

Flocculation with FReTA

August 16, 2012

Abstract

Data from the flocculation residual turbidity analyzer is providing insight into the fundamental flocculation mechanisms. The existing data sets from FReTA can be mined for additional relationships and new experiments can be conducted to extend our knowledge of flocculation.

- Skills: Fluids, Plumbing Design, Fabrication, Process Controller

1 Introduction

Flocculation has been a poorly understood unit process and the flocculator design that we are using is very similar to flocculators that were build 100 years ago. Our goal is to use our new understanding of the flocculation mechanisms to optimize the design of the hydraulic flocculator. We will begin by testing approaches for improving laminar flow flocculation and based on those results will test promixing methods on turbulent flow hydraulic flocculators. It is possible that the hydraulic flocculator design from 100 years ago is already close to optimal. It is likely that with our new understanding of the fundamental flocculation mechanisms that we will be able to design flocculators that are much more efficient. Improved efficiency could be through a reduction in coagulant or required residence time.

The conversion of colloids into settle-able flocs by a laminar flow flocculator is first order with respect to collision potential where the collision potential is given by $(Gt\Gamma\phi^{\frac{2}{3}})$.

$$\frac{dC_{Colloids}}{d(Gt\Gamma\phi^{\frac{2}{3}})} = -kC_{Colloids} \quad (1)$$

$C_{Colloids}$ is the concentration of colloids that can not be captured in the sedimentation tank, G is the average velocity gradient, t is time in the flocculator, Γ is the fractional coverage of the colloids by coagulant, and ϕ is the floc volume fraction for flocs that are not yet full size.

$$\phi \approx \frac{C_{Colloids}}{\rho_{Colloids}} \quad (2)$$

The derivative form of the equation is based on the assumption that flocs that have grown to full size set by the level of shear in the flocculator can not continue to aggregate. Thus the floc volume fraction is for flocs that still have growth potential. Separating variables and integrating we obtain

$$\int_{C_{Colloids_0}}^{C_{Colloids}} \frac{dC_{Colloids}}{C_{Colloids}} = -k \int d \left[Gt\Gamma \left(\frac{C_{Colloids}}{\rho_{Colloids}} \right)^{\frac{2}{3}} \right] \quad (3)$$

$$\ln \left(\frac{C_{Colloids}}{C_{Colloids_0}} \right) = -kGt\Gamma \left(\frac{C_{Colloids}}{\rho_{Colloids}} \right)^{\frac{2}{3}} \quad (4)$$

The constant k was empirically determined to be given by

$$k = \frac{\eta_{Coag}}{V_{Capture}} \quad (5)$$

where η_{Coag} is currently determined empirically for each coagulant and $V_{Capture}$ is the capture velocity of the plate or tube settlers.

$$t = \frac{1}{G\Gamma} \frac{V_{Capture}}{\eta_{Coag}} \left(\frac{\rho_{Colloids}}{C_{Colloids}} \right)^{\frac{2}{3}} \ln \left(\frac{C_{Colloids_0}}{C_{Colloids}} \right) \quad (6)$$

Although this flocculation model does not yet take into account the performance gain provided by the floc blanket, it does provide insight into the flocculation mechanisms and suggests that flocculator performance could be enhanced by increasing the concentration of flocs that are not at their maximum size, $C_{Colloids}$.

2 Improving flocculator performance by breaking flocs

There are three methods that we need to investigate for increasing flocculator efficiency.

1. Reduce the energy dissipation rate step by step in the flocculator to allow flocs to grow in stages and thus continue to capture colloids (tapered flocculation)
2. Break large flocs at regular intervals in the flocculator to maintain all flocs at a size where they can continue to grow
3. Add additional small flocs to the flocculator by recycling flocs from the floc blanket. (this will be studied by the floc sed optimization team)

The flocculation team will evaluate the second option for improving flocculator performance.

The relationship between floc size and the average energy dissipation rate in a laminar flow flocculator was obtained by (Tse, et al)

$$\varepsilon = \left(\frac{D_{Floc}}{75\mu\text{m}} \right)^3 \frac{W}{kg} \quad (7)$$

It would seem appropriate to create flocs that are small enough to capture colloids and yet large enough to be removed by the tube settlers. Given a capture velocity of 0.12 mm/s the floc diameter is estimated to be approximately 50 μm and from 7 an energy dissipation rate of approximately 270 m^3/kg would be required to produce flocs that small. This high energy dissipation rate could be produced with an orifice that creates a jet.

$$\varepsilon_{Max} = \frac{(\Pi_{Jet} V_{Jet})^3}{D_{Jet}} \quad (8)$$

where Π_{Jet} is estimated to have a value of 0.4 for a free axisymmetric jet. The orifice could be a single orifice inserted into the flocculator tube or it could be many orifices in parallel. The extreme options are a single orifice or a wire mesh with holes that are larger than D_{Floc} . The spacing of the floc breakup orifices in the flocculator would be determined by how long it takes for a significant fraction of the flocs to grow to their terminal size. One possibility would be to add about 10 floc break up points in a flocculator and then compare performance to see if the floc break up improves or degrades performance.

3 Glue applicator chamber

It is possible that a diffusion chamber immediately after rapid mix could provide an opportunity for the coagulant to diffuse to the colloid surfaces. The diffusion chamber could be a CMFR (completely mixed free reactor) with mixing provided by the incoming water. We could try a residence time of approximately 100 s to see if this chamber improves performance. The goal of the mixing chamber would be to reduce loss of coagulant to the flocculator walls by providing time for diffusion to the colloidal surfaces in a reactor with a low specific surface area. This would be a cubic tank with a to be determined residence time that would allow most of the coagulant to attach to colloids. It would be designed for a low turbidity case. This could be especially effective at reducing coagulant demand for laboratory scale flocculators. This test will provide validation to our hypothesis that loss of coagulant to the flocculator walls is significant in small scale flocculators.

4 Dissolved Natural Organic Matter (Spring 2013)

Our flocculation model is based on dosing kaolin suspensions, we need information on how the presence of suspended and dissolved organic matter influences dose. The highest demand for coagulant likely comes from dissolved organic matter. Conventional wisdom suggests that the high charge density of the dissolved organic matter is responsible for the high coagulant demand. Given our

new understanding of the importance of coating the colloids with coagulant it is quite possible that dissolved molecules of organic matter are removed from solution by attaching to coagulant globs and thus the dissolved organic matter exerts a strong demand on the coagulant. The dissolved organic matter may also form complexes that remove dissolved aluminum. To simplify the system it may be appropriate to study the dosing requirements for a single component system that consists of dissolved humic acid. Humic acid can be removed by flocculation. The removal efficiency for humic acid could be measured with a UV-Vis spectrophotometer. This is too ambitious for fall of 2012, but could be implemented during the spring of 2013. It will be necessary to create external code for the process controller that can read the humic acid concentration from the UV-Vis spectrophotometer.

5 Particulate Natural Organic Matter (Spring 2013)

The ability of a flocculator to remove pathogens could be investigated by growing up suspensions of bacteria or algae. This particulate natural organic matter would be measurable with the turbidimeters and thus the dose response for the coagulants could readily be measured. It will be important to thoroughly wash the suspensions to remove the media used to grow the bacteria or algae because the dissolved organic matter could have a significant demand for the coagulant.