SRSF theory

Location: HLS 160

Major findings in summer 2013

- Subsurface injection eliminates the formation of the layer of clay on top of filter that can't be removed during backwash. It is likely that this clay layer that forms on the surface of RSF is what produces mudballs and why a surface wash system is essential for RSF and not for SRSF
- Difficulty controlling raw water turbidity

Goals

One of the strengths of the AguaClara model for technology development and innovation is that we have gradually developed a fundamental understanding of unit processes. The insights that come from a fundamental understanding can then be used to optimize the performance of the system. The overarching goal for this team is to conduct experiments that lead to a fundamental understanding and parameterization of SRSF performance. The way to create a theoretical understanding of SRSF is to conduct well controlled experiments while varying the input parameters that we expect to be important. The important filter inputs are filtration velocity, coagulant dose and clay concentration. The important parameters to monitor are influent turbidity, effluent turbidity, and head loss.

Filtration model

Our initial experimentation with stacked rapid sand filters suggests that their performance is slightly different from conventional filters in part because there is no surface layer of sediment. This may make it easier to develop a performance model because all of the particles are removed within the filter bed rather than having some particles removed on top of the sand and others removed within the filter bed.

A simple model of SRSF behavior is that particles are initially captured in the pores following a first order removal with respect to depth. As a pore clogs the diameter of the pore decreases and by mass conservation ($Q=VA$) the velocity in the pore increases. As the velocity increases the shear stress on the walls of the pore increase. The head loss through the filter is directly related to the shear stress through the pores. As the shear stress increases it eventually reaches a level where the incoming particles are unable to attach to the walls of the pore because the fluid shear exceeds the strength of the coagulant bonds. That pore becomes ineffective for particle removal and the zone of particle removal migrates deeper into the filter. The head loss increases approximately linearly with time as the depth of filled pores gradually increases. Eventually effluent turbidity begins to increase because the depth of clogged pores begins to approach the depth of the filter layer.

The filter model leads to a number of hypotheses that can be tested and the ability to create mathematical models describing filter performance. We expect filter head loss to increase linearly with the mass of particles captured given a constant influent composition. We expect the rate of increase of head loss to be small for low coagulant/clay doses and high for large coagulant to clay doses. The strength of attachment is expected to vary with surface coverage, Γ in the flocculation model.

The filtration performance model (see the end of the filtration notes online) includes a parameter for attachment efficiency. In our flocculation model we replace attachment efficiency with surface coverage by the coagulant. That same assumption may well be applicable for filtration as well. Thus, given a target effluent turbidity, the filter run time will be longer for higher coagulant/clay doses and the terminal head loss will be much higher.

- Can we develop a predictive model for the relationship between coagulant/clay dose and filter head loss as a function of cumulative influent particle volume?
- What is the influence of the size distribution of raw water flocs on filter performance

First steps

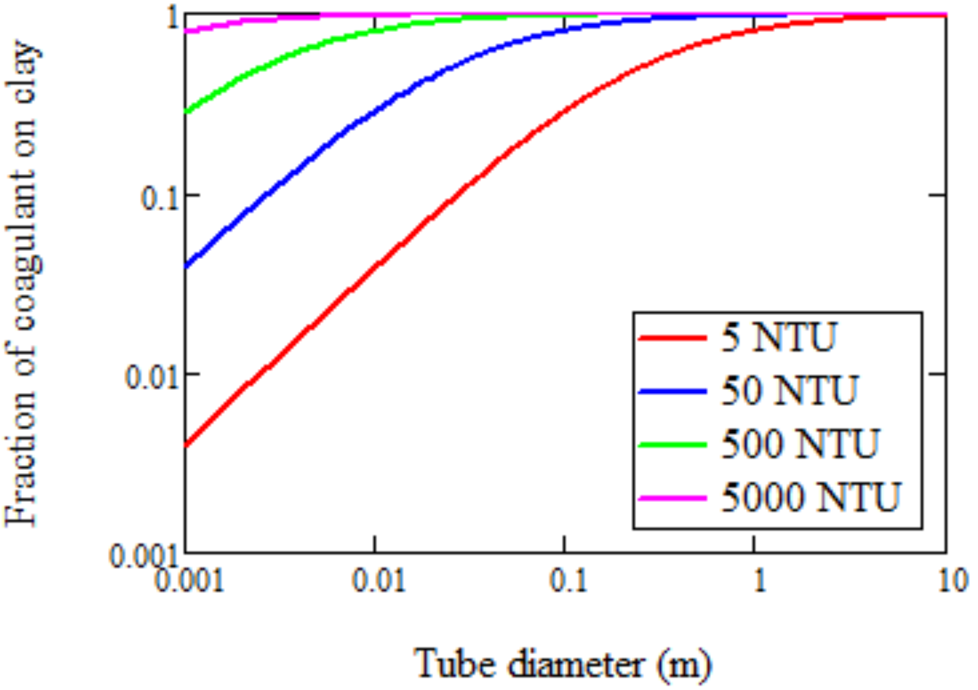
Design the filtration apparatus (perhaps modify one of the filters in the lab). We need to decide if the filter needs to be 6 layers, 2 layers, or just 1 layer. The challenge with one layer is that the filter inlet must be below the surface of the sand. The layer of sand above the filter inlet (assuming downflow filtration) will likely collect some particles as streamlines from the line source initially travel radially away from the source before all turning downward. Ideally the boundary condition at the top of the filter would be an impermeable wall at the middle of the inlet manifold. An equivalent boundary condition could be created by using a two layer filter with the inlet in the middle of the sand column. Thus a two layer filter may be the simplest configuration that adequately models a SRSF. The two filter outlets should probably be screen ports that are identical to the filter inlet. The velocity through the openings in the inlet and outlets should be similar to the velocity through the slots in the full scale SRSF. Contact the design team expert to get that velocity.

Check the current turbidity feed system to see if it can maintain the turbidity within about 10% of the target. If it can't, then design an improved turbidity feed system, perhaps by implementing PID feedback control of the clay pump.

Carefully consider the design of the coagulant addition because we now know that a high fraction of the coagulant is lost to the tubing walls. It is difficult to solve this problem at small scale. A 5 NTU suspension passing through a 4.3 mm inner diameter, ID, tube (0.17 inch) the fraction of the coagulant that ends up on the clay is less than 2%. 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 tubing to the total area of the tubing walls plus clay. A graph of the equation for 4 different concentration clay suspension as a function of tube diameter is shown below.



The application of coagulant to the clay can be made more efficient by increasing the diameter of the tube where the coagulant attaches to surfaces. One option is to create a larger contact chamber that has a diameter closer to 10 cm where the coagulant application efficiency is almost 30%. The other option would be to add the coagulant to the clay stock. The concern with this approach would be that the clay could flocculate and settle in the raw water turbidimeter. However, if the flow rate is kept high through the raw water turbidimeter by recirculation if needed, then this could provide close to 100% of the coagulant attaching to the clay. To test this approach conduct an experiment where the coagulant and clay are mixed in a concentrated stock tank that is titrated to pH 7.5 using sodium hydroxide. The titration is necessary because the pH of the stock solution will be lowered by the high concentration of PACl and if the pH is low, then the PACl won't precipitate. Check the reproducibility of this as a function of time using the same stock to see if the coagulant properties change over time. Run a set of 3 experiments with each experiment having a duration of perhaps 5 hours. If the experiments are repeatable, then the mixed stock with coagulant and clay should be a viable method for the remainder of the experiments.

Design experiments that measure head loss, influent turbidity, and effluent turbidity over the course of a filter run. The length of the experiment should be set based on maintaining an effluent turbidity of less than 0.3 NTU (after an initial ripening period) given an influent turbidity of 5 NTU. We expect filter run times to be approximately 12 hours, but confirm this by experimenting. Collect a family of performance curves (pC* and head loss) by varying the coagulant dose while maintaining a constant raw water turbidity.

While the experiments are running, develop a model for the mass of clay that can fill a pore before the flow path through the pore has a small diameter, the velocity is high, the shear is high and hence no more particles attach. See if you can create a model with a minimum of unknown parameters for the pore storage volume as a function of the coagulant dose. The model should also predict head loss as a function of coagulant dose and mass of solids accumulated.

One of the possible applications of this research will be to evaluate the selection of 20 cm as the layer depth for SRSF. In addition it may be possible to provide guidance for the maximum head loss that a SRSF can sustain before particle breakthrough becomes excessive. Finally, it may be possible to provide recommendations on the optimal coagulant/clay ratio for efficient filtration.