Sedimentation Tank Hydraulics

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Abstract

In the sedimentation tank of an AguaClara water treatment plant, water flows through the inlet manifold with vertical diffusers that channel the water into the bottom of the tank as a line source. As water exits the vertical diffusers, a semi circular half pipe jet reverser directs the water upward to resuspend flocs to form a floc blanket, or a dense, fluidized bed of particles, in the sedimentation tank below the plate settlers. A floc blanket increases the particle removal efficiency of the sedimentation tank by capturing smaller flocs that would otherwise escape through lamellar sedimentation. A floc blanket also leads to less clean water waste because without a floc blanket, sludge builds up at the bottom of the tank and will require constant draining. While current plant designs use a 0.5" radius jet reverser and centered jet placement, other jet reverser sizes and jet placements were explored to increase floc resuspension and floc blanket stability. A 1.5" radius reverser with asymmetric jet placement was found to be the optimal design for floc resuspension. Floc blanket stability in relation to coagulent dose was also explored, and optimal alum doses for several influent turbidities were determined.

1 Background

As previous teams have shown, the relationship between hydrodynamic pressure of the jet to the hydrostatic pressure of solids on the incline at the lip of the jet reverser is crucial to the resuspension of flocs. Hydrodynamic pressure is given by the equation

$$P = \rho \int \frac{V^2}{R} dn \tag{1}$$

where ρ is the density of the fluid, V is the fluid velocity, and R is the local radius of curvature. Equation 1 applied across streamlines determines the dynamic pressure of the jet and shows that holding all else constant, a decrease in the radius of curvature will result in an increase in dynamic pressure. The Fall '11 sedimentation tank hydraulics team (STHT) has shown that a small, 0.5 $inch$ radius jet reverser results in the best resuspension of flocs[STHT Fall '11]. However, smaller diameter jet reversers will be difficult to fabricate in the field, as

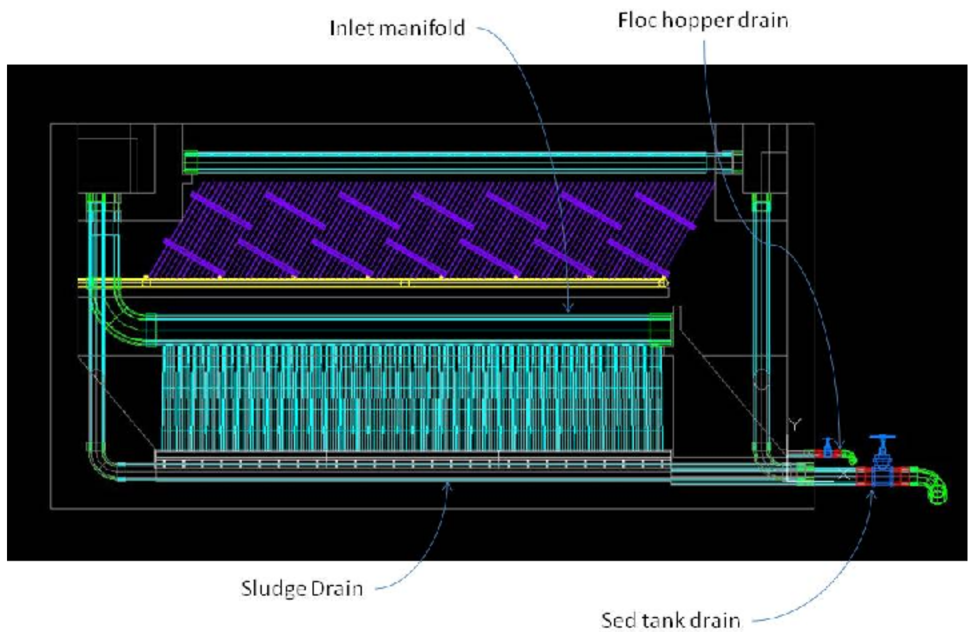


Figure 1: AutoCAD rendering of the AguaClara sedimentation tank, side view.

it will require precise alignment of the diffuser tubes and the jet reverser. The relationship between jet reverser radius, jet displacement, and floc blanket stability will be a main focus of this summer's research. We hope to determine if larger radius jet reversers are a viable option for floc blanket formation in plants, and the tolerance of the floc blanket to slight jet displacements resulting from errors in construction.

It has also been shown by previous teams that the alum dose is crucial to the stability of a floc blanket, but the exact relationship between influent turbidity and minimum alum dose for a stable floc blanket is not known. Alum is a coagulant that causes particles to clump together. An alum dose that is too low will result in inadequate coagulation of particles and the number of interactions between particles will be too low for a floc blanket to form. A very high alum dose will result in large, low-density flocs. The Spring '12 STHT has shown that increasing the alum dose results in a decrease in floc blanket concentration, most likely due to the lower-density flocs [STHT Spring '12]. We hope to determine the minimum alum dose at which a stable floc blanket can be formed at a given influent turbidity. A lower alum dose is desirable because we believe it will result in a denser floc blanket that will capture more small particles, as well as less clumpy sludge in the floc hopper, which can be more easily drained. A lower coagulent dose will also reduce overall plant costs.

2 Methods

We used the same experimental apparatus and procedure as with the experiment documented in the Summer 2011 STHT's Research Report 1 [STHT Summer '11]. A thin $1.27\,cm$ wide tank was used to model a thin slice of the full scale sedimentation tank. Figure 1 in the STHT's Final Research Report, Summer '11 shows AutoCAD renderings of the side view and front view setups for the one half inch wide sedimentation tank and light panel system. We used a MathCAD file to calculate the appropriate plant flow rate and alum dose according to our desired upflow velocity. Typical parameters for our experiments include a flow of $456\,mL/min$ of aerated raw water containing $45\,mg/L$ of alum. An average influent turbidity of $100\,NTU$ made from a concentrated kaolinite clay stock regulated by Process Controller was run through a tube flocculator before being expelled through a vertical downward-pointing jet. Unless otherwise indicated, the jet was aligned with the lip of the the jet reverser and centered in the tank. $100\,NTU$ was chosen for the influent turbidity because it was a well characterized turbidity from previous studies [**?**, **?**]. Upflow velocity above the floc-water interface was $1.0\,mm/s$, which reflects the upflow velocity in an actual plant, constraining the initial jet velocity to $0.011\,m/s$, as it is dependent on flow rate and cross-sectional area of the inlet tube:

$$V_{up} = \frac{Q}{A} \tag{2}$$

where $V_{up}$is the average upflow velocity, Q is the jet flow rate, and A is the cross sectional area of the clarifier [**?**, **?**].

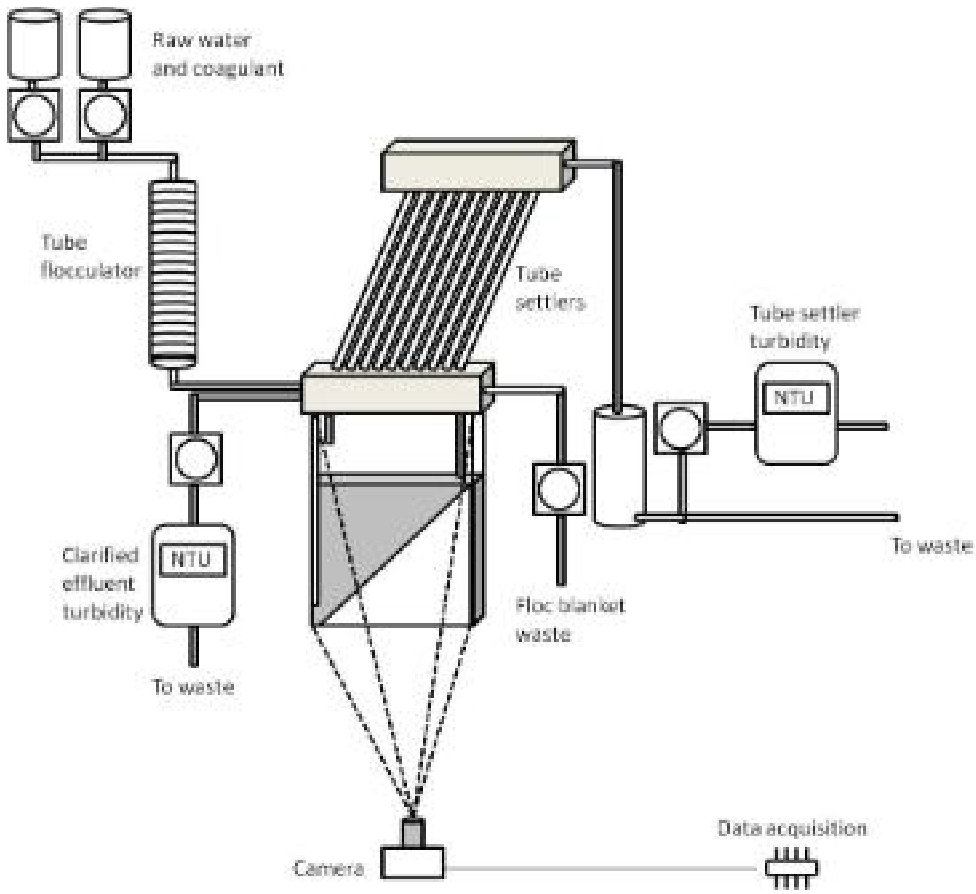


Figure 2: Schematic of turbid water flow through flocculator and sedimentation tank.

Experiments were performed using foam inserts of various geometries made from 1.27 cm wide foam board inserts laminated with tape. Magnets were used to secure the position of the inserts. Jet reversers with 0.5”, 1”, and 1.5” radii were fabricated such that the sides and bottom of the attachment are 10 cm long and the incline up to the jet reverser is 60 degrees in order to match the foam inserts. The incline begins at exactly one radius above the bottom of the jet reverser, so that the jet reverser is a half-circle.

3 Jet Reverser

3.1 Jet reverser sizes

We want to determine a relationship between the radius of the jet reverser and the upflow velocity at failure, average concentration of the floc blanket,

	0.5" jet reverser	1.0" jet reverser	1.5" jet reverser
Time to Floc Blanket Formation	$33.5\,min$	$38.4\,min$	$25.2\,min$
Floc Blanket Failure Flow Rate	$456\,mL/min$	$496\,mL/min$	$456\,mL/min$

Table 1: Jet Reverser size vs. floc blanket formation and failure times

average effluent turbidity, and time for floc blanket formation. This will help us to show if larger diameter jets are viable in AguaClara plants. Jet reversers of 0.5", 1", and 1.5" radii were fabricated. For each radius jet reverser a floc blanket was formed at an inlet jet velocity of $556\,mL/min$, corresponding to a sedimentation tank upflow velocity of $1.46\,mm/s$. After two hours of initial floc blanket formation time, the inlet jet velocity was turned down every $30\,min$ by an increment of $20\,mL/min$, corresponding to a decrease in upflow velocity of $0.052\,mm/s$. The camera was initially placed $150\,cm$ from the tank but was moved closer to the tank after the initial floc blanket formation to better capture instances of failure at low flow rates. Images were taken every $30\,seconds$.

Approximate floc blanket formation times and floc blanket failure times could be determined from experimental images for each trial. Floc blanket formation time is defined as the first time a floc-water interface can be clearly observed, and jet reverser failure is defined as the time that the resuspension zone, or the zone at which the jet comes in contact with the solids built up on the incline to resuspend them, enters the jet reverser.

As can be seen in table 1 above, there is no clear correlation between jet reverser size and floc blanket formation time. Floc blanket failure was much more sensitive to jet placement errors than to the jet reverser size, and the effects of slight placement errors were amplified in smaller jet reversers. At similar flow rates, jet reversers of smaller radii and slightly displaced jets would have entrained significantly more sludge than larger radii jet reversers with no significant error in jet displacement (Figure 3). This effect is due to the differences in hydrodynamic pressure on each side of the jet: a displacement of the jet to the left will cause the jet stream to preferentially flow to the right side of the jet reverser, resulting in a higher jet velocity on the right side of the reverser and consequently a higher hydrodynamic pressure. By the same reasoning, the dynamic pressure of the jet on the left side of the reverser will be much lower. Since we have hypothesized that floc resuspension is directly related to the hydrodynamic pressure of the jet, solids will begin entering the left side of the jet reverser at a much lower inlet jet velocity than the right side, and floc blanket failure will occur at a significantly lower velocity.

The table below shows images of the 0.5", 1.0", and 1.5" radii jet reversers at various inlet jet flow rates. The larger radius jet reversers are less sensitive to a slight displacement, but are more likely to fail at low flow rates due to the inverse relationship between hydrodynamic pressure and local radius of curvature (Equation 1).

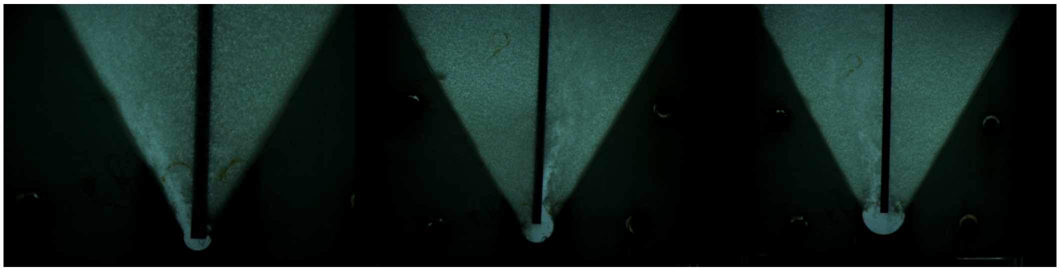
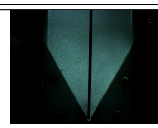
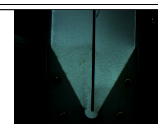
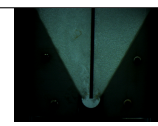
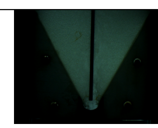


Figure 3: Jet reverser sensitivity to placement errors (Left to right: 0.5 inch, 1 inch, 1.5 inch radii jet reversers).

Inlet Jet Flow Rate	0.5" jet reverser	1.0" jet reverser	3" jet reverser
$556\, mL/min$			
$496\, mL/min$			
$456\, mL/min$			
$376\, mL/min$			

The average floc blanket concentration at various points in time was also determined at a region of interest approximately 10 cm above the jet reverser to gain insight into the effects of jet reverser size on speed of floc blanket formation and changes in floc blanket concentration after formation (Figures 4,5).

From analysis of the floc blanket concentration versus time graphs, the 1.5 inch radius jet reverser had the steepest slope in the first 40 minutes, creating the floc blanket the fastest. The second fastest forming floc blanket was the one from the 1 inch radius jet reverser and last was the 0.5 inch jet reverser. The 1 inch jet reverser initially had a slow blanket formation rate with a slope smaller than the 0.5 inch jet reverser, but started increasing at around 18 minutes into the experiment. At the time of flow rate ramp down at 120 minutes, the 1.5 inch jet reverser had the highest concentration of flocs at $1794.69mg/L$, followed by 1 inch at $1733.92mg/L$, and lastly the 0.5 inch jet reverser at $1532.75mg/L$.

During ramp down, the experiment seems to have encountered a problem at around 200-300 minutes for the 0.5 inch and 1.5 jet reversers. The floc concentration dipped, disrupting the trendline. We suspect that this have be

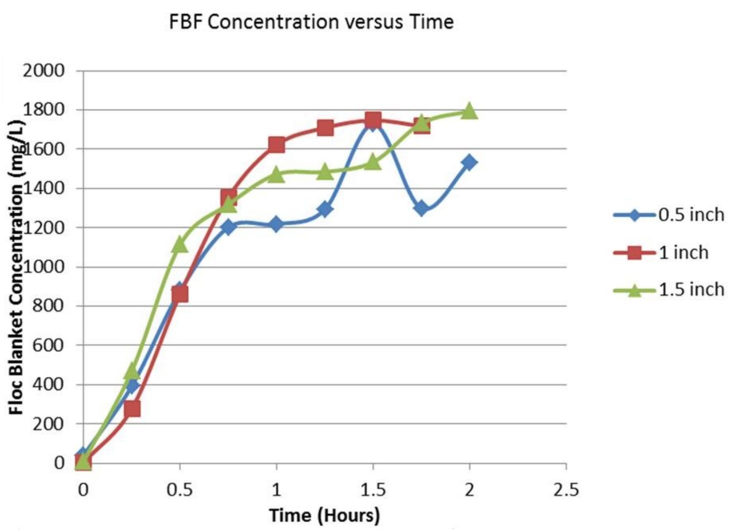


Figure 4: Average concentration during floc blanket formation at constant upflow velocity of .

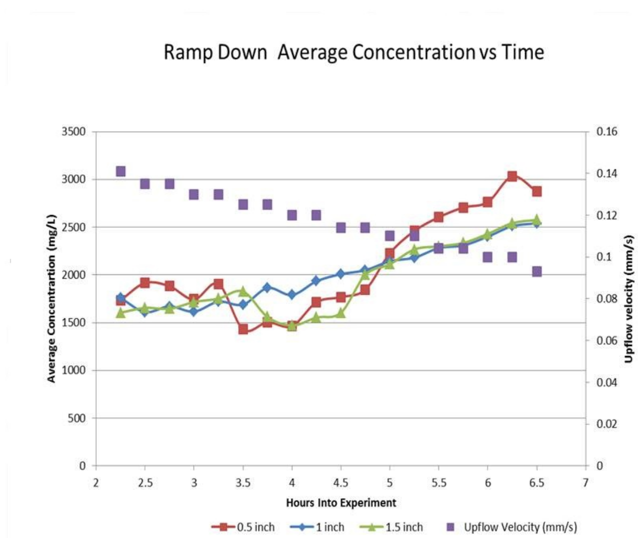


Figure 5: Average concentration during ramp down phase.

attributed to the fluctuating raw water turbidity. However, if the data between time points 200-300 was interpolated, then there is a clear trendline for all three jet reversers. The 1.5 inch radius reverser had the most obvious and largest increase in concentration as flow rate decreased with around $5.26 mg/L$ increase per minute. The 1 inch and 1.5 inch radius jet reversers were fairly close in their trendlines and it is hard to distinguish which one had smaller increase in concentration.

The 1.5 inch radius jet reverser is ideal for fast floc blanket formation; however, it also has lower hydrodynamic pressure at the point where the jet contacts the solids, which would theoretically result in less particle resuspension (Equation 1). Although it maintains the highest hydrodynamic pressure, it is unclear whether the 0.5 inch jet reverser is better than the other two radii jet reversers. A more concentrated floc blanket after formation, as observed the 0.5 inch radius jet reverser, could trap smaller flocs as they are resuspended from the jet reverser, but also could mean that sludge buildup is faster on the side inclines of the tank. It is unknown whether a more concentrated floc blanket is better for the capture of more small particles.

4 Jet Placement

To determine a relationship between the horizontal or vertical displacement of the jet from the center of the jet reverser and floc blanket stability, a floc blanket was formed using a $1.5\,inch$ radius jet reverser and various jet positions at an inlet jet velocity of $556\,mL/min$ and an upflow velocity of $1.4\,mm/s$. After an initial floc blanket formation period of $2\,hours$, the inlet jet velocity was turned down by $20\,mL/min$ every 30 minutes to observe the effects of low flow rates on floc resuspension in the jet reverser. Jet placements initially tested were $0.75\,inch$ downward displacement, $0.75\,inch$ upwards displacement, $0.75\,inch$ horizontal displacement, and $1\,inch$ horizontal displacement. The jet was also displaced vertically in increments to determine extreme limits of jet placement. Finally, different jet entry angles were explored. Jet reverser failure was defined as either sludge collecting in the jet reverser, or the resuspension zone entering the jet reverser.

4.0.1 Downward displacement

The $0.75\,inch$ downward jet displacement resulted in floc blanket formation, but the exact time of floc blanket formation could not be determined due to bubbles entering the tank and breaking up flocs, delaying the formation time. The resuspension zone in the jet reverser was not at the lip of the reverser, but began at approximately the height of the jet at higher upflow velocities and gradually moved down the reverser as the upflow velocity was decreased (Figure 6). According to our definition of jet reverser failure, downwards jet displacement does result in failure. However, having the resuspension zone in the jet reverser does not appear to negatively impact floc blanket formation. We

Figure 6: Downward jet displacement at jet flow rates of 556 mL/min and 396 mL/min, respectively.

can say that displacing the jet downwards is analagous to changing the geometry of the reverser to a smaller reverser with the resuspension zone defining the end of the reverser. While a floc blanket can still be formed with downwards displacement of the jet, this positioning is not ideal because it will waste material in the sedimentation tank, jet reverser lip only needs to be at the height of the resuspension zone and the jet reverser will extend higher than necessary. The jet is also directly colliding with the debris flow at the resuspension zone, which may cause unnecessary floc break-up and divert the path of the jet.

4.0.2 Upward displacement

Displacing the jet $0.75\,inch$ upwards did not significantly impact floc blanket formation. A floc blanket formed and no sludge built up in the jet reverser even at the lowest upflow velocity of $0.146\,mm/s$. The effects of displacing the reverser a greater distance upwards were explored in later experiments.

4.0.3 Horizontal displacement

The jet was first displaced$0.75\,inches$ to observe the effects of a slight jet misplacement during construction. This jet placement caused the jet stream to follow a preferential flow path to the left side of the reverser after hitting the right side of the reverser. This preferential flow path resulted in a 'dead-zone' on the the right side of the reverser. With inadequate jet flow to resuspend flocs on the right side of the reverser, a 'dead-zone' formed and sludge collected in this area (Figure 7). When the jet was displaced $1.5\,inches$ to the right so that the jet was aligned with the edge of the jet reverser, the dead-zone on the right side of the reverser was eliminated and sludge no longer collected in the reverser (Figure 8). Sludge on the right incline was pulled into the path of the jet, carried the length of the reverser, and pulled upwards by the jet on the left

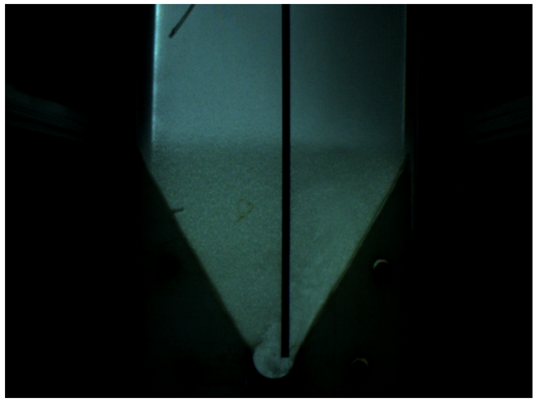


Figure 7: 0.75 inch displacement at inlet jet flow rate of 316 mL/min and upflow velocity of 0.83 mm/s.

side of the reverser, and sludge on the left incline was directly resuspended by the jet. Some sludge collected at the point where the jet contacted the right side of the reverser, but this build-up could be fixed by displacing the jet upwards slightly so that sludge can fall directly into the path of the jet.

4.1 Asymmetrical Jet Placements

Displacing the jet so that it is in contact with the side of the reverser is advantageous because it eliminates the possibility of sludge buildup in the reverser due to preferential flow paths taken by the jet. It will, however, require different design and construction techniques, as the manifold will not be centered in the sedimentation tank, but will have to be shifted to one side to allow for vertical entry of the jet into the reverser. Another possibility is keeping the manifold centered in the tank, but rotating the manifold so that the diffuser is in contact with the side of the reverser but hits it at an angle (Figure 9).

We hypothesize that the stream of water exiting the jet parallel to the lip of the jet reverser would lessen dissipation of energy the most; thus, even though the tilted jet will hit at an angle, it will resuspend flocs better than a centered jet, which would have water hit the bottom of the jet reverser at a perpendicular angle. Accordingly, to determine the effects of the above hypothesis and jet placements, we conducted experiments with a centered jet, vertical asymmetrically placed jet, and angled asymmetrically placed jet (20 degrees from vertical). In the asymmetric jet experiments, the jet was lifted slightly from the lip of the reverser to allow flocs to enter the jet reverser and the path of the jet. Images of the jet at various positions and upflow velocities are shown in the table below.

From comparison of the horizontally placed and angled jet, the amount of sludge accumulated in the jet reverser is comparable except for the upflow velocity of $0.059mm/s$. The resuspension zone of the angled jet has entered farther

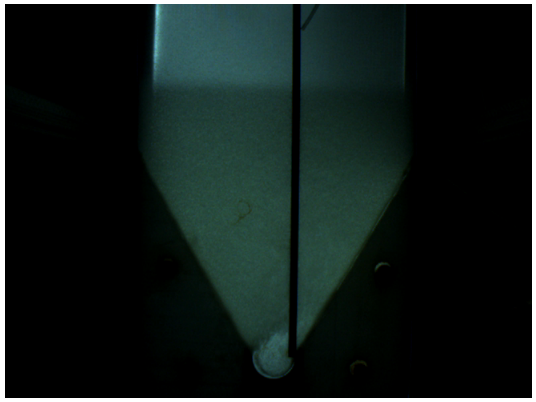


Figure 8: 1.5 inch displacement at inlet jet flow rate of 376 mL/min and upflow velocity of 0.49 mm/s.

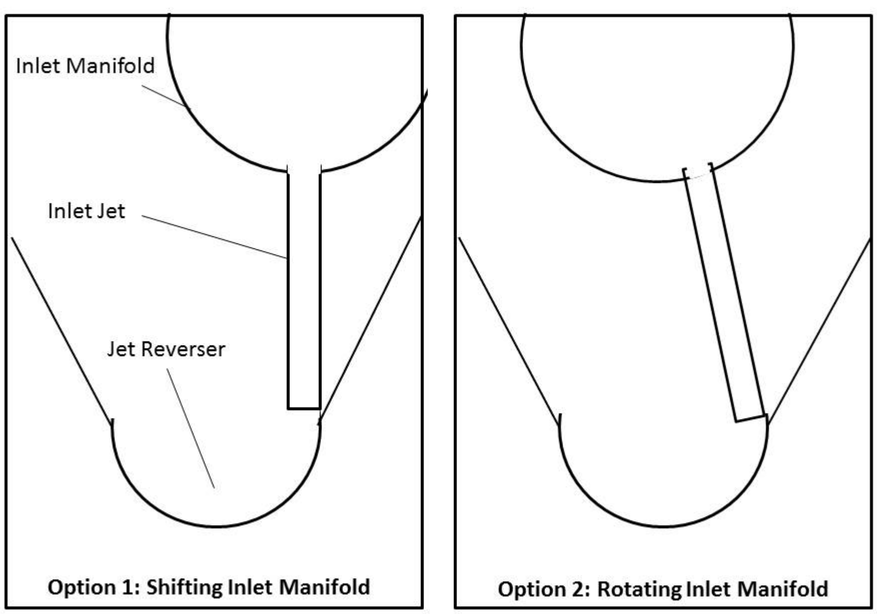


Figure 9: Options for fabrication of asymmetric jet position

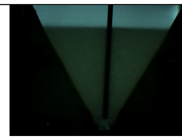
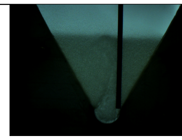
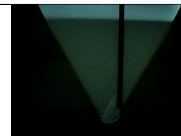
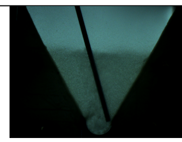
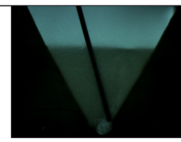
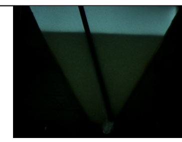
	0.064 mm/s	0.059 mm/s	0.049 mm/s	0.0394 mm/s
Centered Jet				
Vertical Asymmetric				
Angled Asymmetric				

Table 2: Asymmetrical Jet Placement

into the reverser than the resuspension zone of the vertically placed asymmetric jet, indicating better floc resuspension with the vertical jet, although the difference between the two is not very significant. The most interesting result from these experiments is that both the angled and horizontally displaced jets resuspended flocs better than the centered jet by a wide margin. The angled jet reverser image at a $0.059mm/s$ upflow velocity has sludge accumulated in the jet reverser but shows a "natural" jet reverser; the centered jet reverser also has sludge, but the flocs are randomly suspended and hinders the upflow of water.

From these experiments, we conclude that a vertically placed asymmetric jet is ideal for floc resuspension. If the inlet manifold cannot be shifted so that water from the jet flows into the vertical part of the reverser, an angled reverser made by tilting the inlet manifold is also viable and greatly enhances the jet's ability to resuspend particles in contrast to a centered jet. Further experiments should be conducted to find a relationship between angle of jet entry and amount of floc resuspension and sludge build up in the jet reverser at different upflow velocities. Our experiment only focused on jet entry 20 degrees from the horizontal. Perhaps there is an angle from the vertical in which tilting the inlet manifold will not longer have much difference from a centered jet.

4.2 Limits of Jet Displacement

To test for errors in the fabrication of the sedimentation tank bottom and jet reverser placement when building the plant, we tested more extreme horizontal and vertical displacements to find a range of viable extremes for the plant. The parameters for failure were sludge accumulation at the bottom of the jet reverser or failure to form a floc blanket.

Our first experiment was an incremental upward displacement of the jet from 2 inches from the bottom of the curve of the jet reverser to around 6 inches.

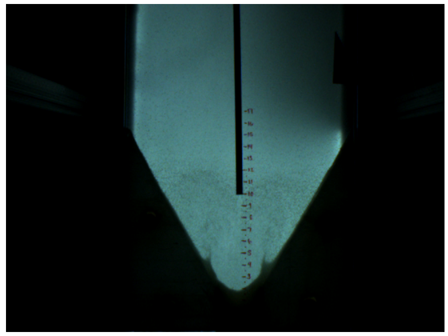
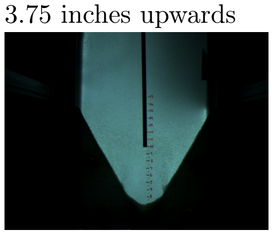


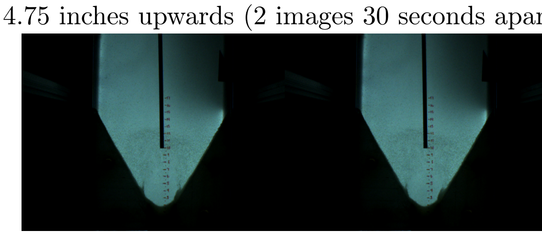
Figure 10: “U” Shaped Sludge Formation

We found that sludge started to build up around 4 inches (some flocs were resuspended, as seen in the two 4.75 inches upwards images below that were taken 30 seconds apart) and permanently stay in the jet reverser at around 5.5 inches.

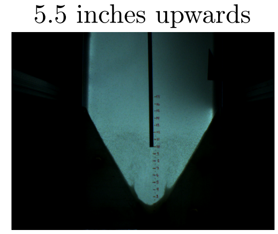
3.75 inches upwards



4.75 inches upwards (2 images 30 seconds apart)



5.5 inches upwards



Our second experiment was an incremental downwards displacement from 12 inches from the bottom of the curve of the jet reverser to around 2 inches. This experiment had run time of around 1.5 hours and the jet was moved downwards at a rate of 1 inch every 10 minutes. In the beginning, as expected, the flocs settled at the bottom of the jet reverser and along the incline of the inserts. It resembled a "U" shape that grew in thickness as the jet was moved downwards (Figure 10).

Interestingly, as the sludge built up on the incline, a "natural" jet reverser made of sludge formed on top of the PVC (polyvinyl chloride) reverser. The jet reverser mimicked the shape of the PVC one and was similar in depth, but had decreased width of around 2 inches. It was also shifted slightly to the left, perhaps compensating for the slight displacement of the jet that caused inlet water flow to direct towards the left. As the jet was moved downwards, we noticed that the flocs on the sides of the incline started to break up, but the flocs at the bottom of the curve of the "natural" jet reverser were harder to resuspend. This may be due to the fact that when water exits the jet and impacts the bottom of the reverser with the highest energy, the flocs there have the most pressure and velocity from the jet, and thus are more concentrated and compact. The flocs directly beneath also do not have an easy exit route except upwards against the direction of the incoming water, compared to flocs on the

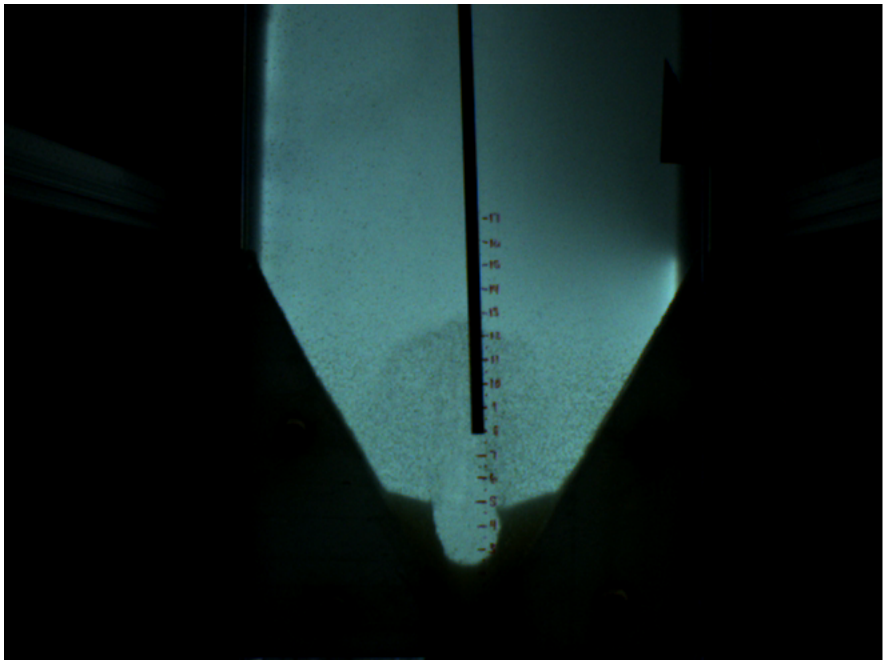


Figure 11: Floc blanket density

two sides of the jet reverser or on the inclines, which can break up horizontally or vertically with the general upwards flowing and water that is dissipating in many directions. Also, we noticed that there was a floc blanket density gradient above the jet reverser. The flocs seemed most concentrated at around 2-3 inches to the left and right of the jet inserted down the middle (Figure 11).

This could be due to the fact that the "natural" jet reverser has a smaller width, directing the upflowing water more vertically. As the jet was moved downwards, the first signs of floc blanket formation was around 8 inches upwards from the bottom of the PVC jet reverser bottom curve. There was a definite floc-water interface around 6 inches (Figure 12).

As the jet was moved farther down, the flocs on the side of the triangular inserts thinned, but the flocs that accumulated at the bottom of the PVC reverser broke up at a much slower rate.

From the first and second experiments, we can set an upper limit from this preliminary data for the erroneous displacement of the jet reverser and a distance between the bottom of the inlet pipe and the jet reverser. It seems that around 6 inches upwards from the bottom of the PVC reverser, a floc blanket can form and little to no sludge accumulates on the inserts or in the jet reverser. Any distance upwards, the floc blanket and clarified water interface will not be as clear and sludge can be seen. Also, even though in the second experiment, flocs didn't break up easily, we observed that the distance between the "natural"

Figure 12: Floc blanket formation

jet reverser and the jet was approximately 4 inches when the floc blanket was steady.

To confirm these results, an experiment was run with the held at a constant 6 inches above the bottom of the reverser. Sludge accumulated in the reverser and grew up until about 4 inches from the bottom of the jet, where it formed a natural jet reverser and remained at a constant height, indicating a maximum jet height of 4 inches for an upflow velocity of $1.2\,mm/s$. Below this height, there is not enough pressure from the jet to resuspend sludge.

5 Alum Dosage and Floc Blanket Stability

Determining the failure modes for alum dosage will allow us to determine the lowest required dose for successful floc blanket formation and maintenance. Coagulant is typically the largest daily operational cost in an AguaClara plant, so utilizing an optimal low dose would reduce these costs. Furthermore, finding a relationship between influent turbidity and required alum dose will allow us to interpolate the appropriate dosage for a given turbidity level. We currently assume that this relationship is linear and that the alum dose is proportional to the turbidity, but this operational standard is certainly not optimal. The efficacy of alum in coagulation varies depending on raw water pH and temperature and so our measurements at the lab conditions of $24°C$ and circumneutral pH may not

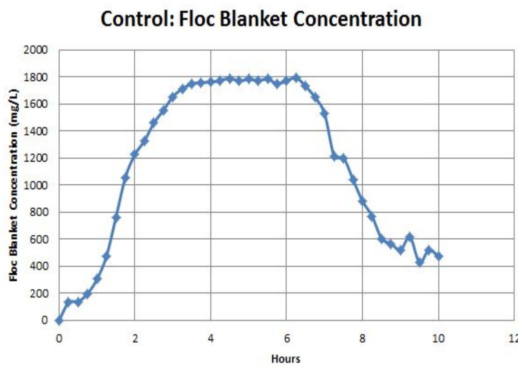


Figure 13: Control Experiment: 50 NTU and $35mg/L$

be representative of operational requirements in the field[Koohestanian]. Our goal is to develop a general relationship between alum dosage and floc blanket stability that can be used to conjecture appropriate low dosages in AguaClara plants.

5.0.1 Control Experiment

A floc blanket was formed at 50 NTU and an alum dose of $35mg/L$ and left at those conditions in order to observe its normal formation and steady state operation. Figure 13 is a graph of the average concentration of a region of the tank over time. It shows that the concentration steadily increases until a floc blanket is formed and then stays at a nearly constant level until the alum source is removed. We had hypothesized that the floc blanket might increase in concentration as more flocs are added, but as long as the floc blanket grows up to the floc weir and is wasted at an appropriate rate this is not the case.

5.0.2 50 NTU Influent Experiments

A floc blanket was formed at $30mg/L$ of alum for an influent turbidity of 50 NTU. After a two hour floc blanket formation period, the alum dose was decreased by $2.0mg/L$ every 30 minutes for 8.5 hours. Figure 14shows that the concentration of the floc blanket actually increases as the alum dose increases, until the floc blanket finally dissolves at a dose of $12mg/L$. Given that the floc blanket in the control experiment did not increase in concentration over time, we conclude that the floc blanket in this experiment increases in concentration because the alum dose is decreased. This is because an alum dosage higher than the optimal level will cause flocs to be less dense and the floc-water interface to be less clear.

With the knowledge that the floc blanket would fail at an alum dose of $12mg/L$, we attempted to form a floc blanket at that dosage to determine if it would be the optimal low dose for an influent turbidity of 50 NTU. We could

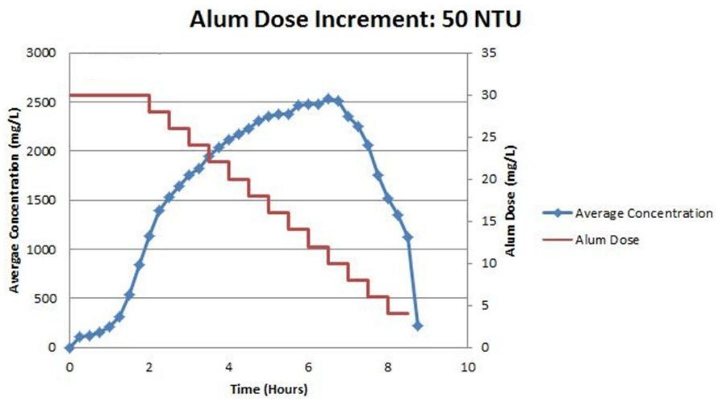


Figure 14: Alum Dose Increment: 50 NTU

not form a floc blanket at $12mg/L$, so we increased the dosage and repeated the experiment for $15mg/L$, $20mg/L$, and $25mg/L$, but we could not successfully form a floc blanket. We conclude that the original dosage of $30mg/L$ is the optimal low dose for 50 NTU.

5.0.3 100 NTU Influent Experiments

A floc blanket was formed at our current standard dose of $45mg/L$ for an influent turbidity of 100 NTU. After a two hour formation period, the alum dose was decreased by $2.5mg/L$ every 30 minutes for 9.5 hours. Figure 15 shows a rapid increase in average concentration until a floc blanket is formed, the floc blanket steadily becoming more concentrated as the alum dose is lowered, and the floc blanket finally dissolving at a dose of $25mg/L$.

We attempted to form a floc blanket at the failure alum dose of $25mg/L$ in order to determine if it could be the optimal low dose for 100 NTU. An intermediate floc blanket was formed, but it was not capable of capturing many of the flocs in the tank and so the floc-water interface was not very clear. This floc blanket was also not capable of forming up to the height of the floc weir and so steady state operation could not be achieved at this dosage (Figure 15).

Next, a floc blanket was formed at $30mg/L$ and 100 NTU. It was fully operational, rose up to the level of floc weir, and appeared more concentrated than the floc blanket we had formed at $45mg/L$. For our laboratory conditions, apparatus set-up, and an influent turbidity of 100 NTU, our experiments show that $30mg/L$ of alum is the optimal low alum dosage. Note that this is the alum dosage just prior floc blanket failure in Figure15.

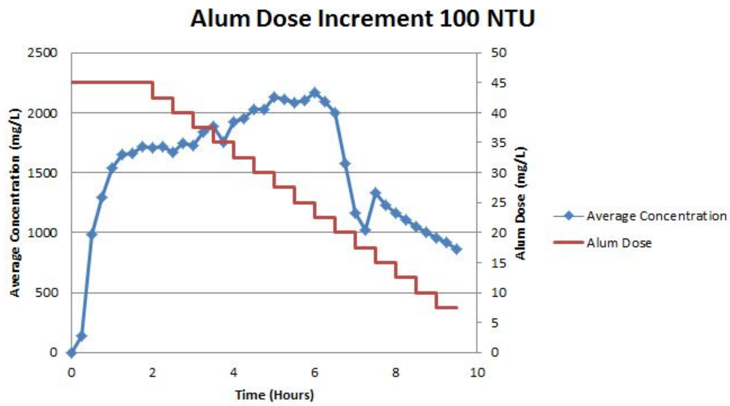


Figure 15: Alum Dose Increment: 100 NTU

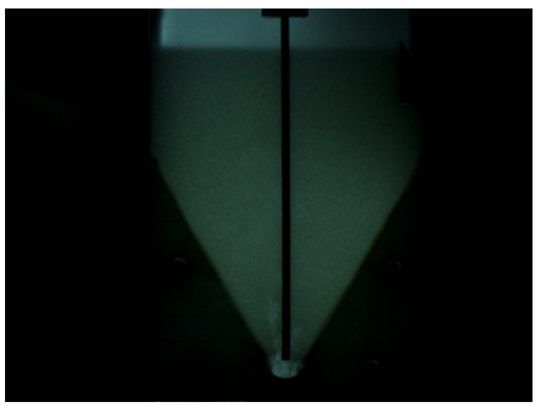


Figure 16: 100 NTU Floc Blanket at $30 mg/L$

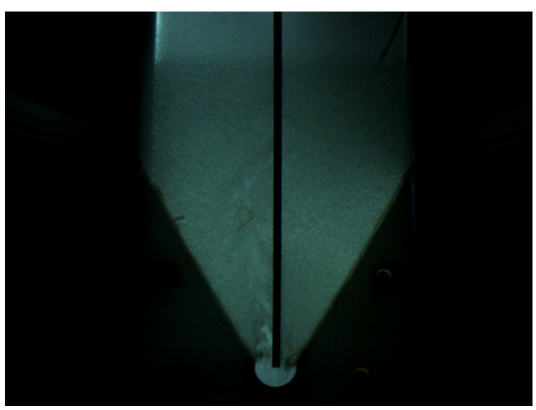


Figure 17: 100 NTU Floc Blanket at $45 mg/L$ is less concentrated

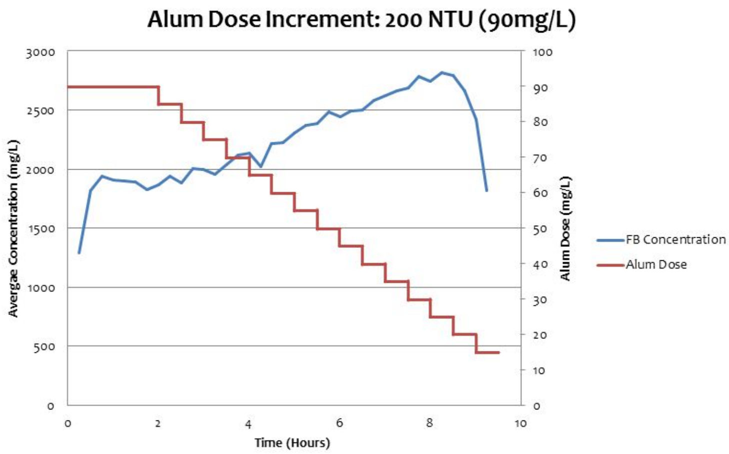


Figure 18: Alum Dose Increment: 200 NTU

5.0.4 200 NTU Influent Experiments

For an influent turbidity of 200 NTU we formed a floc blanket at an alum concentration of $90mg/L$ for two hours and then decreased the alum dose by $5.0mg/L$ every 30 minutes for 9.5, hours. The floc blanket did not dissipate until our apparatus ran out of alum stock. We suspect that there was enough flocculent particles accumulated in the system that the floc blanket could sustain itself for the duration of the experiment. Increasing the time between dose changes could have been more enlightening.

We successfully formed a floc blanket at $50mg/L$ and 200 NTU. When we stepped the alum dose down to $40mg/L$, a floc blanket formed, but the floc water interface was not as clear. Therefore, the optimal dose is around $40mg/L$, but further testing could determine a more exact dosage.

5.0.5 Relationship between Coagulant and Turbidity

It is possible that the relationship between influent turbidity and proper alum dose is linear, but the required increment in alum dose is much smaller than suspected. We found that both 50 and 100 NTU experiments could form floc blankets at $30mg/L$ of alum and 200 NTU only needed $10mg/L$ more for floc blanket formation. We hypothesize that the non-porportional relationship between coagulant and turbidity is related to the higher collision potential for particles in highly turbid influent. Particles that are already very likely to collide and coagulate need less alum to form a stable floc blanket, such as at 200 NTU. Conversely, particles in 50 NTU influent needed more alum to coagulate because they have less collision potential.

6 Future Work

6.1 Floc Hopper Geometry

The previous mathematical model for the wasting rate of sludge from the hopper [STHT Spring '12] should be reviewed, and improvements to the model should be explored. The sludge wasting rate from the hopper given by the model depends on the influent turbidity and the concentration of sludge that is being wasted. A relationship between the settling time of sludge and the concentration of sludge should be determined through both a literature review and total solids tests, and this relationship should be incorporated into the model.

A relationship should also be determined between the ratio of floc hopper plan-view area to floc blanket plan-view area and volumetric growth rate of sludge in the hopper at various influent turbidities by varying the with of the hopper and measuring the volumetric growth rate of sludge in the hopper for each influent turbidity. For a given hopper size and influent turbidity, a constant wasting rate equal to the instantaneous volumetric growth rate of sludge that would maintain steady state for this system at a given sludge height should be presented. The effects of an angle in the hopper on the volumetric growth rate of sludge in the hopper should also be explored.

References

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