Flocculator and Sedimentation Optimization

August 16, 2012

Abstract

The addition of floc blankets and stacked rapid sand filters to the AguaClara suite of technologies provides an opportunity to redesign flocculation and sedimentation to be more cost effective. Our new model of flocculation provides an opportunity to gain new insights into options for improving plant performance and reducing the operating costs. The big question is whether recycle of flocs from a floc blanket to the beginning of the flocculator could be used to reduce coagulant demand and improve performance.

- Skills: CEE 4540, fluid mechanics, process controller, data analysis

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 flocculor. 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 $\left(Gt\Gamma\phi^{\frac{2}{3}}\right)$.

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

$C_{Colloids}$ 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 $\phi$is the floc volume fraction for flocs that are not yet full size.

$$\phi \approx \frac{C_{Colloids}}{\rho_{Colloids}} \tag{2}$$

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

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

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

The constant k was empirically determined to be give by

$$k = \frac{\eta_{Coag}}{V_{Capture}} \tag{5}$$

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

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

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, $C_{Colloids}$. 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.

The floc sed optimization team will evaluate this third option for improving flocculator performance.

2 Floc Recycle

Floc recycle is expected to have two important consequences that could significantly reduce the required coagulant dose. First, the higher floc volume fraction will reduce the amount of coagulant that is lost to the walls of the tube flocculator. Second, the higher floc volume fraction will increase the collisions between flocs. Both of these influences should result in a marked decrease in the required coagulant dose and/or a decrease in settled water turbidity. Set the raw water turbidity to approximately 15 NTU, build a floc blanket with up flow velocity of 1 mm/s and then measure performance from the 0.12 mm/s tube settler. Vary the coagulant dose with each coagulant dose held constant for 2 residence times of the clay in the floc blanket. Then add floc recycle and repeat with the range of coagulant dosages. Compare the performance with and without floc recycle. The floc recycle line should pull flocs from the bottom of the floc blanket and inject them at the same location as the coagulant addition.

An additional parameter that should be explored is the size of the flocs that are returned to the flocculator. It is possible that these flocs need to be broken so that they have significant growth potential in the flocculator. The flocs can be broken by passing them through a small orifice or by sending them through a wire mesh.

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

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

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 $0.12\,{}^{\mathrm{mm}}/_{\mathrm{s}}$ the floc diameter is estimated to be approximately 50μm and from 7 an energy dissipation rate of approximately $270{}^{\mathrm{mW}}/_{\mathrm{kg}}$ would be required to produce flocs that small. This high energy dissipation rate could be produced with an orifice that creates a jet.

$$\epsilon_{Max} = \frac{\left(\Pi_{Jet} V_{Jet}\right)^3}{D_{Jet}} \tag{8}$$

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 recycle 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} .