Sedimentation Tank Hydraulics

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Abstract

The goal of this research is to evaluate sedimentation tank bottom geometry, jet location, and the design requirements for a floc hopper in an AguaClara sedimentation tank. Inlet jet geometry along the bottom of the sedimentation tank is critical in the resuspension of flocs. The inlet end of the sedimentation tank needs to be redesigned to re suspend flocs. 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.

students 4

skills fabrication, experimentation, fluids, process controller

1 Sedimentation tank geometry

AguaClara sedimentation tanks have evolved rapidly from

1. flat bottom with 3 large pipe inlets (Ojojona)
2. sloped bottom with 3 large pipe inlets (Marcala 1 and Tamara)
3. sloped bottom with inlet ducts under the sloped bottom (Cuatro Comunidades)
4. sloped bottom with simple inlet manifold with orifices (Agalteca)
5. sloped bottom with inlet manifold with diffuser drop tubes (Marcala 2)
6. sloped bottom with small radius jet reverser and line source jet (proposed design for Atima)

The design for the diffusers on the inlet manifold was modified in August of 2011 and fall 2011 to improve the ability of AguaClara plants to form floc blankets. This new design is currently being constructed in Atima, Santa Barbara, Honduras. The conceptual design for the diffuser was created in summer of 2011. We now have a method to fabricate the inlet manifold system and we will build on the technology used to fabricate the diffusers at Marcala (figure 1).

Figure 1: Spring 2011 version of the sedimentation tank inlet manifold and diffusers. These diffusers do not provide the continuous line source that is required to suspend all flocs that slide down the slopes of the sedimentation tank. In addition, the flat sludge drain cover does not provide the geometry for a jet reverser that can easily suspend the settled flocs.

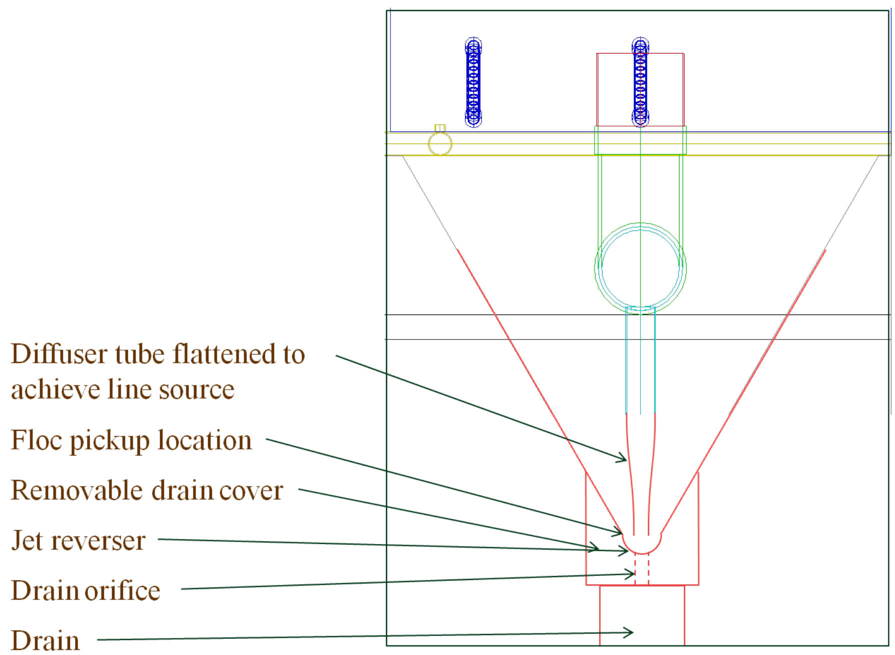

Figure 2: Preliminary sketch of the inlet manifold with diffuser tubes and jet reverser.

The preliminary design for the Atima, Santa Barbara plant calls for a 6 inch diameter manifold, 1.2 cm diameter ports every 4 cm, diffusers that are 1 inches in diameter and approximately 20 cm long. The diffusers pipes will be heated, reshaped, and stretched by 20% into a rectangle that is 1.1 cm wide and 4 cm long. A preliminary cross section of the design is shown in figure 2.

The evolution of the sedimentation tank design continues as we learn more about what is required to produce floc blankets and as we improve how we handle the sludge. The focus of our current research is to carefully design the interaction between the flocs that settle on the bottom slopes as they return to the central valley of the sedimentation tank and the jets produced by the diffuser drop tubes. The design of the interaction between the settled flocs and the inlet jets is critical because it is the jets that re-suspend the settled flocs and thus create the floc blanket. As we improve tank geometry to reliably create floc blankets it will necessary to also control the depth of the floc blanket (with a floc blanket weir) and use a floc hopper to provide time for the wasted flocs to consolidate or dewater to reduce the amount of water that must be wasted with the resulting sludge.

The fall semester saw the development and testing of several bottom geometry configurations. Now that lamellar sedimentation is utilized in the reactor, several existing and new bottom geometries may be tested in conjunction with formation and performance results. There are several directions with which to go in improving our understanding of floc re-suspension and best available bottom geometries and flow conditions for formation and stabililty of floc blankets in AguaClara plants.

(1) Testing hypothesis: The hindered sedimentation velocity of the floc blanket is equal to the upflow velocity at the floc-water interface during floc blanket operation. Such hypothesis testing is critical to our understanding of fluid and solid interactions inside the floc blanket and could leader to a better understanding of hindered sedimentation occuring in the floc blanket and spur the development of a physically based model of hindered settling.

Our current understanding leads to two alternative interpretations of hindered sedimentation velocity in a floc blanket based upon the point of view of the observer. In the first point of view, the observer notes the change in hindered velocity in an aggregate floc blanket. Such a point of view conforms to the current hypothesis in the literature in that the hindered sedimentation velocity is equal to the upflow velocity immediately above the floc-water interface. In a stationary floc-blanket where the growth rate of the floc blanket is a result of mass accumulation (and not fluid perturbations), the floc blanket height remains relatively stationary and has no velocity relative to the fluid velocity above the floc-water interface. The fluid velocity above the floc-water interface is set by the planar area immediately above the floc-water interface and the plant flow rate. If one were to shut off flow to the floc blanket, then it is anticipated that initially (~5-10 seconds) the floc blanket would fall at a rate proportional to the perceeding upflow velocity.

The second point of view, however, is that the hindered sedimentation velocity of an individual floc particle must counteract the upflow velocity that the particle perceives inside the floc blanket below the floc-water interface. Such an upflow velocity in the floc blanket is proportional to the planar area, the plant flow rate, and the porosity of the floc blanket. For the floc blanket to remain stationary, it is then hypothesized that on average each floc particle experiences a hindered sedimentation velocity that is equal to the upflow fluid velocity in the floc blanket.

The following point of views give different interpretations for hindered sedimentation velocity in a floc blanket. As of right now, both potentially seem valid, and it is necesary to test this hypothesis. To test this hypothesis three distinct floc blankets can be built under turbidity of 100 NTU and dosing of 45 mg/L. The upflow velocity will be varied: 0.6 mm/s, 1.2 mm/s, and 1.8 mm/s for the tests. In each test, a floc blanket will be formed at a floc blanket height of 60 cm (defined from the bottom of the jet reverser to the floc-water interface of the floc blanket). Once the floc blanket is formed, flow will be shut off for 10 seconds and a series of images will be taken ever 0.05 s. Each image should be subsequently analyzed to the reveal the position of the settling floc blanket over time. The first attempts at this analysis may be difficult, so try changing the position of the camera and zooming in on the area of interest if necessary to provide higher resolution spatial data. In addition, local turbulence may delay settling at the floc-water interface, so don't be surprised by an initial flat line in the data plot. After these results are collected, an effective settling velocity will be measured by dividing the relative change in position over time of the floc blanket by time. It is also expected that the initial settling data (~5-10 seconds) should be close to linear, but unknown, so fitting a curve may also be as useful as taking average of the data points.

Deliverables: Three plots of the projected hindered sedimentation velocity immediately after flow is shut off to the floc blanket.

(2) Build a settling curve of several floc blanket conditions to estimate a reasonable concentration and solids residence time for compression settling in the floc hopper for the three upflow velocities previously tested in (1).

The settling curve can be continued from (1) after it is agreed that the pertinent data has been collected. When imaging take a zoomed out picture of the sed tank so that all ranges of floc blanket heights can be acquired. The solids curve will be analyzed and a decision may be made for initial design parameters for a floc hopper. In addition, if image analysis does not give a reasonable estimate of the debris flow concentration (although I think it should), a TSS (Total Supsended Solids Test from Standard Methods 1691) of three samples should give a reasonable answer. The floc blanket should take approximately a day to completely settle so plan accordingly!

Deliverables: A plot of the settling curve for three floc blankets of upflow velocities of 1.8 mm/s, 1.2 mm/s, and 0.6 mm/s. An estimate of a concentration range for a solids residence time in a floc hopper.

(3) Testing Hypothesis: hydrodynamic pressure must exceed the maximum hydrostatic pressure of the jet

The radius of curvature will influence the extent of floc re-suspension that occurs. The most concentrated and highest hydrostatic pressure occurs at the point where the jet interacts with the debris flow. Primary experimental data suggests that the debris flow could have a maximum concentration of 13,000 mg/L under experimental conditions of 100 NTU, 45 mg/L and an upflow velocity of 1.2 mm/s.

Floc re-suspension is hypothesized to be the result of hydrodynamic jet forces exceeding the hydrostatic pressure of the returning debris flow. Two variables that influence the hydrodynamic force of the jet include the radius of curvature of the bottom insert and the initial jet velocity. The most efficient known bottom geometry design based upon experiments conducted in Fall 2011 appears to be the W-shape. The radius of curvature is inversely proportional to the hydrodynamic pressure, thus a smaller radius of curvature is expected to provide a higher hydrodynamic pressure. The minimal radius of curvature for one circle in the W-shape that will not cause jet contraction beyond that expected for a vena contracta is hypothesized to be equal to one half the diameter of the initial jet.

For these sets of experiments, we will test the extent which solids may be re-suspended under several bottom geometries with the following radii of curvature: 0.5", 1", 2". There is no need to test a higher radii of curvature, tests in the summer revealed that the hydrodynamic pressure at a radius of curvature of 10" for a single circle shape failed to adequately re-suspend particles. To test the extent to which the jet may re-suspend solids, the floc blanket will be built under conditions of 45 mg/L, 100 NTU, and an upflow velocity of 1.2 mm/s. Then the jet velocity will be decreased until the jet is unable to re-suspend particles. The jet velocity will be pulsed from a low flow rate back to a high flow rate so that the rate of solids return remains constant so that the hydrostatic pressure remains constant. The hydrostatic pressure will be recorded based upon concentration readings taken for a rectangular ROI for the image. The hydrodynamic pressure of the jet at contact with the debris flow will be calculated based upon the initial jet velocity and the radius of curvature. For this calculation, it will be assumed that the jet changes from a circular to rectangular shape at point of contact with the debris flow.

Deliverables: Data set showing

(4) Effect of upflow velocity on performance and formation of a floc blanket

Once the bottom geometry is established (which will likely be a W-shape with a radius of curvature of 0.5"), the experiment will test the range of upflow velocities that will form a floc blanket. Previous experiments revealed that the range of upflow velocities that effectively formed a floc blanket ranged from 0.6 mm/s to 2.4 mm/s. Given the need to minimize the cross sectional area of the sedimentation tank, this range will be tested once again and coupled with the new performance and imaging data.

Imaging data will reveal the average steady-state concentration of the floc blanket, and the extent of flux across the floc-water interface. At high upflow velocities, the effective kinetic energy is significantly higher leading to a greater probability of large-scale eddies at or near the floc-water interface. These eddies are likely to carry a greater amount of solids across the floc-water interface and also increase the extent of variability of flux across the interface. It is expected that performance at these high upflow velocities will be more highly variable and will show up in the performance data. However, what constitutes success for this experiment will not be the best performance data, but the maximum upflow velocity that will still reliably give performance below 2-3 NTU. Such change in thought is the result of the addition of the rapid stacked sand filter downstream that can easily handle such turbidity.

(5) Effect of energy dissipation rate of jet at contact with debris flow on performance

At higher upflow velocities, the energy dissipation rate where the jet interacts with the returning solids will be higher. The higher energy dissipation is anticipated to increase the local shear rate each particle experiences. Greater local shear rates will likely lead to a higher extent of break-up of floc particles yielding more and smaller particles after break-up, however, it is not simply the intensity, but distribution of shear forces that affect particle break-up.

Increasing upflow velocity will also decrease solids concentration and increase particle-particle separation distance which is hypothesized to decrease the effectiveness of particle capture in the blanket. Thus, it will be difficult to understand the contribution of floc break-up on performance solely from running at a higher upflow velocity. To eliminate this effect, high flow rates will be pulsed for thirty seconds through a blanket formed under conditions of 45 mg/L, 100 NTU and an upflow velocity of 1.2 mm/s and then set back at the original upflow velocity of 1.2 mm/s for at least five minutes before another pulse. It is anticipated that these bursts of high flow rates will show up in the performance data as spikes in turbidity. The delay could be up to one hydraulic residence time, so the time required to collect these spikes in turbidity will have to be tested experimentally before data is collected.

(6) Effect of recirculation on floc blanket formation

Collision potential in flocculation is influenced by separation distance of particles which is a function of solids concentration. Dosing has been previously confirmed in other studies to not be stoichiometric and is instead a function of collision potential. Higher collision potential is related to higher probability primary particles will be coated with aluminum hydroxide. Solids re-circulation in the flocculator has the potential to greatly increase collision potential which could result in significantly lower alum dosing required for the same raw water turbidity.

For these experiments, floc blankets will be built under low turbidity and low dosing conditions (i.e. 3 NTU and 1.5 mg/L alum dosing) with and without floc re-circulation. It is anticipated that floc blankets without re-circulation will not be able to form as quickly. The central reason is that lower collision potential will delay growth of some clay particles, partly because some clay particles to not be adequately coated with aluminum hydroxide and partly because there will be less particles with which to collide in the flocculator. The result is that the blanket will lose a significantly larger portions of its solid after lamellar sedimentation.

2 Floc hopper geometry

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 possible 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 (Figure

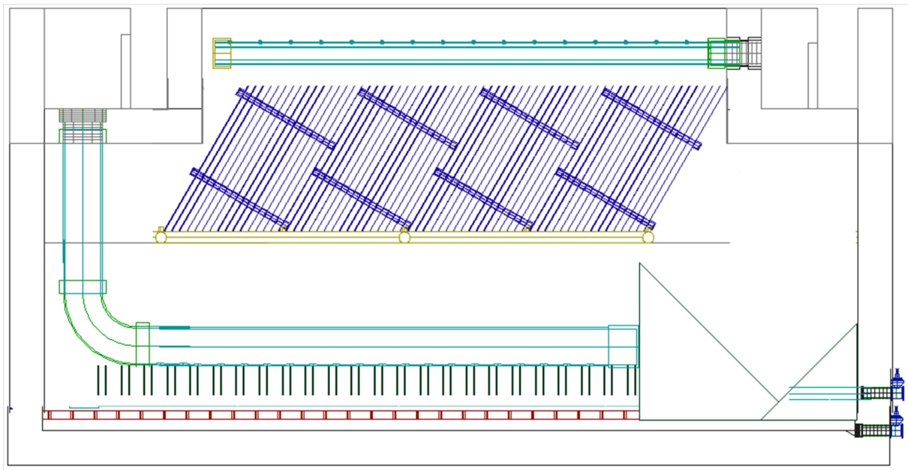

Figure 3: Preliminary sketch of a floc hopper with a double bottom slope.

??). 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. 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.

1. Z.SedFlochopperWeir - The height of the top of the floc hopper weir that will then set the depth of the floc blanket. It is probably best if the floc blanket doesn't reach the bottom of the plate settlers and thus we may want to set the top of the floc hopper weir to be approximately 10 cm below the bottom of the plate settlers.

2. AN.SedFlochopper - The angle of the floc hopper could be 60° or perhaps as low as 45°. The goal is to be able to have the sludge slide down the incline easily. It may be best to make this 60° to reduce the risk that sludge will accumulate and not slide into the drain.

3. ND.SedFlochopperValve - Ten state standards suggests that the minimum diameter for any sludge valve should be 3 inches. That seems rather large given what this valve has to handle. I believe we have used 2 inch valves on sedimentation tanks and they performed well. The flow rate for this valve will be very low. We should estimate the sludge flow rate. My intuition is that the valve should be at least 1 inch in diameter so that it won't clog too easily. In normal operation the plant operator may leave the valve open slightly with a low continuous flow rate discharging the sludge as it accumulates and consolidates in the floc hopper.

4. L.SedFlochopper - distance between the drain end wall of the sedimentation tank and the floc hopper weir. This would be estimated based on the floc hopper plan view area required to consolidate the flocs.