PSS Spring 2010 Velocity Gradients Experiment

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Velocity Gradient Experiment

Introduction

Stepping from previous research with velocity gradients, this experiment seeks to uncouple their effects on tube settler performance deterioration from those of the capture velocity. In the team's last experiments (detailed in Exploring the Coupled Effects of Capture Velocity on Settler Performance), it was hypothesized that maintaining a constant length to diameter ratio in tube settlers would minimize the effects of the capture velocity on performance.

The results showed that at a length to diameter ratio of 20, high capture velocities contributed significantly to poor settler performance at high flow rates. This can best be explained by the fact that at high capture velocities, our settlers fail to eliminate a large portion of the floc particles generated in our floc blanket system from the effluent stream. The flocs exist in this system in a wide range of densities and settling velocities, in a distribution that is currently unknown.

After considering these results, the team decided to allow the length to diameter ratio to change in order to keep the capture velocity constant among tubes of different diameters. A range of tube diameters (1", 1/2", 3/8", 1/4") was chosen based both upon available material and the fact that these diameters represent a reasonably applicable range for AguaClara spacing values. The team's original plan was to fix capture velocity at 0.12 mm/s because it corresponds to the value currently used in AguaClara plants; however, erroneous calculations resulted in the team fixing capture velocity at 0.1 mm/s. The flow rate equation listed below is the correct equation used to calculate the flow rate through the tube given a length, diameter, and capture velocity. When the calculations were originally done for a 0.12 mm/s capture velocity, the wrong equation to calculate flow rate was used. The team has adjusted the parameters for this experiment. The following parameters and methodology was used to design the experiment.

Starting from a capture velocity of 0.1 mm/s, the team chose to test three different up-flow velocities: 0.86, 1.73, and 4.32 mm/s. The first value is that currently used by AguaClara, and the range represents a considerable spectrum of flow rates, and thus velocity gradients, experienced in the tube settlers. The velocity of the influent water increases as it enters the settlers due to hydraulic contraction, and this is a velocity of interest to the team since it also represents the average flow rate through the settler, taking into account also its angle of inclination. These values for this experiment are: 1, 2, and 5 mm/s, and can be calculated from the following relationship:

$$V_\alpha = \frac{V_{up}}{\sin\alpha}$$

Failure is defined as Π V, the ratio of the average floc's settling velocity (a function of both the capture velocity and the floc's density, and thus also a function of the flocculation process), to the velocity experienced by the particle at its diameter exposed to the effluent stream. Particles on the bottom wall of the settler that experience a higher velocity at their exposed edge than the velocity at which they settle out of the tube will experience a torque upwards that causes them to exit with the effluent. Thus when Π V is less than one under specific circumstances, roll-up is expected to occur. A value of unity suggests an equilibrium point where roll-up may or may not occur.

The procedure to calculate the required lengths for tubes is as follows:

1. Choose a range of tube diameter (1" ½" 3/8" ¼") based on available materials and to ensure a good range of spacings.
2. Fix capture velocity at 10 m/day based on the value used for AguaClara plants
3. The team used the following relationship for Vα to find the necessary length for each tube diameter required to achieve average velocities of 1.04 mm/s, 2.31 mm/s, and 5.77 mm/s.

$$\frac{V_\alpha \sin(\alpha)}{V_c} = \frac{L}{S}\cos\alpha\sin\alpha + \sin^2\alpha$$

4. From the V_α's, the team determined the associated velocity gradients by the equation:

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

where
v_{ratio} = 2 for tubes and 1.5 for plates

α = 60 degrees
R = radius of the tube

5. The necessary flow rates were calculated from the capture velocities, diameters, and lengths determined above by the following relationship:

$$Q = \left[L\cos(\alpha) + d^2\sin(\alpha)\right]\frac{\pi n_{Tube} V_C}{4}$$

where
L = length of the tube
d = diameter of the tube
α = 60 degrees
r = radius of the tube
n_{tube} = number of tubes

6. Π_V ratios were determined for each tube evaluated by the following equation:

$$\Pi_V = \frac{\frac{g\sin(\alpha)d_0^2\rho_{floc.0}(C_{Alum},C_{Clay})-\rho_{H20}}{18\varphi\nu\rho_{H20}}\left(\frac{d_{floc}(V_C)}{d_0}\right)^{d_{fractal}-1}}{\frac{2V_{UP}}{\sin\alpha}\left(1-\left(\frac{\frac{d}{2}-d_{floc}(V_C)}{\frac{d}{2}}\right)\right)^2}$$

where
d_0 = diameter of clay particle
d_{floc} (V_C) - diameter of floc captured based on capture velocity
$d_{fractal}$ number generally between 2-3 for flocs that describes the volume of dirt in the floc compared to the volume of water. A value of 3 indicates that the floc has no water within it.
$\rho_{floc.0}$ (C_{Alum},C_{Clay}) - density of floc based on concentration of alum and clay, respectively
ρ_{H20} - density of water
v - kinematic viscosity of water
Φ - shape factor

An updated materials list and velocity gradient model can be found on the PSS Fall 2010 Velocity Gradients Experiments page.

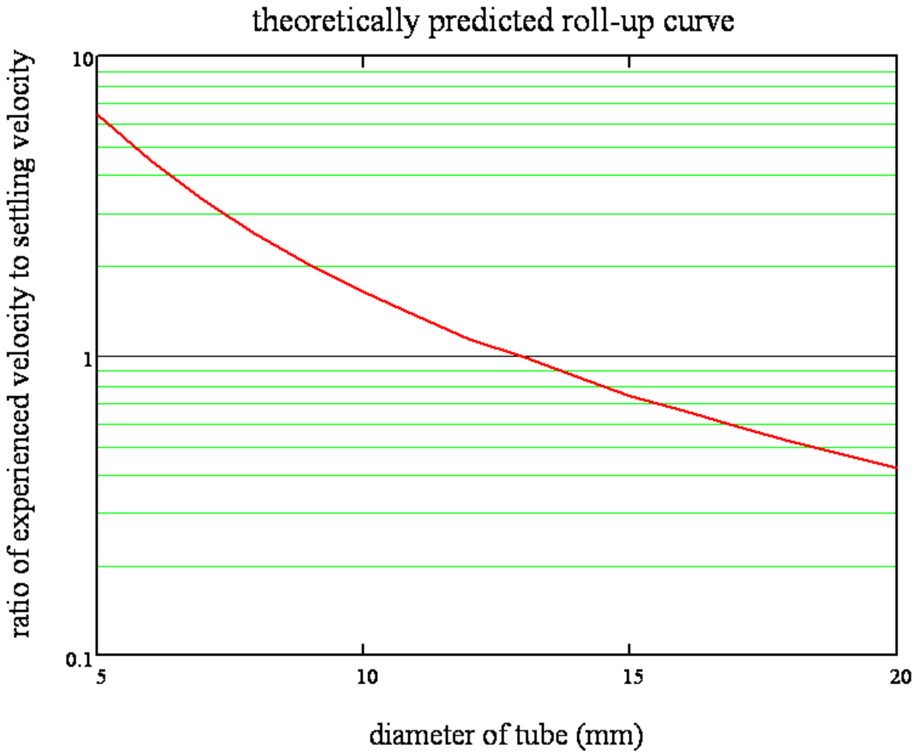
Experimental Methods

Conclusions from the previous experiments (Exploring the Coupled Effects of Capture Velocity and Velocity Gradient on Settler Performance) showed that there was a problem with particles settling out in the turbidimeter at low flow rates. The team performed an experiment in which it found that to prevent this settling, a flow rate of at least 50 mL/min needs to be driven through the turbidimeter. Table 1 of the conclusions indicates that for the smaller tube, flow rates were considerably lower than this value. To address this, the team has decided to use bundles of tube joined by a manifold and a reservoir system. Equal flow distribution is ensured by placing small orifices in the manifold to provide 1 cm of headloss. The flow rate through the tube bundles is pumped into the reservoir continuously until a certain level is reached. This time is called the loading state. At that point, a pump begins to pull water from the reservoir to the turbidimeter at a flow rate higher than 50 mL/min, called the withdrawal state. The pump shuts down when a minimum water height is reached, allowing the reservoir to refill to the maximum specified height before repeating the cycle. The reservoir's sample is continuously stirred and mixed; this should provide an average turbidity reading the turbidimeter. A full analysis of residence times is still in progress.

Aside from the reservoir and bundled tubes, the system is the same as in the previous team's experiments. For data collection, the team plans to collect usable data for at least three residence times in the system, containing: tube settlers, connecting tubes, reservoir, and turbidimeter. With the reservoir system, usable data can only be collected in the withdrawal state. Data collected during the loading state is unusable and should be discarded.

Results

The experiments have not been performed, but the materials list in the introduction elaborates on the expected results. The following figure shows the inverse of the pi ratio plotted against the diameter of tube settler. For diameters at which the inverse is greater than one, roll-up is expected to occur.


theoretically predicted roll-up curve
ratio of experienced velocity to settling velocity
10
1
0.1
5
10
15
20
diameter of tube (mm)

No labels