Laminar Tube Floc (FReTA I)

Location: Right end of bench in B60

Major findings in summer 2013

- tested 4 and 8 clamps using 28 m flocculator with a residence time of about 5 minutes
- Coagulant dose from 0 to 8 mg/L as PACl
- No significant improvement, but some evidence of improvement at higher coagulant doses for 4 clamps
- The spacing of the floc breakup points put the clamps at the center of each equal length section of the flocculator. So the last clamp was at the location 2n-12nLFloc where n is the number of clamps. It is likely that there is some production of non-settleable flocs at each breakup point and thus it may be better to not place any clamps near the end of the flocculator.

Goals

The primary goal is to develop a method to improve the performance of hydraulic flocculators. A secondary goal is to provide additional proof (or to disprove!) that the growth limited flocculation hypothesis is on the right path. A classic method of proving a theory is to take a prediction that is based on the hypothesis and test if that prediction is correct. One of the predictions of the growth limited flocculation hypothesis is that large flocs are useless for capturing colloids because the shear on surface of the large flocs is too high for colloids to attach. Thus colloid removal efficiency potentially could be improved if the large flocs were broken into smaller flocs. The goal would be to create flocs that are small enough to capture colloids and large enough so that they can be captured by the tube settlers.

The growth limited flocculation hypothesis or empirical measurements of residual turbidity can be used to determine when a significant fraction of the flocs will reach their maximum size. The flocs should be broken to a smaller size when perhaps 50% of the flocs have reached their maximum size. This suggests that floc breakup will only be useful for flocculator lengths and coagulant dosages that already result in removal of a high fraction of the colloids. Thus experiments to measure the effect of floc break up should be conducted with a long flocculator (high residence time), high coagulant dose, and high turbidity.

The growth limited flocculation hypothesis model predicts that colloid surface coverage by the coagulant precipitate, , can be estimated based on the properties of the suspension, the coagulant, and the reactor geometry.

$$\Gamma = 1 - e^{-\frac{\phi_{Coag}}{\phi_{Clay}}\frac{D_{Clay}}{D_{Coag}}\frac{1}{\pi}\frac{1}{\left(\frac{1}{2}+\Pi_{HD}\right)\left(\frac{2}{3\Pi_{HD}}\right)^{\frac{2}{3}}+\frac{2D_{Clay}}{3D_{Tube}\phi_{Clay}}}}$$

The time required to achieve a particular C* (ratio of effluent to influent turbidity) can then be calculated by rearranging the following equation.

$$-\frac{\ln\left(C^{*}\right)}{C^{*\frac{2}{3}}} = \Gamma G t \phi^{\frac{2}{3}}\,\frac{\eta_{Coag}}{V_{Capture}}$$

It would be reasonable to begin placing restrictions in the flocculator after C* has reached a level of something between 0.5 and 0.1.

Another approach would be to assume that restrictions should at least be helpful in the middle third of the flocculator and to conduct experiments by varying the number of restrictions and the energy dissipation rates for each restriction. To ensure that a significant fraction of the flocs have reached their maximum size, the research on the potential benefits of floc break up should use the 84 m long laminar flow flocculator and should use coagulant doses that result in less than 2 NTU in the effluent.

1. Set up pressure sensors to measure the head loss through the flocculator. Use the head loss measurements to check our model calculations for the energy dissipation rate through the floc break-up devices.
2. Determine the optimal orifice size for floc break up systems with four, eight, and sixteen clamps by gradually decreasing the clamp size based on the relationships between energy dissipation rate, floc size, terminal velocity, and clamp size until the flocculator performance worsens.
3. Compare the performance of tapered tube flocculation with regular tube flocculation. Design a tapered system -- small tube at the beginning, medium tube in the middle, and large tube at the end (same length for each size of the tubing) using 10 mg/L PACl dose and 28 m tube flocculator length (N://files.Cornell.edu/EN/aguaclara/RESEARCH/Tube Floc/Spring 2013/Experiments/Single PACl 10 mgL.pcm/). As tube size (diameter) increases, energy dissipation rate decreases, allowing flocs to continue to grow. The larger that flocs can grow, the lower the residual turbidity will be.

Tapered flocculation

Tapered flocculation has long been assumed to be a good design for flocculators. A common design was to use 3 different sections of the flocculator with 3 different energy dissipation rates. However, there has not been a rational method to choose the energy dissipation rate in each of the 3 sections and there is a lack of evidence that the system is an improvement over a constant energy dissipation rate. The appropriate comparison would be based on the same head loss and reactor volume.

Contact chamber for coagulant attachment to colloids to reduce coagulant loss to reactor walls.

This could be a new research team. We need a method to measure this coagulant loss. We could easily measure the amount of coagulant that is in the suspension. A grab sample of the flocculated suspension could be acidified to dissolve the aluminum and centrifuged to remove the clay. The supernatant aluminum concentration could then be measured with the AA or with the UV spectrophotometer.

We now know that a high fraction of the coagulant is lost to the tubing walls. It is noteworthy that at many water treatment plants the turbidity is less than 10 NTU for much of the year and thus it is possible that there is significant loss of coagulant precipitate to the rapid mix and flocculator walls. A change in design of the coagulant injection point could significantly reduce the need for coagulant.

A 5 NTU suspension passing through a 10 cm inner diameter, ID, the fraction of the coagulant that ends up on the clay is less than 30%. Thus loss of coagulant to reactor surfaces is likely significant for community scale water treatment plants. The equation for this calculation is

$$\Pi_{A_{Clay}A_{Total}} = \frac{1}{1 + \frac{2D_{Clay}}{3D_{Tube}\Pi_{ClaySphere}\phi_{Clay}}}$$

where ClaySphere is the ratio of the surface area of a clay platelet to the surface area of a sphere of equivalent volume. AClayATotal is the ratio of the clay surface area in the flocculator to the total area of the flocculator walls plus clay.

It is possible that coagulant loss at full scale is not as significant as our simple model predicts due to slow diffusion through the laminar boundary layer at the reactor walls.

At laboratory scale we could explore methods to reduce coagulant loss to the walls. The coagulant could be injected into the center of a fluid jet of the raw water and the jet should be discharging into a large contact chamber. The contact chamber should be designed so that the jet doesn't contact the walls of the chamber for at least several seconds. If possible we should develop a model for the time required for the majority of the coagulant precipitate to diffuse to the clay surfaces and design the jet to not contact the reactor walls during that time. The efficiency of the contact chamber could be

Breaker failure issue

The breaker tripped repeatedly during the summer. Figure out the source of the problem and fix it before doing experiments. It is likely the mixer motors. If needed we should purchase new motors. Perhaps we could use 12V DC mixer motors.