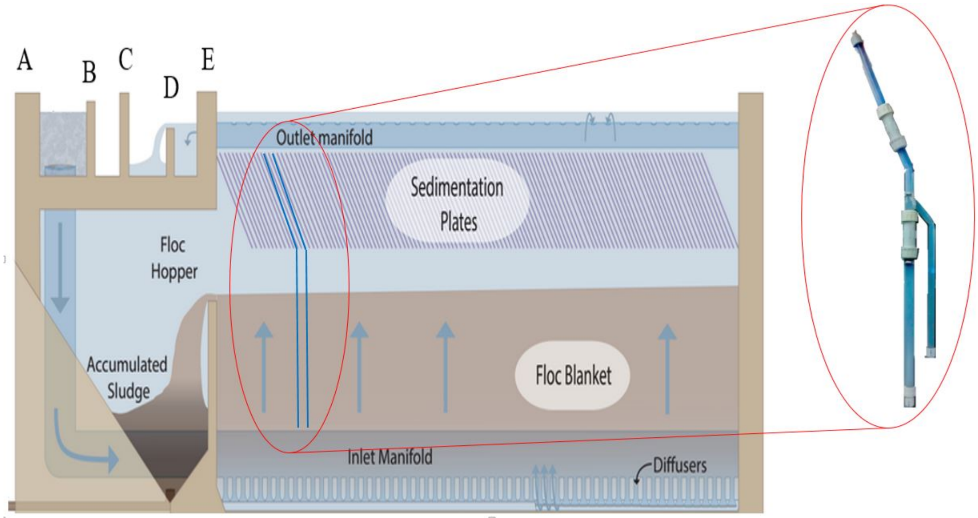

Figure 1: The recirculator and tube settler simulate the sedimentation tank basin and plate settlers respectively. Since the behavior of a section of fluid is characteristic of the entire tank, tubing can be used to simulate a simple pathway in the reactor. This allows for a practical form of experimentation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

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 HRS team hopes to design a tank that will yield an effluent of 0.3 NTU or lower with maintaining high upflow velocity. While the World Health Organization has a standard of at most 1 NTU for drinking water, the EPA standard is 0.3 NTU. AguaClara currently achieves this with an upflow velocity of 1 mm/s, but not at upflows of 3 mm/s or greater.

The Fall 2017 team has reduced the size of the sedimentation basin by half and transitioned to a 1 inch tube diameter. Although geometry is minimal and upflow velocity was high, the Fall 2017 plans to achieve NTUs below 0.3 through floc size selection, a feat manageable through capture velocity manipulation. The reason for this is to find alternatives to the complex geometry indicative of the trapezoidal design fabricated by the Spring 2017 team.

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 of water, but in a more compact size. Since sedimentation is the slowest unit process of the treatment process, using higher upflow velocities to reduce residence time and treat more water at once is essential. This will save time, money, space, and materials required to construct this section of a standard AguaClara plant.

1.1 Literature Review

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.

1.2 Previous Work

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).

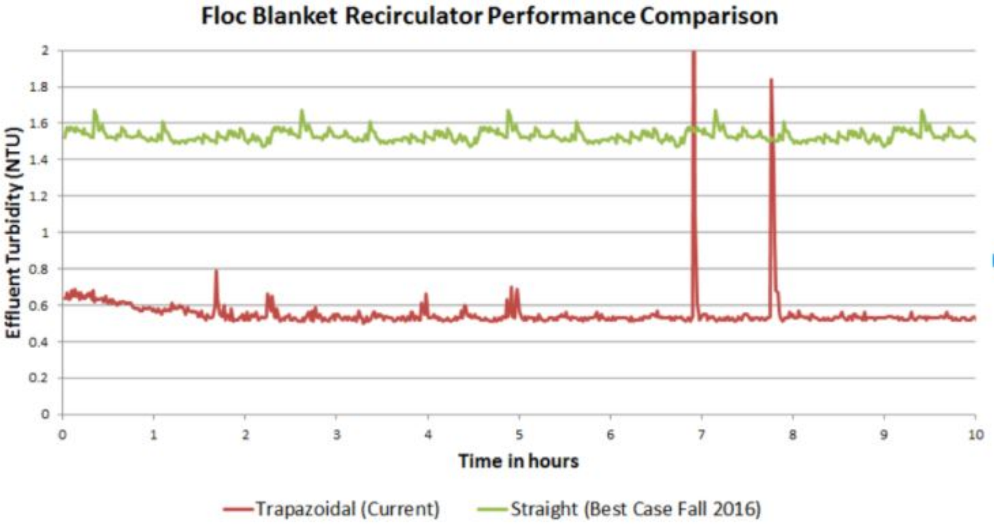

Figure 4: The trapezoidal recirculator produced effluent turbidity over three times lower than the straight 1 m recirculator. The 2016 experiment only lasted about 2 hours, and has been extrapolated out for comparison to the trapezoidal results (cite spring 2017).

These findings are substantial. The Spring 2017 team was able to achieve an NTU of about 0.5 with an upflow of 3 mm/s and an influent turbidity of 100 NTU. However, the materials and complex geometry that the trapezoidal design conveys, as seen by Figure 5 and 6, has driven the team to further investigate the bend and understand why the trapezoidal had such considerable performance.

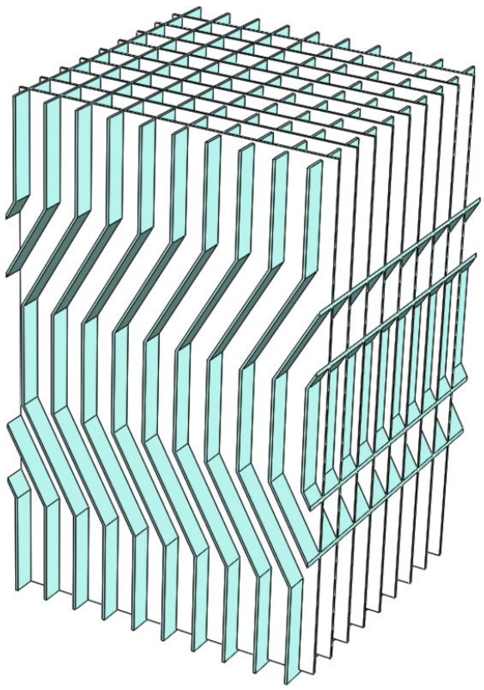

Figure 5: A 3-D rendering of the plate settlers that the trapezoidal design suggests.

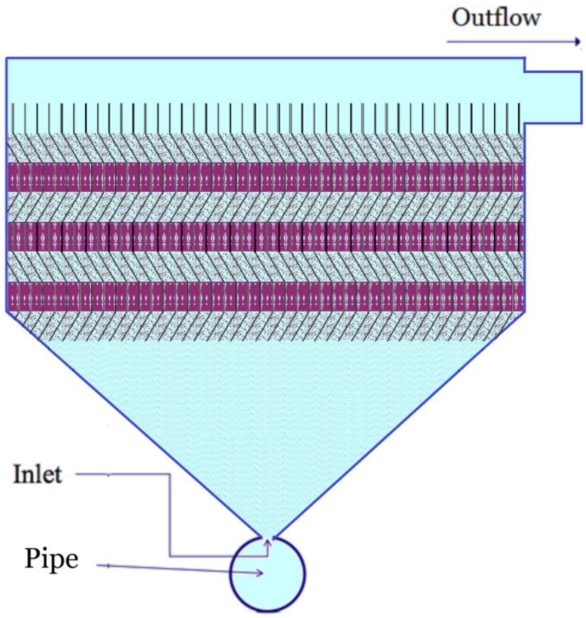

Figure 6: This figure provides a conceptual take on the location of the trapezoidal plate settlers within the sedimentation tank. Note that this figure is produced without the downward facing jet reversers characteristic of current AguaClara sedimentation tanks.

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 8) and the smooth bend (Figure 7). 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 7: The model with a smooth bend.

Figure 8: The model with a dimpled bend.

Although experiencing a lot of difficulties for the majority of the summer, the Summer 2017 team designed the Low Bend reactor which demonstrated that numerous bends in the recirculation zone may not necessary to create an established floc blanket.

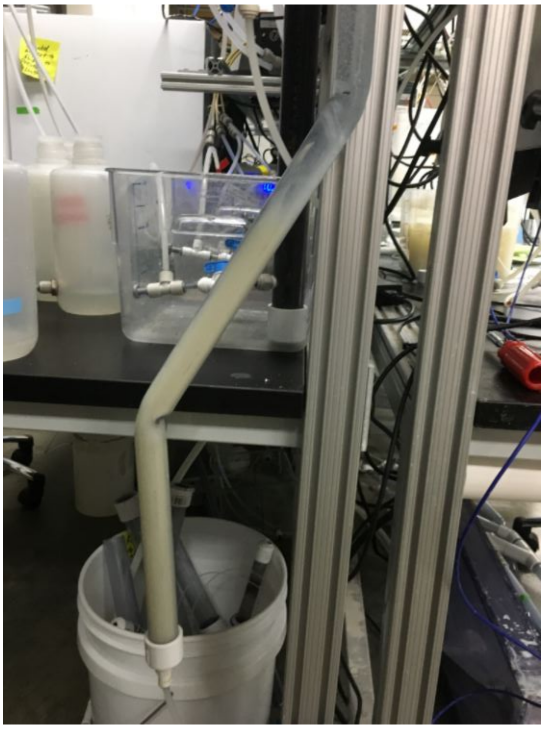

Figure 9: The floc blanket produced by the Low Bend recirculator. This floc blanket was not only dense, but shorter than the floc blanket produced by the Trapezoidal recirculator.

The Fall 2017 continues to work off these findings to further reduce reactor size and geometry in order to produce a compact, yet efficient design. This includes weir manipulation and the shortening of the recirculator and/or tube settler.

2 Experimental Setup

2.1 Lab Bench Setup

The overall lab bench set up of the HRS team is composed of several parts (Figure 10). They are the pumps, the stocks, the flocculator, and the turbidimeters.

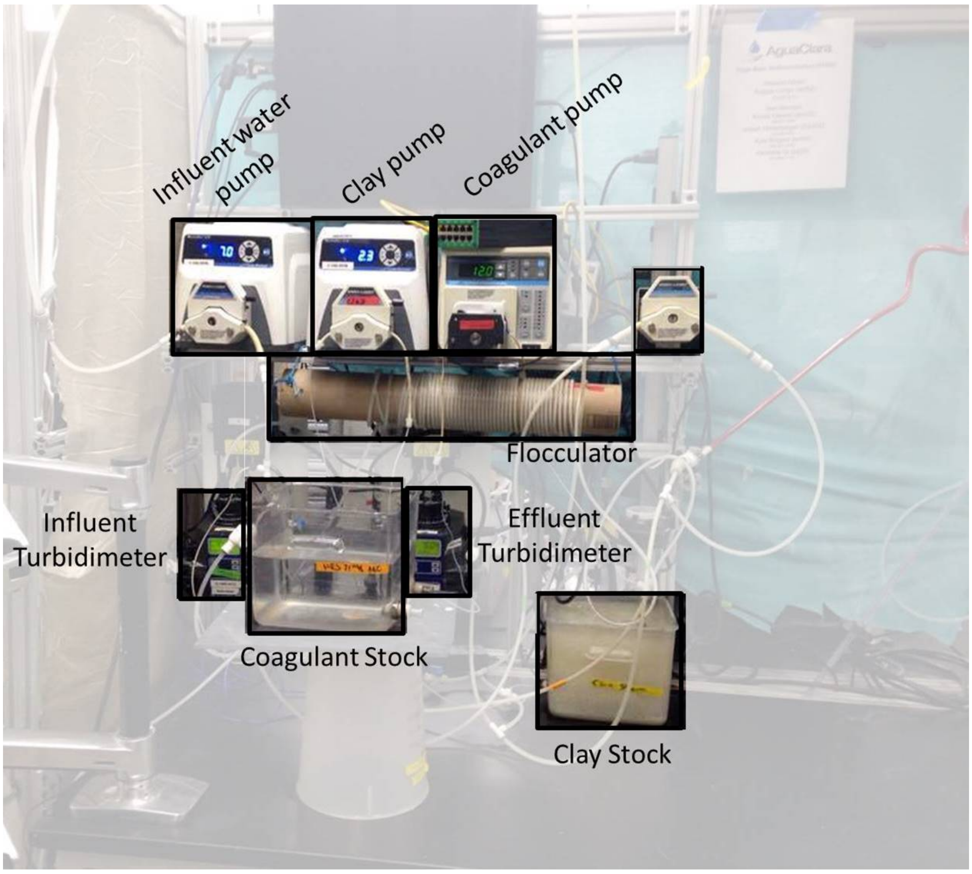

Figure 10: The HRS lab bench setup is composed of the turbidimeters, stocks, pumps, and flocculator. This allows the team to simulate non-potable water and its treatment through high rate sedimentation while keeping track of performance via NTU.

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 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 0.3 or lower. After the effluent turbidimeter, the wastewater flows out towards the wastewater drainage.

2.2 Flocculator

This Fall semester, all particle removal teams are utilizing the HRS standard apparatus design and a flocculator designed by the High G Flocculation Fall 2017 team. The flocculator's purpose is to mimic the flocculation process in an actual AguaClara plant with a sufficient collision potential (G). The High G flocculation team provides information on the following table with the flocculator's dimensions and the resulting values for an upflow velocity of 3 mm/s.

V.sed	Sed tank upflow velocity	3 mm/s
D.sed	Sed tank inner diameter	1 inch
Q.sed, Q.reactor	Flow rate (based on sed tank velocity)	1.52 mL/s
D.Floctube	Floc tube inner diameter	0.17 in
R.c	Radius of curvature of floc coils	5 cm
Gtheta	G*theta	20000
G	Shear	175.5 Hz
Theta	Residence time	1.899 min or 113.9 s
L.Flocc	Length of flocculator tubing	11.827 m
Epsilon.floc	Energy dissipation rate	30.814 mW/kg

Figure 11: The HRS lab bench setup consists of a flocculator developed by the High G Flocculation Fall 2017 team. The following are the parameters and resulting values of the current flocculator design.

2.3 Troubleshooting

There was one major drawback for this semester. Over the summer of 2017 and for the first quarter of the Fall semester, the team sampled effluent incorrectly. Although the experiment seemed to have been granting extremely good results such as the .3 NTU observed over the summer and the .16 found early on in the Fall semester, the effluent reading was not an accurate sample of the water flowing out of the apparatus. This was because both the bypass and the effluent turbidimeter valves were open. Although this may not seem like a big issue, since the concentration of particles in the split flow rates should be equal, it has detrimental impacts on data. With the bypass valve open, the effluent took the path of least resistance. That is, instead of moving through the complicated geometry of the internal workings of the effluent turbidimeter, water was sent immediately to waste. Therefore, the water being sampled was just a measurement of the clarity of an already cleaned turbidimeter vial whose quality improved over time as particles settled to the bottom of the glass container.

It is imperative that water quality sampling is accurate in order to prevent setbacks and the nullifying of data.

2.4 Constructing the Standard Design

This section contains the theories, steps, and progress the Fall 2017 team follows in order to fabricate the five reactors that all particle removal teams are to use for their experiments (flouride removal, high G flocculation, etc.). For more information on the work that these teams are involved in, see AguaClara's Research section on Confluence.

- Design: The geometry of the apparatus is based on the concept of "capture velocity." Capture velocity is the slowest moving particle that an area can capture and is a property of the sedimentation tank. In other words, the greater a particle's terminal settling velocity, the less distance it must travel and the more likely it is to be captured.

  Terminal settling velocity is reached when the frictional force (viscous shear) of the fluid, combined with the buoyant force, balances with the gravity. The larger the diameter of a particle, the greater its terminal velocity. This relationship may be shown through Stoke's Theorum as seen in the following formula:

$$V_t = \frac{d^2 g}{18v} * \frac{\rho_{floc} - \rho_{H_2O}}{\rho_{H_2O}} \tag{2}$$

  Where d is the diameter of the pipe, g the gravity force, v is viscosity and ρ the densities of the water and the floc.

On the other hand, capture velocity depends on the dimensions of the apparatus being used, as one can see in the following formula:

$$V_c = \frac{SV_\alpha sin\alpha}{Lsin\alpha cos\alpha + S} \tag{3}$$

where α is the angle of the tube settler, V_α is the upflow velocity, L is the length of the tube settler (after the floc weir), and S is the diameter of the tubing. If a floc has a terminal settling velocity that is too low, it will not be captured and instead will escape with the effluent.

A floc blanket has the potential to climb up to the weir, so it is the distance after the floc weir that is used as the active length of the tube settler in the capture velocity calculation. In the case of the standard design, with an effective length of 27.08 cm, the resulting capture velocity is .462 mm/s. In order to be consistent with previous research teams, the tube settler is at a 60° bend in relation to the x-axis in the Fall 2017 model. Also, the inner diameter is set to 1 inch rather than 3/4 inches.

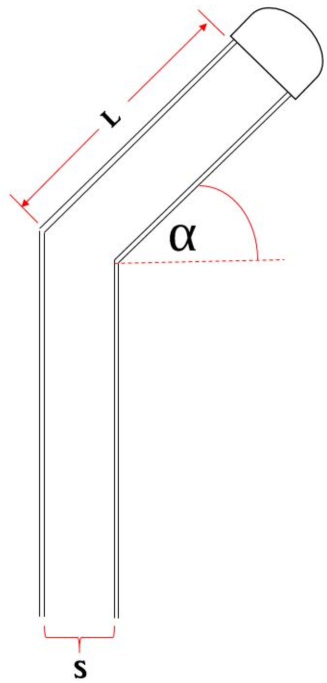

Figure 12: A diagram of the active tube settler length L, the inner diameter of the apparatus S, and the angle α.

- Materials In the Fall 2017 model, the floc weir is welded onto the tube settler rather than the recirculator and compression fittings enclose the apparatus. The reason for an intermittent floc weir on the tube settler is due to the findings of the Summer 2017 team. If a floc blanket could be established with a low bend, then further investigation is required on whether multiple bends characteristic of the trapezoidal apparatus are necessary for performance, or just keep essential flocs low and recirculating.

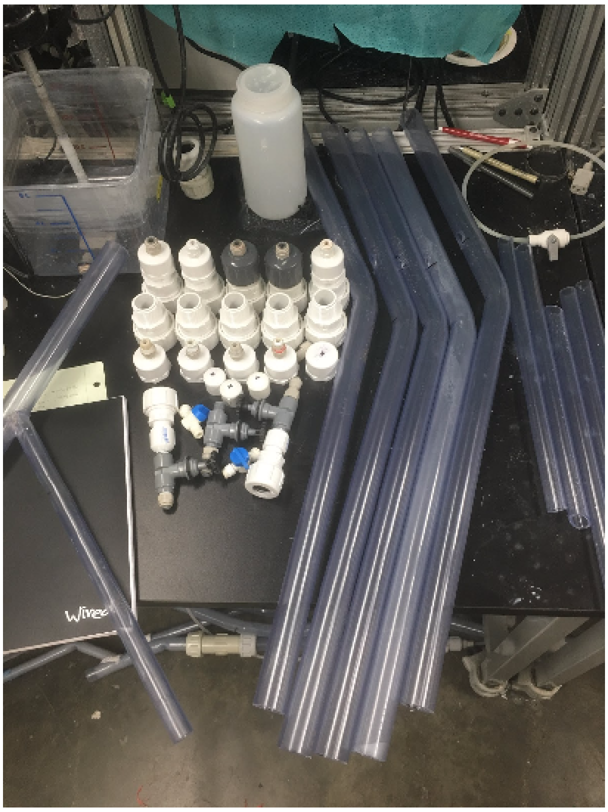

Figure 13: The HRS Fall 2017 team compiled the materials necessary for all particle team apparati. This includes compression fitting, push-to-connects, PVC tubing, tubing, and valves for floc hopper drainage.

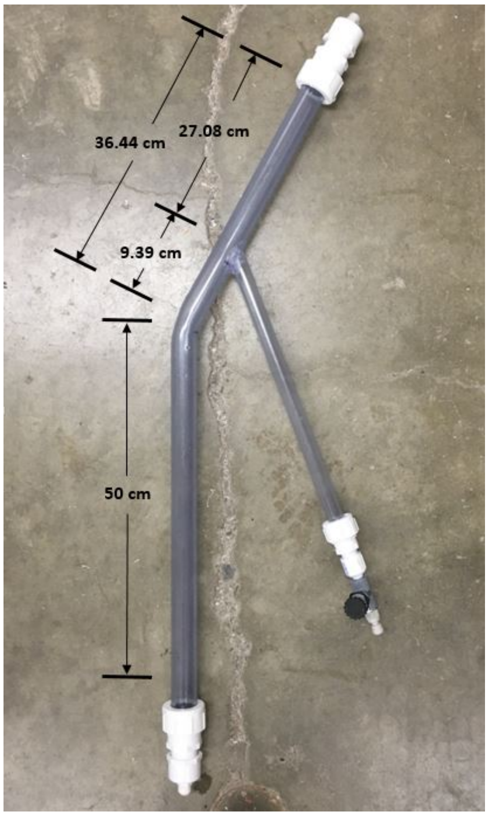

Figure 14: The standard design includes a 50 cm recirculation zone, a 36.47 cm tube settler, an a 40 cm long floc weir. The inner diameter of the PVC tubing is 1 inch rather than 3/4 inches like previous semesters

Compared to previous semesters, the size of the apparatus has been reduced a considerable amount. It is important to note that the team's goal is not necessarily to reduce turbidity more than what the trapezoidal was able to achieve, but rather to investigate possible alternatives to sedimentation tank design in order to avoid the complex geometry that the trapezoidal design implicates.

- Construction process: The team obtains 5 PVC tubes with 1 in inner diameter and a 60^o bend from the horizontal. From there, the team implements the following:
  1. Cut the tubes to the necessary length (50 cm recirculator and 36.47 cm tube settler)
  2. Cut floc weirs from $\frac{1}{2}$ inch tubing
  3. Weld weir to tube settler
  4. Layer of glue as a failsafe sealant
  5. Install fittings on all the apparatus.

Since the tubing size increased from 3/4 inch to 1 inch, the flow rate of influent water had to be altered in order to achieve the 3 mm/s upflow velocity that is unique to high rate sedimentation. The following equation is used in order to help the team determine these values:

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

where Q_{floc} is the volumetric flow of water through the system and D_{pipe} is the inner diameter of the PVC pipe.

3 Experiments

3.1 The Standard Design

3.1.1 Setup and Methods

In order to maintain consistency with the Summer 2017 team, the Fall 2017 team ran the first experiment at a theoretical dose of 1.4 mg/L PAC. This dose was obtained by adding 2.5 mL of 70.9 g/L of PAC to 5 L of deionized water and pumped out of the reservoir at 17.4 RPM. This RPM calculation is done through the current MathCAD file (see MathCAD).

3.1.2 Results and Analysis

The resulting effluent turbidity for this experimental setup is shown in Figure 15. From the figure, it is clear that effluent turbidity rapidly improves during the early part of the experiment, which corresponds with the development of a floc blanket. While a minimum turbidity of 1.7 NTU is reached, the floc blanket does not remain stable. This causes the removal performance to decrease as the experiment progresses. This significant observation shifts the focus of the project towards identifying what causes this floc blanket instability.

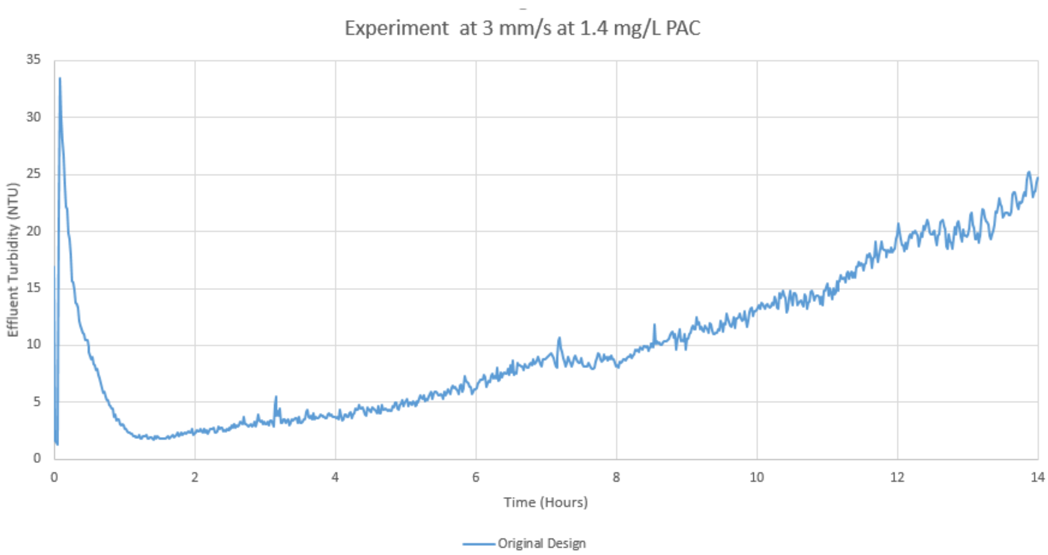

Figure 15: The gradual degradation of effluent turbidity as the Standard Design experiment progressed.

This floc blanket disappearance can be clearly scene in Figure 16. As time progressed, the floc blanket began to thin out at the bottom before becoming thin and almost entirely transparent.

Figure 16: As the Standard Design experiment progressed, the floc blanket dissipated from the bottom up.

3.2 Two Floc Weir Design

3.2.1 Setup and Methods

Since the team continues to obtain degrading results and an unstable floc blanket with the standard design, they decide to incorporate an additional floc weir at the top of the recirculator in hopes that the sloped floc blanket is the issue. This hypothesis is based on the gradual wasting of essential flocs.

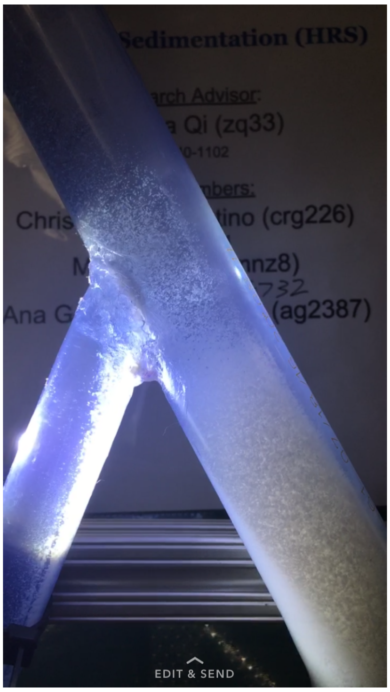

Figure 17: When the floc blanket reaches the intermittent floc weir, the team hypothesizes that the flocs that would've been captured by the tube settler are instead directly deposited into the floc weir and not returned into the recirculation zone. As a result, the floc blanket gradually degrades over time due to aging of old flocs.

Given that the weir is on the tube settler itself, once the floc blanket climbs toward the weir's edge, the 1 mm/s capture velocity of the tube settler section preceding the intermittent weir gradually increases since effective capture area is shortened by the climbing blanket. As a result, the flocs that the 9.39 cm section captures become bigger and bigger, preventing what the team believe to be the flocs crucial for floc blanket formation and maintenance to return back into the recirculator.

Figure 18: The general setup for the addition of a second weir at the top of the recirculator. The Fall 2017 team includes this addition in hopes that the floc blanket will stabilize and performance will stop deteriorating over time.

3.2.2 Results and Analysis

Addition of the second weir does not produce the expected results. Figure 19 displays the effluent turbidity, which follows a similar trend to the standard design experiment. The performance is stable for a longer period of time, but performance degrades more quickly than the steady decay of the standard design's performance. These results disprove our previous hypothesis that a climbing floc blanket is the source of performance degradation.

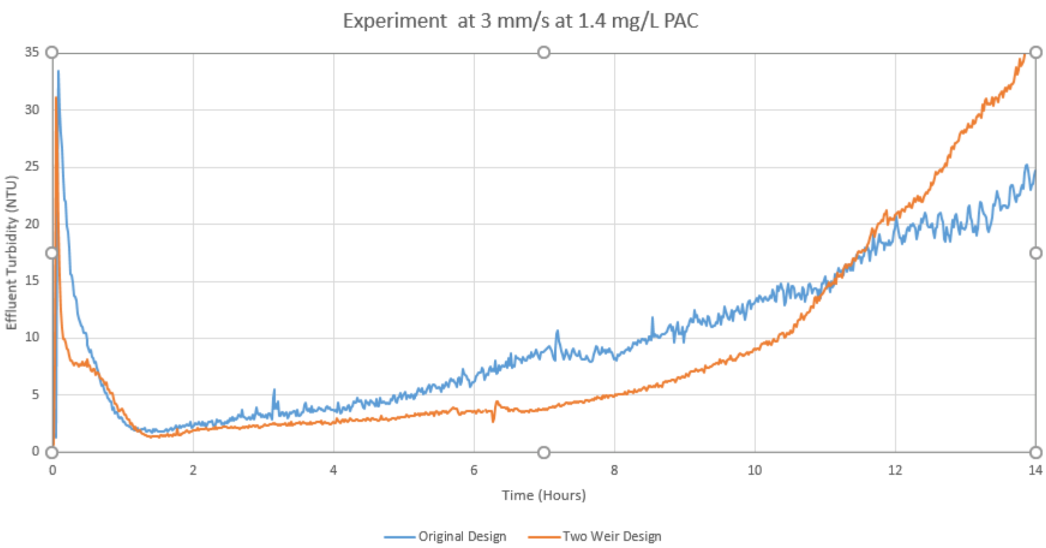

Figure 19: The effluent turbidity after the addition of a second weir before the tube settler. Performance is better than the standard design.

3.3 Intermittent Weir Removal

3.3.1 Setup and Methods

Once again, the Fall 2017 team does not get the results they are looking for. So, the team develops a new hypothesis. Perhaps the intermittent weir is wasting essential flocs from the beginning of the sedimentation process. With the intermittent weir, none of the finer particles above the weir return into the recirculator. Instead, the upper tube settler section captures these flocs and sends them directly to waste. The team theorizes that maybe these finer particles are essential for floc blanket longevity after its establishment. The dose remains at 1.4 mg PAC/L

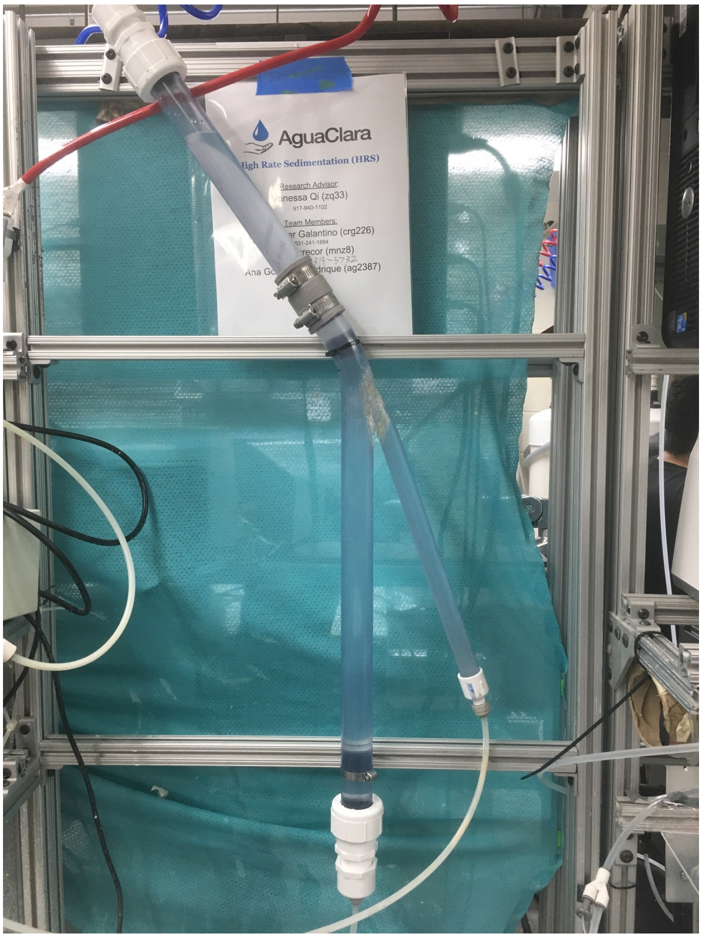

Figure 20: The general setup for the apparatus with the intermittent weir removed.

3.3.2 Results and Analysis

Removing the intermittent floc weir led to worse performance than the previous designs, as shown in Figure 21. The effluent turbidity deviates more drastically in the experiment than any of the previous designs. This disproves the hypothesis that the intermittent floc weir is wasting essential flocs. It is unclear why performance becomes much worse in such a short period of time.

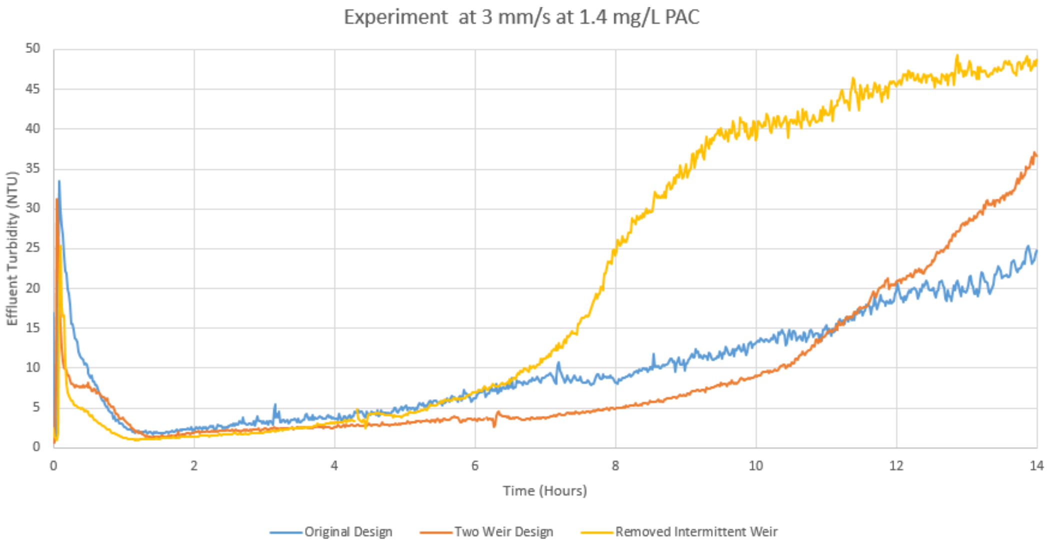

Figure 21: The effluent turbidity after the removal of the intermittent floc weir. Performance fell off more quickly than the Standard Design and the Two Weir experiment. It remains unclear as to the reason behind this occurrence.

3.4 Floc Blanket Re-establishment Experiment

3.4.1 Setup and Methods

The removal of the intermittent weir and its subsequent experiment disproves all previous hypotheses on floc removal and recirculation. However, this consistent occurrence of degrading performance makes the team question whether the experimental apparatus is to blame at all. Therefore, the team turns to the flocculator itself. After consulting with Monroe, the team wishes to confirm their suspicion that the flocculator is the source of degrading floc quality.

In order to test whether the flocculator poses as a potential source of experimental error, the team theorizes that if a flocculator can establish a floc blanket once, then it should be able to do it again if the experiment is restarted without cleaning the flocculator tubing. The following experiment entertains this concept.

3.4.2 Results and Analysis

The results of this experiment are shown in Figure 22. The red vertical line marks when the floc blanket is drained, while the green line marks where effluent readings stabilize enough to be reliable.

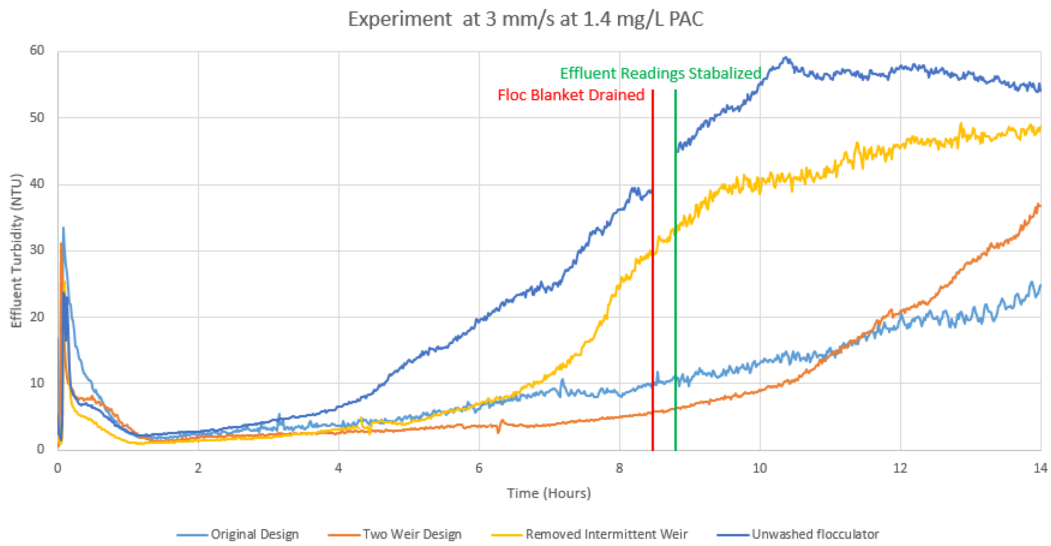

Figure 22: The effluent turbidity before and after restarting the experiment without cleaning the flocculator tubing. Since no floc blanket reforms and turbidity remains the same, the team confirms that the flocculator is the source of floc blanket degradation.

Readings between these two points are excluded due to massive fluctuations that do not provide any useful insights. The effluent turbidity does not drop after the floc blanket is drained, and a new floc blanket does not develop. This supports the hypothesis that a change is occurring during the course of the experiment that causes floc blanket degradation. This means that varying sedimentation tank geometry is not causing the effluent degradation complication. The current theory is that a film is developing in the flocculator which increases shear and breaks up flocs.

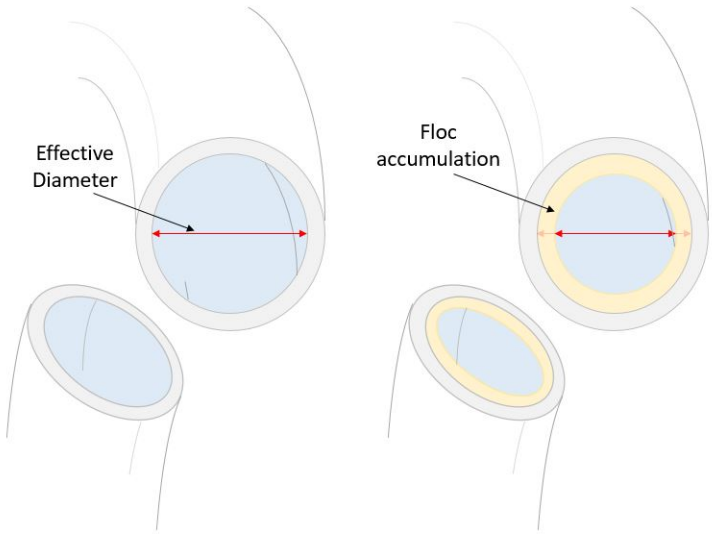

Figure 23: The team hypothesizes that the source of degrading water quality over time is not a feature of the apparatus itself, but rather the flocs being introduced by the flocculator. At the beginning of an experiment, the effective diameter and length of the flocculator produces a specific shearing force for floc promotion. However, the team believes that as the flocculation process continues, the tubing becomes "caked" with flocs.

3.5 Pulse Inhibitor

3.5.1 Setup and Methods

In their next experiment, the Fall 2017 team decides to add a pressure sensor in order to measure the possible pressure changes inside the flocculator and test if there is a significant change between the inlet and the outlet. This pressure is measured in cm of head. If a change does occur in the flocculator over time and the floc blanket degrades respectively, then there exists an increase in shear within the tubing. This in turn supports the hypothesis that the diameter of the tube is shrinking as experimentation continues and will require further investigation.

Due to significant spikes in the data, an impulse inhibitor is added in order to easily observe a linear trend in the pressure sensor data while also reducing the pressure impulses seen in Figure 24. In addition to the accumulation of flocs within the flocculator tubing, the team fears that these pulses of shearing force from the pumping process are tearing flocs apart and undoing the effect of the flocculation process. The impulse inhibitor is composed of a capped, laboratory grade plastic bottle with an influent and an effluent push-to-connect.

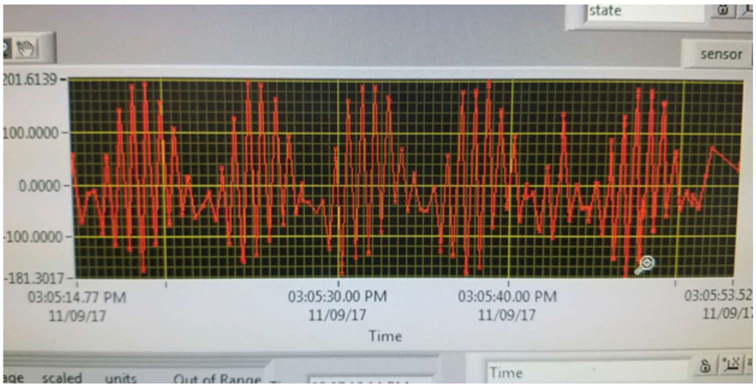

Figure 24: Significant spikes obtained when the pressure sensor is initially added. Adding the pulse inhibitor smooths out this data for easy reading and more accurate results.

The reason for these impulses of high shear can be explained by the manner in which water traditionally flows through the system. Since the AguaClara lab makes use of peristaltic pumps, water is "massaged" through the system in pulses of water. By adding the pulse inhibitor, water can flow smoothly and consistently throughout the system.

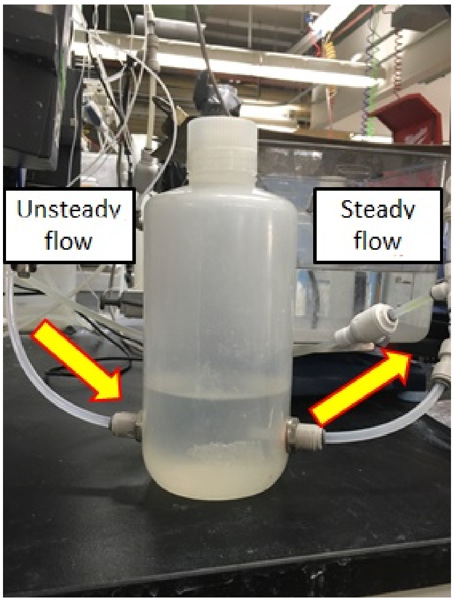

Figure 25: The pulse inhibitor is placed in between the incoming pulses of water from the peristaltic water pump and the influent turbidimeter where clay is dosed and NTU is monitored. When the water level in the bottle becomes constant, the system is at steady state and the flow in equals the flow out. However, the flow is no longer characterized by spurts of water and instead by a smooth, steady flow rate.

The Fall 2017 team runs this last experiment as an ordinary one, but with those new items included.

3.5.2 Results and Analysis

The results of this experiment are shown in Figure 26. These results indicate that the increased maximum shear caused by the pump is not causing the performance decrease over time. These results also show that a floc blanket does not fully form without the pulses of high shear. Smoothing out the flow rate ends up hurting sedimentation. The team does not currently have an explanation for this, but is something worth exploring in the future.

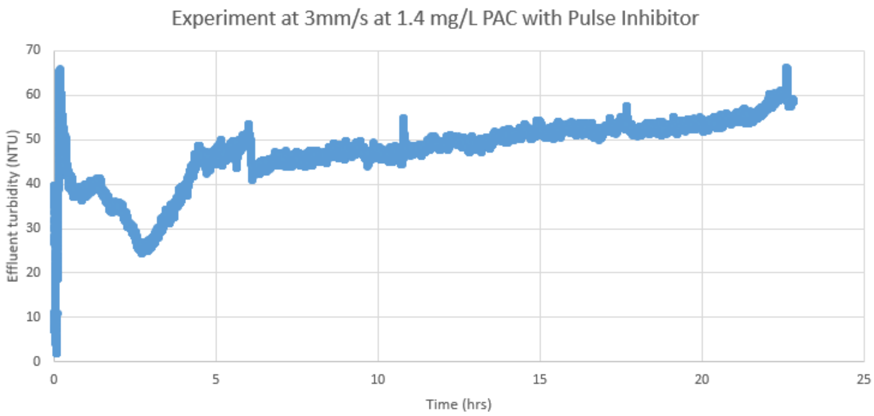

Figure 26: The effluent turbidity after adding the pulse inhibitor. This confirms that the pulsing caused by the pump used in the experiment is not causing enough shear to break apart flocs.

The team also observes the pressure changes through the flocculator as time passes. The pressure sensor is calibrated to read 0 cm of head with clean water flowing through flocculator.The pressure increases rapidly at the start of the experiment from 0 to 6 cm, then gradually increases to 13 cm. These results are shown in Figure 27.

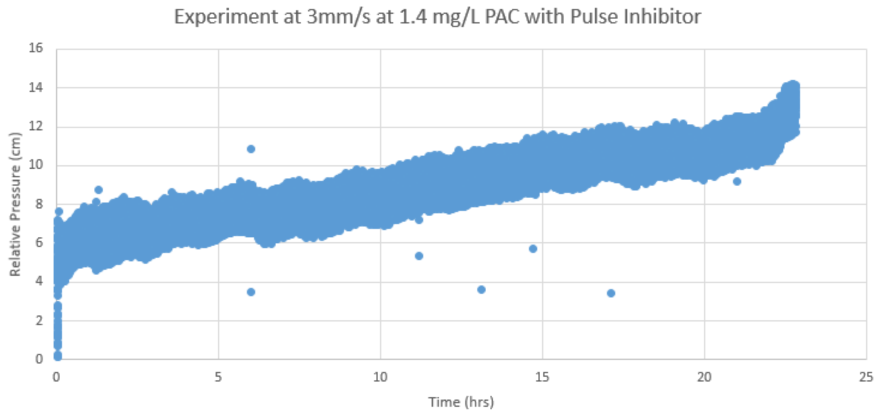

Figure 27: The flocculator pressure differential over the course of the experiment. From this, it is clear that the pressure gradually increases, which also leads to increasing shear.

4 Conclusions

This semester's work raises more questions than it answers. Although the Fall 2017 team worked extensively with apparatus geometry, specifically weir location and number of weirs, the direction of experimentation shifts when the team observes a consistent drop in performance over time in each experiment. The team investigates the floc blanket degradation phenomenon and attempts to pinpoint its cause. Despite eliminating shear pulses from the list of possible causes, it is found that the floc blanket performs worse with a steady supply of water versus an intermittent, pulsing flow rate.

However, removing pulsing shear forces from the equation does not solve the increase in headloss within the flocculator. This supports the hypothesis that there is floc accumulation on the inside of the flocculator tubing that is proving detrimental to long term performance of the sedimentation process. Further experimentation is needed in order to confirm these suspicions.

From these experiments, it is abundantly clear that before experiments at high upflow velocities can continue, this problem of floc production and quality must be solved.

5 Future Work

Future work on this team should focus on pinpointing the cause of floc blanket instability. The current hypothesis is that the development of a film inside the flocculator is causing shear values that break apart flocs. While the current team has determined that a film does develop, additional research would be required to determine whether this is substantial or the case at all. Additionally, because this instability does not occur at lower up flow velocities, determining an upflow velocity threshold could be beneficial.

Another avenue of research to consider is floc size selection. As seen with the experiments where an intermittent floc weir is present, quality is maintained for the longest period of time. This raises the question of whether there is a relationship between the size of flocs that are initially recirculated back into the basin and floc blanket longevity.

By fine tuning the experimental process for testing apparatuses at high upflow velocities, the HRS subteam is one step closer toward revolutionizing the speed of water treatment while maintaining impeccable water quality.

6 Bibiliography

Balwan, K. (2016). Study of the effect of length and inclination of tube settler on the effluent quality. 3(1):36-40.

Culp, G., Hansen, S., and Richardson, G. (1968). High-rate sedimentation in water treatment works. 60(6):681-698.

Hinterberger, Josiah (et.al) (2017). High-rate sedimentation spring 2017 report.

Hurst, M. (2010). Evaluation Of Parameters Aecting Steady-State Floc Blanket Performance.

Swetland, K. (2014). Flocculation-sedimentation performance model for laminar flow hydraulic flocculation with polyaluminum chloride and aluminum sulfate coagulants

7 Appendix

7.1 Task Map

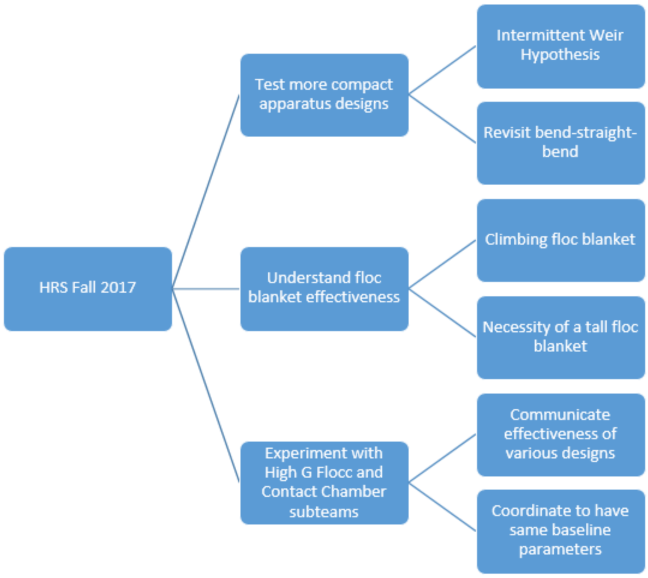

Figure 28: High Rate Sedimentation Fall 2017 Task Map

7.2 Manual

7.2.1 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.

7.2.2 Experimental Setup

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, increase the RPM of the water pump.
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 the respective RPM for your experiment. 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.

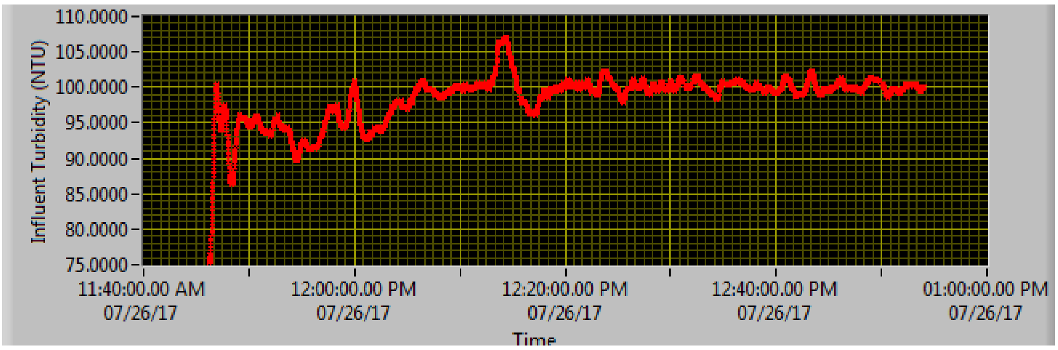

Figure 29: Once the P and i values are established, the pump will correct itself in order to oscillate the NTU around the target turbidity. Above is a graphical representation of this adjustment. For High Rate Sedimentation experiments, the target NTU is 100.

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

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, then close the effluent bypass valve. Insert text that the effluent turbidimeter is recording on ProCoDA by clicking on the text log and typing the respective message.

11. ProCoDA: turn on the "1 rpm pump" and "on off switch" on configuration/edit rules. Open the weir valve.

12. Make sure everything is running properly

7.2.3 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 dose 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, NTU response, and P and I values.

7.3 ProCoDA Method File

The HRS method file has been manipulated slightly throughout the semesters. Below is a current description of the method file and is split up into two sections: States and Set Points.

States

In order to properly begin an experiment, the ProCoDA method file must be turned ON. When an experiments in not in progress, ProCoDA is turned off.

- ON - The active state of ProCoDa. The 1 rpm pump drain is turned on (for draining the floc hopper) and the the clay pump is control (with PID) is turned on.

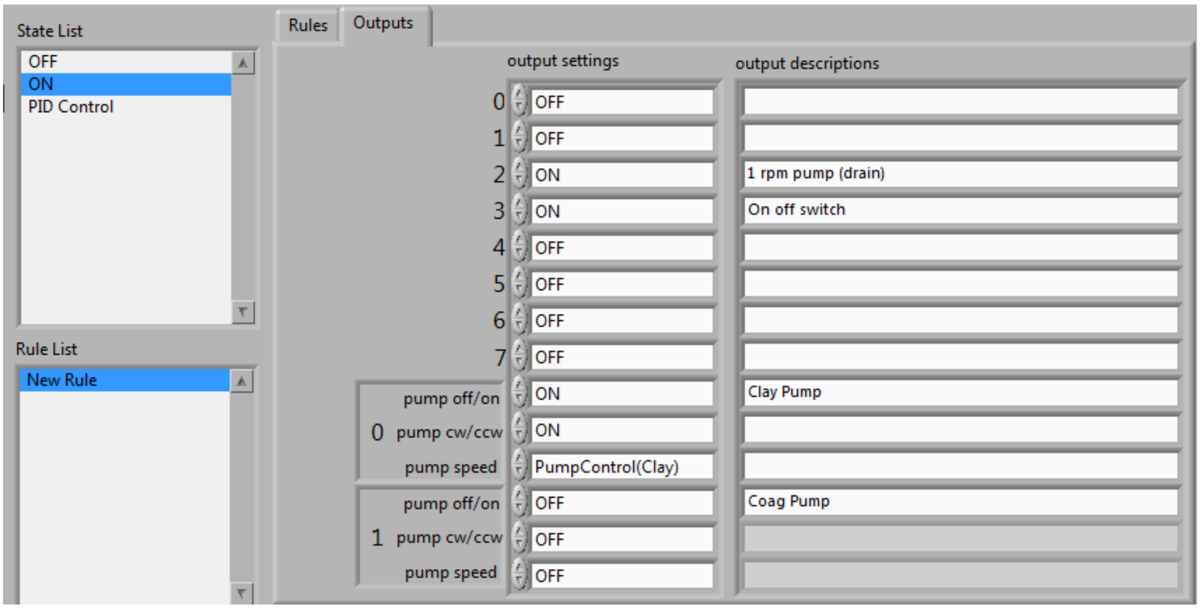

Figure 30: The ON state of the HRS ProCoDA method file. The floc hopper drain and clay pump are the active items controlled by the pump.

- OFF - Resting state of ProCoDA. All sensors, relays, and pumps are turned off.

Set Points

The following is a list of all the Set Points in the method file and their values. Exact location of these points in the method file can be seen in Figure 31.

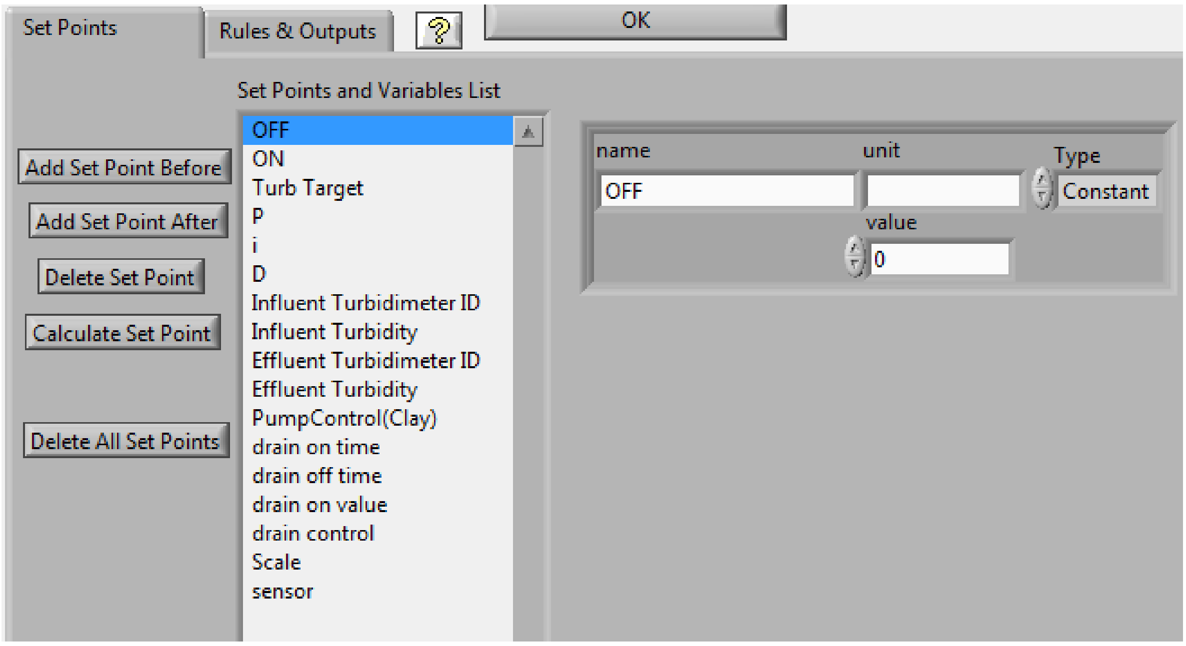

Figure 31: Overall order of the Set Points for the HRS method file

- OFF - no units, value of 0, constant
- ON - no units, value of 1, constant
- Turb Target - NTU, value of 100, constant. Value determined as the influent turbidity desired by the pump control
- P - no units, value of 300m, constant. Value determined through method mentioned in "PID Control" section of report and trial and error.
- i - no units, value of 2.3, constant. Value determined through method mentioned in "PID Control" section of report and trial and error.
- D - no units, value of 0, constant

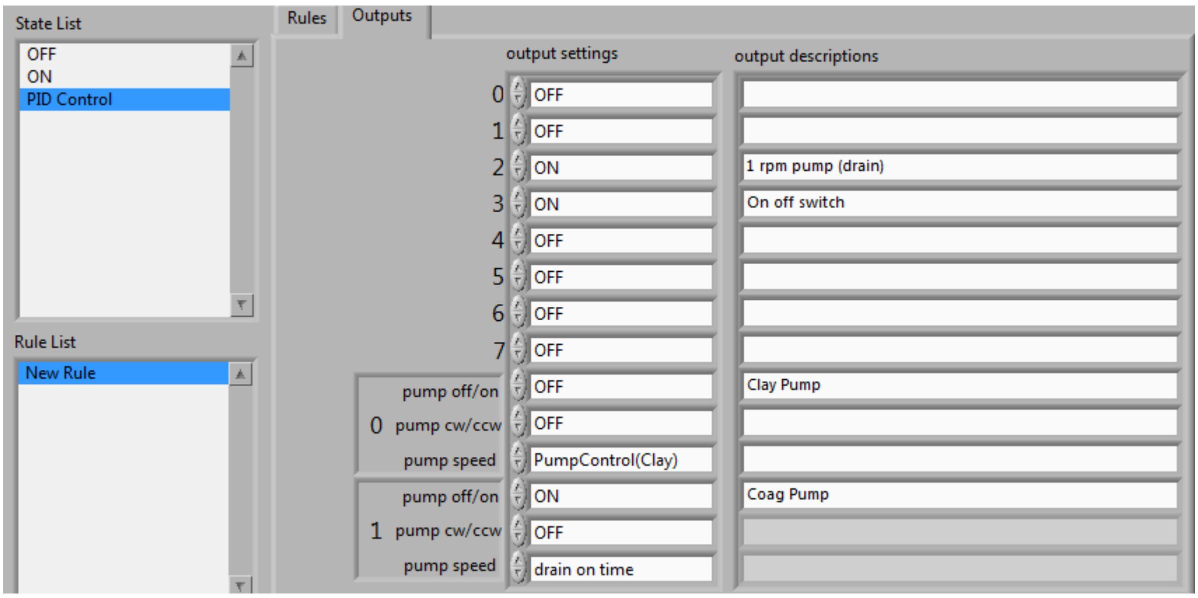

Figure 32: The output settings for the PID state. This process runs in the background and only needs to be set up at the beginning of a semester's work. Note that PID controls the clay pump and whether it is turned on or not at any given time.

- Influent Turbidimeter ID - no units, value of 1, constant. Value is due to the step in which the turbidimeter is installed and acknowledged in the data recording process. Effluent Turbidimeter ID is 2 since it takes in data later down the line.
- Influent Turbidity - no units, value of 0, variable. See Figure 33

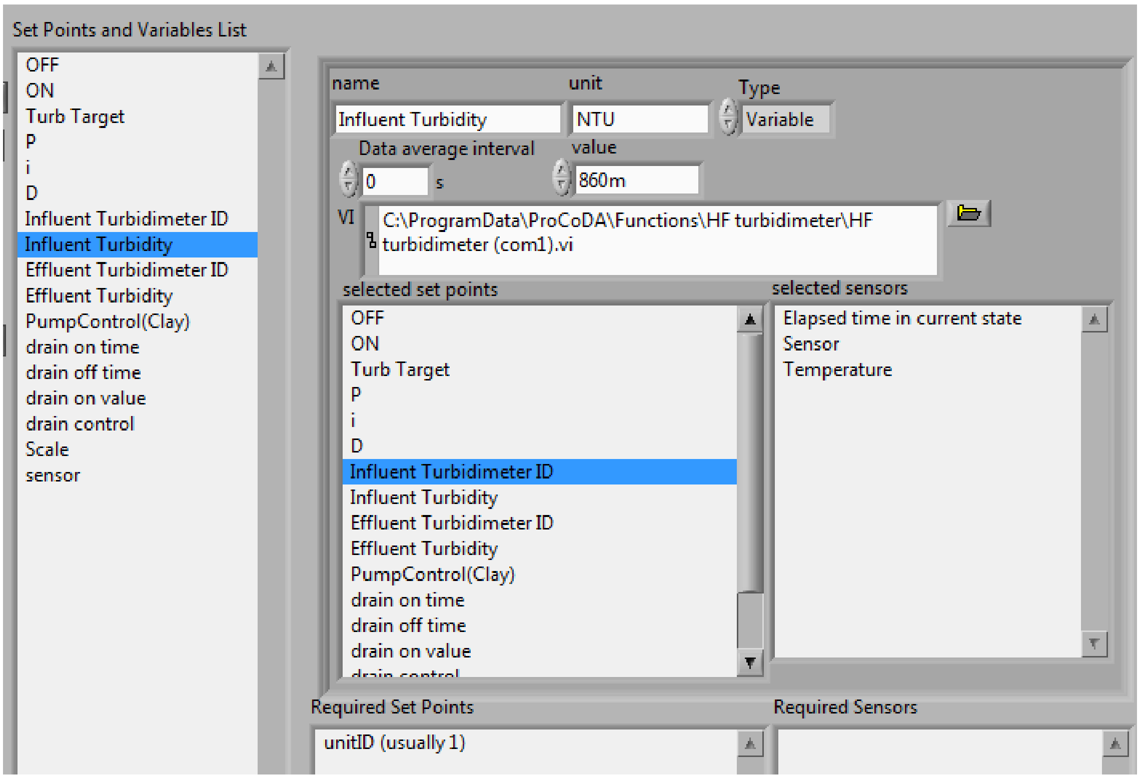

Figure 33: The influent turbidity Set Point and the selected sensors to establish the relationship

- Effluent Turbidimeter ID - no units, value of 1, constant.
- Effluent Turbidity - no units, value of 2. See Influent Turbidity and Figure 33.
- PumpControl(Clay) - no units, value of 0, variable. See Figure 34 for set point relationships.

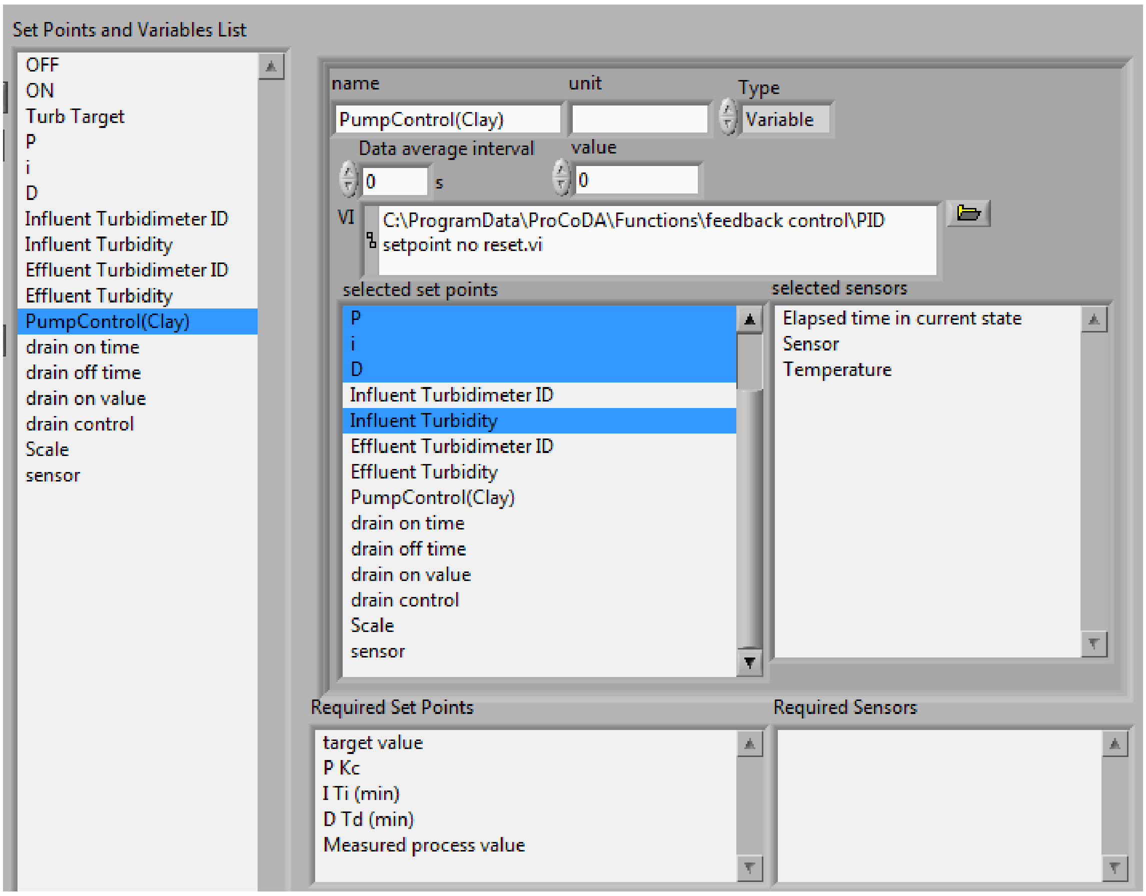

Figure 34: The relationship between the PumpControl(Clay) variable and other predefined set points.

- Scale - units of g (grams), value of 0, variable. This point keeps track of the mass of coagulant in the reservoir in order to show the team that coagulant is leaving the reservoir at a constant rate.
- sensor - units of cm, value of 2, constant. This set point is linked with a 7 kPa pressure sensor and is used to measure the headloss in the flocculator tubing.