Tube Flocculator Team Research Report

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Part I

Introduction

According to the predictive flocculation model proposed by Swetland et. al., 2012, large flocs do not significantly contribute to turbidity removal – only small colloids can collide effectively and aggregate to a size that will be removed by sedimentation. It is assumed that large flocs reach an equilibrium point after which they will no longer grow in size. Based on the hypothesis that "large flocs are useless", a floc breakup procedure was devised. Results obtained using a coiled tube flocculator and flocculation residual turbidity analyzer (FReTA) shows that higher turbidity removal was achieved after breaking the flocs, as compared to results using the same method but without floc breakup. Therefore breaking flocs at intervals to maintain continuous growth will promote better performance of flocculation. However, the optimal number of floc breakup devices, as well as constriction intensity (size), still needs to be determined so that large flocs which are "useless" can be fragmented while small colloids are allowed to grow.

Previous experiments have shown a decrease in residual turbidity under the control condition of no added coagulant. The measurement of the influent and effluent turbidimeters were at least 10 NTU apart with the same water flowing through the two turbidimeters. This implies that there may be some malfunctioning of the turbidimeters. It is also possible that clay is becoming attached to the apparatus due to attraction between the particles and the tube walls. In order to counteract this behavior, the tubing has been replaced by hydrophobic silicone tubing.

1 Apparatus

The complete experimental assembly consists of synthetic raw water (SRW) and coagulant metering system, rapid mix and tube flocculator, and flocculation residual turbidity analyzer (FReTA). The new apparatus arrangement is shown in 1.

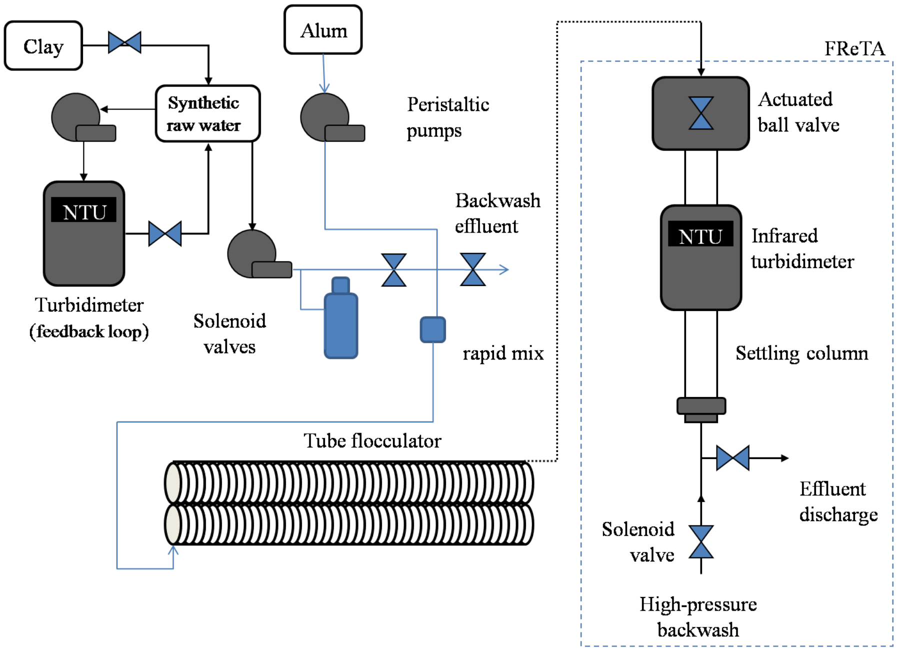


Figure 1: Schematic of complete experimental assembly (Updated from Ian Tse's master thesis, Aug. 2009)

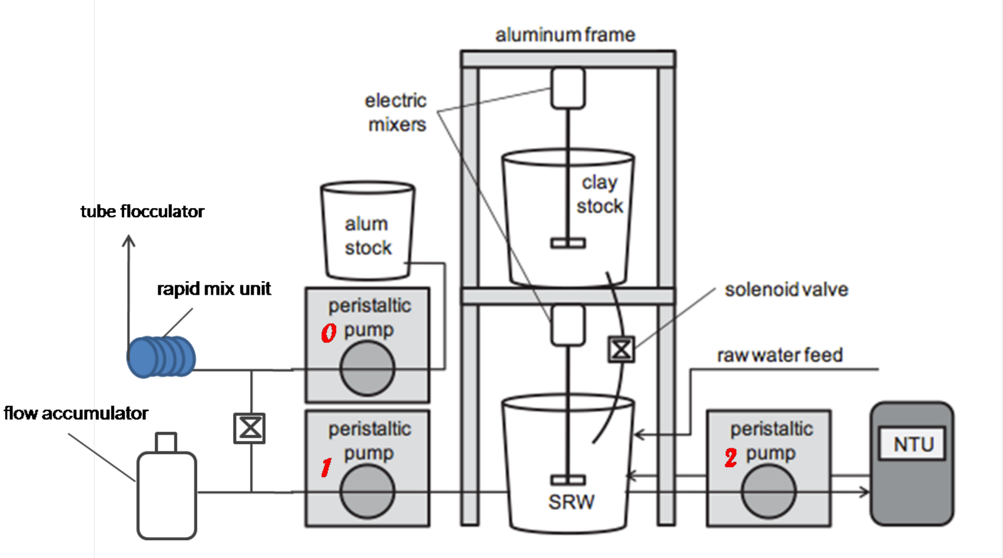


Figure 2: Synthetic Raw Water (SRW) and coagulant metering system. (Updated from Ian Tse's master thesis, Aug. 2009)

The turbidimeter with a feedback loop is used to measure the influent turbidity and the turbidimeter of FReTA measures the effluent turbidity.

The SRW and coagulant metering system includes a reservoir of clay suspension (10 g/L), a reservoir of tap water and three pumps (2). The clay suspension is added to the tap water periodically by the regulation of a solenoid pinch valve. Both alum stock and raw water (with added clay suspension) are drawn by the pumps to mix together. A portion of raw water is pumped into a turbidimeter for the measurement of influent turbidity and then flows back into the raw water feedstock to maintain a constant volume. A flow accumulator connected to the pump dampens the periodic pulses caused by the pump rollers.

After the flow of the raw water and alum is merged, they enter into a spiral "rapid mix coil " to accelerate their blending. The mixture then flows through the laminar tubular flocculator. The tube flocculator is comprised of three spiral tubing units (3/8") wrapped in a figure eight to six parallel support cylinders (two cylinders per unit, see 3). The tubes are arranged in a helical coil because the flocs would stay at the bottom in a straight tubing system, restricting the growth of the flocs. A calibrated pH probe is inserted in to the beginning of the flocculator tube and provides a readout of the mixed suspensions hydrogen ion activity. A pressure sensor is also connected to the tubing to protect the system. Energy dissipation in the tube cause particles to collide and form flocs. For coiled tube flocculators, energy dissipation rate is a function of the flow rate and the inner diameter of the tube. [2]

$$\varepsilon = \frac{64\nu Q_{plant}^2}{9\pi^2 r^6}$$

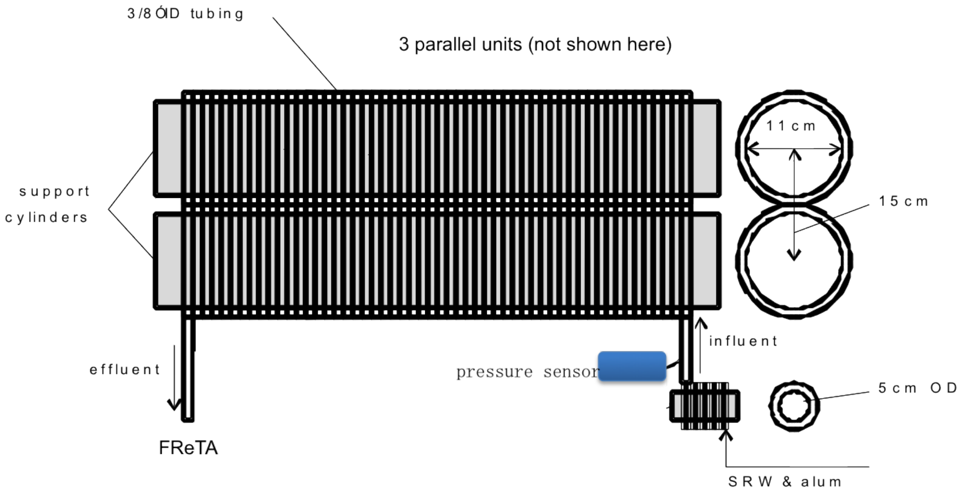


Figure 3: Tube flocculator. (Updated from Ian Tse's master thesis, Aug. 2009)

$\varepsilon = Energy$ dissipation rate
$Q_{plant} = volumetric$ flow rate in the flocculator
$r = Inner$ radius of the flocculator

FReTA is an apparatus for measuring the sedimentation velocity and the effluent residual turbidity from the flocculator (4). There are basically three components of FReTA: an inline turbidimeter, a settling column, and an computer-actuated ball valve. The plastic housing of the HF Scientific MicroTOL 2 IR inline nephelometric turbidimeter was changed in our apparatus to allow a glass column to fit through the entire housing and through the measurement area. Before use, FReTA is carefully calibrated using a HF Scientific, Inc. Primetime Calibration Standards kit.

The glass settling column served as a chamber for floc settling without affecting the structure of flocs. Before measurement of floc settling velocity, it is important to minimize the movement of fluid inside the column. This is accomplished by ramping the flow to a stop and closing the valve at the top of the tube.

The function of the electrically actuated ball valve (Gemini Valve model 630) was to prevent flocs in the tube flocculator from falling into the settling column once the measurements begin and to hydraulically isolate the water in the tube. The distance between the bottom of the ball valve and the center of the LED zone of the turbidimeter is used to calculate floc settling velocities. The equation for sedimentation velocity of flocs is given below. [1]

$Vs = \frac{Z}{t}$

Vs = sedimentation velocity

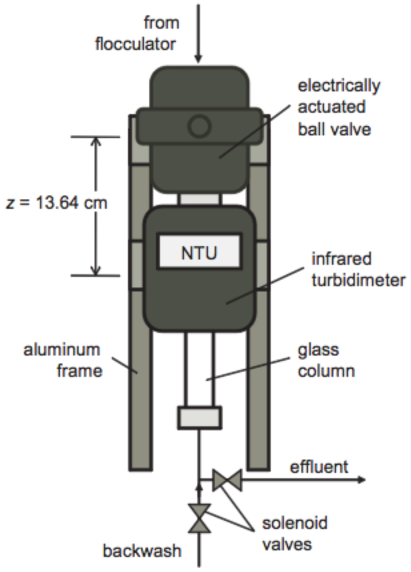


Figure 4: FReTA. (From Karen Swetland's dissertation, Aug. 2012)

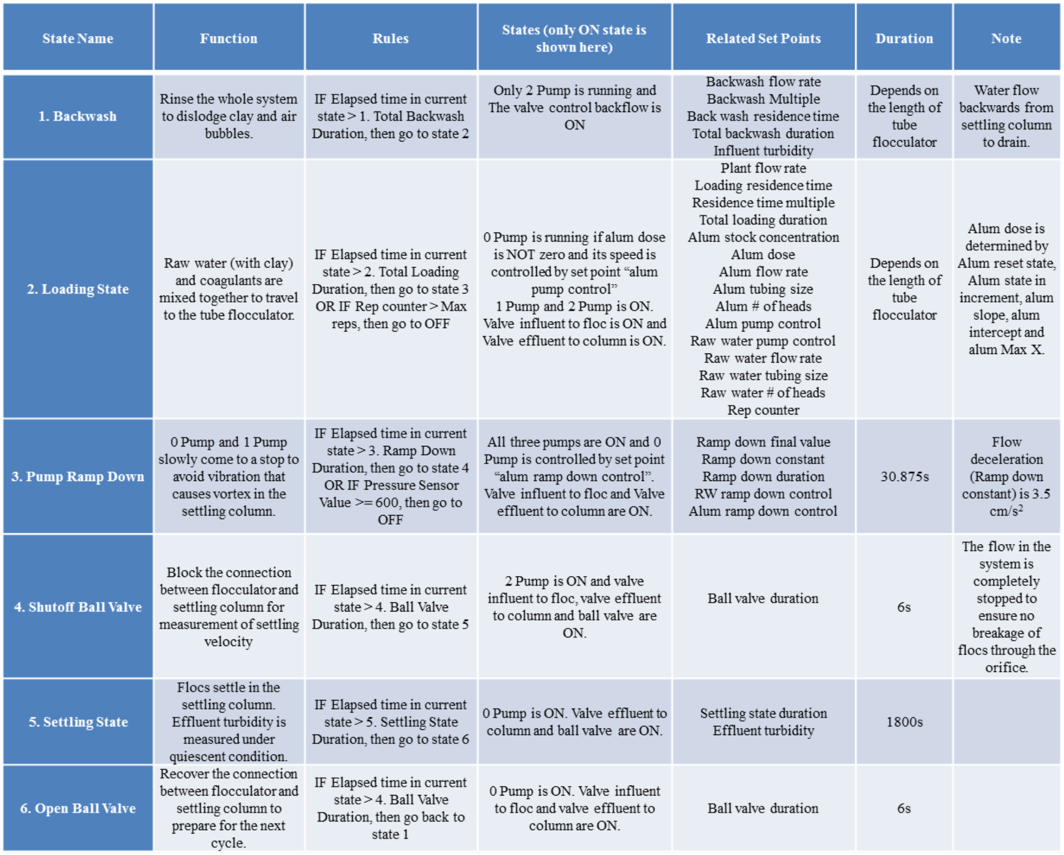
Z = distance between the bottom of the ball valve and the center of the LED zone of the turbidimeter
t = settling time

2 Process Controller

Experiments were conducted by the apparatus described above. The apparatus assembly is managed by Process Controller, a software program written in LabVIEW to automatically control the whole experiment. There are six operational states regulated by Process Controller to run the experiment. Each of these states consists of a different set of inputs, rules and set points. The description of each state is provided in Table 1. This table provides a reference for operators to check if the rules and states are set correctly and what set points to search when they meet problems. At "automatic operation" mode, the experiment proceeds continuously from the first stage to the last state and then jumps back to the first state for the next cycle. The number of cycles is set by the operator at the set point " Max reps".

According to the rules for the settling state, when the number of reps is bigger than the Max reps, then the experiment will stop. The collected data is recorded and processed on a spreadsheet in a Mathcad program called Data Processor (N://files.Cornell.edu/EN/aguaclara/RESEARCH/Tube Floc/Spring 2013/Data processor/Data Processor 10-25-12.xmcd). All the data are saved under this di-

Table 1: Process Controller Operational States



State Name	Function	Rules	States (only ON state is shown here)	Related Set Points	Duration	Note
1. Backwash	Rinse the whole system to dislodge clay and air bubbles.	IF Elapsed time in current state > 1. Total Backwash Duration, then go to state 2	Only 2 Pump is running and The valve control backflow is ON	Backwash flow rate Backwash Multiple Back wash residence time Total backwash duration Influent turbidity	Depends on the length of tube flocculator	Water flow backwards from settling column to drain.
2. Loading State	Raw water (with clay) and coagulants are mixed together to travel to the tube flocculator.	IF Elapsed time in current state > 2. Total Loading Duration, then go to state 3 OR IF Rep counter > Max reps, then go to OFF	0 Pump is running if alum dose is NOT zero and its speed is controlled by set point “alum pump control” 1 Pump and 2 Pump is ON. Valve influent to floc is ON and Valve effluent to column is ON.	Plant flow rate Loading residence time Residence time multiple Total loading duration Alum stock concentration Alum dose Alum flow rate Alum tubing size Alum # of heads Alum pump control Raw water pump control Raw water flow rate Raw water tubing size Raw water # of heads Rep counter	Depends on the length of tube flocculator	Alum dose is determined by Alum reset state, Alum state in increment, alum slope, alum intercept and alum Max X.
3. Pump Ramp Down	0 Pump and 1 Pump slowly come to a stop to avoid vibration that causes vortex in the settling column.	IF Elapsed time in current state > 3. Ramp Down Duration, then go to state 4 OR IF Pressure Sensor Value >= 600, then go to OFF	All three pumps are ON and 0 Pump is controlled by set point “alum ramp down control”. Valve influent to floc and Valve effluent to column are ON.	Ramp down final value Ramp down constant Ramp down duration RW ramp down control Alum ramp down control	30.875s	Flow deceleration (Ramp down constant) is 3.5 cm/s^2
4. Shutoff Ball Valve	Block the connection between flocculator and settling column for measurement of settling velocity	IF Elapsed time in current state > 4. Ball Valve Duration, then go to state 5	2 Pump is ON and valve influent to floc, valve effluent to column and ball valve are ON.	Ball valve duration	6s	The flow in the system is completely stopped to ensure no breakage of flocs through the orifice.
5. Settling State	Flocs settle in the settling column. Effluent turbidity is measured under quiescent condition.	IF Elapsed time in current state > 5. Settling State Duration, then go to state 6	0 Pump is ON. Valve effluent to column and ball valve are ON.	Settling state duration Effluent turbidity	1800s	
6. Open Ball Valve	Recover the connection between flocculator and settling column to prepare for the next cycle.	IF Elapsed time in current state > 4. Ball Valve Duration, then go back to state 1	0 Pump is ON. Valve influent to floc and valve effluent to column are ON.	Ball valve duration	6s	

rectory path: N://files.Cornell.edu/EN/aguaclara/RESEARCH/Tube Floc/Spring 2013/Experiments/. Different experiments are organized in different folders with the experiment date as the name. Inside each folder there are two kinds of excel spreadsheets, “datalog” and “statelog”. “Datalog” records all the data information for the experiment such as time fraction, influent and effluent turbidity, backwash duration time, loading duration time, and coagulant flow rate. “Statelog” provides each state name and its corresponding time. Before using Data Processor to plot the data, the basic experimental information, such as when this experiment begins and how many days it lasts should be saved in the MetaFile (N://files.Cornell.edu/EN/aguaclara/RESEARCH/Tube Floc/Spring 2013/Data processor/Meta File.xls). To check the experimental results, the metaID should be entered into the area highlighted in yellow in Data Processor.

Part II

Literature Review

3 Flocculation Model

In laminar flow, velocity gradient (G) is a function of $\varepsilon$and viscosity (υ). [2]

$G = \sqrt{\frac{\varepsilon}{\nu}}$

G=velocity gradient, the difference in velocity between adjacent layers of fluids

ε=energy dissipation rate, a measure of mixing intensity

υ= kinematic viscosity of water

A predictive model that shows the relationships between the flocculation and dependent variables is expected to guide the design and operation of hydraulic flocculators.[1] Swetland et. al. 2012 proposed a laminar flocculation model which is governed by the following equations.

$$C* = \frac{1}{\beta G\theta\Gamma\phi^{2/3}} \tag{1}$$

where:

G = mean velocity gradient

θ=hydraulic residence time

Γ= fractional coverage of colloids by coagulant

ϕ= floc volume fraction

C*= residual settled water turbidity divided by influent turbidity

β= $\frac{\eta_{PACl}}{V_{Capture}}$, where$\eta$ is a fitted parameter, and$V_{Capture}$= capture velocity

$pC^* = -log(C^*) = log(\beta G\theta\Gamma\phi^{2/3})$

From 1we can see that as average energy dissipation rate (or the average velocity gradient) increases, the effluent turbidity decreases, meaning a high turbidity removal given the same influent turbidity. However, if the average energy dissipation rate is too high, the flocs may be broken into the small ones that couldn't be captured by sedimentation tank. Thus the flocculator should be designed to create the energy dissipation required to limit the floc size that corresponds to the capture velocity.

Dr. Monroe Weber-Shirk et. al. raised two different flocculation hypotheses. One is called "large flocs are useless". In this hypothesis, the floc volume fraction for successful collisions is only related to the colloid fraction. The other is "colloids can attach to all flocs". This hypothesis claims that floc volume fraction depends on floc size, which is related to the maximum energy dissipation in the flocculator. Based on the latter hypothesis, the time that allows the collisions to happen between the colloids is very short and the higher the turbidity is, the shorter the collision time is, thus the higher the turbidity removal rate is. This conclusion does not agree with the data obtained using FReTA. However, the first hypothesis "large flocs are useless" seems more reasonable and therefore floc breakup design will be useful to improve flocculator performance.

Figure 5: Floc breakup set-up showing two Hoffman clamps.

Part III

Methods and Materials

4 Silicone tube

Dr. Monroe Weber-Shirk made the assumption that the coagulant and clay particles will be resistant to silicone tubing because of its hydrophobic nature. 100 feet of the silicone tube was cut to about 28 meters – the length of one parallel unit of the tube flocculator. After one unit of the flocculator was dissembled, the 28 m silicone tube was installed in its place. The residual turbidities for each type of tubing must be compared in order to determine whether or not the new silicone tubing decreases the tendency of coagulant and clay to collect on tube walls.

5 Floc breakup procedure

The experiments from last semester imply that once flocs reach a certain size they can not continue to grow and collect particles. Therefore, flocculation is more efficient when big flocs are intermittently broken up. To investigate this theory further, a floc breakup procedure was devised based on the relationship between energy dissipation rate and orifice size 5. Two Hoffman clamps were evenly placed onto tube flocculator (see 5). An equation was derived to determine energy dissipation rate as a function of the orifice size of the tubing clamps. We made several assumptions when deriving this equation:

1) The vena contracta in this scenario is eliminated because there is no abrupt change of the flow.

2) The circumference of the inner diameter of the tube is conserved after deformation by the clamp.

3) The geometry of the tube after deformation can be approximated as a rectangle and two half circles (6).

4) The wall thickness is conserved after deformation.

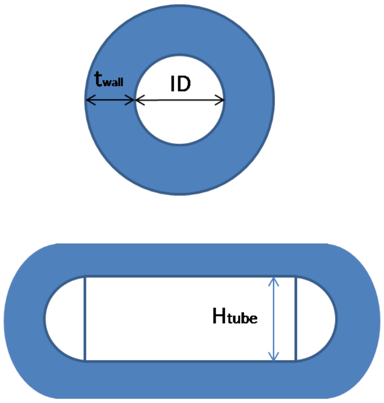


Figure 6: Geometry of tube before and after deformation

The length of the rectangle after deformation shown in 6 is the circumference of the circle created by the half circle ends of the deformed tube subtracted from the inner circumference of the original tube all divided in half.

$$L_{rectangle} = \frac{\pi * ID - \pi * H_{tube}}{2} \tag{2}$$

The area of the clamped orifice is approximated as the area of the rectangle added to the area of the two half circles.

$$A_{orifice} = L_{rectangle} * H_{tube} + \pi * \frac{H_{tube}^2}{4} \tag{3}$$

The average velocity of the fluids traveling through the orifice is the plant flow rate divided by the area of the orifice.

$$V_{fluids} = \frac{Q_{plant}}{A_{orifice}} \tag{4}$$

The desired energy dissipation rate would be

$$\varepsilon_{breakup} = \frac{(\Pi_{jet} * V_{fluids})^3}{H_{tube}} \tag{5}$$

The relationship between energy dissipation rate and the orifice size can be determined by plugging 2 into 3, 3 into 4, and 4 into 5, and rearranging:

$$\varepsilon_{breakup} = \frac{64 * \Pi_{jet}^3 * Q_{plant}^3}{H_{tube}^2 * (8ID^3 - H_{tube}^3 - 12H_{tube}ID^2 + 6H_{tube}^2 ID)} \tag{6}$$

For better measurement of the clamp sizes that create the desired energy dissipation rate, orifice size is substituted by clamp size.

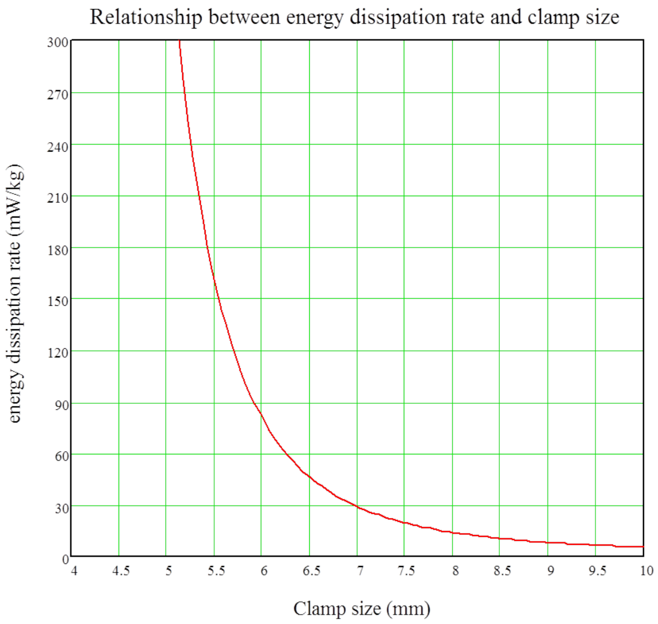


Figure 7: Relationship of energy dissipation rate (mW/ kg) and clamp size (mm)

Note:
ID= inner diameter of the tube, 3/8 in
H_{tube} = flow constriction height, mm
$L_{rectangle}$ = length of the rectangle shown in 6, mm
$A_{orifice}$ = the area of orifice (white area in 6), mm^2
Q_{plant} = volumetric flow rate, 5.5 mL/s
V_{fluids} = velocity of fluids traveling through the orifice, mm/s
$\varepsilon_{breakup}$= energy dissipation rate for floc breakup points, mW/kg
Π_{jet}= contraction factor in a jet, approximately 0.4 for axis symmetric jet.
T_{wall}= the wall thickness of the tube, 1/16 in
Clamp Size = the clamp opening height, $H_{tube} + 2T_{wall}$, mm

Based on 7, we chose two energy dissipation rates – 90 mW/kg and 300 mW/kg, and the corresponding clamp sizes are 5 mm and 6 mm. We also used a 4 mm clamp in order to include a high energy dissipation rate ($>$1000 mW/kg).

6 Process controller method

All the current experimental methods were recorded in AguaClara's archive with the following directory: N://files.Cornell.edu/EN/aguaclara/RESEARCH/Tube Floc/Spring 2013/Experiments/. The specific description of this method is

Table 2: Description of method PACl 28m floc increment rep 1.pcm

Set point	Value
Target influent turbidity max	100 NTU
Raw water flow rate	5.5 mL/s
Length of tube flocculator	28 m
PACl base	1.1
PACl coefficient	0.9
Max reps	15

recorded in Meta File (N://files.Cornell.edu/EN/aguaclara/RESEARCH/Tube Floc/Spring 2013/Data processor/Meta File.xls).

First we used the method named *PACl 28m floc increment rep 1.pcm* for the 10 and 11 experiments. Detailed information about this method is provided below.

[1]

The residual turbidity results for the experiments with coagulant dose ranging from 0 to 3.1 mg/L (multiple orifice sizes) shows that the residual turbidities increase with a decrease of orifice size or an increase of energy dissipation rate. These results contradict what the Tube Floc Team discovered last semester. It's very likely that breaking flocs does not apply to this range of coagulant dose. It is possible that for low coagulant dose, the flocs are small (see 8) and breaking them will make them too small to be removed by the sedimentation tank. Floc breakup is expected to only be beneficial if the floc sedimentation velocity is much larger than the capture velocity. Therefore, we assume that at a higher dose, such as 5 mg/L PACl, will break the large flocs to a size that can be captured by the sedimentation tank and therefore, the flocculation performance will be improved.

We designed a new method that keeps the PACl dose at 5 mg/L and changes the clamping size. This method named *Single PACl dose 5mgL floc 28m.pcm* is the same as the method *PACl 28m floc increment rep 1.pcm*, except the coagulant dose is anchored at 5 mg/L (no PACl base or coefficient or max reps) and a new rule is implemented that stops the system after one full cycle. Aluminum pieces with a 5.2 mm opening were made in order to maintain a more accurate and consistent orifice size (see 9). These pieces replaced the Hoffman clamps on the apparatus for experiments using the new method.

The results for 5 mg/L PACl dose were similar to the results in the range of 0 to 3.1 mg/L PACl. Our hypothesis is floc breakup is only effective if a large fraction of the flocs are at their maximum size and if the size of the broken flocs is large enough to be captured by the sedimentation tank. Therefore, at low coagulant dosages and short residence time in the flocculator, the floc breakup

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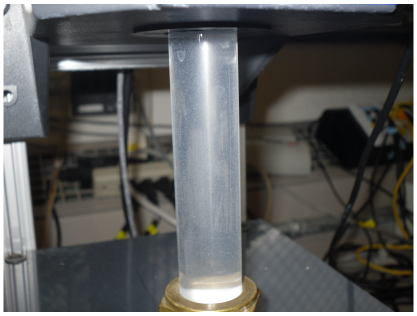
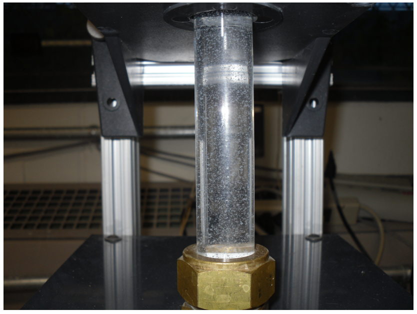
[1] A power law relationship is used to set a range of coagulant dose to spread out the residual turbidity vs. dose curve. This equation shows how we set the dose of alum.

Coagulant dose $= coefficient \times (base)^{reps}$ Max reps means the number of experimental cycles, which is set by operators.



(5 mg/L PACl)



(10 mg/L PACl)

Figure 8: Comparison of floc sizes at the beginning of settle state with a PACl dose of 5 mg/L (left) and 10 mg/L (right). The floc size for the 10 mg/L PACl dose were estimated to be approximately 1 mm in diameter.

device will break the flocs to a size that can't be captured by the sedimentation tank (lower than the current typical capture velocity of 0.12 mm/s). In order to find the right dose to break the flocs, a wider range of coagulant doses was created by changing the PACl base to 1.2. The dosages vary from 0 to 9.6 mg/L. We noticed that the flocs grew much bigger at 9.6 mg/L PACl dose compared with 5 mg/L (8). We assume that breakup flocs will be beneficial for improving flocculation performance at 10 mg/L PACl dose. Based on this assumption, four experiments were conducted with a range of clamping sizes using the same 10 mg/L PACl dose (3). Clamping sizes were chosen based on desired energy dissipation rate (7).

According to the results of (13), 5 mm clamping size as floc breakup constriction performed the best among the 3 sizes (4 mm, 5 mm, 6 mm). Two subsequent experiments were conducted with 4 and 8 clamps in order to determine the optimal number of clamps for a 28 m flocculator (1 unit).

Figure 9: New floc breakup devices (aluminum pieces)

Number of clamps	Clamp size (mm)	Additional energy dissipation at breakup points (mW/kg)
0	–	0
2	6	90
2	5	300
2	4	>1000

Table 3: Experiments with a range of clamp sizes using single 10 mg/L PACl dose

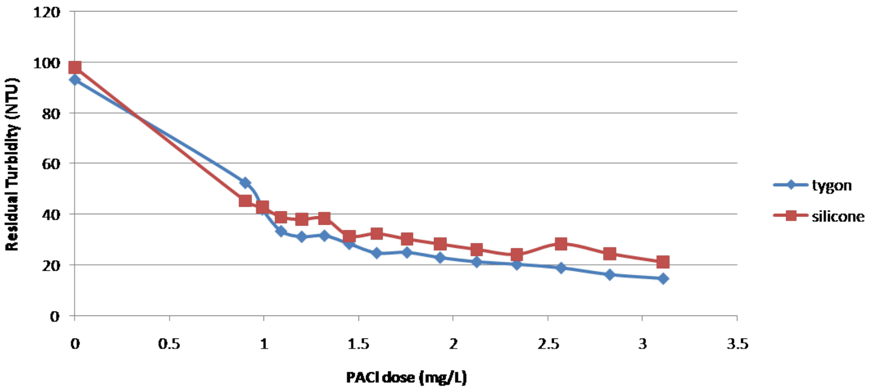


Figure 10: Comparison of performance of silicone and tygon tube flocculators

Part IV

Results

The measurements of the influent and effluent turbidimeters are recorded in Data Processor at the end of loading state during the cycle with no added coagulant. At this time, there is essentially no difference between the water flowing through the influent and effluent turbidimeters. Therefore, the discrepancy between the readings of the influent and effluent turbidimeters is negligible.

If the hydrophobic surface properties of the silicone tubing prevents attachment of coagulant precipitate, the silicone tube flocculator is a more ideal reactor because the walls are less reactive and thus are less of a sink for coagulant or clay. This results in an increase in residual turbidity. In other words, silicone tube should have a smaller drop in residual turbidity between each cycle if it's coagulant resistant. 10shows that the residual turbidities of the silicone tube experiment are slightly higher than with the tygon tube as the flocculator.

Floc breakup is expected to have the most significant impact for high turbidities raw water and coagulant dosages that are high enough to support rapid floc growth. Floc breakup is only effective if a large fraction of the flocs are at their maximum size. This suggests that the ideal test conditions are the more typical full scale plant operating conditions with a residual turbidity that is below 5 NTU. Under those conditions it should be possible to further reduce the residual turbidity by breaking the large flocs. At low coagulant dosages and short residence times as shown in 11 the benefit of floc breakup may not be significant because few flocs grow to their maximum size.

The experience of the typical full scale plant operating conditions implies that the ideal situation for floc breakup is what achieves a residual turbidity below 5 NTU. Thus we picked a series of coagulant dosages – from 0 to 9.6 mg/L in order to find the coagulant dose that gives us a residual turbidity lower than

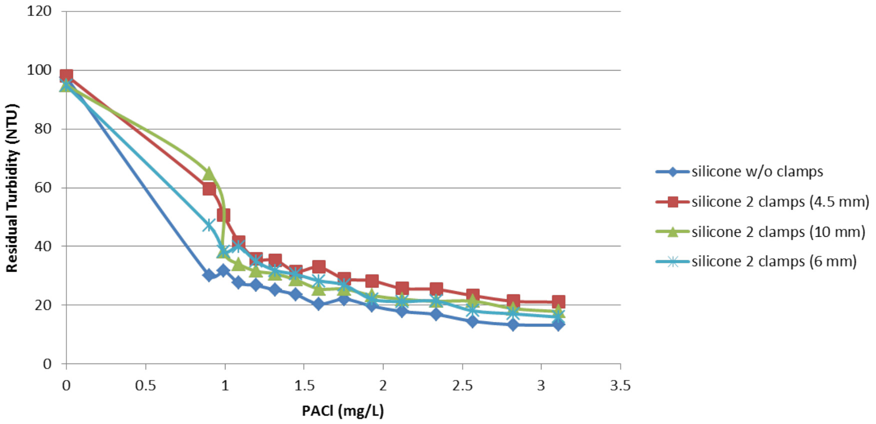


Figure 11: Comparison of residual turbidity with two floc break up points (multiple orifice sizes)

5 NTU. 12shows that at about 10 mg/L, the residual turbidity is below 5 NTU. Thus 10 mg/L PACl dose was chosen to be the effective point for subsequent floc breakup experiments.

According to 13, the experiment without clamps has the highest residual turbidity. This result confirms that moderate floc break up will increase the turbidity removal and thus improve the flocculation performance. The residual turbidity for the 5 mm clamp is the lowest and was considered the best clamp size for turbidity removal among the 3 clamping sizes.

In order to determine the optimal number of break up points, the clamp number was varied while orifice size and coagulant dose were kept constant at 5.2 mm and 10 mg/L, respectively. 14 shows that after two clamps, doubling the number of clamps to 4 and then again to 8 does not improve flocculator performance. One possible explanation for this is the positioning of the clamps. Since they are evenly spaced on the flocculator, as more clamps are added, there are more break up points closer to FReTA. This may not allow enough time for flocs to grow before they settle in the settling column. It may also be related to the assumption that the orifice size should be consistent at every break up point. Although a 5 mm clamp size is optimal for a two clamp system, this may not be true when more clamps are added to the apparatus.

The optimal clamp size was chosen based on using 2 clamps. The energy dissipation rate of the 5.2 mm clamp is 285 mW/kg and thus the energy dissipation rate is 28 times higher than the normal energy dissipation rate in the flocculator. This means that the floc volume after breakup will be 28 times smaller. Given that the original floc diameter was estimated to be 1 mm the broken flocs were estimated to have a maximum diameter of 0.033 mm. The sedimentation velocity for flocs with a diameter of 0.033 mm is 0.05 mm/s and this is less than the capture velocity of the sedimentation tank.

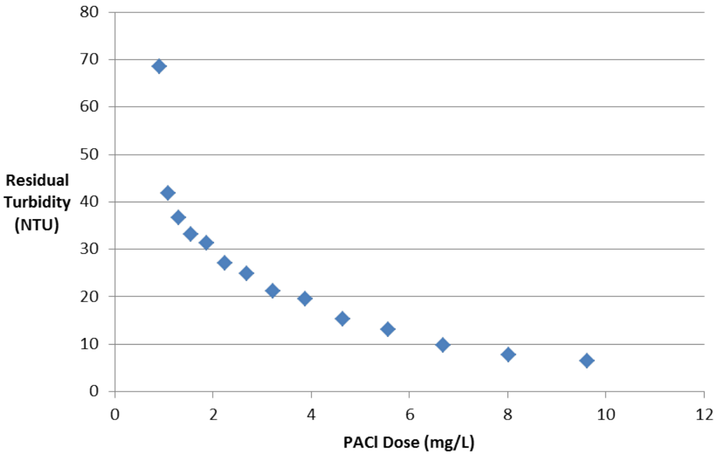


Figure 12: Residual turbidities for 0 to 9.6 mg/L PACl dosages (28 m silicone tube)

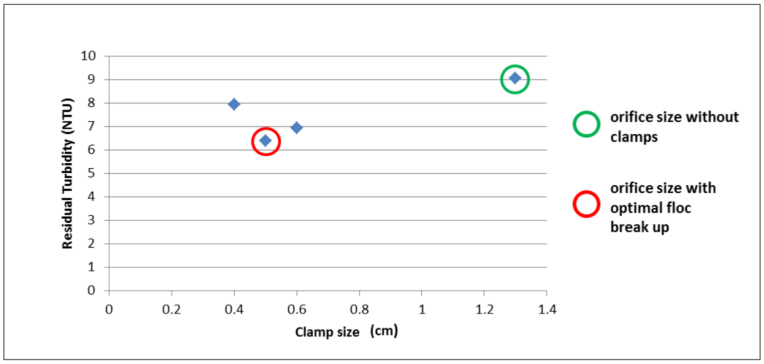


Figure 13: Residual turbidities with multiple clamp sizes (4 mm, 5 mm, 6 mm) at 10 mg/L PACl dose. The dot in green circle is the control (with no clamps).

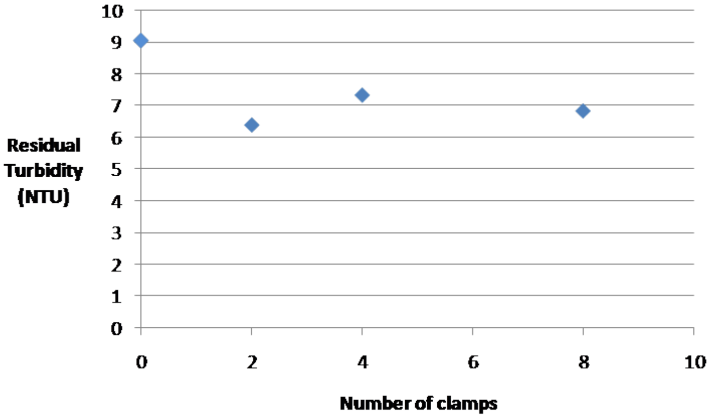


Figure 14: Effect of number of clamps for 10 mg/L PACl dose.

Part V

Conclusions

1. The influent and effluent turbidimeter readings at the end of loading state without coagulant are within ten percent. There will always be a slight discrepancy due to expected turbidimeter error, but this discrepancy appears to be negligible.
2. Flocculators composed of silicone tubing are preferable to those made of tygon tubing. Under the same experimental conditions, silicone tubing achieved slightly higher residual turbidity, suggesting less coagulant and clay attachment to tube walls. Particularly, at the end of loading state with no coagulant added, the ratio of average effluent turbidity over influent turbidity is about 1.05 and 0.95 for silicone and tygon tubing, respectively. Therefore, silicone tube provides a more accurate environment for measuring effluent turbidities compared with tygon tube. We suggest ordering more silicone tubing to use as the tube flocculator for future experiments.
3. For floc break up experiments, a higher dose of coagulant should be used. This way, flocs will grow to a size such that when break up is achieved, there will be a greater proportion of flocs that have velocities above capture velocity. Therefore we need to apply a high dose (above 10 mg/L) in order to improve flocculator performance through floc break up.
4. Adding 2 or 4 or 8 floc break up points to the apparatus at a coagulant dose of 10 mg/L leads to a decrease in residual turbidity compared with that of the apparatus without floc breakup . This verifies last semester's

Tube Floc Team conclusion that floc break up, at a high coagulant dose, improves flocculator performance.

5. For a two clamp floc break up system, the optimal clamp size is approximately 5.2 mm with an energy dissipation rate of 285 mW/kg. However, when more clamps are added at this orifice size, flocculator performance does not improve. Therefore, it should not be assumed that a 5.2 mm clamp size remains optimal when clamp number is increased.

7 Troubleshooting

7.1 Problems with tubing and connectors

When the connections of tubes are leaking, you should check the tubes to make sure they are fully plugged into the connectors– the tube can not be easily pulled out if it is fully inserted. To ensure no leaking, you need to verify each connection is robust before beginning the experiment. If there is a leak at the top of the settling column, stop any experiment and drain the column. You may need to remove the turbidimeter to adjust the connection.

7.2 Problems with apparatus

1. If the apparatus is not on when you turn on the switch, that is because the power strip sometimes trips the GFI protection. When you meet this problem, press the GFI reset button which is on the outlet behind the water tank.

2. If raw water pump is running at backwash, then press the START/STOP button on the raw water pump.

3. If influent turbidity is too high (meaning it is at least 10 NTU more than the target turbidity max), use a 1L plastic container to scoop out some water from the raw water bucket. This water will automatically be replaced by clean tap water to keep the volume constant and you should see the turbidity go down.

4. If the alum pump is not running at loading state, first ask yourself if this is the first cycle. If it is the first cycle, then this is normal because the alum dose is set to be zero at the first replication. If it's not the first cycle, go to settling state and then click loading state to see if the coagulant dose incrementally increases. If there is an increase, then the valve (between the rapid mixer and raw water pump) may be mistakenly closed. If it is not, then check if the set points are set correctly by locating the set points at rule editor to ensure the variables match the code. Process Controller Set Points used to control the experimental apparatus.

5. If water is filling up the flow accumulator, check the cap of the accumulator to make sure it's tight.

6. If residual turbidity is not decreasing as coagulant dose increases, the coagulant dose may be too low due to one of the following: 1) inaccurate running rate of coagulant pump; 2) the air inside the coagulant pump tube; 3) water trapped in the coagulant pump tubes; 4) malfunctioning of valves that connect with the coagulant pump; or 5) the loading duration is too short (not taking into account the wrong set-up on Process Controller). If the pumps were recently calibrated, the first reason can be ruled out. If the residual turbidity does not significantly decrease after a residence time, the second cause can be eliminated. You can check for water trapped in the coagulant pump tubes by opening the tube connection between the coagulant pump and the rapid mix unit. If there is water present, it may be due to high pressure during backwash.

7.3 Problems with Process Controller

1. If you turn on all the switches, and none of the green indicator lights on Process Controller are on, that means you are not connecting with the right server or the server may have crashed. Check the main server to make sure it is functioning properly and check the data server on Process Controller (should be "aguadata.cee.Cornell.edu").

2. When you're operating from one state, sometimes nothing is shown on the "current state" and the "state list" is not shown at "rules and states" at the next state. When this happens you need to reload the method file and save it in your experiment folder.

7.4 Problems with Data Processor

1. If you're having trouble loading the data from Metafile of Data Processor, first you need to check the directory to make sure it's on the right track to locate the Metafile (an excel spreadsheet in the "data processor" folder). Second check all of the information for a certain MetID (the one retrieves your experiment). Pay attention to the dates and duration (if your experiments span 2 days, you need to put in the both dates and a duration of 2).

2. Sometimes the graph on the MathCAD file of Date Processor is not shown due to memory loss, then you may have to restart the computer to reload the data.

Part VI

Future Work

1. Determine the optimal orifice size for floc break up systems with four, eight, and sixteen clamps by gradually decreasing the clamp size based

on the relationships between energy dissipation rate, floc size, terminal velocity, and clamp size until the flocculator performance worsens.

2. Determine optimal positioning for floc break up points by comparing the residual turbidity of an evenly distributed clamp system with clamp systems that gradually decrease the number of clamps toward one or both ends of the flocculator. As residual turbidity decreases the flocculator performance improves.
3. Compare the performance of tapered tube flocculation with regular tube flocculation. Design a tapered system – small tube at the beginning, medium tube in the middle, and large tube at the end (same length for each size of the tubing) using 10 mg/L PACl dose and 28 m tube flocculator length (N://files.Cornell.edu/EN/aguaclara/RESEARCH/Tube Floc/Spring 2013/Experiments/Single PACl 10 mgL.pcm/). As tube size (diameter) increases, energy dissipation rate decreases, allowing flocs to continue to grow. The larger that flocs can grow, the lower the residual turbidity will be.

References

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