Sedimentation Tank Hydraulics

August 20, 2012

Abstract

The goal of this research is to evaluate floc hopper geometry and floc blanket stability to improve the design of the AguaClara sedimentation tanks. A floc weir will be needed to set the upper limit of the floc blanket level and a floc hopper will be needed to consolidate the wasted flocs.

- skills: fabrication, experimentation, fluids, process controller

1 Introduction

The maximum turbidity that can be treated by the flocculation/sedimentation processes will be set by the solids handling capability of the floc hopper, the cost of coagulants, and the fraction of water that must be wasted to discharge the solids. The volume of water wasted will be set by the concentration of solids that can be produced by the floc hopper. The flow rate of flocs from the floc blanket that will be handled by the floc hopper is directly related to the raw water turbidity. We need design guidance for the floc hopper and we need to learn what is required for stable floc blanket operation.

2 Hindered Sedimentation Velocity

We need to know the relationship between the solids concentration and the hindered sedimentation velocity for a variety of floc suspensions. The sedimentation tank hydraulics apparatus is ideal for making these measurements because the upflow velocity in the sedimentation tank is the same as the hindered sedimentation velocity. Thus the solids concentration as a function of upflow velocity provides the desired empirical relationship. The hindered sedimentation velocity is a function of coagulant type and coagulant dose. There is also some evidence that the solids concentration increases with time. It is likely that there is already a set of experimental data that can be used to extract good information. Identify gaps in the data and conduct additional experiments to obtain the empirical relationship.

3 Floc hopper geometry

The floc hopper takes the production of flocs from the floc blanket, $Q_{FlocBlanket}$, and concentrates those flocs into a waste sludge, Q_{Sludge}, and returns relatively clean water, Q_{Return} back into the sedimentation tank (1).

The parameters of interest are the ratio of the plan view area of the floc hopper to the plan view area of the rest of the sedimentation tank, the volume of the floc hopper, and possibly the angle of the bottom of the hopper. We are also interested in knowing how the geometry of the floc hopper influences the required sludge flow rate. The depth of flow and flow rate over the floc hopper weir is also of interest. The depth of flow over the floc hopper weir is not expected to be significant design constraint.

The critical design constraint is expected to be during high turbidity events when the floc volume fraction is high and hence the flow of flocs into the floc hopper will be the greatest. The fractal flocculation model predicts that at 500 NTU the floc volume fraction is 0.08. Thus the flow over the weir would be $0.08Q_{SedBay}$. The floc volume fraction is proportional to the turbidity for high turbidities and thus at 1000 NTU the floc volume fraction is 0.16. Without consolidation of the flocs it would be necessary to waste 16% of the flow during a 1000 NTU event. AguaClara plants have already treated water in excess of 700 NTU and so it would be reasonable to design the floc hopper to handle a 1000 NTU event.

A floc hopper can be installed in the 2d sedimentation apparatus. You could start with a floc hopper that occupies 15% of the plan view area of the sedimentation tank. The bottom slope could be very steep so that the sludge hopper extends all the way to the bottom of the sedimentation tank or it could be a 50 degree angle and be shallower. A peristaltic pump can be used to remove sludge from the very bottom of the floc hopper. The flow rate of the pump can be slowly varied and the depth of the flocs in the floc hopper can be measured. This will give a relationship between the required plan view area of the floc hopper and the corresponding required sludge wasting rate. The steady state depth of sludge in the floc hopper will increase as the sludge wasting rate decreases. There may be problems with this experimental method because the sludge may consolidate so well that the pump won't be able to remove it.

The plan view area and time required for floc consolidation is not easily estimated. The fractal flocculation model predicts that at 1000 NTU the floc volume fraction is 0.16. Thus the flow over the weir would be $0.16Q_{SedBay}$. Does this mean that the area of the floc hopper should be about 16% of the sedimentation tank area? We need some modeling work here to understand what controls this consolidation process. A literature review would be useful and experimental work is needed. Images of this floc weir in action and the consolidation would be very useful in understanding how these processes work.

The goal is to develop an understanding of how floc consolidation works and to determine the top width of the floc hopper. A key relationship that is needed in order to model the floc hopper is the relationship between hindered sedimentation velocity and the solids concentration in the floc hopper. We are

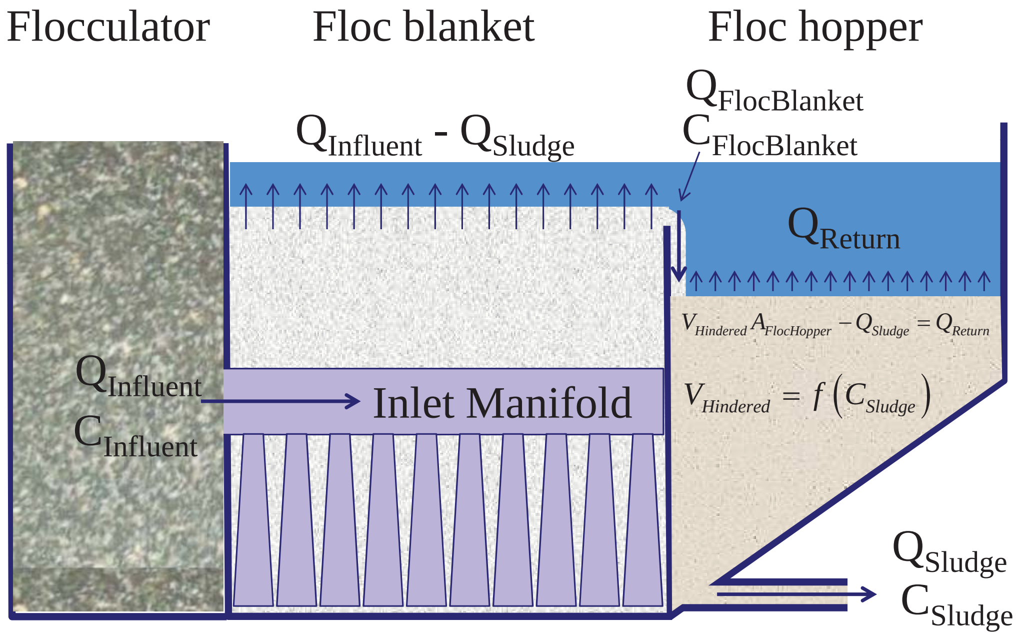

Figure 1: Mass balance for a flocculator, floc blanket, and floc hopper.

assuming that the floc hopper is dominated by hindered sedimentation and not by compressive dewatering.

4 Floc blanket failure at low coagulant dose

We have evidence from the summer of 2012 using the STH apparatus that the floc blanket fails dramatically when the coagulant dose is reduced too far. Our plant operators need to know the indicators that the coagulant dose is getting too low. In order to provide guidance to the plant operators so that they can detect when the coagulant dose is too low we need to understand the failure mode and based on that understanding develop an appropriate indicator that failure is imminent. The floc blanket failure mode is hypothesized to be related to the floc strength, resulting floc size, and floc sedimentation velocity.

Floc blanket flocs are broken apart and reduced in size when they are re-suspended. The resulting sub-millimeter flocs must grow in size before they reach the top of the floc blanket or else they will be carried into the plate or tube settlers. The ability of flocs to grow in the floc blanket is dependent on their fractional coverage with coagulant (Γ). A confounding factor is that floc strength is presumably related to the fractional coverage with coagulant and thus the size of the broken flocs is likely proportional to the coagulant dose. Thus reducing the coagulant dose reduces the size of flocs leaving the flocculator and the size of the resuspended flocs and reduces the ability of the broken flocs to grow large enough to be retained in the floc blanket.

It will also be important to develop a protocol for recovering from imminent failure. Perhaps coagulant could be added directly to the floc blanket. Develop a method to detect imminent failure and to prevent failure. Develop a method to detect the difference between high coagulant dose failure and low coagulant dose failure.

5 Stable Floc Blanket

Performance data (blanket formation time, and steady state performance) are needed for differing input turbidities, differing flows. Performance results need to be replicated to ensure differences are significant. We need to evaluate system stability to fluctuations in flow, and input turbidity. We need to measure and model the mass flux through the system to get a suitable mathematical form for particle removal.

There are anecdotes that floc blankets can suddenly expand and cause effluent turbidity problems. The goal is to learn about floc blanket instabilities and identify what causes the floc blanket to expand or contract. The expectation is that a reduction in floc strength would lead to smaller flocs, reduce the floc sedimentation velocity, and thus decrease the floc concentration. Thus a reduction in coagulant dose could cause the floc blanket to rapidly expand.

Conduct experiments with varying influent characteristics (turbidity or coagulant dose) to see how the floc blanket responds and how effluent turbidity is affected. Provide guidance for plant operators.