High Rate Sedimentation, Spring 2017

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Abstract

The High Rate Sedimentation team designed, fabricated, and tested several bench-model sedimentation tank designs in Spring 2017, motivated to reduce space and cost for sedimentation tanks by increasing the upflow velocity while maintaining low effluent turbidities. To this end, the team continued investigation from Fall 2016 on effects of floc blanket height and tube settler length on the effluent turbidity, assessed alternative reactor geometries, and tested the size-driven floc blanket formation hypothesis. Two bench models significantly outperformed the existing model, and formation experiments showed mixed results.

Introduction

In conventional water treatment plants sedimentation is an important process, in which clumped masses of dirt, bacteria, and coagulant particles (known as "flocs") settle out by gravity and are removed from water. Part of the efficiency of the 2017 AguaClara sedimentation design derived from what was known as a floc or sludge blanket - a fluidized bed of suspended flocs colliding in a bottom zone of the tank known as the "recirculator." These collisions allowed many of the lightest and smallest particles, which would otherwise have been carried out in the tank effluent, to be assimilated into larger, heavier flocs which settle out during their residence in the basin (Anyene et al., 2016).

AguaClara designs also used plate settlers to catch smaller particles and return them to the floc blanket area below. These inclined plates suspended in the sedimentation tank increased the available horizontal area for flocs to settle upon, from which point the flocs slid down the plates back into the floc blanket, colliding with other flocs and growing in size along the way. The theoretical effectiveness of a settler is computed as "capture velocity," which describes the slowest moving particle that the plate settler can capture – in other words, if the terminal downward velocity of the particle is slower than the capture velocity, it will be swept out of the tube settler with the effluent water.

AguaClara plants in 2017 utilized vertical sedimentation tanks, which allowed the water to flow from the bottom to the top of the tank, through the floc blanket. This can be seen in the Spring 2016 bench model in Figure 1, where water flows from the bottom right-hand corner, through the floc blanket, and out the top of the tank (plate settlers were not a part of this apparatus). Because water flows from the bottom to the top of the tank, the flow velocity which maintains the floc blanket is known as overflow rate or upflow velocity. Flow rate, upflow velocity, and tank size are related through the continuity equation

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

where Q is total flow rate, V is upflow velocity, and A is surface area ("plan-view area") of the tank. Although the time that the water spends in an AguaClara sedimentation tank, or residence time, is short compared to industry standards, sedimentation usually takes around three times longer than the next slowest process of flocculation. The low velocity required for the 2017 AguaClara design (1mm/s) translated into a significant residence time and an allocation of plant area that, while smaller than the industry standard, was nonetheless the largest component of the treatment process. Lower velocity and longer residence time implies a larger sedimentation tank needed to be treat the same amount of water.

AguaClara sedimentation designs aimed for an effluent of 1 NTU, which was established standard of the World Health Organization. While the US standard was 0.3NTU, 1 NTU was deemed acceptable due to the lack of a polishing step in the apparatus, such as filtration, to remove residual turbidity.

The Fall 2016 Team explored the effects for effluent turbidity with changing floc blanket height and tube settler length. The Spring 2017 team verified some of the previous team's conclusions, and experimented with new designs for floc recirculator region of the sedimentation tank. "Trapezoidal" and "Zigzag" recirculators were designed and tested with synthetic 100 NTU influent water at upflow velocities ranging from 1-3mm/s, coagulant dosages from 0.5-3.5 mg PAC-Al/L.

The results of this semesters experiments indicated that modifying the recirculation zone of the bottom of the sedimentation tank enabled increased upflow velocity and flow rate without compromising water quality. A high rate sedimentation tank designed on these principles could produce the same quality and quantity of water as a standard sedimentation tank, but in a much more compact size, which would save time, space, and money, and allow more communities to access AguaClara technology.

Figure 1: The floc blanket reached the top of the floc weir and then wasted into the floc hopper, as seen on the lefthand side of the apparatus. The jet reverser can be seen in the bottom righthand corner of the apparatus (Anyene et al., 2016)

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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 Hurst2010. 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 deg angle with respect to the horizontal provided continuous sludge removal while showing effective sedimentation performance. Future experiments could be based on Culp's2016 optimal result, and other aspects, such as length, could be changed.

Previous Work

The Fall 2016 High Rate Sedimentation team spent the bulk of their semester designing, building, and troubleshooting the "tube" model of the high rate sedimentation tank, shown in Figure 2.

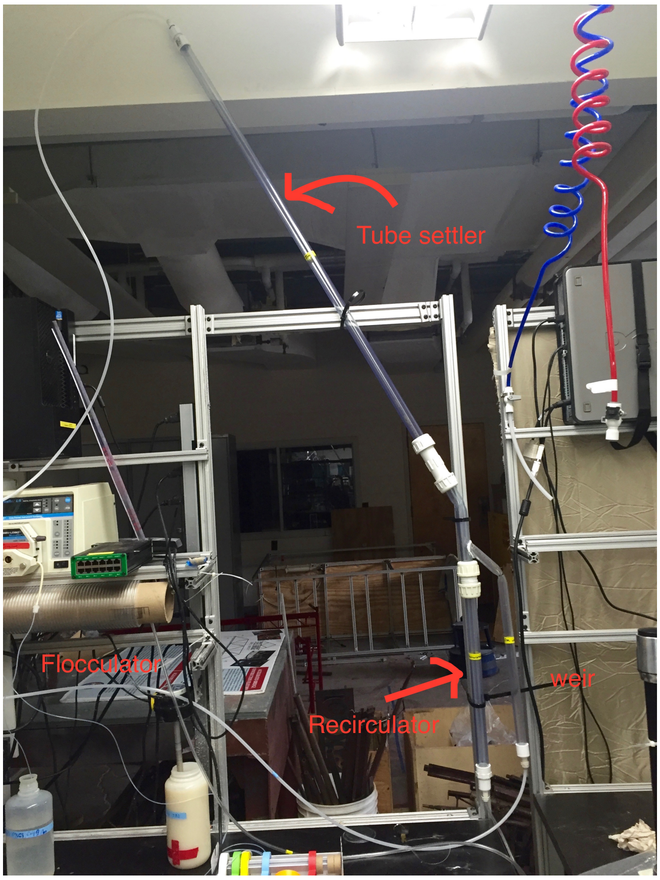

Figure 2: The "tube" model built by the Fall 2016 HRS team.

The team's plan was to independently gauge the effectiveness of two variables in the current sedimentation tank, but at three times the current upflow velocity of 1mm/s. After design and construction of the model, some preliminary experiments were performed using this model at the end of the semester.

The first variable tested was the height of the floc blanket. In the model, the floc blanket was represented by a straight, vertical tube known as the "recirculator". Floc blanket height could be changed by varying the length of the recirculator. The Fall 2016 team tested recirculators of length

0.5m, 1.0m, and 1.5m. Preliminary tests confirmed the hypothesis that a taller floc blanket provides a longer residence time within the blanket, and therefore more time for collisions between small particles. After several collisions, the small flocs grew bigger and heavier flocs until they could settle out into the floc hopper, thereby reducing effluent turbidity. The data showed that a floc blanket height of approximately 1.5m produced the lowest effluent turbidity.

The second variable being tested was the length of the plate settlers, represented in the model by the angled tube known as the "tube settler". The length of the tube settler was changed by swapping out the tube settler for a longer or shorter tube. By changing the length but maintaining the diameter of the tube settler, the team was effectively testing the efficacy of faster or slower capture velocities, which is the necessary speed for a floc to travel from the top of of tube to the bottom along the total length of the tube. The team hypothesized that a longer tube settler (slower capture velocity) would produce a lower effluent turbidity, but that the effectiveness would eventually plateau with increasing length. In other words, the team was searching for the tube settler length of diminishing returns. Preliminary experiments indicated that a longer tube settler is much more effective at reducing effluent turbidity, as shown in figure 3. However due to time constraints, the relationship between tube settler length and effluent turbidity was unable to be explored further during the Fall 2016 semester.

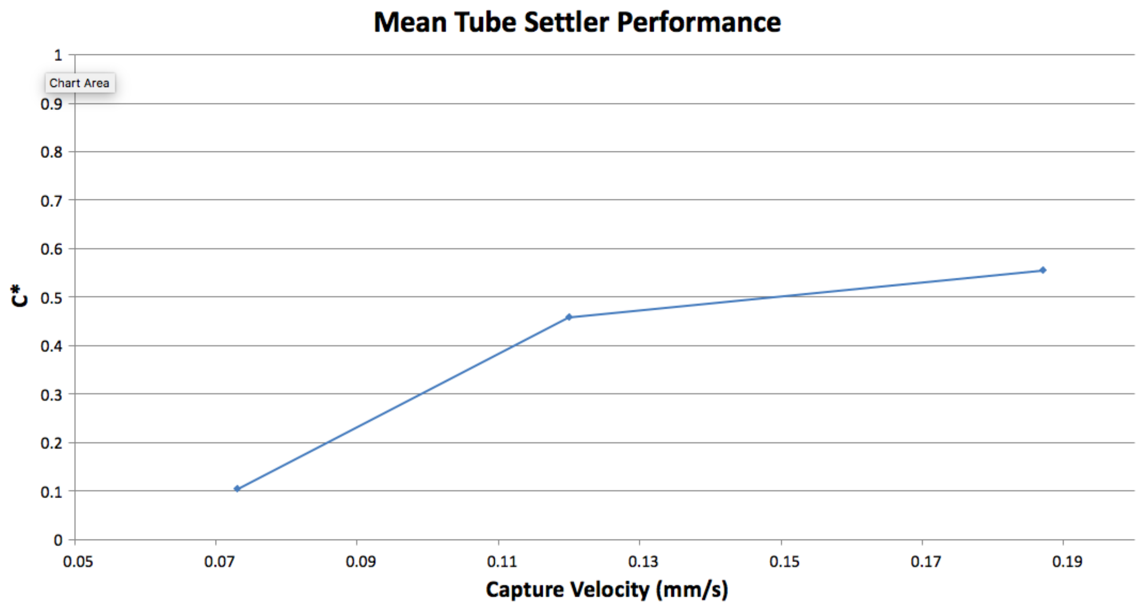

Figure 3: The mean relationship between capture velocity and performance observed over the course of three experiments. As tube settler design capture velocity increased, so did C*, the fraction of effluent turbidity over influent turbidity.

The work from last semester provided the current HRS team with some experimental results which inspired this semester's new experiments and designs. The Spring 2016 HRS team began by attempting to replicate the experiments from the previous semester, and ended up investigating interesting anomalies, phenomena, and new designs potentially related to the floc blanket performance.

1 Troubleshooting

As the team progressed through the semester, many problems with the model were discovered and addressed.

Pump Heads

As the team performed experiments, the effectiveness of the model decreased from experiment to experiment. The team weighed the coagulant reservoir during one experiment and discovered the reservoir was actually *gaining* weight over time, indicating that the size 13 tubing in the pump head was allowing water to backflow into the coagulant reservoir. This problem was solved by replacing the normal three roller pump head with a five roller head designed for smaller tubing (Yellow-Blue 3-stop). Since these tubes were much smaller, the pump RPM could be much higher, providing enough pressure to block backflow.

The team similarly swapped out the influent water pump head for a 3-stop tubing Purple-White to provide a more constant water flow into the system. However this did not noticeably change the operation of the apparatus, and near the end of the semester the 3-stop tubing started failing, and was replaced with size 18 tubing.

Turbidimeters

During many of the experiments, the effluent turbidity first reached a low effluent turbidity steady state and then increased slowly and linearly over several hours. In attempting to understand this phenomenon, the team took the vial out of the turbidimeter and discovered that because experiment run time was so long (on the order of days), a thin film of clay slowly built up on the glass walls of the effluent turbidimeter vial, giving the turbidity readings an upward skew over time. Once the vial had been washed and returned to the turbidimeter, the effluent turbidity readings would be slightly lower than before cleaning.

To fix this problem, the team used a system of valves to create bypasses to the influent and effluent lines of the turbidimeters so that they could be periodically cleaned. When the turbidimeters needed to be cleaned, influent water was sent through the bypasses. Once the turbidimeter vials were cleaned and replaced, the bypasses were closed and water was sent back through its normal paths through the turbidimeters.

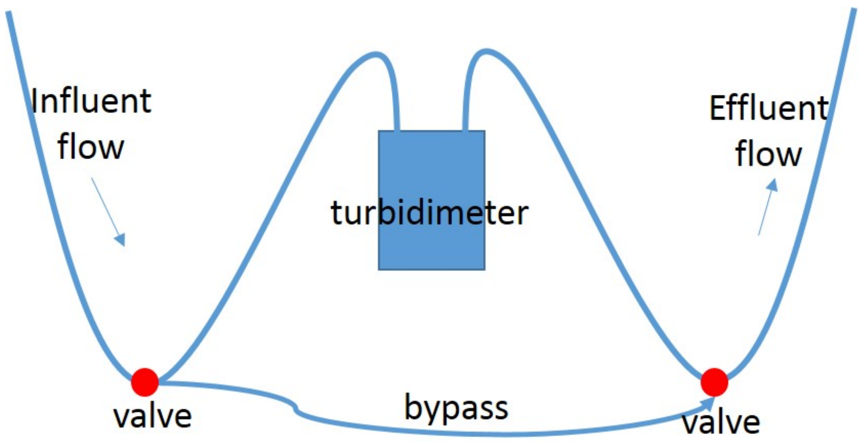

Figure 4: Adding bypasses to the system allowed the turbidimeters vials to be cleaned without disrupting flow through the system.

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2 Previous Experiment Verification

Methods

Due to time constraints, the Fall 2016 team did not have enough trials to prove their tentative result that a longer tube settler improved the sedimentation tank efficiency. Thus at the beginning of the semester, the Spring 2017 team decided to recreate the same experiments as the Fall semester, using a 1m recirculator and 1.35m(53in) tube settler constructed by the previous team. Effluent turbidity was used to quantify experimental results.

The initial experimental parameters, shown in Table 1, were consistent with the Fall 2016 team's experiments. PID control was used to maintain the influent turbidity.

Table 1: Initial Experiment Parameters

Parameter	Value
influent water flow rate	1 mL/s
coagulant dose	3.2 mg/L
coagulant reservoir concentration	55 mg/L
influent turbidity (clay)	100 NTU

Experimental Apparatus

In order to obtain comparable results, the Spring 2017 team used the same model used by the Fall 2016 team, shown in Figure 5. Clear PVC pipes, with inner diameter 3/4", were connected by compression fittings. The recirculator was 1m long, and the tube settler was 53in long. A valve at the end of the floc hopper allowed the hopper to be easily emptied. For more details on the fabrication of the model, please see *reference previous semester's report*

Figure 5: The model built by the Fall 2016 HRS team.

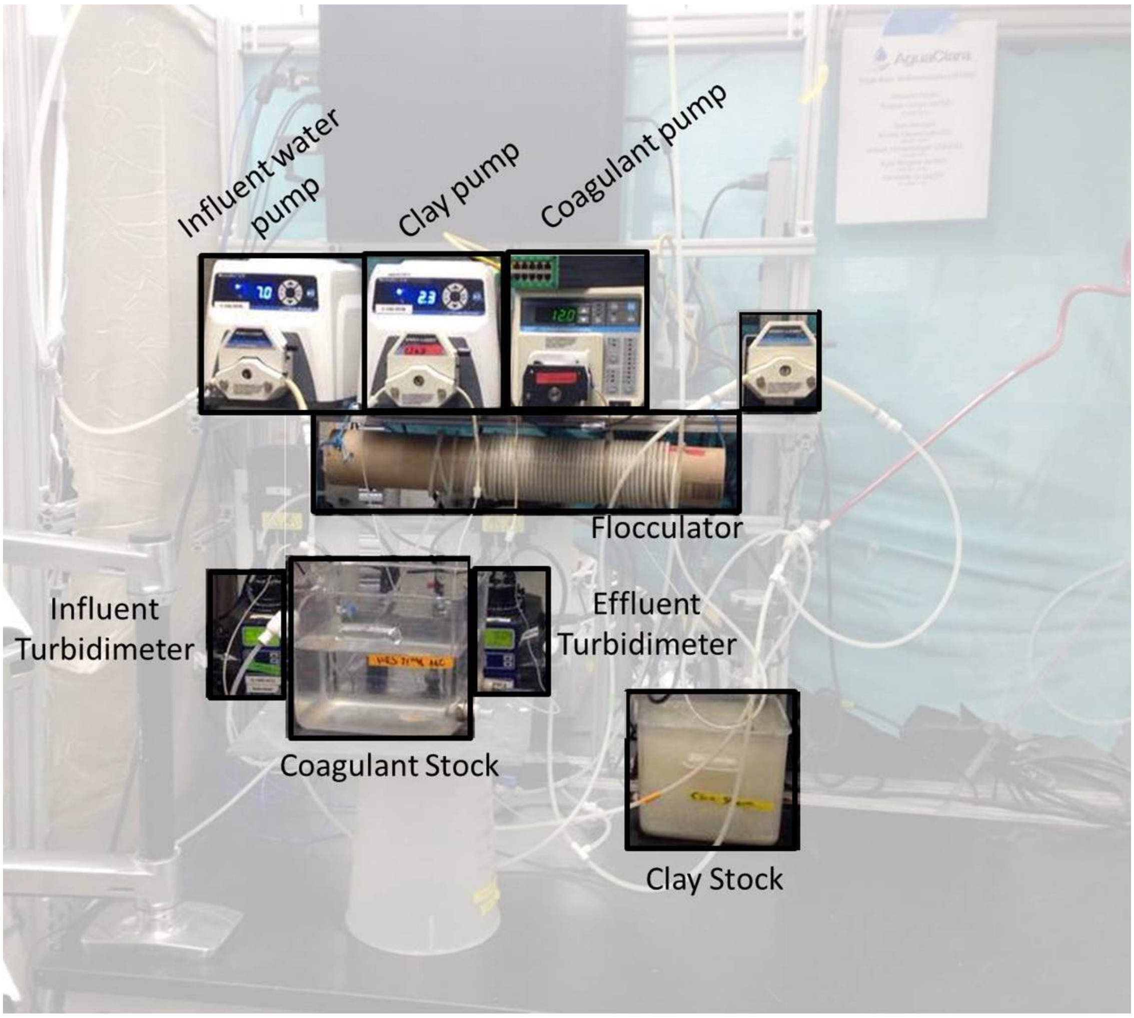

Figure 6: The lab bench set up used by the Spring 2017 team.

Results and Analysis

The result from the first verification experiment was the inspiration for the designs and experiments for the rest of the semester. Initially, the model performed unusually well, producing a steady state effluent turbidity of 0.5NTU. The Spring 2017 team decided to leave the experiment running all night, and in preparation cleared the floc hopper and refilled the coagulant reservoir. In order to make sure the coagulant reservoir would not run empty during the all-night run, the concentration of the reservoir was increased tenfold from 55mg/L to 550mg/L. The pump flow rate was adjusted accordingly.

However, almost immediately after the team left for the night, the effluent turbidity increased from 0.5NTU to 2.5NTU, as shown in Figure 7. This increase was due to failing coagulant pump tubing (see Troubleshooting section); decreasing the speed of the pump to match the increased concentration meant backflow was a much greater fraction of total flow, reducing the amount of coagulant dosed below what was intended.

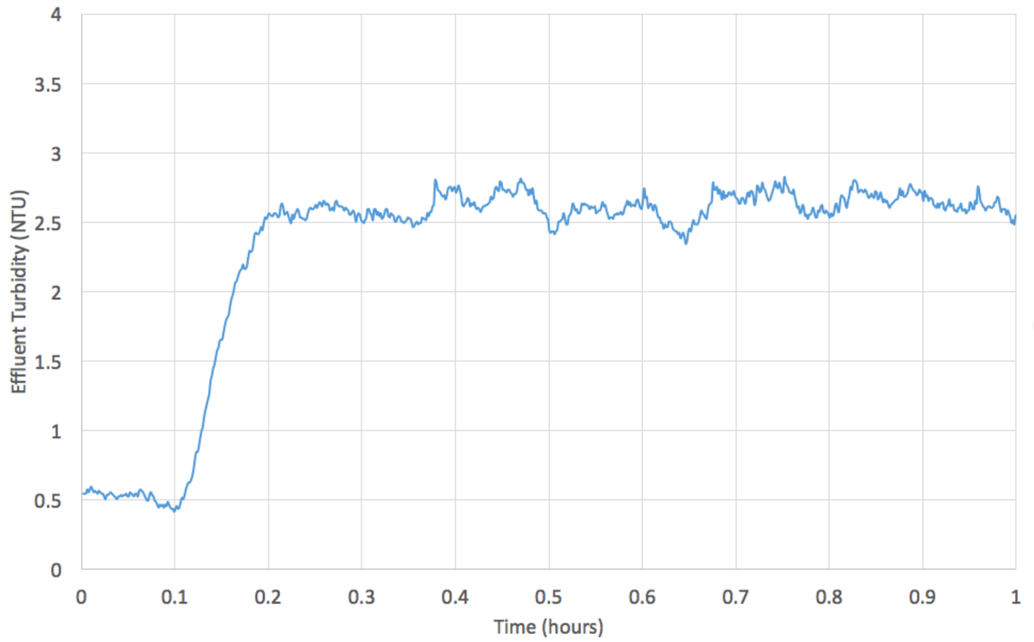

Figure 7: The first verification experiment. Effluent turbidity increased unexpectedly from 0.5NTU to 2.5NTU.

The team spent the next month attempting to recreate the 0.5NTU result of the first verification experiment and trying to understand why it had increased so quickly after a steady optimal result was obtained. Unfortunately, the team was unable to duplicate the results of the first verification experiment. The results of one of these attempts is shown in Figure 8. Failure to recreate was interpreted as the 1st verification experiment being an anomaly. There were various reasons which might cause this result. For example, clay accumulated at the bottom of turbidimeter's vial and had to be cleaned manually. Or the result could be related to the floc weir overfilled with clays, which interfere the floc blanket's continuous formation.

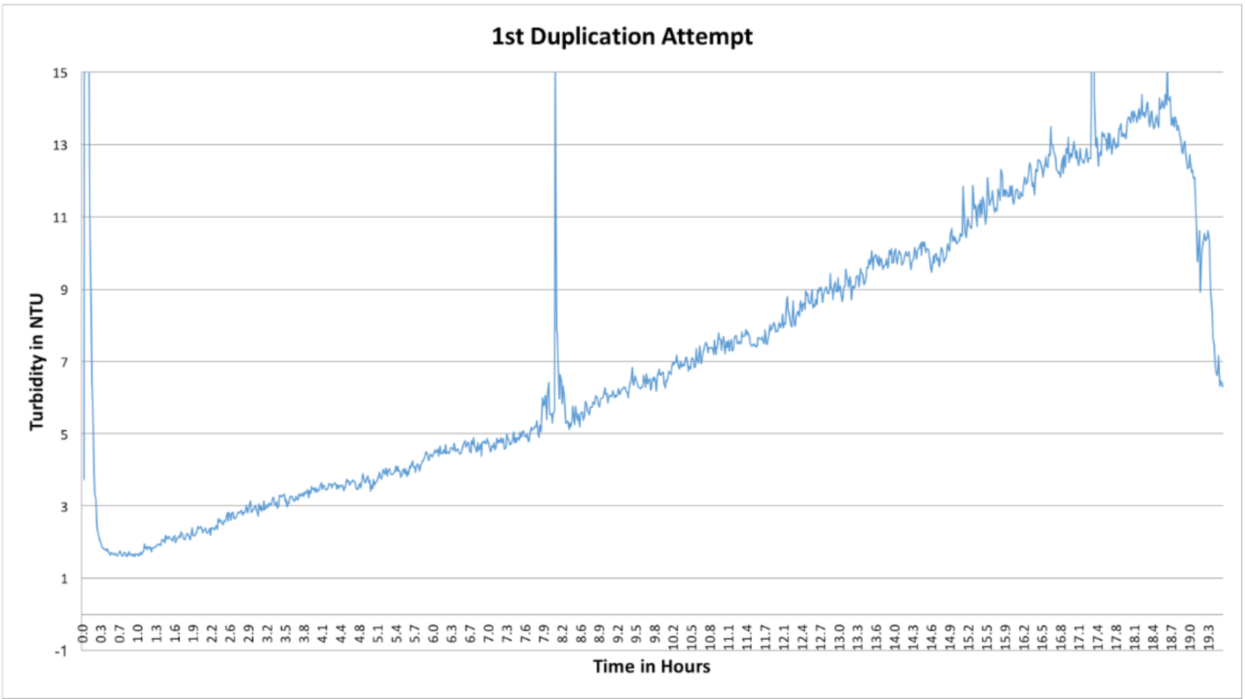

Figure 8: All of the attempts to duplicate this first verification experiment were unsuccessful. The results of one are shown above, with effluent turbidity starting at above 1NTU and increasing to nearly 15NTU.

During the first verification experiment, the team observed another phenomenon in addition to the steady state effluent turbidity of 0.5NTU. The team observed that a small floc blanket, dubbed the ”pinch puddle”, formed in the bend between the recirculator and tube settler, just above the floc hopper (Figure 9). The team decided to design some experiments to explore whether the optimal steady state result was related to the formation of the ”pinch puddle”.

3 Pinch Puddle: Trapezoidal Recirculator

As mentioned previously, the team observed that at an upflow rate of 3 mm/s, a small floc blanket, dubbed the ”pinch puddle”, formed in the bend between the recirculator and tube settler, just above the floc hopper (Figure 9). The state of the floc blanket in the recirculator varied with experiment. At times it consisted of medium-sized flocs and was was nearly as dense as the pinch puddle while at other times it was very dilute with only a few large flocs remaining in the recirculator.

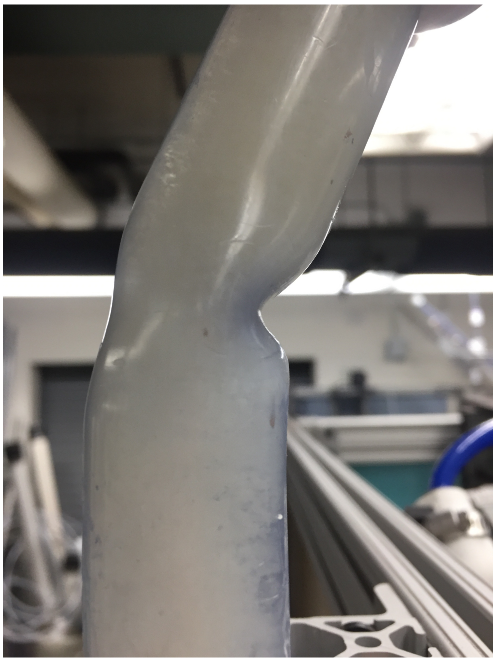

Figure 9: The pinch puddle formed in the bend.

The team hypothesized that the pinch puddle, which did not appear in experiments with an upflow velocity of 1mm/s, could be key to understanding their results. Thus, they were inspired to create a recirculator that was made entirely of bends, dubbing it the ”trapezoidal recirculator” (Figure 10). Each bend in this recirculator was designed to mimic the pinch puddle, developing similar flow patterns and floc blanket density.

Methods and Procedure

To allow for comparison between the trapezoidal recirculator results and first verification experiment results, experimental parameters were consistent with the first verification experiment parameters (see Table 1). Again, ProCoda was used to control the pump flow rates, and effluent turbidity was measured to test the efficiency of the apparatus. The trapezoidal recirculator took the place of the straight recirculator.

Experimental Apparatus

To fabricate the trapezoidal recirculator, a 110cm long PVC pipe (ID=3/4”) was split into lengths alternating between 10cm and 15cm. At each mark, the pipe was heated using the welder, and then bent at an angle of 60° to the horizontal. The length of 110cm was chosen to keep the trapezoidal recirculator length equal to that of the straight 1m recirculator.

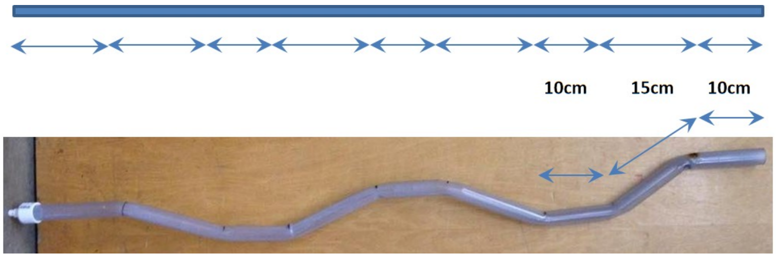

Figure 10: The trapezoidal recirculator started as a 110cm PVC pipe and was bent.

Results and Analysis

The trapezoidal recirculator resulted in a much lower steady state effluent turbidity compared to any of the previous designs. Figure 11 provides a clear comparison of the overall performance of the 1m straight recirculator and the trapezoidal recirculator. The effluent turbidity of the trapezoidal recirculator, represented by the red line, reached a steady state of around 0.5NTU. The best results obtained using the straight 1m recirculator (obtained in Fall 2016), represented by the green line, reached a steady state of about 1.5 NTU.

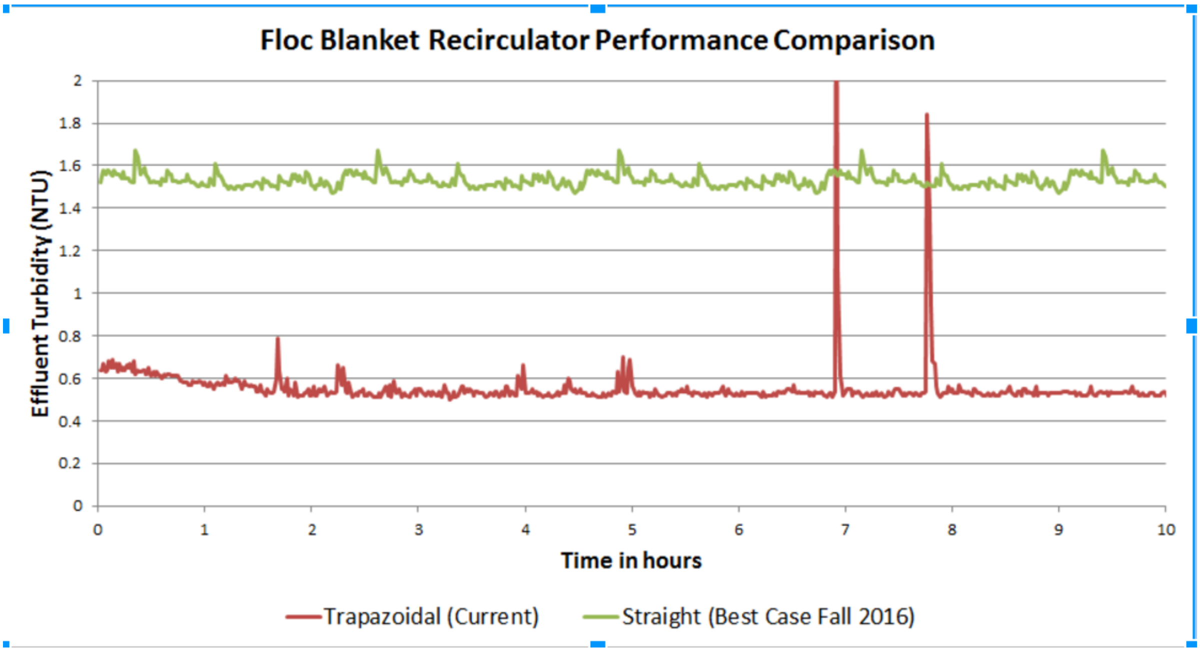

Figure 11: The trapezoidal recirculator produced effluent turbidity over three times lower than the straight 1m recirculator. The 2016 experiment only lasted about 2 hours, and has been extrapolated out for comparison to the trapezoidal results.

Comparing these two experiments, we see that the trapezoidal recirculator produced smaller effluent turbidities than the straight recirculator by a factor of three. Although the team currently cannot explain why the trapezoidal recirculator performs better than the straight recirculator, the result motivated the team experiment with a new recirculator design, dubbed the ”zigzag” recirculator.

4 Zigzag Recirculator

Another recirculator geometric design similar to the trapezoidal was constructed. Different from the trapezoidal recirculator, the zigzag recirculator did not have the vertical part between each bent so that through experiments, the team could determine if the vertical parts in the trapezoidal recirculator play important roles in lowering the effluent turbidity.

Methods and Procedures

To explore how would coagulant concentration in the reactor influence the effluent turbidity, the coagulant solution was diluted in the reservoir. The experiment parameters were shown in the Table 2. To compare, the same experiment was also run for the pre-built trapezoidal recirculator with the same experimental parameters. ProCoda was used to control the clay pump.

Table 2: Zigzag Experiment Parameters

Parameter	Value
influent water flow rate	1 mL/s
coagulant dose	0.5 mg/L
coagulant reservoir concentration	13.8 mg/L
clay influent turbidity	100 NTU
waste pump flow rate	0.038 mL/s

Experimental Apparatus

A 110cm long PVC pipe(ID=3/4") was marked every 15 cm from the top from the bottom excluding the top 10cm and bottom 10cm (to keep the top/bottom 10cm parts vertical), and bent by heat at the mark. The angle between adjacent bending parts was 120 degrees.

Figure 12: The zigzag recirculator produced lower effluent turbidity than the straight recirculator, but higher effluent turbidity than the trapezoidal recirculator.

Results and Analysis

Compared with using the trapezoidal recirculator , the effluent turbidity of zigzag recirculator was higher in the steady state, indicating that the zigzag recirculator gave a poorer result than the trapezoidal recirculator. This result also demonstrated that the vertical part between the bent parts for the trapezoidal recirculator were important for the apparatus's performance.The experiment result of zigzag recirculator was presented in Figure 13.

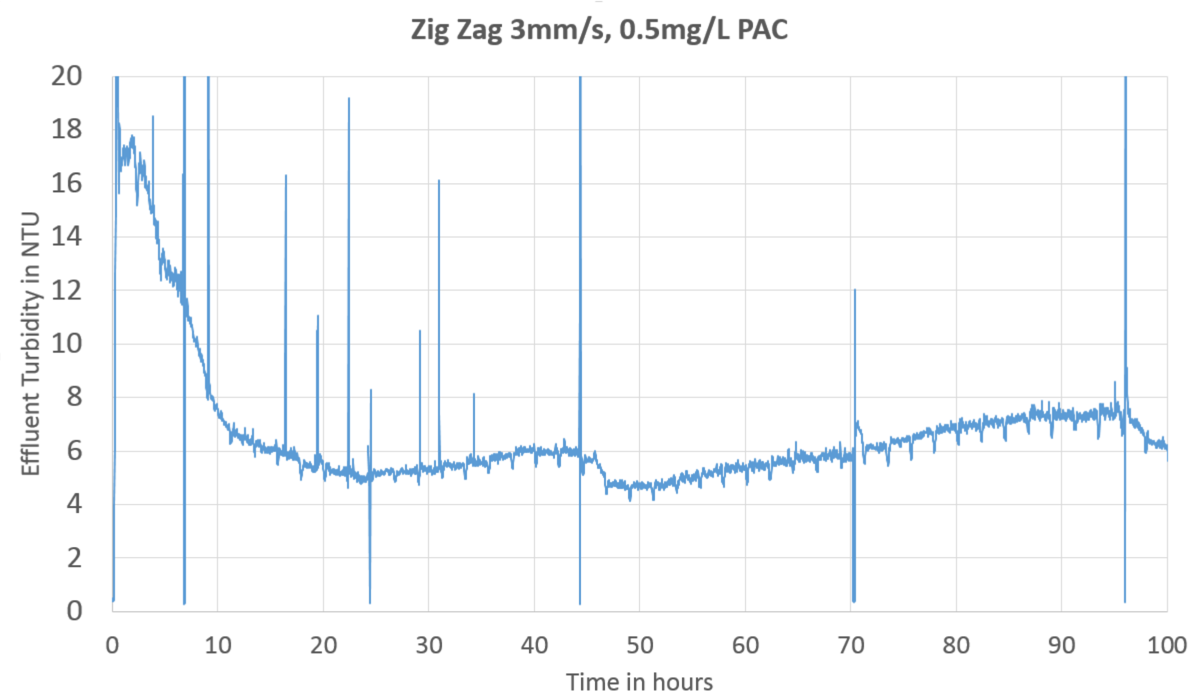

Figure 13: The effluent turbidity change as the experiment proceeded

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The experiment result of the trapezoidal recirculator at the same conditions was presented in Figure 14

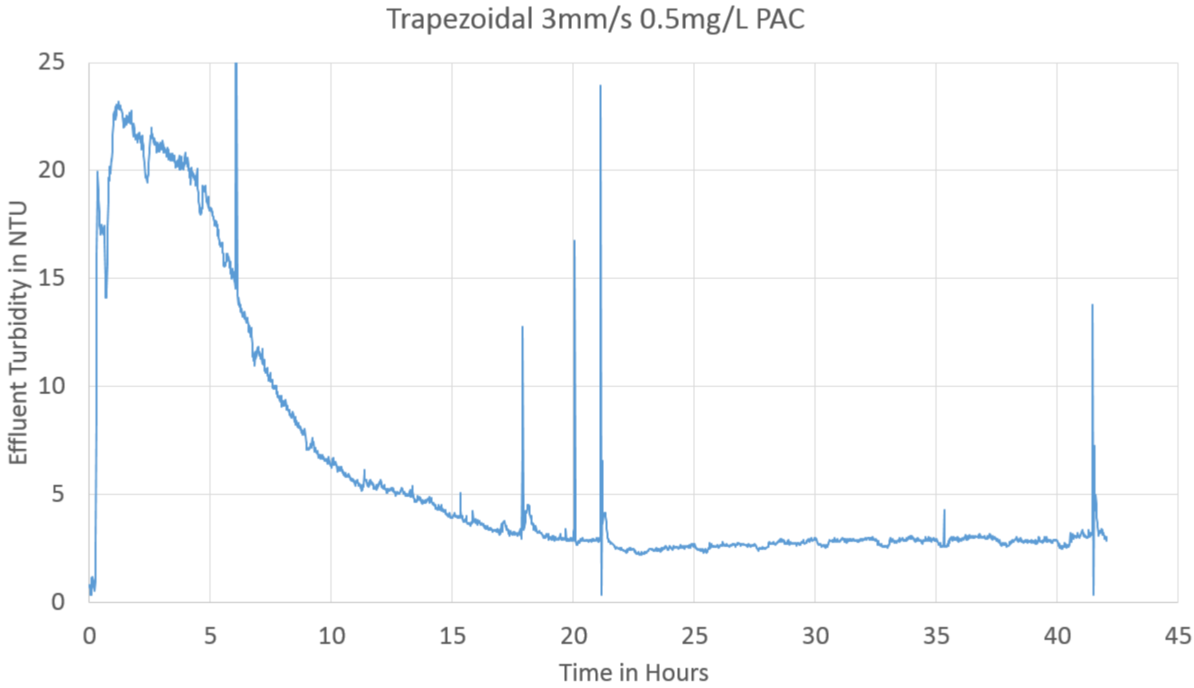

Figure 14: The effluent turbidity changed as the experiment proceeded

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5 Pinch Puddle: Bend v. Dimple

In order to better understand the pinch puddle phenomenon and the success of the trapezoidal recirculator, the team decided to replicate the model used by the Fall 2016 team, but with a slight difference. In the model constructed by the Fall 2016 team, the bend between the recirculator and the tube settler had a small dimple, while the model for this experiment had a smooth bend. Up to this point, the dimple bend had been used in all experiments. A comparison of the models was shown in Figures 15 and 16.

Figure 15: The model with a smooth bend.

Figure 16: The model with a dimpled bend.

Methods

Table 3 shows the experimental parameters.

Table 3: Smooth Bend Experiment Parameters

Parameter	Value
influent water flow rate	1 mL/s
coagulant flow rate	2 mg/L
coagulant reservoir concentration	55 mg/L
clay influent turbidity	100 NTU
waste pump flow rate	3.8 mL/s

Again, ProCoda was used to control the pump flow rates, effluent turbidity was measured to test the effectiveness of the apparatus. The data was smoothed by taking the median of the 30 data points centered around the time in question, as shown by the orange line.

Experimental Apparatus

For easy comparison to many of the other experiments and model designs, this version of the model used a straight 1m recirculator and a 53in tube settler.

To fabricate the smooth bend (instead of a dimpled bend), the PVC was filled with sand, and then bent to a 120 degree angle after heating using the welder. After the PVC cooled, the sand was removed. The floc weir, a PVC pipe with an ID of 1/2", was welded on. The waste was pumped out periodically to avoid the accumulation of flocs in the weir.

Results and Analysis

The effluent turbidity produced by the smooth bend model was shown in Figure 17, where the orange line represents the smoothed data. This model performed similarly to the dimple model (see Figure 8, indicating that the effect of the dimple was negligible and the bend itself played a much more important role.

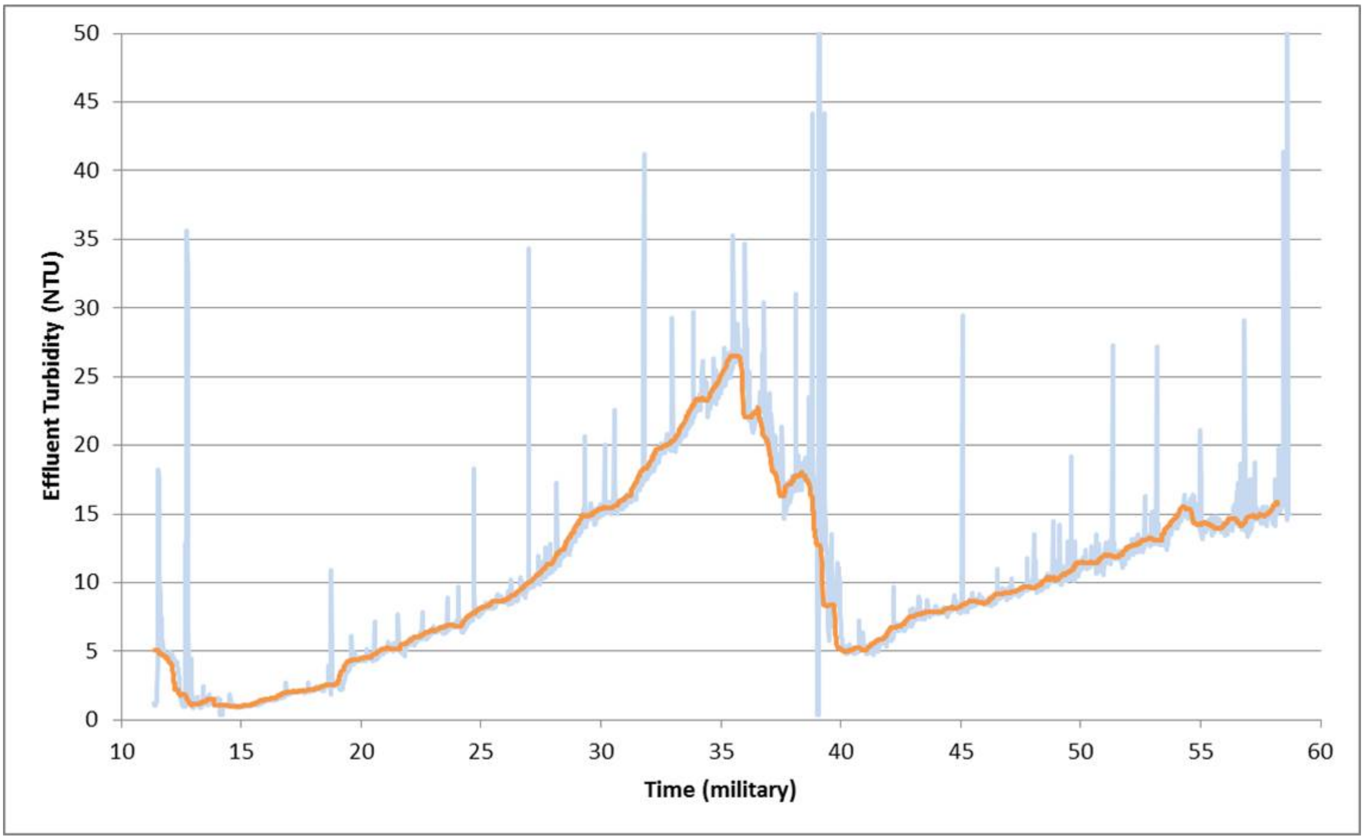

Figure 17: Effluent turbidity from smooth bend model at an upflow velocity of 3 mm/s.

6 Slanted Recirculator

In AguaClara plants, plate settlers help to significantly improve sedimentation tank performance. The team decided to explore the idea that a slanted recirculator and a slanted tube settler could improve performance. Instead of having a separate recirculator and tube settler, this model was simply a PVC tube tilted at a 60 degree angle to the horizontal.

Methods

For comparison to other experiments, the experimental conditions were kept consistent with previous experiments and shown in the Table4

Table 4: Smooth Bend Experiment Parameters

Parameter	Value
influent water flow rate	1 mL/s
coagulant flow rate	2 mg/L
coagulant reservoir concentration	55 mg/L
clay influent turbidity	100 NTU
waste pump flow rate	3.8 mL/s

Experimental Apparatus

The model was built using a single 8ft PVC pipe (ID=1/2"). At 15" from the top end, the pipe was cut using the Sawzawl. A wye fitting was glued into place to connect the two pieces, and additionally served as the floc weir. The PVC pipe was tapped and a 1/4" push-to-connect was placed on each end to allow for connection to the flocculator and the effluent tube.

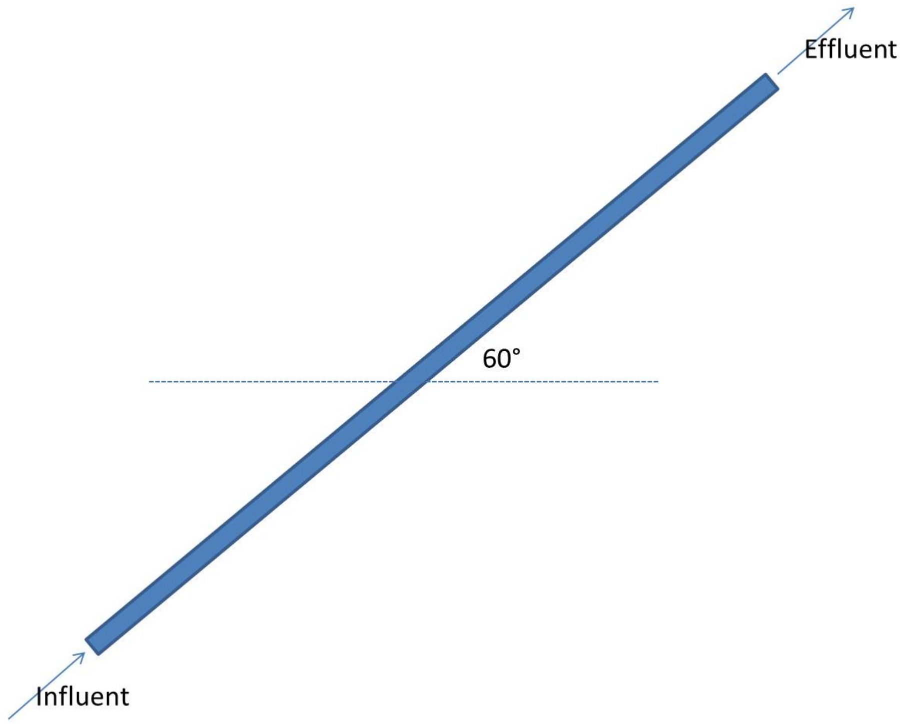

Figure 18: A simple representation of the slanted recirculator.

Results and Analysis

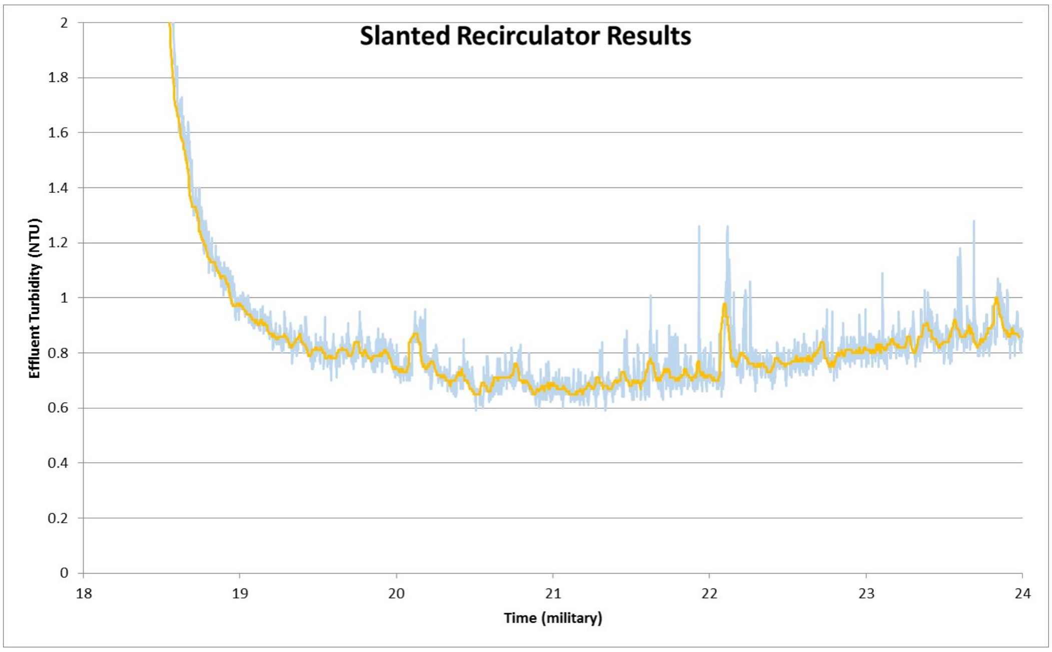

Figure 19: The effluent turbidity change as the experiment proceeded. The orange line represents the smoothed data.

As with most of the team's experiments at 3mm/s, the effluent turbidity started high and dropped quickly as the floc blanket reached equilibrium. However after the brief steady state, effluent turbidity began to increase from 0.7NTU to nearly 1NTU over the course of several hours. This result motivated the team to explore the reason behind increasing turbidity after steady state. The team hypothesized that older, larger flocs are less effective than young, small flocs. The next set of experiments describes the team's attempt to prove or disprove this hypothesis.

7 Floc Age Hypothesis: Parallel Settlers

The results of the slanted recirculator experiment led the team to test the "floc age hypothesis". When flocs enter the sedimentation tank, they are small (only a few conglomerated particles). During sedimentation, the small flocs stick together and become large, old flocs. It was hypothesized that these large old flocs were less effective than the small young flocs; the difference in rotational velocity between large old flocs (high rotational velocity) and small young flocs (low rotational velocity) makes it difficult for small and large flocs to connect. Along this line of logic, it follows that large flocs are less effective at decreasing effluent turbidity. The floc age hypothesis speculated that as the floc blanket reached steady state, it filled up with large old flocs. After steady state was reached and the floc blanket was majority old flocs, the incoming small flocs were unable to grow larger, and simply left the system with the effluent.

To test the hypothesis that larger, older flocs were less effective at particle removal than smaller, newer flocs, an apparatus was constructed to selectively waste small flocs and observe if performance was adversely affected. Two parallel tube settlers were constructed on a single recirculator, with the top tube settler the same as the ordinary tube settler and the bottom one attached with another floc weir to prevent small flocs sliding down and rejoining the floc blanket (Figure 20 This design provided a more straightforward comparison between the performances of these two types of tube settlers. To simplify the construction, the team scaled down the size of the model.

Methods

The experimental conditions were set the same as Table4. Because much more is understood about the sedimentation process at 1mm/s, this experiment was also run at 1mm/s.

Experimental Apparatus

A 0.5m PVC pipe (ID=3/4") was used for the straight recirculator and two 15in PVC pipes(ID=3/4") were used as tube settlers. The recirculator and two tube settlers were connected by a wye fitting, which was glued to inserted pipes. A floc weir was attached to the bottom tube settler.

For several of the later experiments, a small hole was drilled into the recirculator just above the influent water entrance. In order to pull water and flocs from the bottom of the recirculator, a push-to-connect and relevant tubing were placed in the hole and connected to a 1RPM pump. The push-to-connect can be seen in Figure 20. In this figure, the tubing had not yet been connected so there is a small plug in the push-to-connect.

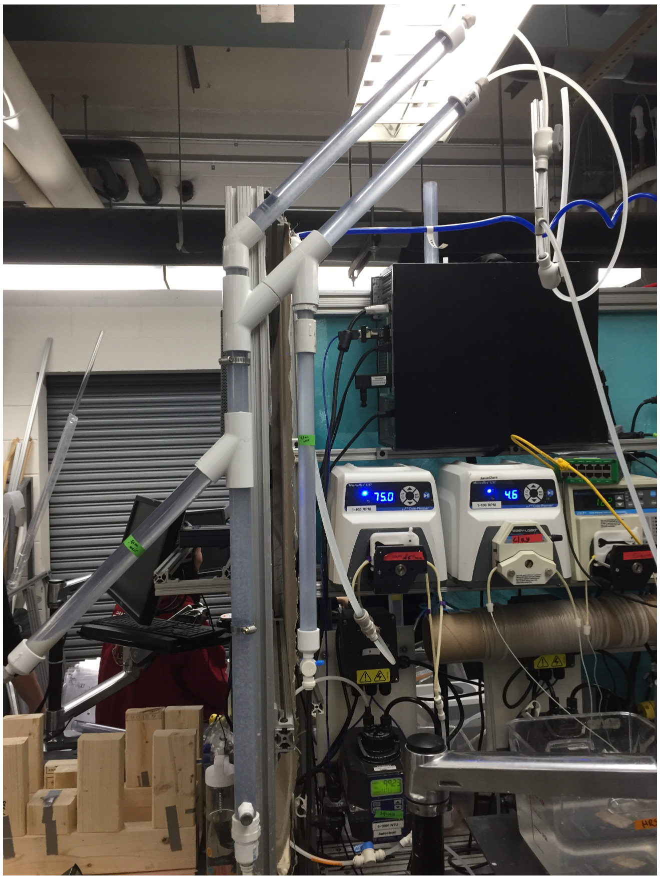

Figure 20: The parallel tube settler apparatus.

Results and Analysis

For the first experiment, a floc blanket was formed with a tube settler that returned small flocs to the floc blanket. After the floc blanket had formed and performance was steady, the tube settlers were switched so that no small flocs were returned to the floc blanket. Performance was unaffected by the change (Figure 21).

For the next two experiments (Figure 22), floc blankets were created with the small floc return (blue line) and without the small floc return (orange line) from the tube settler. Steady state performance was identical for the two systems.

The results of the first three experiments indicated that the return of small flocs from the tube settlers is thus not responsible for the efficient removal of residual particles by floc blankets.

Next, the team tested if removing large flocs from the bottom of the floc blanket (presumably where the majority of large flocs would be) would decrease effluent turbidity. The hypothesis was that removing large flocs would make more room for small flocs to be in the floc blanket. Again, the results of this experiment showed no significant drop in effluent turbidity, indicating that the removal of large flocs from the floc blanket is not responsible for the efficient removal of residual particles by floc blankets.

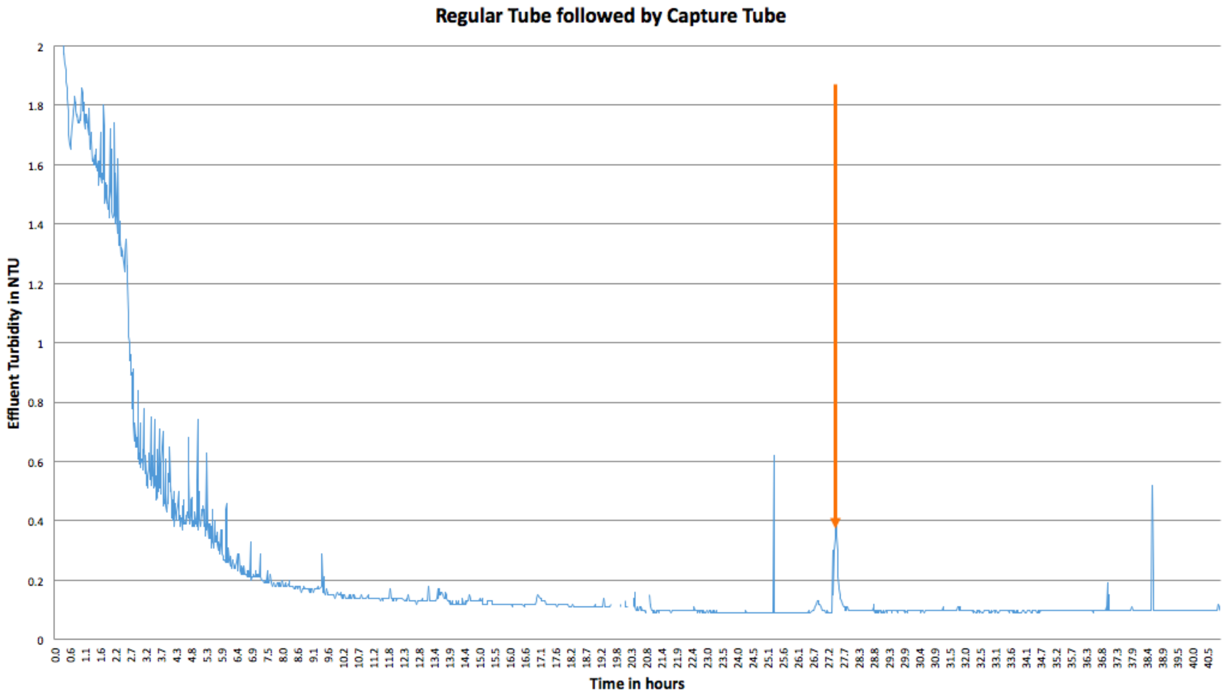

Figure 21: Performance unaffected by selective removal of small flocs.

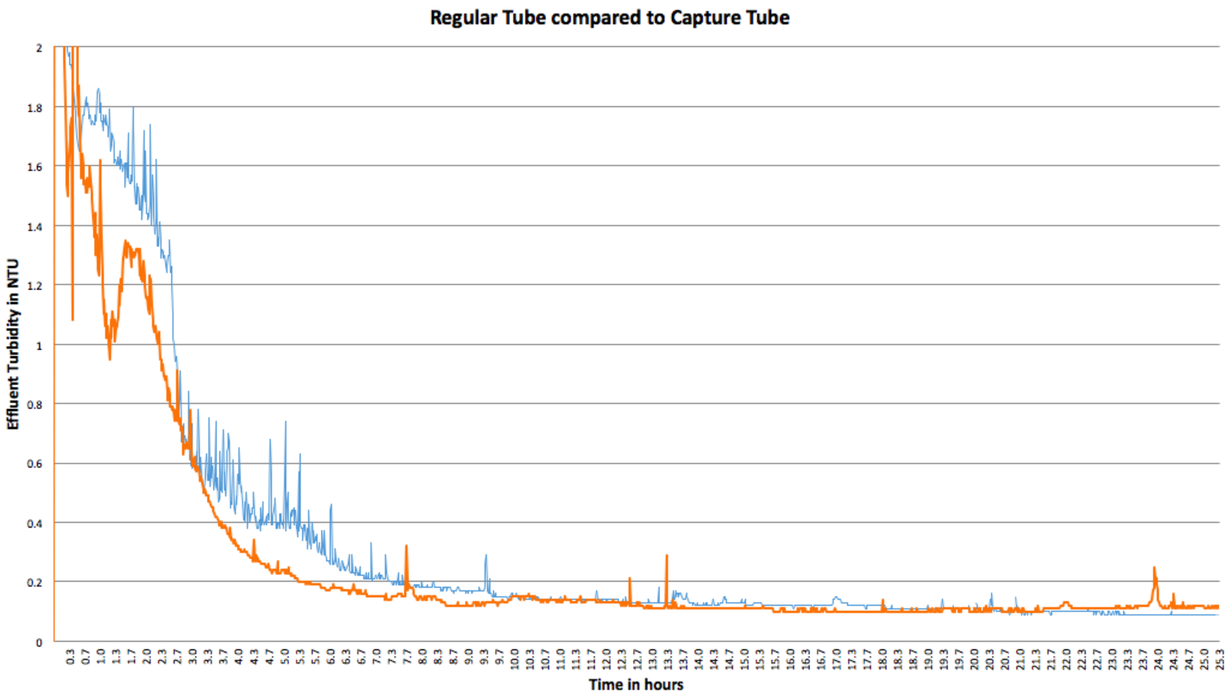

Figure 22: Floc blanket steady state unaffected by selective removal of small flocs.

Conclusions

This semester, the team used a small-scale lab version of the sedimentation tank to explore the effectiveness of various geometric recirculator designs at an upflow velocity of 3mm/s. The two main designs, the trapezoidal and zigzag recirculators, were proven to be more efficient than an equally long simple vertical recirculator, and the trapezoidal recirculator had even better experimental performance than the zigzag recirculator, as evidenced by the lower effluent turbidity. These new recirculator geometries prevented the steady increase in turbidity that plagued the straight recirculators at a high upflow velocity.

Additionally, the team found that there was virtually no difference in performance when using a dimple bend versus a smooth bend at the connection between the recirculator and tube settler.

The team also explored the old floc hypothesis and discovered that selectively removing small flocs from the floc blanket did not affect the efficient turbidity.

Future Work

The outperformance of the trapezoidal recirculator as compared to a typical sedimentation tank design was significant. These results provide hope that this type of modification will allow a high rate sedimentation tank to produce the same quality of water as a typical sedimentation tank, saving time, space, and money, and allowing more communities to access AguaClara technology. As such, more recirculator designs and modifications should be explored in order to maximize high rate sedimentation performance.

As the floc age hypothesis was proved to be incorrect, more investigation into the formation of floc blankets will be essential.

References

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

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Semester Schedule

Task Map

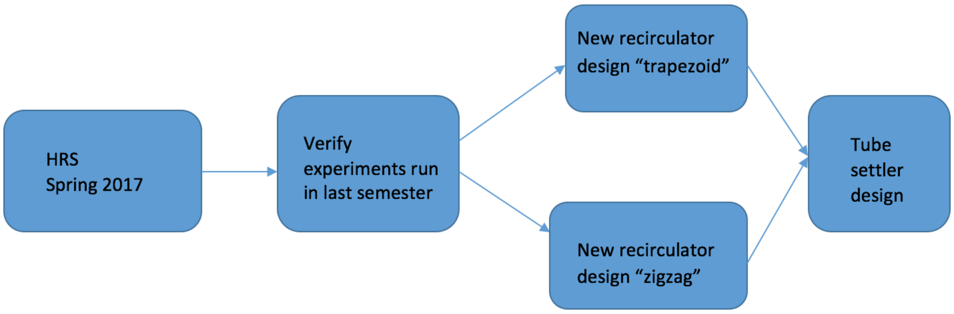

Figure 23: Task Map

Task List

You should keep and update your detailed task list from the first assignment in each of your reports. Denote completed tasks and modify your deadlines to reflect your most recently completed progress and any delays.

1 ✓Previous experiment verification(Week 3 Feb.6-Feb.10): Run experiments with models built last semester (1m recirculator, 53in tube settler) to obtain repetitive result.

2 ✓Duplicate the first verification experiment(Week4 Feb.13-Feb.17): Try to duplicate earlier 0.5NTU experiment with straight reactor and 3.2mg/L PAC (5.8RPM)

3✓Troubleshoot system and coagulant dosage(Week5 Feb. 22-Feb.24): Solve problems encountered in the failing experiments and update ProCoda codes.Continue to duplicate the first verification experiment.

4 ✓Trapezoidal recirculator design(Week6 Feb. 27-Mar 3): Determine the dimensions of the trapezoidal recirculator and start the construction.

5 ✓New recirculator experiment(Week7 Mar.6-Mar.10): start running new experiments using the trapezoidal recirculator at 100NTU, 3.2mg for cogulant dosage and collect results.

6 ✓Experimental result analysis(Week8 Mar.13-Mar.17) : compare the result from the trapezoidal recirculator with the regular straight recirculator and discuss further modification for the apparatus.

7 ✓Monroe's old flocs hypothesis and Symposium preparation(Week9 Mar.20-Mar.24): Design two-parallel-tube-settler apparatus to prove Monroe's old floc hypothesis and prepare for the symposium

8 ✓Run experiments to about old flocs hypothesis(Week10 Mar.27-Mar.31): Run experiments using the fabricated two-parallel-tube-settler apparatus to test Monroe's hypothesis. Analyze the collected results to determine if further exploration is necessary.

9 ✓Old floc test(Week 12 Apr 10-Apr 14):Discuss the results with Monroe and change to hight influent turbidity.

10 ✓Old floc test(Week 13 Apr 7-Apr 21): Compare the results from previous tow weeks and decide to continue exploration.

11✓Old floc test part2 (Week 14 Apr 24- Apr 28): drain the old flocs at the bottom of the recirculator out periodically and analyze the experimental results.

12 ✓Design application(Week 15 May 1 - May 5): summarize the ideas/results collected in this semester and brainstorm how to apply these ideas to real AguaClara plant.

13 ✓Final report and presentation(Week 16 May 8 - May 12):Work on the final report and presentation.

Report Proofreader: Aimee Owens, Vanessa Qi

Manual

Experimental Methods

1. Calculate experimental conditions needed. Set up ProCoda variables.
2. Prepare necessary stock solutions.
3. Set up experiment. Make sure to check that the turbidimeter vials are clean. Open ProCoda to record and save data to Google drive so everyone in the team could access.
4. Data analysis after the experiment

Cleaning Procedure

(a) Clean the turbidimeter vials using brushes and the flocculator using a little sponge.
(b) Clean the all apparatus by running through regular water.

Experimental Checklist

Check every tubing is connected well with the apparatus. The pump should be set up appropriately and ProCoda should be ready to control any pump or collect data. There should be enough stock solution for the planned experimental time. Before starting the ProCoda control, the reading of effluent turbidimeter should be close to tap water's turbidity.