Plate Settler Spacing Final Report Fall 2010

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AguaClara Reflection Report

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Abstract

The goal of the Plate Settler Spacing Team (PSS) is to study the lamellar sedimentation process in plate settlers and the efficiency of the removal of flocculated particles and establish improved guidelines for plate settler spacing. The traditional guidelines for plate settlers state that the spacing between plates cannot be less than 5 cm and little to no justification can be found for this. The team's results show that performance in accordance with the US drinking water standard of 0.3 NTU can be achieved with spacings smaller than 5 cm. Also, all but one of the experiments meet the World Health Organization standard of 5 NTU. For AguaClara plants, having smaller spacings between plate settlers allow the sedimentation tank to be shallower and therefore cheaper. Smaller spacings also allow for increased head loss across the plate settlers. This would help even out the distribution of flow in AC plants and allow the plate settler system to function at its design capture velocity of 0.12 mm/s throughout. The team had finished velocity gradient experiments with a clay aluminum hydroxide system; however, a recently discovered mistake in documentation caused the team to reassess the data collected this semester and more tube trials must be run. Due to this error, the team changed the capture velocity for the velocity gradient from 0.12 mm/s to 0.1~~3~~0 mm/s. **The major tasks completed by the Fall 2010 PSS team are catching a documentation error that happened at the end of Spring 2010, studying the effects of high velocity gradients and floc rollup on plate settler performance, developing a macro that significantly facilitates data analysis and a plate settler dynamics model that may better shed light into processes governing plate settler performance.**

Keywords: plate settler spacing, velocity gradient, capture velocity, PI ratio, failure, dynamics model, floc blanket, aluminum tubes, clay, entrance region blob.

Introduction

The team's research this semester focused on a failure mechanism called floc roll-up, where the fluid velocity gradient in a counter-current plate settler system forces floc particles predicted to settle out by the capture velocity to roll up the plate settler and into the finished water. The team used a bench scale water treatment plant model with tube settlers to simulate plate settler performance in AC plants. Due to geometric differences, a tube settler with diameter, *d*, experiences larger velocity gradients than a plate settler system with spacing, *d*. The team assumes that if a tube settler of diameter, *d*, does not fail, neither will the plate settler system with spacing, *d*. Plate Settler performance failure is determined by how much floc roll-up is present in the experiment. Floc roll-up occurs when the high velocity gradients in smaller diameter tube settlers exceed force of gravity pulling the flocs down. This causes flocs to roll up the side of the wall and exit with the finished water.

The Spring 2010 team developed a **floc roll-up model** that the Fall 2010 team has attempted to justify in a set of experiments using a clay and aluminum hydroxide bench scale system. For this set of experiments, the team had originally planned to fix the capture velocity at 0.12 mm/s; however, a documentation error revealed that the fall team worked off erroneous information the transition from Spring 2010 to Summer 2010 so the new capture velocity is 0.10~~3~~ mm/s. The control or "success case" for this experiment was a tube with an inner diameter of 1" at a capture velocity of 0.10~~3~~ mm/s. Again this was originally supposed to be 0.12 mm/s but the flow rate used actually corresponded to a 0.10~~3~~ mm/s capture velocity. The control case quantified successful plate settler performance at 0.25 NTU.

The floc roll-up model assumes that velocity gradients in tube settlers are responsible for forcing floc particles with settling velocities greater than the capture velocity to roll up the tube settler. The model assumes fully developed laminar flow and a linearized velocity profile near the wall instead of a parabolic profile because the floc diameters are so small compared to the tube settler diameters.

One of the main equations used in the floc roll up model is the "Performance Ratio Equations" (CEE 4540 Sedimentation Notes, Slide 24, 25):

$$\boxed{\frac{V_{\uparrow Plate}}{V_c} = \frac{L}{S}\cos\alpha\sin\alpha + \sin^2\alpha}$$

Equation 1 - Performance ratio for lab set ups (see Figure 1)

$$\boxed{\frac{V_{\uparrow Plate}}{V_c} = \frac{L}{S}\cos\alpha\sin\alpha + 1}$$

Equation 2 – Performance ratio for field geometry (see Figure 1)

where V_{plate} is the upflow velocity, V_c is the capture velocity, L is the length of the tube, S is the diameter of the tube settler, and α is the angle of inclination.

The difference between these two equations is the geometry of the settlers. Equation 1 corresponding to Figure 1 - Left is used for lab tube settler geometries because the tube settler entrances are horizontally level. Equation 2 corresponding to Figure 1 - Right is used for horizontally level settler configurations.

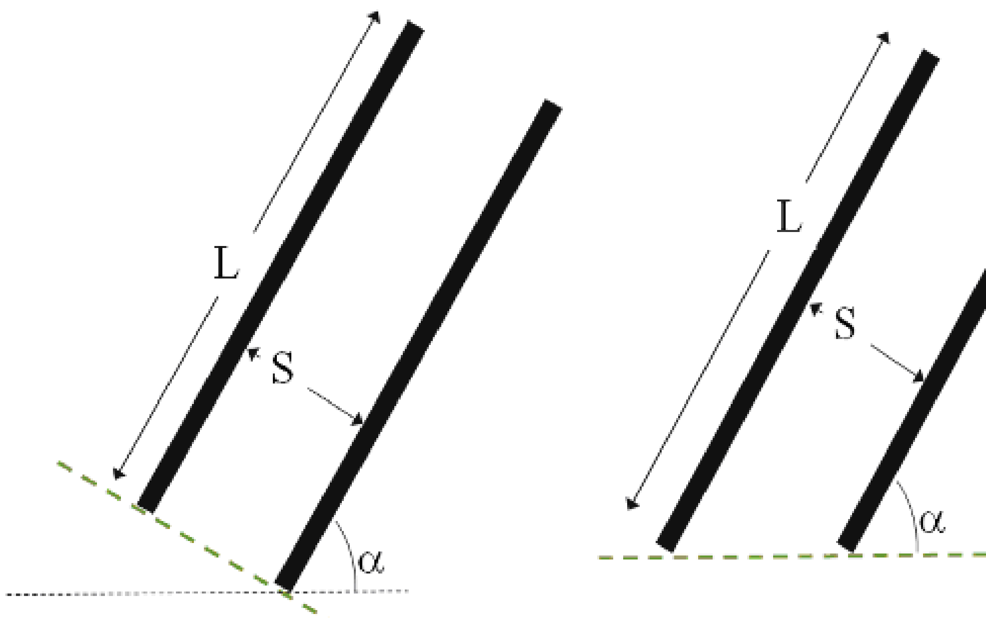

Figure 1 – Left: Tube Settler Interface. Right: Plate Settler Interface.

Equation 1 was rearranged to develop Equation 3 below that was used to calculate the length of a tube, given the diameter, upflow velocities, and capture velocity:

$$L = \left[\frac{V_{\alpha}\sin(\alpha)}{V_C} - \sin(\alpha)^2\right]\frac{d_{tube}}{\sin(\alpha)\cos(\alpha)}$$

Equation 3 - Rearrangement of Equation 1, used to calculate the length of the tube settler given other parameters

The length from Equation 3, along with the capture velocity, diameter values, and angle of inclination was then used in the following equation to determine the necessary flow rate:

$$Q = \frac{\pi V_C}{4}\left(Ld\cos(\alpha) + d^2\sin(\alpha)\right)$$

Equation 4 - Equation used to calculate flow rate. This is the performance equation with the definition of the upflow velocity plugged in and rearranged to solve for flow rate.

From there, the equation below was used to calculate the velocity gradient:

$$\frac{\mathrm{d}v_z}{dr} = \frac{2v_{ratio}V_\alpha}{R}; r = R$$

Equation 5 – Linearized velocity gradient equation

where $\frac{\mathrm{d}v_z}{dr}$ is the linearized velocity gradient at the tube settler walls, v_{ratio} is 2 for tube settlers and 1.5 for plate settlers, and V_α is the average velocity through the tubes.

For these experiments failure is described by a term called the PI ratio governed by the equations given below (Equations 6 and 7). Equation 6 is the definition and Equation 7 shows the full equation for the pi ratio.

$$\Pi_V \text{ failure criterion} = \frac{\textbf{capture velocity}}{\textbf{experienced velocity due to velocity gradient}}$$

Equation 6 - Pi ratio definition

$$\Pi_V = \frac{\frac{g \cdot \sin(\alpha) \cdot {d_0}^2}{18 \cdot \phi \cdot \nu} \cdot \frac{\rho_{Floc.0}(C_{Alum}, C_{Clay}) - \rho_{H2O}}{\rho_{H2O}} \cdot \left(\frac{d_{Floc}}{d_0}\right)^{D_{Fractal}-1}}{2\,V_\alpha(v_{up}) \cdot \left[1 - \left(\frac{\frac{d_{tube}}{2} - d_{floc}(v_{capture})}{\frac{d_{tube}}{2}}\right)^2\right]}$$

Equation 7 – Floc roll-up equation (PI ratio equation)

If the PI ratio is less than 1, failure (tube settler effluent in excess of 0.25 NTU) is expected.

More detailed information about the floc roll-up model can be found at the Spring 2010 Velocity Gradient Experiment page.

Dynamics model

For a given set of geometric parameters of the plate settlers the PI ratio is only able to predict if tube settler effluent will be in excess of 0.25 NTU. It does not give any information about the relationship between the tube settler parameters and the magnitude of the failure (discussed in the Results and Discussion part). This is due to one or more of the following reasons:

a) the PI ratio implicitly assumes that particles paths are following straight lines which would be true only if the velocity profile inside a tube was linear in shape,
b) there is an entrance region with high velocities that could stop the movement of flocs down the plate settlers, in turn affecting the flow profile and plate settler performance,
c) as flocs settle out toward the bottom plate, they experience a shear force which can break less dense flocs, producing smaller flocs that are not captured
d) some small flocs could collide and hence improve the settler's performance by producing flocs with higher settling velocities

Therefore, the team decided to develop a model that would incorporate these processes in order to get a more accurate estimate of the failure in terms of turbidity measurements and have a better understanding of the different effects induced by the velocity gradients inside the plate settlers.

Experimental Design

The PSS team's present setup is to test for tube settler performance failure for different diameter tube settlers (6.35 mm, 9.53 mm, 12.7 mm, and 15.88 mm) at upflow velocities of 1 mm/s, 2 mm/s, and 5 mm/s.

The **capture velocity was adjusted to 0.10~~3~~ mm/s** for all experiments.

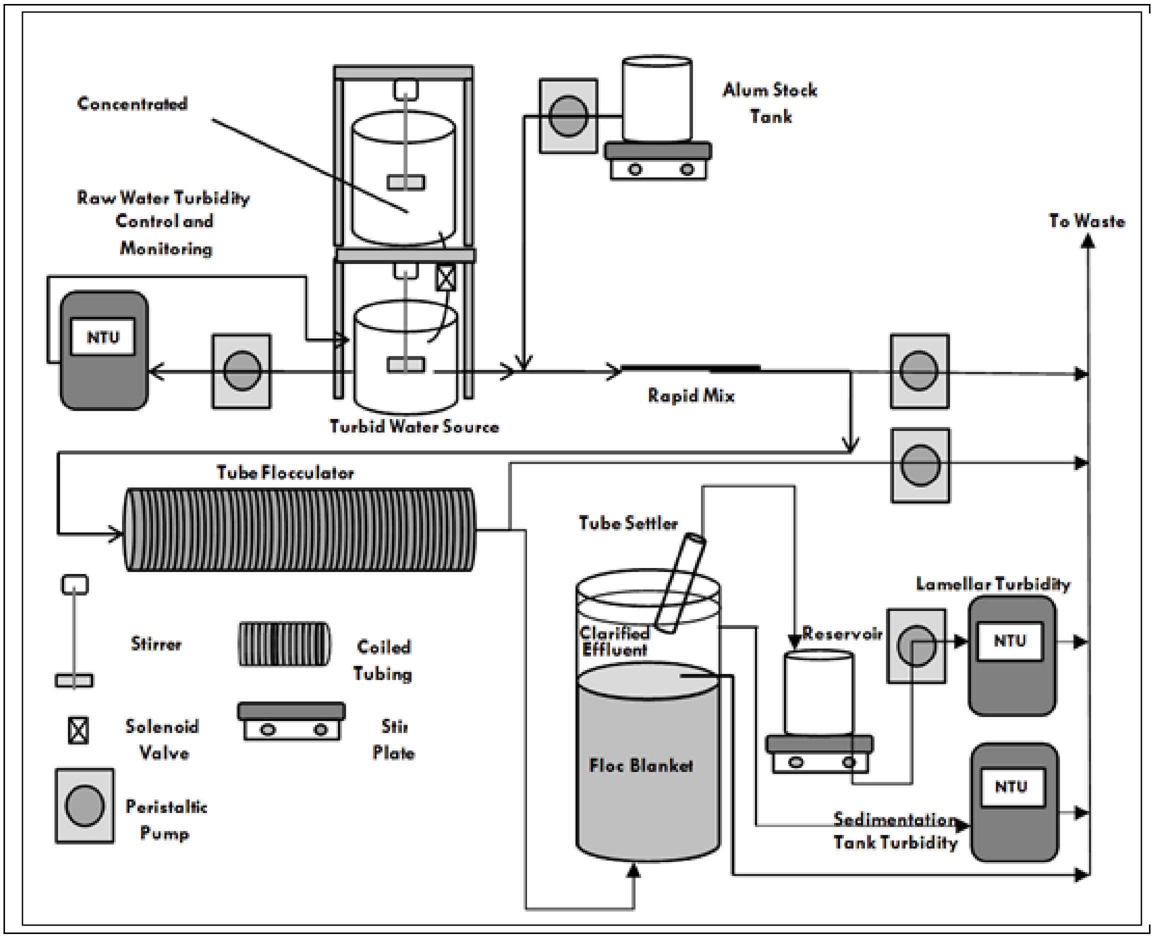

Figure 2~~3~~ – Schematic of a bench scale water plant.

The typical sequence of a tube settler experiment is as follows:

- The concentrated clay (10g/L) is diluted into the turbid water source until it reaches 100 NTU.
- The system switches to a floc blanket formation state, adding alum before mixing and flocculation. Prior experimental data indicated that an alum dose of 45 mg/L was optimal for an influent of 100 NTU.
- After the floc blanket forms, the system enters a loading state where tube settler effluent is sent to a reservoir (installed to prevent settling in turbidimeters that happens at around 50 mL/min for suspended clay particles). The reservoir delivers finished water to the turbidimeters at greater than 50 mL/min during a withdrawal state. As a consequence data collection for tube settlers is cyclical. The clarified effluent zone above the floc blanket is sampled so the tube settler effluent can be assessed relative to the tube settler influent.

Clay Velocity Gradient Experiment Adjustments

The purpose of clay velocity gradient experiments is to differentiate the effects of velocity gradients from capture velocities on tube settler performance. Clear PVC tube was used for this set of experiments. The equations above were used to calculate the appropriate flow rates and lengths to achieve a 0.10 mm/s. The team's original plan was to use a capture velocity of 0.12 mm/s because that value is used for AguaClara plants; however, an error in the model resulted in the majority of tube designs with a capture velocity of 0.1 mm/s. In order to salvage most of the data collected, the team adjusted the capture velocity to 0.1 mm/s for all tubes. This adjustment requires that the team re-run the 9.53 mm and 6.35 mm tubes. As a consequence of this adjustment, the upflow velocities have also been adjusted from 1 mm/s, 2 mm/s, and 5 mm/s to 0.87 mm/s, 1.73 mm/s, and 4.32 mm/s. The resulting average velocity is 1 mm/s, 2 mm/s, and 5 mm/s.

The adjusted specifications used for these experiments are shown in Table 1.

Table 1 - Adjusted parameters for clay velocity gradient experiments

Inner Diameter (mm)	Velocity Gradient (s^{-1})	Length (m)	Flow (mL/min)	Π.V
25.4 (Control)	0.32	0.46	30.402	4.63
15.875	0.5	0.29	11.876	2.9
	1.01	0.61	23.752	1.45
	2.52	1.56	59.38	0.58
12.7	0.63	0.23	7.601	2.32
	1.26	0.49	15.201	1.16
	3.15	1.25	38.003	0.46
9.53	1.15	0.17	4.278	1.75
	2.27	0.36	8.544	0.87
	5.63	0.93	21.343	0.35
6.35	2.74	0.12	1.9	1.17
	5.26	0.24	3.785	0.59
	12.82	0.62	9.486	0.23

High Velocity Gradient Experiments Using Aluminum Tubes

The purpose of this set of experiments is to show significant performance deterioration due to high velocity gradients (within 10 s^{-1} to 20 s^{-1}) that will cause massive floc roll-up through the tube settlers. The Spring 2010 team has already visually observed this phenomenon in the range of 12 s^{-1} velocity gradients; however, PSS has not yet obtained results over a 10 – 20 s^{-1} velocity gradient range.

In order to test this range of high velocity gradients, we have decided to use smaller diameter tubes (inner diameters (ID) less than ¼”) because larger tubes would require very large tube lengths to achieve high velocity gradients. The lengths required could not be tested in lab.

We were not able to find clear PVC tubes with ID less than ¼”, so we decided to test with Aluminum Alloy 3003 tubes instead. Because the difference in tube material may result in adhesive forces along the wall, we decided to have a control ¼” ID Aluminum tube to compare the difference in performance with the ¼” ID clear PVC tube tested in the clay velocity gradient experiments.

The PI ratio for this set of experiments is very low (around 0.1 with the exception of the control tube with a PI ratio of 1.187). With these PI ratios we expect to see close to 100% failure.

A separate process controller method was also developed to test the aluminum tubes. This method is functionally the same as the method for the PVC tubes but contains the parameters for the aluminum tubes.

The specifications for these experiments are summarized in Table 2.

Table 2 - Adjusted specifications for aluminum tubes for a capture velocity of 0.1 mm/s

Inner Diameter (mm)	V.up (mm/s)	V.grad (s^{-1})	V.α (mm/s)	Π.V	Length (m)	Flow Rate (mL/min)
6.4	0.87	1.238	1	1.187	0.117	1.943
6.4	7.77	11.16	8.977	0.13	1.144	17.512
4.1	4.32	9.85	4.987	0.15	0.397	3.856
3.3	4.31	12.23	4.981	0.12	0.319	2.493
2.5	4.33	16.23	4.997	0.09	0.242	1.43

Dynamics Model Design Methodology

In terms of modeling the plate settlers - or in this case: tube settlers - we chose to first focus on building a code that would solve the particles paths based on their local experienced velocities throughout their travel inside the tube. This numerical model implements a Velocity-Verlet algorithm to compute the particles positions.

Once a particle would fall on the bottom plate, it would be experiencing the velocity of the fluid at its edge. The algorithm runs as follows:

1) Set some initial conditions such as the geometry and the upflow velocity.
2) Generate a particle distribution size and positions.
3) Then, for each time step and for each particle.
    a. The program computes the new position.
    b. Then checks if the particle has been captured or has been carried out of the settler in the effluent water.
        i. If the particle has been captured then the program goes to next particle after marking the particle as captured.
        ii. If the particle is outside of the settler then the program jumps to the next particle.

4) Once all particles have been run through the settler, the program compares the distributions of the water turbidity and the settling column turbidity.

Figure 3~~Figure 4~~ summarizes the algorithm principle.

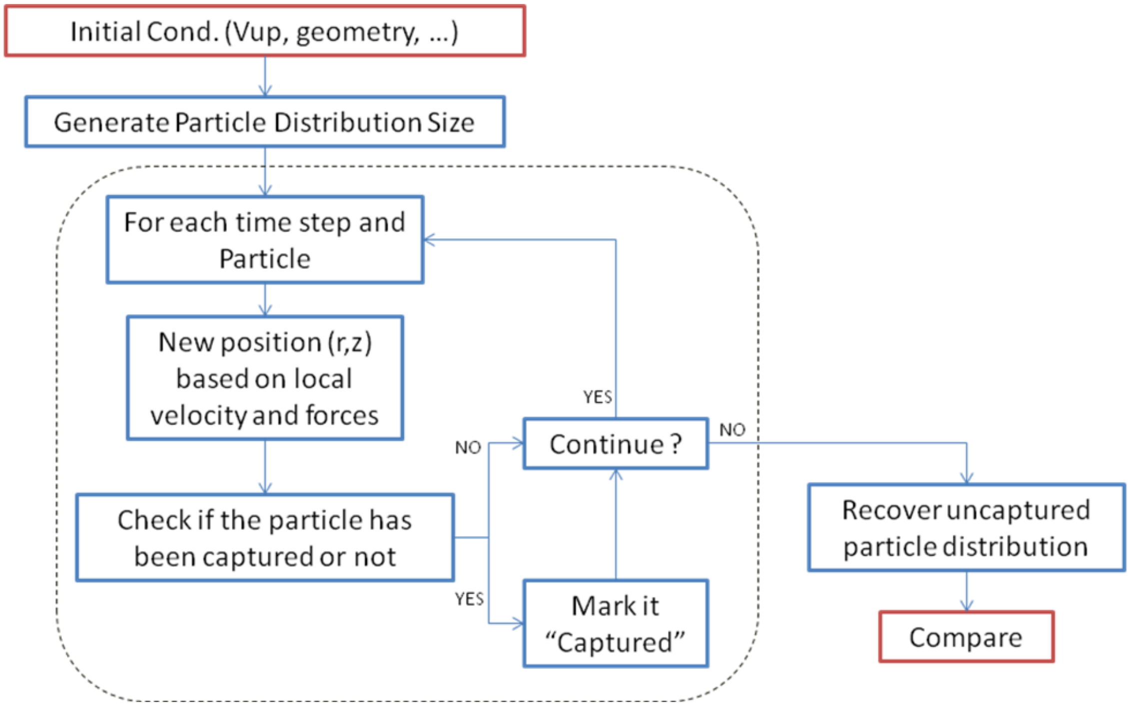

Figure 34 - Numerical model algorithm. The initial conditions are set by the plate settler geometry and the fluid upflow velocity through the plate settler. A numerical velocity Verlet algorithm is used to compute each particle position inside the settler. Tests are run after each step to mark a particle as captured or not. This is the main loop that is circled on the figure. At the end, the particle distributions are compared.

To calibrate and test the model we input available parameters from one or more of our previous experiments to help us assess some parameters which are not scalable:

Input values

D	Diameter of the tube
L	Length of the tube
Vup	Upflow velocity
iterations	Maximum allowed number of iterations
t	The time step used in the calculations
Alpha	The angle of the plate settlers

Geometric factor	=2 for tubes and =1.5 for plates
Particles	Number of particles to run
dflocsp	Diameters of the flocs
dfrac	The fractal dimension

Output values

Position	A multi-array element of dimensions iterations x particles x 2. containing: (i) the iteration number, (ii) the particle number (iii) the r position inside the tube, (iv) the z position inside the tube.
Partpassed	A vector of the size of the particles that is reporting how many particles have not been captured

The Matlab code for this model is available and discussed in Appendix B – Dynamics model.

Results and Discussion

The PSS team uses Process Controller to gather real-time data for floc blanket and tube settler effluent. This uses a loading state and a withdrawal state for each tube to distinguish between usable and unusable data. Data is constantly collected; however, during the loading state, no water from the reservoir is sent to the turbidimeter. In the withdrawal state, a pump is turned on and sends water to the turbidimeter to collect usable data. During the data analysis, usable data is distinguished from unusable data by checking the time the method switched to the withdrawal states. This is a tedious procedure, so the team developed an excel macro detailed in Appendix A – An average PI-ratio and its implications

When computing the PI ratio, one assumes a worst case scenario where the particle with the lowest settling velocity is experiencing the value of the fluid velocity at its edge when it hits the bottom plate. We decided to compute another PI ratio which would include a "more optimistic" scenario.

In this scenario, the slowest settling floc would experience an averaged fluid velocity at its center, assuming that the particle can be approached by a spherical shape.

The result is the following PI ratio:

$$\Pi_{V.Average}(C_{Alum}, C_{Clay}, d_{fractal}, d_{tube}, v_{capture}, v_{up}, geometry) := \frac{V_t(C_{Alum}, C_{Clay}, d_{fractal}, d_0, d_{floc})}{V_{ParticleExperiencedAverage}(v_{up}, d_{tube}, d_{floc}(v_{capture}), geometry)}$$

With the average velocity taken as:

$$V_{ParticleExperiencedAverage}(v_{up}, d_{tube}, d_{particle}, geometry) := \frac{1}{d_{particle}} \cdot \int_{\frac{d_{tube}}{2} - d_{particle}}^{\frac{d_{tube}}{2}} V_{ratio}(geometry)\, v_{\alpha}(v_{up}) \cdot \left[1 - \left(\frac{r}{\frac{d_{tube}}{2}}\right)^2\right] dr$$

With these two PI ratios, we have a range of failure values that can confirm if a given spacing in a sedimentation tank with a given capture velocity will fail or succeed giving a target turbidity of less than 0.25 NTU.

For example, a tube settler of 1in in diameter and a length of 0.463m will have a capture velocity of 0.134mm/s for an up flow velocity of 1.155mm/s.

The worst case scenario PI ratio gives a value of 3.21 and the best case scenario PI ratio yields 6.412. Success is therefore expected in this case.

If one raises the upflow velocity to 5.774 mm/s, the worst case PI ratio gives 0.642 (failure due to floc rollup) while the best case PI ratio gives 1.283 (success). This means that it is not certain that failure will occur.

When both PI ratios are less than unity, it means that failure should occur.

Appendix B – Dynamics model

The matlab code will be available on the wiki page
https://confluence.cornell.edu/display/AGUACLARA/PSS+Dynamics+Model+page

Appendix C – Macro~~Appendix A – An average PI ratio and its implications~~. The macro checks the times from Process Controller State Log, which reports the times the program switched states, and searches through the data collected to isolate the usable data from withdrawal periods.

The data collected is analyzed by assessing the mean, relative error, and the number of outliers (points outside ±3 standard deviations). All the withdrawal intervals deemed acceptable based on those criteria are then averaged to yield the results in Table 3 below and graphically in Figures 5 - 7.

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Table 3. Results collected from the clay velocity gradient experiments.

Inner Diameter (mm)	Capture Velocity (mm/s)	Velocity Gradient (s^{-1})	Π.V	Tube Settler Effluent (NTU)	Floc Blanket Effluent (NTU)	Failure %
25.4	0.1	0.32	4.63	0.25	12.77	0.00%
15.875	0.1	0.5	2.9	0.25	11.27	0.24%
	0.1	1.01	1.45	0.22	9.26	0.43%
	0.1	2.52	0.58	0.37	10.43	1.57%
12.7	0.1	0.63	2.32	0.21	9.85	0.18%
	0.1	1.26	1.16	0.21	8.59	0.43%
	0.1	3.15	0.46	0.32	11.5	0.80%
9.53	0.14	1.15	1.37	1.21	10.63	9.43%
	0.14	2.27	0.69	0.29	12.13	0.41%
	0.13	5.63	0.28	0.41	8.07	3.12%
6.35	0.22	2.74	0.65	0.36	15.14	0.43%
	0.21	5.26	0.33	0.46	10.43	2.49%
	0.2	12.82	0.14	4.04	15.19	24.63%
6.434 (Aluminum)	0.10	12.92	0.118	3.74	11.15	31.58%

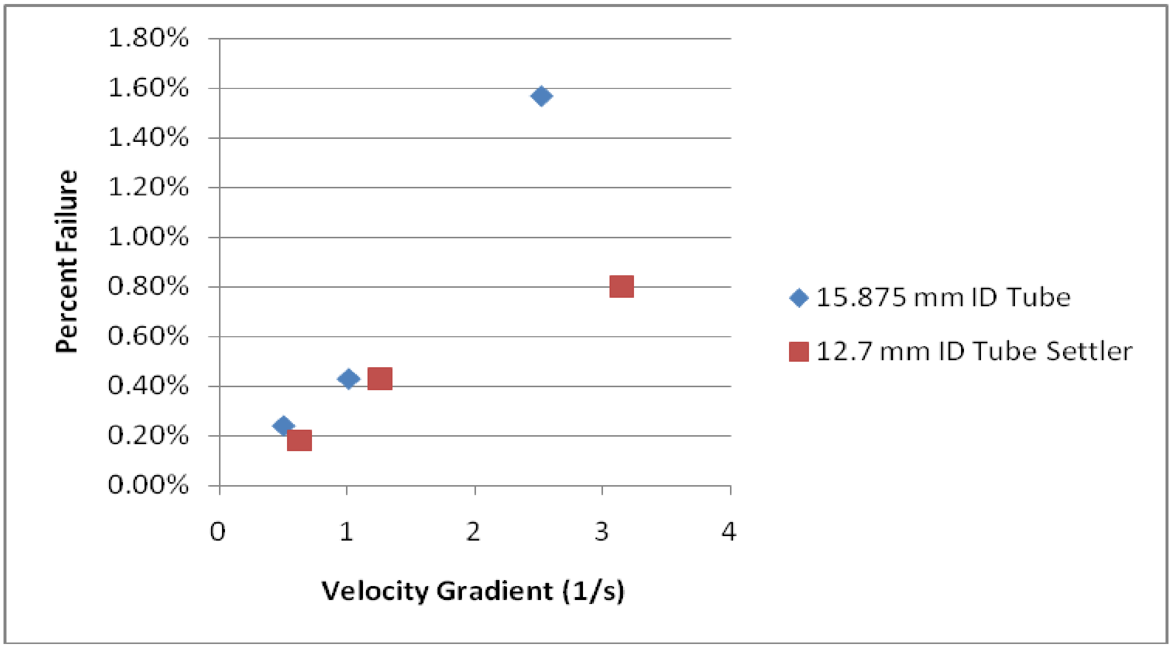

Figure 4~~5~~ - Graphical depiction of 15.875 mm and 12.7 mm ID tube results. These are deemed salvageable if the team fixes capture velocity at 0.1 mm/s.

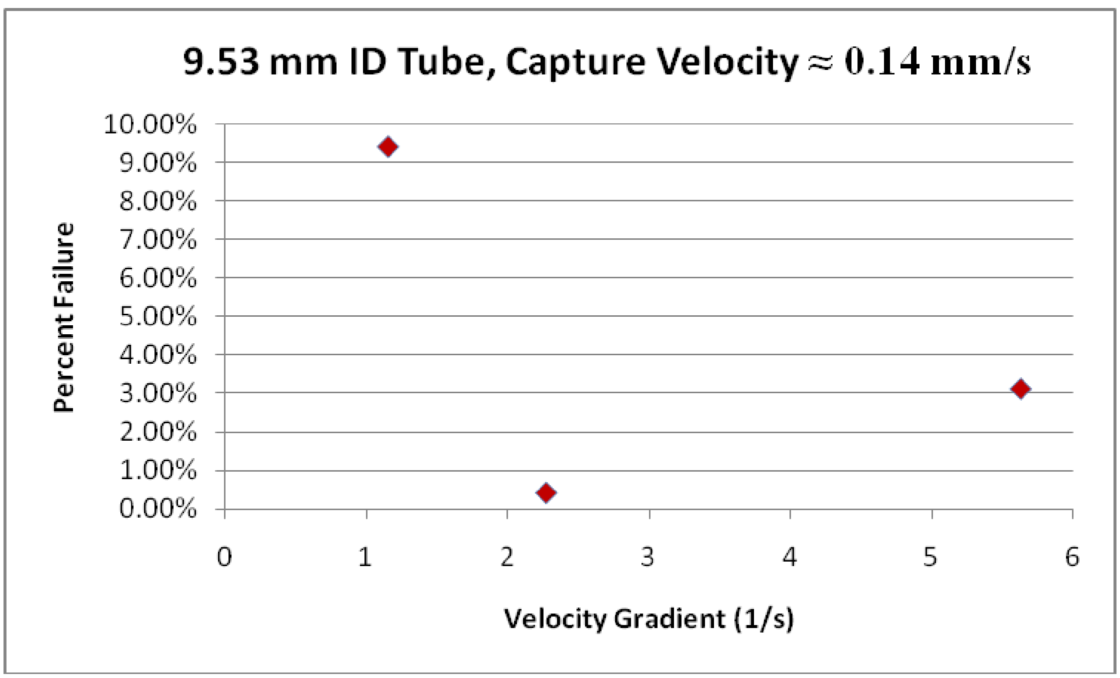

Figure 5~~6~~ - Depiction of just the 9.53 mm tube diameter. The trend is still surprising and may be due to ERB effects, but more data needs to be collected to see if this trend will recur with a capture velocity of 0.1 mm/s.

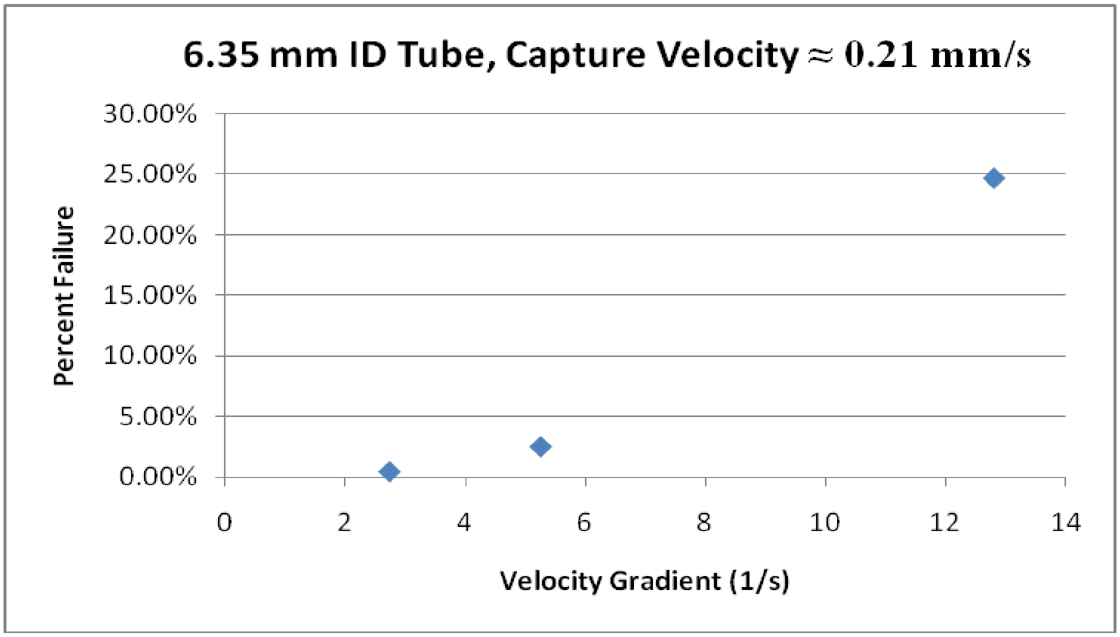

Figure 6~~7~~ - Graphical depiction of results from 6.35 mm tube. The trend fits the expectation that performance gets worse with increasing capture velocity.

The data in Table 3~~Table 3~~ includes the actual parameters for the tubes tested this semester. To reiterate, the team planned to hold the capture velocity constant at 0.12 mm/s and the tube trials were run with the notion that the tube geometries and associated flow rates would achieve this capture velocity. However, after running the trials, the team identified an error in the flow rate equation of the velocity gradient model that produced the parameters above.

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The 25.4 mm inner diameter (ID) control tube, the 15.875 mm (ID), and the 12.7 mm (ID) were run at a capture velocity of 0.10 mm/s. However, the 6.35 mm and 9.53 mm ID tubes had capture velocities in the range of 0.~~13~~10-0.22 mm/s. This means the team cannot make any meaningful comparisons across tube diameters with different capture velocities. To address this error, the team is planning to rerun the 6.35 mm and 9.53 mm ID tube sets with a 0.10 mm/s. The team determined the new tube parameters while keeping the tube length constant so no adjustments to tube geometry would have to be made (Listed in the Introduction in Table 1~~Table 1~~).

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As a result of this error, the team must re-run the tubes highlighted green in Table 3~~Table 3~~. The blue data can be salvaged since the associated capture velocity is 0.1 mm/s. However, the team believes that the data highlighted green may be used as supplementary information since within the tube trials, the capture velocities are effectively the same. That is, the 9.53 mm tube set effectively has a capture velocity of 0.14 mm/s, while the 6.35 mm tube set has a capture velocity of 0.21 mm/s. Because of this, the effects of the velocity gradient can still be observed for the 9.53 mm or 6.35 mm tubes independent of the larger tube diameters.

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Plate Settler Dynamics Model results and discussion

Before introducing any of the phenomena that could complicate the model, we decided to restrict the model to only account for:

1) A parabolic velocity profile.
2) Floc roll up condition at the edge of the floc.
3) An entrance region length where the velocity profile varies linearly over the distance starting as a uniform velocity profile and gradually expanding to reach the parabolic profile.

The following figures (See Figures 8 – 11) show the current results of the dynamics model and indicate obvious problems.

Error! Reference source not found.~~Figure 8~~ shows the output of the particles paths inside the tube when all the particles start from the top of the tube (the worst case scenario). The values have not been tested in the lab. Some of the particles are not captured, while others are carried out into the effluent water. The paths are describing the particles centers. **Error! Reference source not found.**~~Figure 9~~ and Figure 9~~Figure 10~~ show the effect of a change in the fractal dimension: in **Error! Reference source not**

found.~~Figure 9~~ the fractal dimension is 2.3 and in Figure 9~~Figure 10~~ the fractal dimension is set as 3 (flocs are hard spheres). Figure 10~~Figure 11~~ shows the output for a tube which is supposed to capture all particles. However, the results from the dynamics model show all the flocs being carried out into the effluent. This is evidence that the model needs to be revised before including more complex processes.

All the figures plot the results for 10 particles with different diameters. For all graphs the y-axis is the radius with centerline at r=0, and the z-axis is the length of the tube with z=0 as the entrance of the tube.

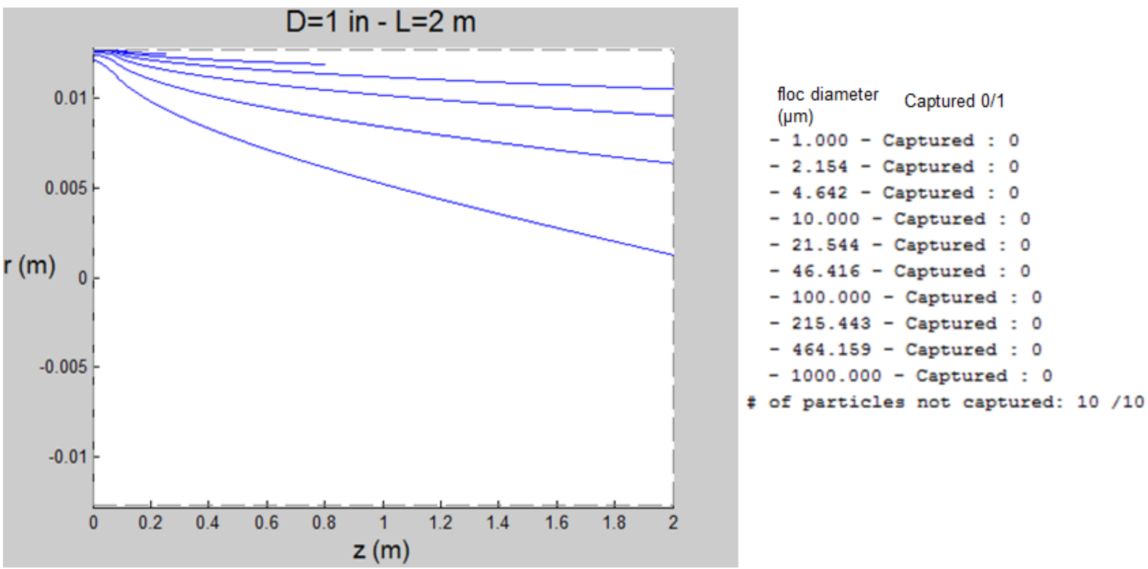

Figure 7~~8~~ - Particle paths and the resulting output for a tube with "non-realistic" parameters (i.e., the particle size distribution is ranging from a micrometer to 1 mm in diameter and we never used a ¼" diameter tube with such a length in our experiments). The particle paths show that some particles have been captured because flocs move towards z=0 after hitting the wall, while some are carried out by the effluent.

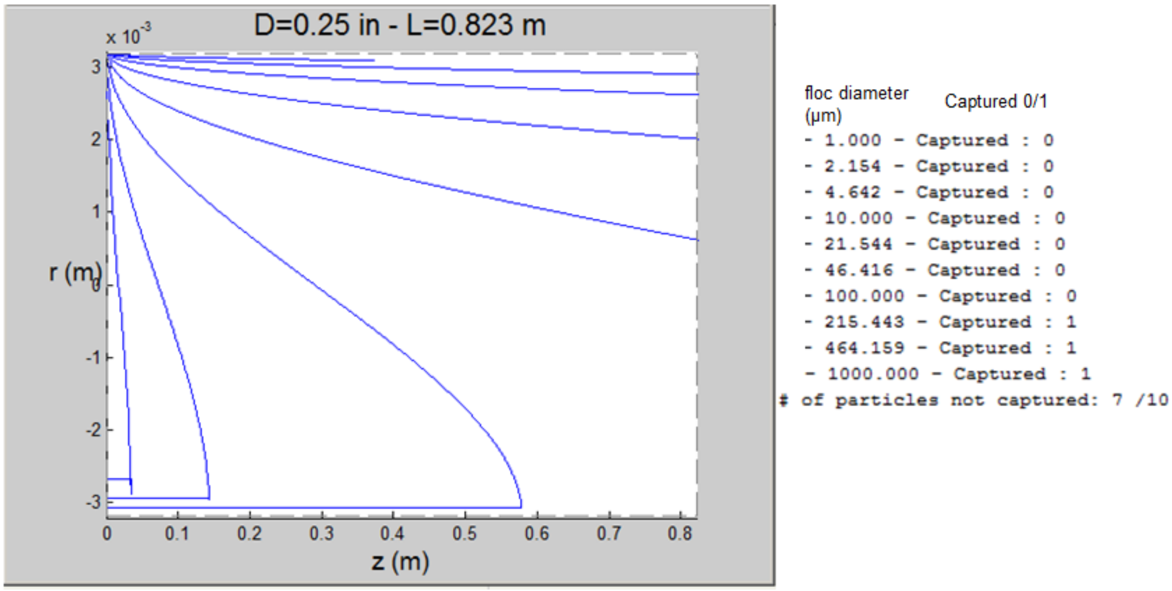

Figure 8~~9~~ - Same comments as in the previous figure. But here we show a case where the fractal dimension is 2.3. We clearly see that no particles are captured.

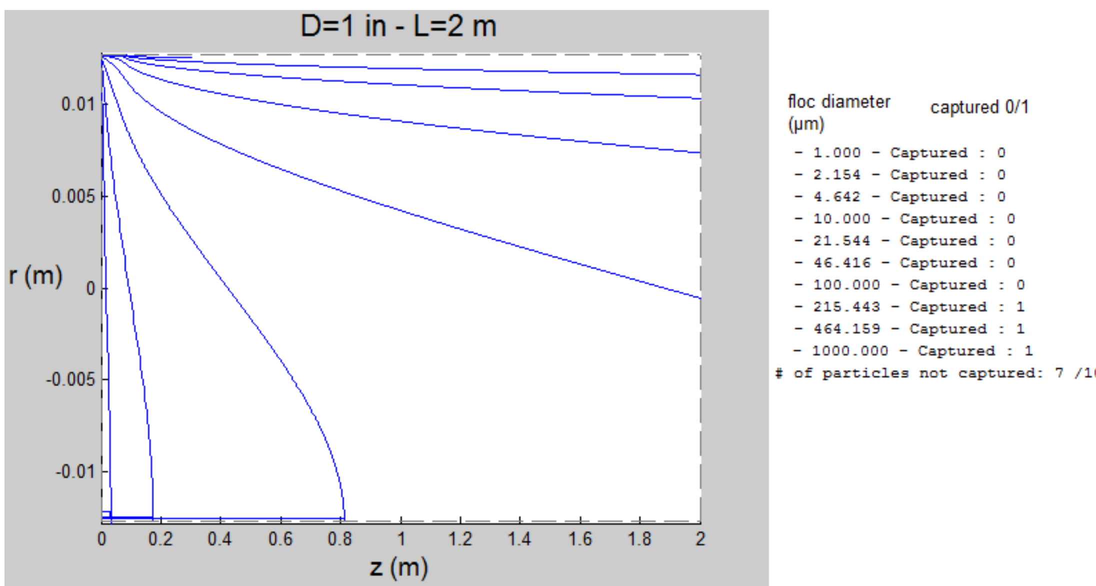

Figure 9~~10~~ – Same comments as for except that the fractal dimension has been set to 3. We see that some of the particles are captured; however, the “hard sphere” assumption corresponding to a fractal dimension of 3 is not realistic.

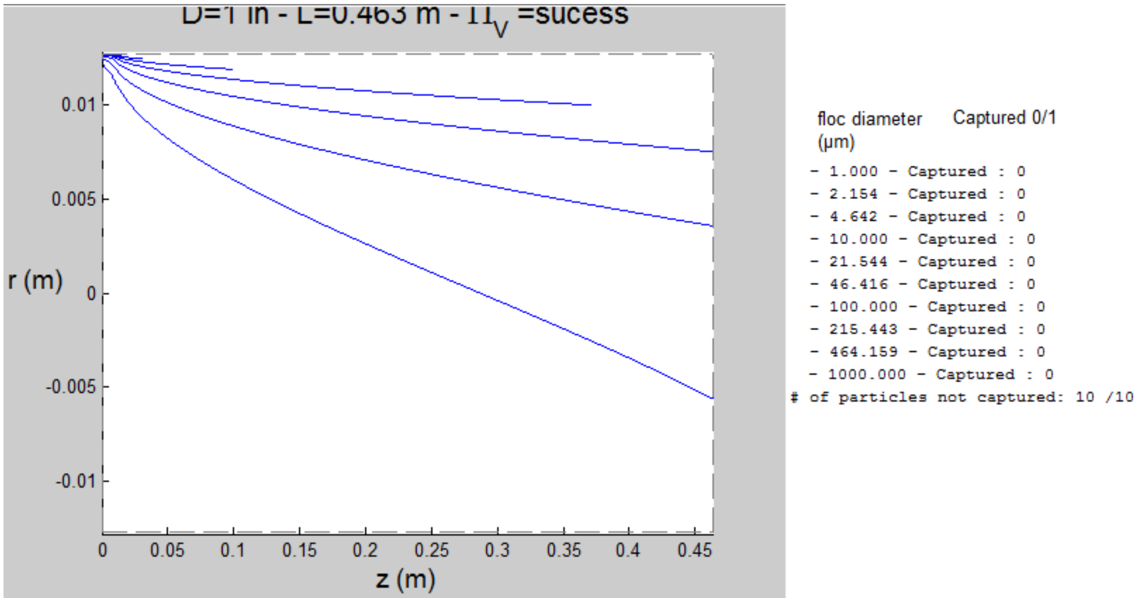

Figure 10~~11~~ - An attempt to simulate the particles paths into a tube settler that is supposed to show successful performance. The PI ratio for this case is greater than one and the simulation is supposed to mimic the experimental results. All particles are carried out into the effluent water instead of hitting the bottom plate and rolling down. This graph shows that the code needs revision since the results are completely counter to what we would expect in lab.

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Future Work

In terms of lab work, the team needs to rerun the 6.35 mm and 9.53 mm ID tubes for the velocity gradient clay experiment at a capture velocity of 0.10~~3~~ mm/s. The team should definitely review all calculations performed at the beginning of next semester to make sure there is no error in either materials documentation or the model itself. The Fall 2010 team has not seen any errors in the Velocity Gradient Model, but checking these calculations would minimize the possibility that any errors existing actually make it through to the published paper. Because of the documentation error, the team plans to interconnect the Excel materials spreadsheet and the MathCAD velocity gradient model in order to minimize the likelihood of error in transferring information.

After rerunning the 6.35 mm and 9.53 mm, the team should focus on running the velocity gradient experiments with an aluminum hydroxide and natural organic matter (NOM) system to test the field feasibility of closely spaced plate settlers. The expectation is that due to the decreased density of the floc particles, roll-up will be much more significant and performance effluent turbidities worse than those listed in Table 3.

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Model

The numerical model is not able to mimic experimental results even by considering extremes cases for the velocity gradient. The model actually predicts that all the experiments we have conducted so far would fail.

However, the particles paths are following curvy paths and an increase in fractal dimension improves the number of captured particles. Floc roll up can also occur. The problem is that, in order to get the experimental solutions, one should input an upflow velocity of at least 1/ 10 of the real upflow velocity.

It is therefore important to first look again at the values used to compute the particles paths before trying to implement more complex mechanisms. Once this is problem is solved, the mechanisms which should be coded are:

- Floc breakup calculation based on local shear experienced by the particle as it is falling down.
- Find an easy way of modeling how the particles affect the local velocity profile while rolling down and may enhance the performance by decreasing the velocity experienced by a particle downstream or increasing it and see how this affects the performance.

Once the model will be able to predict failure or success of a plate settler spacing it could be set so that, for a given particle distribution, the model can predict the order of magnitude of the effluent turbidity and thus set the dimensions of a sedimentation tank given a capture velocity and a target spacing effluent turbidity.

Team Reflections

The biggest setback to the team occurred this week when the documentation error was found. The data collected may still be salvageable and used as supplementary material in the paper; however, the team needs to further evaluate whether that would be appropriate. Otherwise, most of the team's issues result from just lack of existing knowledge about processes occurring in plate settler systems. For example, there is little information on the interplay of shear flocculation and floc breakup and their effect on the particle distribution. Additionally, there is little information on how floc blankets affect the particle size distribution leaving the flocculator. If this information cannot be found after an extensive literature search, the team must find a way around this and develop surrogate means of quantifying these processes.

Also, the PSS team feels like the Reflection Reports seriously detract from the time the team has to work in lab and on modeling projects. The team feels like considering the length and detail required for these reports, they should be monthly reports instead biweekly. The biweekly reports give the team too little time to make any significant progress with almost half the time going into reflection report formulations. A monthly would make each document more of a stand-alone report that references previous reflection reports but is not too heavily dependent on it since each report will be able to incorporate more new information. The team feels like monthly reports would be a "more bang for your buck" approach. That is, there would be much more valuable information for the time investment going into each report. At this point, we are required to reiterate the theory and procedure for every report even when little progress is made and the formulation of the experiment were reported just two weeks prior. This would be fine if the reports were not due every two weeks. In terms of progress indicators, the team suggests putting more weight on meeting minutes or a one page summary that would be just for the team and team leaders to keep track of their own progress until reports are due. Either that or it may be profitable for each team to have biweekly 20-30 minute progress meetings with Monroe or the team leader. The team does find these reports very valuable for spreading information in laymen's term so we would like to keep them; however, we feel that the format and expectations are too much for a biweekly report.

Appendix A – An average PI-ratio and its implications

When computing the PI ratio, one assumes a worst case scenario where the particle with the lowest settling velocity is experiencing the value of the fluid velocity at its edge when it hits the bottom plate. We decided to compute another PI ratio which would include a “more optimistic” scenario.

In this scenario, the slowest settling floc would experience an averaged fluid velocity at its center, assuming that the particle can be approached by a spherical shape.

The result is the following PI ratio:

$$\Pi_{V.Average}(C_{Alum}, C_{Clay}, d_{fractal}, d_{tube}, v_{capture}, v_{up}, geometry) := \frac{V_t(C_{Alum}, C_{Clay}, d_{fractal}, d_0, d_{floc})}{V_{ParticleExperiencedAverage}(v_{up}, d_{tube}, d_{floc}(v_{capture}), geometry)}$$

With the average velocity taken as:

$$V_{ParticleExperiencedAverage}(v_{up}, d_{tube}, d_{particle}, geometry) := \frac{1}{d_{particle}} \cdot \int_{\frac{d_{tube}}{2} - d_{particle}}^{\frac{d_{tube}}{2}} V_{ratio}(geometry) \, v_{\alpha}(v_{up}) \cdot \left[1 - \left(\frac{r}{\frac{d_{tube}}{2}}\right)^2\right] dr$$

With these two PI ratios, we have a range of failure values that can confirm if a given spacing in a sedimentation tank with a given capture velocity will fail or succeed giving a target turbidity of less than 0.25 NTU.

For example, a tube settler of 1in in diameter and a length of 0.463m will have a capture velocity of 0.134mm/s for an up flow velocity of 1.155mm/s.

The worst case scenario PI ratio gives a value of 3.21 and the best case scenario PI ratio yields 6.412. Success is therefore expected in this case.

If one raises the upflow velocity to 5.774 mm/s, the worst case PI ratio gives 0.642 (failure due to floc rollup) while the best case PI ratio gives 1.283 (success). This means that it is not certain that failure will occur.

When both PI ratios are less than unity, it means that failure should occur.

Appendix B – Dynamics model

The matlab code will be available on the wiki page
https://confluence.cornell.edu/display/AGUACLARA/PSS+Dynamics+Model+page

Appendix C – Macro

A macro has been developed to help us deal with our experimental data. This macro enables us to select the data that is relevant during tube runs. Our apparatus sends the collected data into a separate spreadsheet than the one where it writes the times it changed states. In order to recover the rows which were corresponding to a withdrawal state (the state when the effluent pump pumps water through the turbidity reader), we need to scroll down into the spreadsheet to find the closest time which correspond to the data we need. To avoid spending huge amounts of time doing this, a macro has been written in the experimental template file. The macro is commented and explained below:

```
' **Macro for helping finding row numbers corresponding to the nearest time 'the system started taking data **
Sub macrotest()'The name can be changed of course !

'Declaring  some of the variables
Dim StateInfo, DataPts As String
Dim StateInfoCol, WithdrawalTCol, n, m, trt As Integer
Dim watcher As Boolean

'Name of the sheet where the state information is:
StateInfo = "State Information"
' The number corresponding to the column number where the state information is written:
StateInfoCol = 11
DataPts = "Withdrawal Interval Data" 'Name of the sheet where the data is copied
WithdrawalTCol = 1 'Column number where the times are written


n = 2 'Starting point Row in Stateinfo
m = 2 'Starting point Row in Withdrawal data sheet
' m is giving the row value of the corresponding time
cellnum = Worksheets(StateInfo).Cells(n, StateInfoCol).Value

While cellnum <> "" 'this is equivalent as checking that the cell is not empty
'Rough Error break part:
If n > 10000 Then 'change 10000 to a greater number if you have more states
MsgBox ("an error occurred because the macro detected too many state changes")
Stop
End If
```

```
  If n > 2 Then
   watcher = CheckChange(n, StateInfoCol, StateInfo) 'True if PM/AM change occurred in the data. The macro subroutine function is given in this file
  End If

  If watcher Then 'If a time change has been detected
  ' MsgBox (watcher) -> uncomment this line to check the bool value

  While (newcellnum > 0.5) 'go down to the new day cell
  m = m + 1
  newcellnum = Worksheets(DataPts).Cells(m, WithdrawalTCol).Value
  Wend
  End If

  newcellnum = Worksheets(DataPts).Cells(m, WithdrawalTCol).Value

  'If Not watcher Then '->if no change state has been detected
  While (cellnum > newcellnum) 'just find the nearest time cell
    newcellnum = Worksheets(DataPts).Cells(m, WithdrawalTCol).Value
    m = m + 1
  Wend

  Worksheets(StateInfo).Cells(n, 10) = m 'The value of the row is given in the State info sheet on the left of the time the system changed state
  Worksheets(StateInfo).Cells(n, 9) = newcellnum 'writes the time corresponding to that row
  n = n + 1 'be prepared to write down the next value
  cellnum = Worksheets(StateInfo).Cells(n, StateInfoCol).Value

Wend

MsgBox (n - 1) 'displays a message box with the number of state changes counted

End Sub

' **The check change subroutine function**
Function CheckChange(ByVal row As Integer, ByVal col As Integer, ByVal shname As String) As Boolean
Dim tfvar As Boolean 'The variable that is going to be true if a change in AM/PM occured
tfvar = False 'By default, it is assumed that there is no day change
CheckChange = False
```

```
If row > 2 Then        'Because it does not make sense to compute it for n=2 since a change will be detected
    cellNext = Worksheets(shname).Cells(row, col).Value
    cellPrev = Worksheets(shname).Cells(row - 1, col).Value

    If cellNext < 0.5 And cellPrev > 0.5 Then 'This is the most important part :-)
        tfvar = True
    End If
End If
CheckChange = tfvar 'Now CheckChange is assigned with the value of tfvar

End Function
```