Dashboard / … / Plate Settler Spacing

PSS Spring 2010 Coupling Analysis Experiment

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Coupled Capture Velocity & Velocity Gradient

Floc roll-up occurs in tube settlers when the torque caused by a differential in the velocity profile exceeds the force of gravity whereby particles fall back out into the sedimentation basin. The Plate Settler Spacing team hypothesized that holding the length to diameter ratio in tubes of different diameters constant at 20 would decrease the capture velocity's sensitivity to flow rate. Two diameters representing the extremes in lamella spacing (23.5 mm and 6.35 mm) were tested in this experiment. Each experiment was run with the tube settler at two different heights (1.3 cm and 2.7 cm) above the floc blanket-clear water interface.

Initially the team tried to visualize velocity gradient failure by slowly incrementing the flow rate through the 15.35 mm diameter tube until what appeared to be roll-up occurred. This happened around a velocity gradient of 12 1/s. The team then used this value as a mean velocity gradient and bracketed it with three equally spaced values lower and higher to generate a reasonably wide range for experimentation (6, 9, 12, 15, and 18 1/s were tested). In order to calculate the flow rates associated with these velocity gradients, the team needed to find a relationship between the volumetric flow rate and the velocity gradient established in the tubes.

This relationship was derived in the following way:

First, begin with the description of the velocity profile for laminar flow in a cylindrical tube set at a vertical angle alpha:

$$v_z = \frac{1}{4\mu \sin\alpha}(\frac{\partial p}{\partial z})(r^2 - R^2)$$

Here, mu is the kinematic viscosity of the fluid flowing through the tube (in this case, water), dp/dz represents the pressure difference across the tube, R is the tube radius, and small r represents the distance between the tube center and the position of itnerest. The key is to determine a relationship that eliminates this pressure term in the equation.
We know that the flow rate can be defined as:

$$Q = \frac{-\pi R^4}{8\mu}\left(\frac{\partial p}{\partial z}\right)$$

Solving this equation for the pressure differential and inserting the term v ratio (equal to 2 for tubes) gives:

$$(\frac{\partial p}{\partial z}) = \frac{-4 v_{ratio}\mu Q}{\pi R^4}$$

This can then be plugged into the velocity profile equation to yield, after simplification:

$$v_z = \frac{v_{ratio} Q}{\pi R^4 \sin\alpha}(R^2 - r^2)$$

The differential of this velocity with respect to the position within the tube gives the velocity gradient:

$$\frac{\partial v_z}{\partial r} = \frac{-2 v_{ratio} Q}{\pi R^4 \sin\alpha} r$$

This term can be simplified by substituting V alpha, which represents the average velocity through the cylindrical tube.

$$\frac{dv_z}{dr} = \frac{-2v_{ratio}V_\alpha}{R^2}r$$

It is important to note that the profile only depends on the tube radius, the flow rate, and r, the distance from the tube wall, which corresponds to the tube radius minus the diameter of the floc particle of interest.The velocity gradient can either be analyzed in terms of the specific radial position of a particle in the tube, or in terms of the velocity gradient that all particles experience at the tube wall. This term corresponds to the previous equation evaluated at the tube wall:

$$\frac{dv_z}{dr} = \frac{-2v_{ratio}V_\alpha}{R}; \quad r = R$$

Results and Discussion

As mentioned in the experimental methods, five velocity gradients (6, 9, 12, 15, 18 1/s) were tested for two tube diameters; 6.35 mm and 15.3 mm. For each of these tubes, two placements of the tube settler were also tested; 1.3 cm and 2.7 cm above the floc blanket. These placements were designated as "low" and "high" heights, respectively, in the following analysis. The team only had a certain amount of flexibility in terms of where the entrance to the tube settler could be placed in the sedimentation column, and thus chose only to look for qualitative differences between the results obtained for experiments at these two different heights.

15.3 mm Diameter Tube

For the 15.3 mm tube, the team collected usable data from five out of six runs performed with the tube settler placed at the low height placement and for three runs at the high height placement. Figures 1a. and 1b. below are graphs of the tube settler effluent turbidity against velocity gradient for the low and high height runs, respectively.

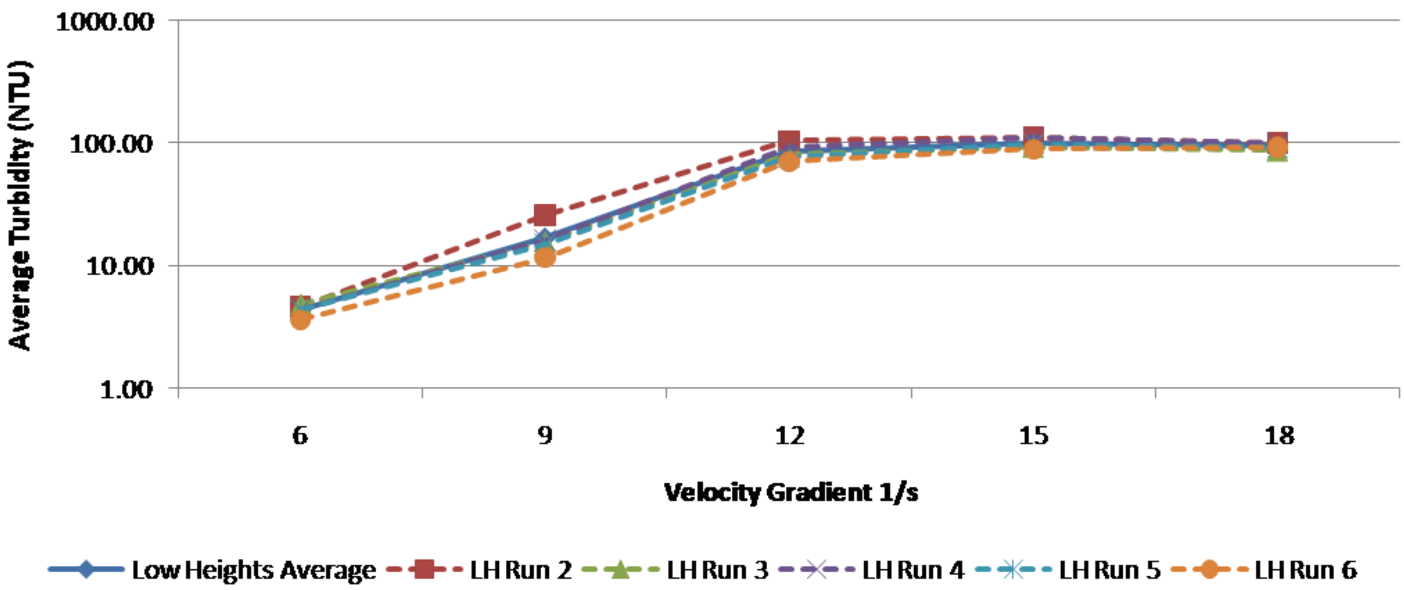

Figure 1a., Average Turbidity vs. Velocity Gradient for the 15.35 mm tube diameter, low height

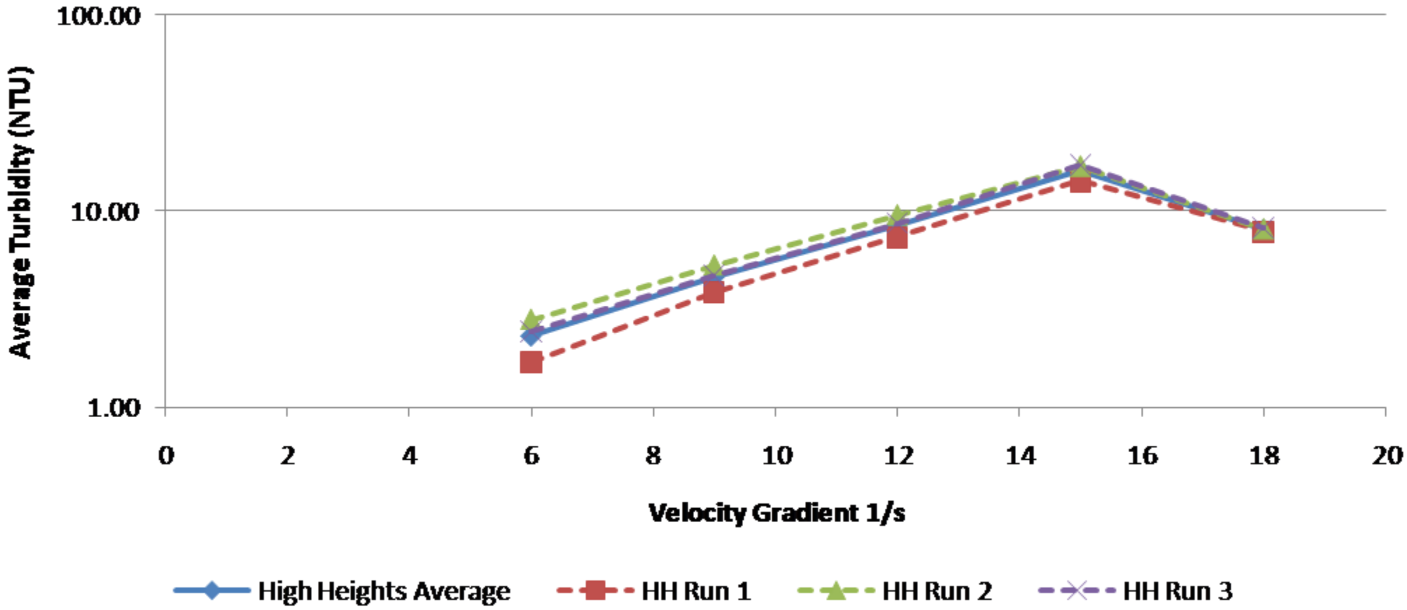

Figure 1b., Average Turbidity vs. Velocity Gradient for the 15.35 mm tube diameter, high height

Comparing these two figures, we see that only a slight difference in the placement of the tube relative to the floc blanket results in a large difference in effluent turbidity. While the team originally postulated that failure would occur at the 12 1/s velocity gradient and beyond, the results from Figures 1a,b indicate failure (defined as effluent turbidity above 1 NTU) for all velocity gradients tested. To shed light on this development, the capture velocities associated with the tested velocity gradients were calculated and the effluent turbidity was plotted against these capture velocities in Figures 2a and 2b below.

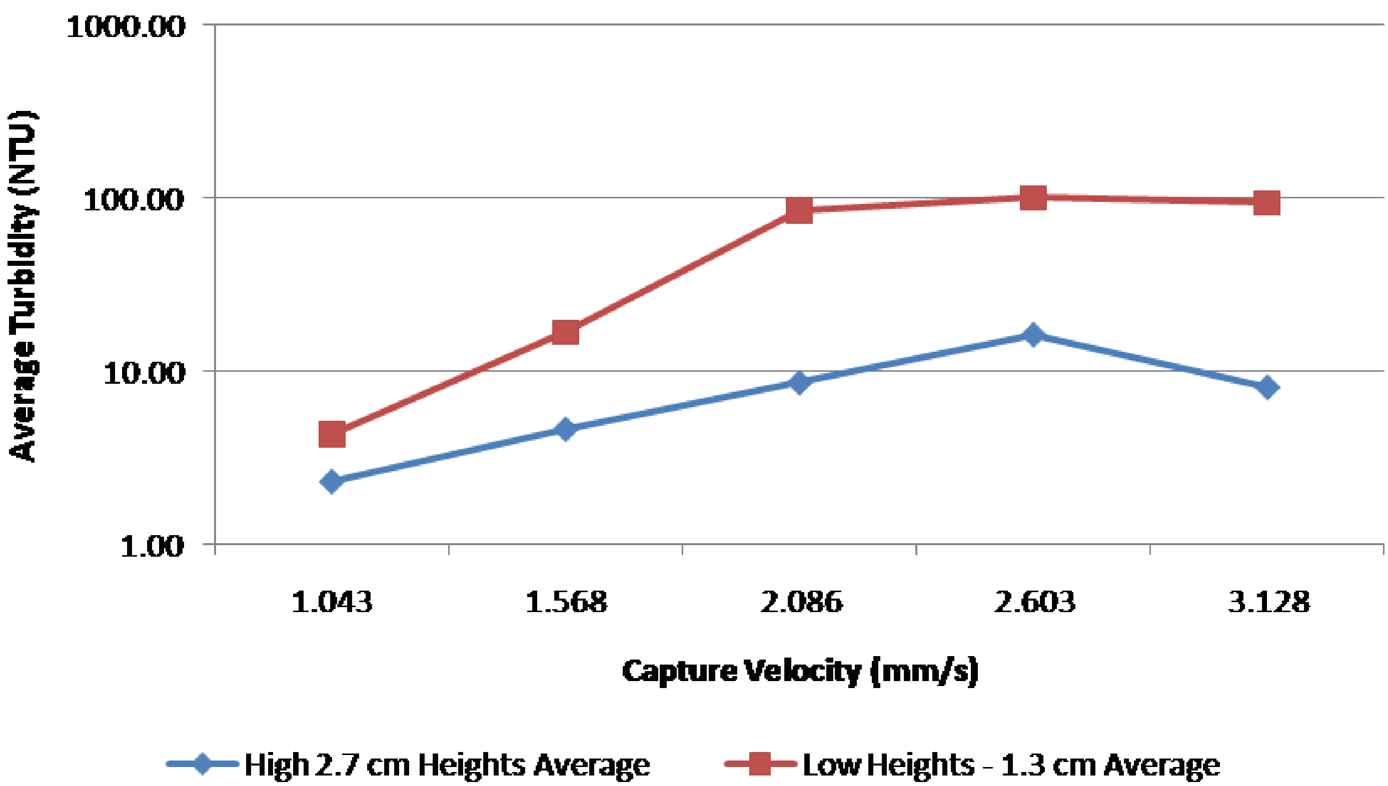

Figure 2., Average Turbidity vs. Capture Velocity for the 15.35 mm tube diameter at low and high heights

The capture velocities depicted in Figure 2 explain the poor performance measured for the runs. AguaClara plants operate with a capture velocity of 0.12 mm/s, while the capture velocities used in the experiments are about 9-27 times greater than those used in plants. The trend in the effluent turbidity depicted in both Figures 1 and 2 are consistent with the performance expected in this range of capture velocities. The turbidity generally increases before leveling off. From the data, we can postulate that the average settling velocity of the particles fall between 1.568 mm/s and 2.086 mm/s. Above this average settling velocity, the bulk of the particles would be pulled up into the effluent without settling. The "peak" observed in the high height line in Figure 2 is the best evidence for this idea. If the majority of particles fall within the range of terminal velocities given above, the largest effluent turbidity will occur at a flow rate that corresponds to a capture velocity that is also in this range. The reason is that while we increment flow rate, we slowly increase the upward forces experienced by particles in the settler. This leads to an accumulation of the most prevalent particles in our distribution (those with terminal velocities in the range given) within the settler. Therefore, once a certain "threshold" is exceeded, this entire suspension will be carried to the effluent. This "threshold" corresponds to the largest effluent turbidity because as we are incrementing flow rate, we are giving the system a lot of time to accumulate the most prevalent particles in the suspension within the sedimentation column. At no other time during these experiments were so many particles accumulating for such a considerable period; hence the "peak" at the threshold. This shows that the greatest weakness in our first round of experiments is distinguishing between which parameter contributes more to failure; capture velocity or velocity gradient. In subsequent experiments we must ensure that capture velocity has no contribution to any failure that may be observed. This means that we must fix capture velocity at values that would theoretically never lead to residual turbidities above 1 NTU while varying velocity gradients in our experiments. Other significant conclusions to be drawn from our inital experiments concern the height of the influent to the settler with respect to the top of the floc blanket.Comparing the results from the high height runs to the low height runs, it can be seen that the average effluent turbidity increases as the tube is placed closer to the floc blanket. The significance of this understanding is discussed further in the conclusions section below.

6.35 mm Diameter Tube

For the 6.35 mm tube, multiple runs were performed; however, the collected data suggested a problem with the 6.35 mm tube experiments. Figure 3 below is a graph of the average effluent turbidities against velocity gradients for both the low and high placements of the tube settler.

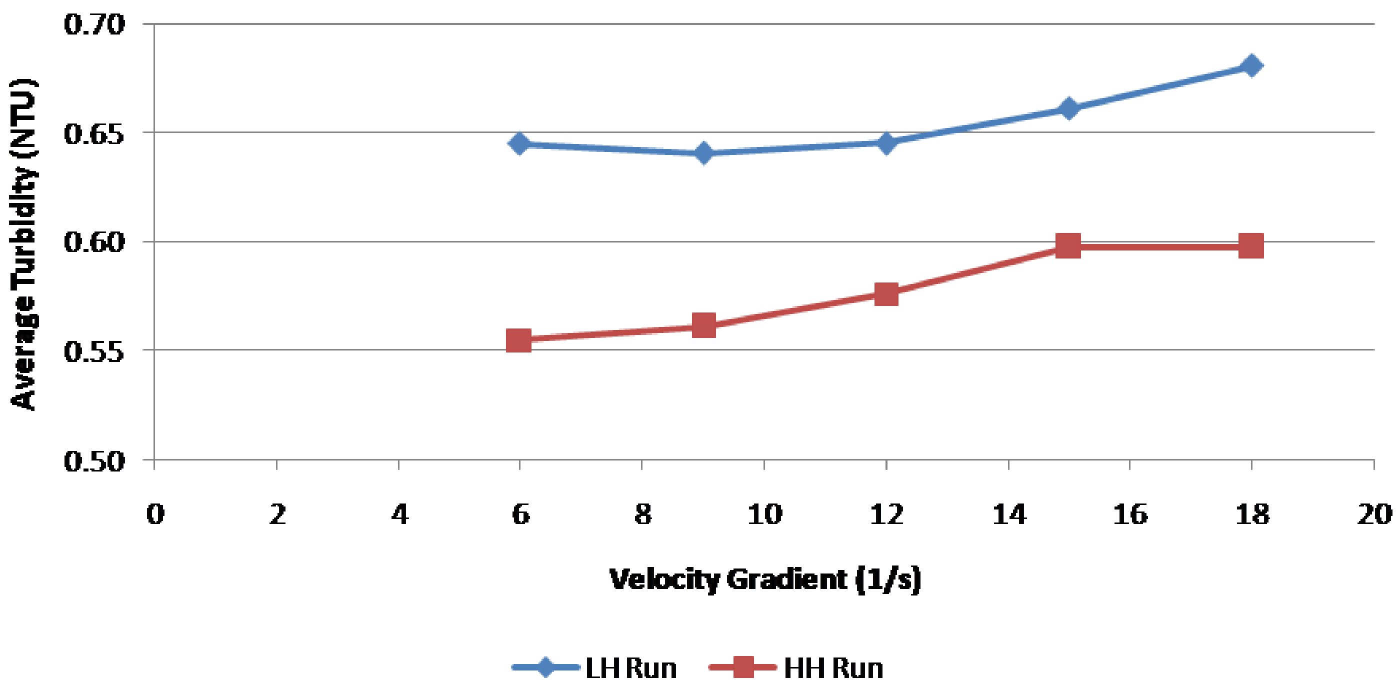

Figure 3., Average Turbidity vs. Velocity Gradient, 6.35 mm diameter tube; low height, high height

The blue line in Figure 3 represents the low placement of the tube settler and the red line, high placement. The trend holds that the effluent turbidity increases as the tube settler is placed closer to the floc blanket. However, Figure 3 indicates that for all velocity gradients, no failure occurred in the 6.35 mm tube. All effluent turbidities were below 1 NTU. The team's original hypothesis was that failure would occur at the 12 1/s velocity gradient and beyond. As in the 15.3 mm tube, the capture velocities corresponding to the velocity gradients used in the 6.35 mm tube were calculated. The results shown for the two tube sizes do not seem to show the same physical phenomena; the "peak" in the graph explained for the 15.3 mm tube is not observed in the results of our experiments on the 6.35 mm tube. This is further evidence that more parameters must be held constant in order to compare the effects of velocity gradients on effluent turbidity for different trials. However, the fact that similar values of capture velocity were tested in the two different tube sizes means that we need to do more than just fix capture velocity in future experiments. Figure 4 below is a plot of the effluent turbidity from the 6.35 mm against the capture velocities used in the experiments.

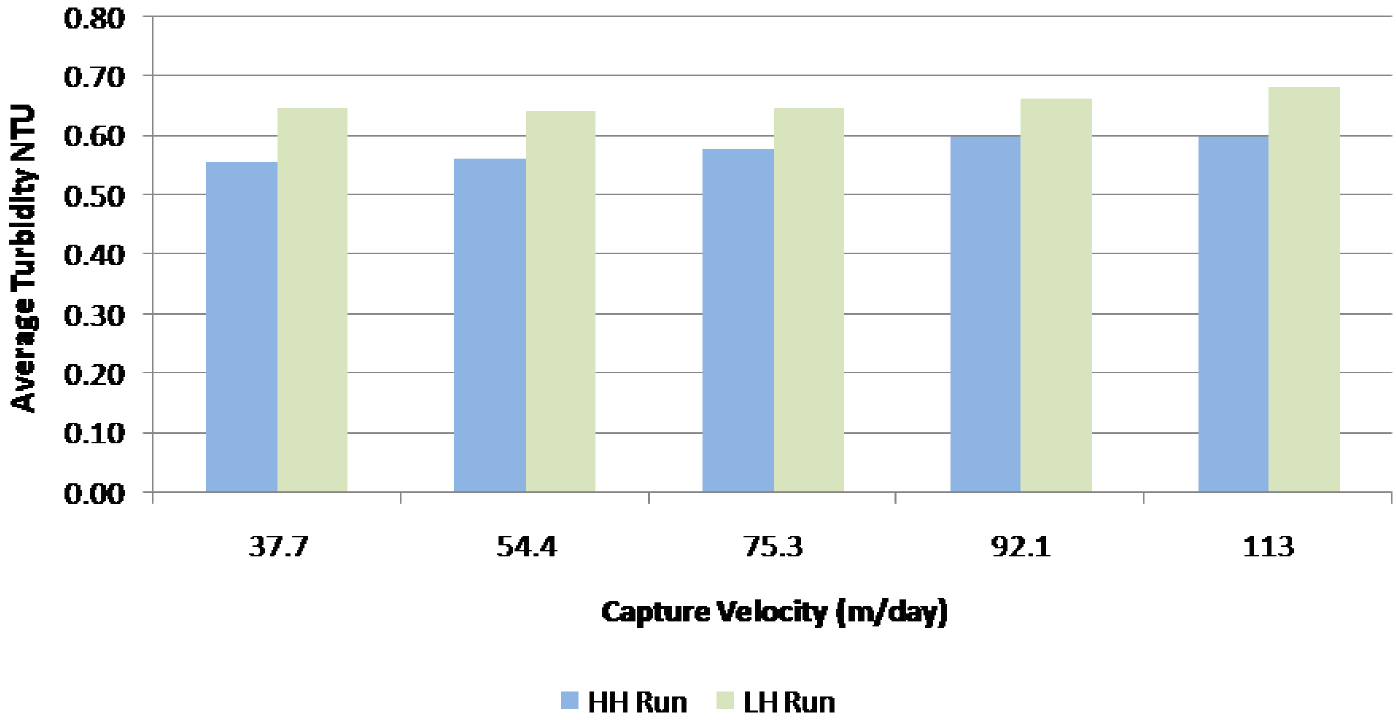

Figure 4., Average Turbidity vs. Velocity Gradient, 6.35 mm diameter tube; low height, high height

Figure 4 indicates capture velocities that are 3-10 times greater than those used in AguaClara plants. With this understanding, the results for the 6.35 mm tube experiments do not make sense. If failure is not occurring, the only parameter that should be affecting performance is the capture velocity. Figure 5 below is a comparison of performance due to capture velocity between the 6.35 mm and the 15.3 mm tube.

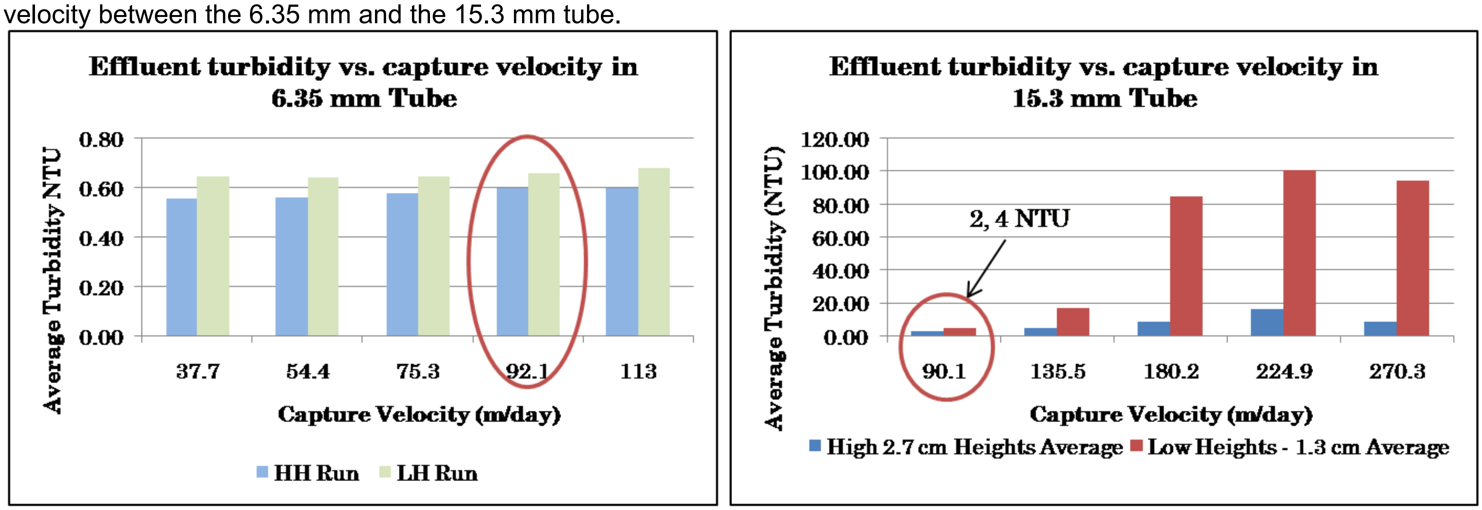

Figure 5., Comparison of Performance Due to Capture Velocity between 6.35 mm and 15.35 mm diameter tubes

Because the two capture velocities circled in Figure 5 are fairly similar, similar performance was expected. However, it can be seen that the measured turbidity between the two capture velocities were significantly different. Due to this observation, the team believes that the flow rates used in the 6.35 mm tube experiments were too low, resulting in a long residence time of the effluent in the turbidimeter. The long residence time might allow floc particles to settle out in the turbidimeter vial creating a clear effluent zone that may result in readings that underestimate the effluent turbidity.

Conclusion

Analysis of the data resulted in three realizations that were pertinent to team's future experimental plans. The first was that the main failure of the experiments was that the capture velocities were too high, resulting in poor performance and making it impossible to test for rollup. For future experiments, the team plans to fix capture velocity at 10 m/day for all tubes tested to ensure adequate performance so that performance deterioration due specifically to floc rollup can be observed. Secondly, the team observed that effluent turbidity readings increased as the tube settler was placed closer to the floc blanket. The team postulated that the effects of floc rollup would be better observed when the tube settler is placed closer to the floc blanket since the magnitude of failure would be greater. Lastly, the team observed inaccurate data collection in the small diameter tube possibly due to flocs settling out in the turbidimeter as a result of very low flow rates. In order to address this issue, the team plans to test the flow rates used in the small tube with unflocculated 100 NTU water. Readings less than 100 NTU in the effluent turbidimeter would be indicative of particle settling in the turbidimeter. Since clay has a slower settling velocity than floc particles, the effects of particle settling would be magnified for floc particles. If settling proves to be a problem, the team plans to bundle small tubes to increase the total flow to the turbidimeter, while still being able to maintain low flow rates in individual tubes.

No labels