Sedimentation Tank Hydraulics

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Abstract

A floc blanket is a dense, fluidized bed of particles that forms in the sedimentation tank and helps to reduce effluent turbidity by trapping small flocs and reduces clean water waste through less frequent draining of the sedimentation tank. Floc resuspension is necessary for floc blanket formation so that flocs are recirculated through the tank instead of settling on the tank bottom as sludge. Research was conducted to examine mechanisms for floc resuspension. Parameters important for floc resuspension include energy of the jet stream on its upward flow path, position of the jet as it interacts with solids, and hydrodynamic pressure of the jet compared to hydrostatic pressure of the returning solids. Several geometries were tested with red dye and fully built floc blankets to observe the jet path and velocity profile around the bottom geometry. Best results are achieved through geometries that preserve jet momentum, especially through splitting the jet flow, and geometries that maintain a high jet velocity when contacting solids. Later, quantitative measurements were taken to determine floc blanket performance for various bottom geometries.

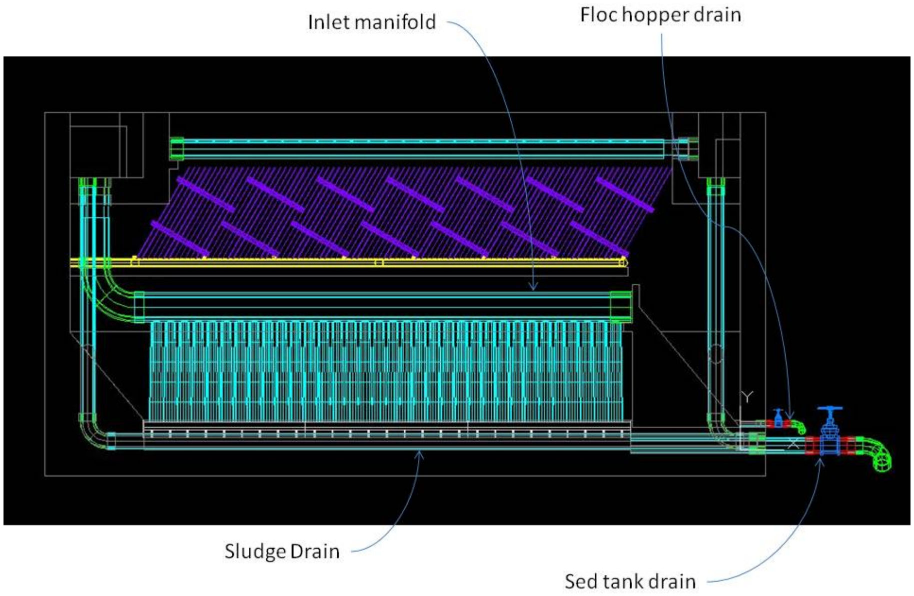


Figure 1: Sedimentation tank

Background

A floc blanket is a dense fluidized bed of flocs that forms above the inlet jet and below the plate settlers in the sedimentation tank. Introducing a floc blanket to an AguaClara sedimentation tank has been confirmed to help reduce effluent turbidity in the sedimentation tank by trapping smaller flocs that would otherwise escape through the plate settlers [Hurst et. al., 2010]. A floc blanket will also waste less clean water as a result of less frequent draining of the sedimentation tank because a floc blanket reduces sludge build up in the tank. Typically, it is necessary to drain the sedimentation tank to remove built settled solids. Draining is accomplished through the sludge drain, located at the bottom of the sedimentation tank (figure 1). It easier and less time consuming for the plant operator to concentrate waste in a floc weir and continually waste than to drain and clean the sedimentation tank.

Floc blanket formation can be described by different stages of floc settling. The second type of settling that occurs in the sedimentation tank is flocculent settling. During flocculent settling, the concentration of particles is high enough so that flocs are present. Flocs collide and grow during flocculent sedimentation. If the terminal settling velocity is less than the upflow velocity of the tank, the particle will enter the plate settlers at the top of the tank.

During hindered settling, the third stage of settling occurring in the sedimentation tank, interactions between particles dominate. The concentration of particles in the suspension is much greater, and the particles are therefore more affected by water displacement. Because of the close proximity of the particles, water displacement slows down the settling speed of surrounding particles. Once particles transition to hindered sedimentation, a floc-water interface can be clearly observed.

A fourth stage of settling in the sedimentation tank is compression settling, during which flocs are highly concentrated. During compression settling, the flocs are in contact with other flocs in the sedimentation tank and solids are compressed underneath solids above them. The weight of the solids above gradually squeeze out water from the floc matrix, resulting in sludge thickening. This type of settling typically occurs at the bottom of the sedimentation tank or on the sedimentation tank inclines in the form of sludge build-up or debris flow. Compression settling occurs in the tank during floc blanket failure and will occur in the floc hopper, from which the sludge will be drained.

Previous AguaClara research teams determined the minimum angle of repose necessary for flocs to fall down the slope to the inlet jet without accumulation on the incline, to be 24 degrees[STHT Spring11]. The flat bottom geometry with 60 degree bottom insert angles contained in several AguaClara sedimentation tanks was found to result in sludge buildup near the inlet jet, and inadequate and poor floc blanket formation. The flat bottom geometry, and not the 60 degree incline, is therefore the cause of failure in current sedimentation tanks. A primary goal for this research for Fall 2011 was to determine optimal bottom geometry for floc blanket formation. This research is being continued to thoroughly examine mechanisms for floc resuspension resulting from specific bottom geometries.

Introduction

Floc resuspension without floc breakup or sludge buildup is crucial to floc blanket formation in the sedimentation tank because with floc breakup, there will be more smaller flocs to potentially escape lamellar sedimentation. We hypothesize that floc resuspension is directly related to the dynamic pressure of the jet and the hydrostatic pressure of solids built up on the incline. The dynamic pressure of the jet is given by:

$P = \rho \int \frac{V^2}{R} dn$

Where: ρ is the density of the fluid, V is the fluid velocity, and R is the local radius of curvature. Equation 1 applied across streamlines determines the dynamic pressure of the jet and shows that holding all else constant, a decrease in the radius of curvature will result in an increase in dynamic pressure. Thus, a narrower rounded trench bottom should result in a greater dynamic pressure and therefore minimal sludge buildup and better floc blanket formation. An increase in jet velocity will also increase the dynamic pressure of the jet, and will have a greater impact on the dynamic pressure than a decrease in the radius of curvature.

Without adequate hydrodynamic pressure, insufficient jet velocity will cause flocs from the incline will fall into the path of the jet or become entrained by it. We hy-

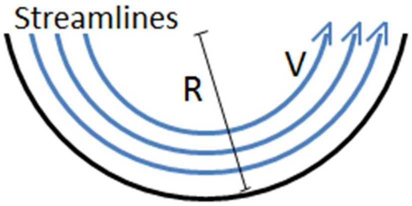


Figure 2: Application of the dynamic pressure equation across streamlines

pothesize that returning debris with higher hydrostatic pressure will enter the trench and divert the path of the jet. This in turn would greatly reduce floc resuspension. The dynamic pressure is dependent on the jet velocity, which is affected the bottom geometry of the tank. The purpose of this semester's research has been to find bottom geometries that maximize the dynamic pressure of jet while minimizing energy dissipation rate and floc breakup. Energy dissipation is given by:

$\varepsilon_{max} \approxeq \frac{(\Pi_{jet} V_{jet})^3}{D_{jet}}$

Where: Π is the vena contracta of the jet and V is the jet velocity, and D is the diameter of the jet. While increasing the velocity of the jet increases its dynamic pressure, it may be detrimental to floc blanket formation and performance because it leads to significant energy dissipation which is correlated with floc breakup.

Dynamic pressure can be visualized by injecting concentrated red dye into the inlet stream for short intervals of time; this method allows us to visualize the flow path of the jet and observe the affects of bottom geometry on fluid flow. Fluid entrainment induced by bottom geometries where streamlines are not preserved will reduce the dynamic pressure and negatively affect floc resuspension due to energy dissipation. The dye tests will also allow us to estimate the dynamic pressure.

In addition to dye tests, an alternative model that we propose for measuring jet pressure is applying the dynamic pressure of the jet (Equation 1) across the streamlines. Assuming jet momentum is conserved and the jet flattens against the wall in a rectangle of a certain width and knowing the flow, we can calculate jet velocity and thus, dynamic pressure.

Methods

We used the same experimental apparatus and procedure as with the experiment documented in the Sedimentation Tank Team's Research Report 1 (Summer 2011). A thin 1.27 cm wide tank was used to model a thin slice of the full scale sedimentation tank. Figure 1 in The Sedimentation Team Final Research Report shows

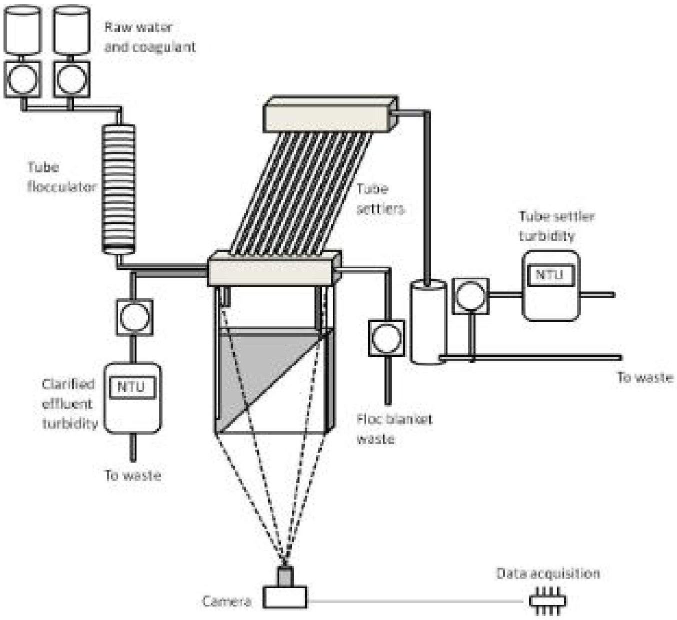


Figure 3: Schematic of turbid water flow through flocculator and sedimentation tank.

AutoCAD renderings of the side view and front view setups for the one half inch wide sedimentation tank and light panel system. A flow of 2 x 228 = 456 mL/min of aerated raw water containing 45 mg/L of alum and an average influent turbidity of 100 NTU made from a concentrated kaolinite clay stock regulated by the Process Controller was run through a tube flocculator before being expelled through a vertical downward-pointing jet suspended 10 cm from the bottom of the sedimentation tank. 100 NTU was chosen for the influent turbidity because it was a well characterized turbidity from previous studies [Hurst et. al., 2010]. Upflow velocity was 1.0 mm/s, which reflects the upflow velocity in an actual plant, constraining the initial jet velocity to 0.011 m/s, as it is dependent on flow rate and cross-sectional area of the inlet tube:

$V_{up} = \frac{Q}{A}$

where $V_{up}$is the average upflow velocity, Q is the jet flow rate, and A is the cross sectional area of the clarifier [Hurst et. al., 2010].

Images of the tank were acquired with a camera at 20 frames per second and recorded using the LabVIEW data acquisition software. The images were compiled using MasterProgram image analysis software to make a video using 30 images per frame, thereby documenting the experiment (figure3).

Experiments were performed using foam inserts of various geometries made from 1.27 cm wide foam board inserts laminated with tape. Magnets were used to secure the position of the inserts. In initial experiments, red dye was injected into the apparatus to observe fluid flow with and without flocs. Red dye, at 10 g/L, was injected into the tank at 6 mL/min by a pump. Injection at 50 cm above the inlet exit allows for sufficient mixing by shear force so that the dye enters the tank uniformly, which can be confirmed by our visual observations. By making a video from photos of the apparatus taken a high frequency of 1 shot/0.1 s,_we can make qualitative observations about the ability of the jet to resuspend solids. In the future, we intend to utilize image analysis to quantify our observations.

Objectives

The following objectives can be considered guidelines for designing a sedimentation tank that utilizes a floc blanket.

No Increase in Energy Dissipation Rate after Flocculation

Energy dissipation of the jet stream results in significant breakup of flocs and a decrease in the hydrodynamic pressure of the jet at the point where it contacts returning solids. Smaller flocs result in an increase in floc blanket formation time and decrease the density of the floc blanket, both which will negatively impact floc blanket performance. Energy dissipation of the jet stream is given by the expression:
$\varepsilon_{max} \approxeq \frac{(\Pi_{jet}V_{jet})^3}{D_{jet}}$
Therefore, lower jet velocities and higher jet diameters will result in minimal energy dissipation of the jet. Energy dissipation is also caused by turbulence induced in the jet, and can be minimized by minimizing orifices and sharp bends both in the jet tube and the reactor.

Minimal Complexity of the Inlet Design

Minimizing the complexity of the inlet design will allow for easier and more accurate construction. An overly complex inlet design may result in increases in energy dissipation rates and potential dead zones in which flocs can settle.

No Flow Obstruction by Placement of the Inlet

Flow obstructions caused by placement of the inlet and can result in sludge buildup by the inlet. Flow obstructions result in differences in head loss on either side of the tank, which can result in preferential flow and ultimately uneven floc blanket formation or large, circulating eddies, which can affect the settling of flocs.

Resuspension of All Returning Solids

Floc resuspension without floc breakup is crucial to floc blanket formation in the sedimentation tank because with floc breakup, there will be more smaller flocs to potentially escape through the plate settlers. Inadequate floc resuspension will result in sludge build-up, which can potentially create flow obstructions and differences in head loss on each side of the tank, negatively impacting floc blanket formation. We hypothesize that floc resuspension is directly related to the dynamic pressure of the jet and the hydrostatic pressure of solids built up on the incline. By holding all else constant, a decrease in the radius of curvature will result in an increase in dynamic pressure. Thus, a narrower rounded trench bottom should result in a greater dynamic pressure and therefore minimal sludge buildup and better floc blanket formation. An increase in jet velocity will also increase the dynamic pressure of the jet, and will have a greater impact on the dynamic pressure than a decrease in the radius of curvature. Without adequate dynamic pressure, flocs from the incline will fall into the path of the jet or become entrained by it. We hypothesize that returning debris with higher hydrostatic pressure will enter the trench and divert the path of the jet. This in turn would greatly reduce floc resuspension. The dynamic pressure is dependent on the jet velocity, which is affected the bottom geometry of the tank.

Tolerance for Asymmetry

It is important that the bottom geometry is tolerant of slight asymmetries since perfect symmetry during fabrication will prove difficult. Slight deviations of the jet location relative to the center of the tank typically results in preferential flow, uneven distribution of flocs, and large eddies. The design must be able to avoid failure and maintain a functioning floc blanket under these conditions.

Minimal Floc Blanket Formation Time

Longer floc blanket formation times result in more small floc particles in the effluent because until the floc blanket is fully formed, small flocs will not be captured by hindered sedimentation. Floc blanket formation time and floc blanket growth rate are affected by the upflow velocity in the tank and the portion of solids reaching the sedimentation tank. If flocs are captured in the form of sludge build up in the sedimentation tank or the flocculator, the floc blanket will take a longer time to form. Floc blanket formation time is also directly related to the solids residence time in the floc blanket because an increase of particle collisions will occur when more flocs are present in the reactor for a longer period of time.

Optimization of Sedimentation Tank Performance

Floc blanket performance is determined by measuring the effluent turbidity of the water. A lower effluent turbidity means that more flocs are captured by the floc blanket. Floc blanket performance is affected by the height and density of the floc blanket–a taller and more dense floc blanket will enhance particle capture because the probability of particle collisions increases[Gregory, R. 1979]. To optimize floc blanket performance, break up of solids must be minimized. Floc break up is due to shearing effects caused by a high energy dissipation rate and should be avoided since small particles are more likely to escape through the floc blanket. Formation time must also be minimized, since flocs can escape to the effluent during formation time.

Ease of Operation and Maintenance

Because designs are made for real life application, they must be easily controlled by a plant operator and easy to repair. The floc blanket must be able to tolerate errors or deviations in operation and flow conditions, such as a temporary decrease in flow rate or periods of highly turbid water. The tank should easily accessible to be cleaned out regularly, so the tank dimensions should not be too small. Sedimentation tank parts should be easily replaceable in case of failure. It is essential that this objective is considered because practicality is imperative for plant operation.

Parameters needed to achieve objectives

We hypothesize that the hydrodynamic pressure of the jet counteracting the hydrostatic pressure of the returning solids at the point of convergence is the primary mechanism for floc resuspension. This location presents the challenge of minimizing the energy lost between when the jet exits the inlet and the point at which it contacts the concentrated debris flow.

In designing tank inserts, important considerations include varying angles of incline, geometry at impact, radius of curvature in rounded bottom shapes, symmetry of the geometry, and the direction of the jet. The angle of incline must be above the minimum angle of repose of 24 degrees. Increasing the angle of incline is hypothesized to decrease the volume of the floc blanket and decrease hydrostatic pressure since solids will fall down the incline at a greater rate.

The geometry of the bottom at jet impact could greatly affects the energy lost by the jet at impact. Flat geometries at the point of impact will result in more energy loss, while a point to guide the streamlines of the jet will result in less energy dissipation and fluid entrainment (figure2). The symmetry of the bottom geometry is an important consideration because, with an asymmetric bottom geometry we do not have to split the jet, which means that the jet will have twice as much flow rate and a greater momentum, and could allow for better floc resuspension. An asymmetric geometry will also result in a more even floc blanket height in the lab scale reactor, since the jet will not be located in the center of the tank to obstruct flow across the tank. This constraint is only applicable to the lab-scale reactor and not at field scale. The direction of the jet as it leaves the geometry affects the resuspension of solids as they interact with the jet. If the jet flow is close to parallel with the particle flow, we hypothesize that solids will be more likely to fall behind the path of the jet and enter the trench.

Results

We want to find an optimal bottom geometry for an AguaClara sedimentation tank that minimizes fluid entrainment and energy dissipation, both which decrease hydrodynamic pressure and negatively affect floc resuspension. Our bottom geometry should work for a half plant flow rate and potentially work to resuspend solids when plant flow rate has been turned off for an extended period of time, conditions that will likely occur on the field.

Failure of current bottom geometry

The red dye tests illustrated that previous bottom geometries created turbulence at jet impact, which resulted in a large energy loss, which is not optimal for floc blanket formation. The energy dissipation decreases dynamic pressure, since the energy lost could otherwise contribute to the upward velocity of the jet stream. Fluid entrainment induced by the geometry also decreases the dynamic pressure because it increases the jet's cross-sectional area and therefore decreases velocity. Other experiments were designed to minimize energy dissipation by minimizing floc breakup. Observations of the jet stream through red dye tests helped us determine possible rounded and double rounded bottom geometries so that the jet would not entrain a significant amount of fluid before contacting the solids.

A red dye experiment was first run to observe the weaknesses in the current bottom geometry (figure4). The jet stream from the inlet pipe hits the bottom and follows the semi-circle, leaving the semi-circle with only an upward velocity component. The dye test illustrated that although upward velocity was achieved, the jet's momentum decreased due to its impact with the bottom of the semi-circle, as illustrated by the turbulence of the stream after impact (figure5).

Achieving upward jet stream velocity at its point of interaction with returning sludge does not necessarily result in solid resuspension. Solids resuspension may not occur if the hydrodynamic pressure of the jet is still significantly low due to energy loss of the jet in the reactor.

Bottom geometries designed to minimize energy losses and fluid entrainment before contact with returning solids

To minimize loss of jet momentum, we must minimize turbulence of the jet by allowing the jet to remain streamlined along the edge of the bottom geometry. We hypothesized that a double semi-circle jet reverser bottom geometry will allow for greater dynamic pressure by reducing energy dissipation compared to that of a single semi-circle geometry (figure6).

In 'Bottom Geometry 1' (figure6), the circular cut outs extend beyond 180 degrees, so that the jet will leave the geometry at an angle as opposed to having a purely vertical path (figure7). We hypothesized that the angled jet path will make it less likely for flocs to fall behind the path of the jet, since the jet stream is approximately normal to the path of the returning solids.

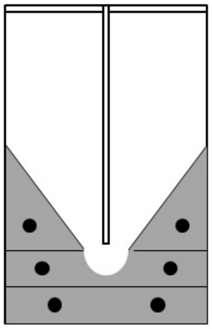
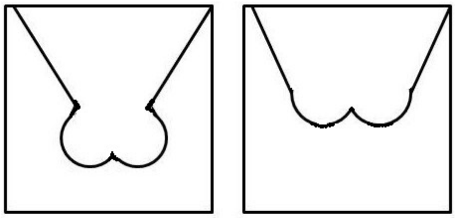


Figure 4: Current bottom geometry

Figure 5: Turbulence in semi-circle geometry.



Bottom Geometry 1 Bottom Geometry 2

Figure 6: Variations of jet reverser bottom geometries

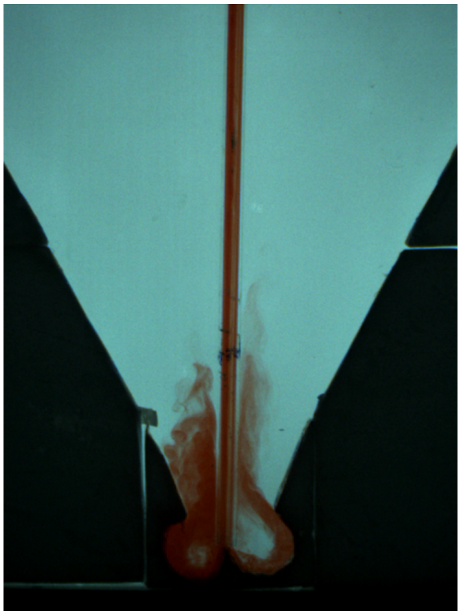


Figure 7: Effects of 'Bottom Geometry 1' on jet stream.

The dye tests showed that the streamline of the jet was preserved on the right side, and the jet diameter after the jet rounded the bottom was smaller than the diameter leaving the inlet jet, suggesting a vena contracta (figure7). The discrepancy between sides is due to lack of perfect symmetry of the insert, as well as uneven flow of the jet on each side of the insert or the inlet tube blocking jet flow between both sides of the reactor, representing one of the challenges presented by this type of bottom geometry. We tried placing magnets on each side of the jet to maximize its stability, but the flow on each side was still uneven.

Other variations of the 'rounded W' geometry were tested and were found to result in a more streamlined jet path, but with a less apparent vena contracta (figure7).

Splitting the jet

A problem presented by our double semi-circle geometry is uneven flow on each side of the bottom geometry due to both difficulty positioning the jet directly above the point of jet splitting and differences in head loss on each side of the tank.

The jet did not allow flow transfer between the two sides of the reactor, which prevents a self-correcting element for uneven jet flow that may occur if transfer was present. If transfer between sides of the tank was possible, flocs from one side could pass to the other, essentially eliminating the difference in head loss that leads to further uneven flow. Transfer between both sides of the tank, although not present in our reactor, will be present in the field, presenting a possible limitation to our

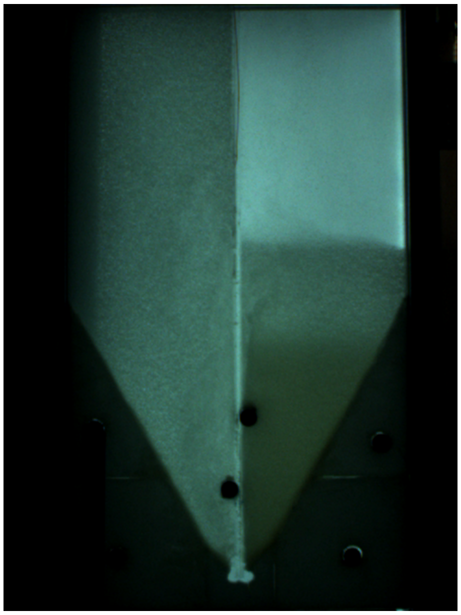


Figure 8: Uneven floc blanket height across tank.

reactor. Uneven jet flow results in uneven floc blanket height on each side of the tank, since the jet prevents flocs from flowing across the tank (figure8). To fix this problem, we bought 2 smaller diameter (0.9525 cm) tubes instead of our previous 1.27 cm diameter tube. The total cross sectional area of the two tubes turned out to be similar to the cross sectional area of the single 1.27 cm jet, so the total jet velocity did not change significantly (5.33 cm/s for the 2 smaller tubes and 6.0 cm/s for the larger tube). The two tubes were glued together, and the jet was positioned so that one tube exit was on each side of the jet reverser. Each tube was attached to a separate flocculator and peristaltic pump so that the flow rates would remain equal. We hypothesize that splitting the jet will allow us to create even flow rates on each side of the jet reverser, as well as even out the floc blanket by allowing flocs to pass freely across the tank, making conditions in our reactor more similar to conditions in the actual sedimentation tank.

Splitting the jet resulted in even flow on each side of the geometry, which could be observed through dye tests. The tube diameter, however, was not narrow enough for flocs to pass freely between each side of the tank, presenting a limitation to our current design.

Asymmetrical geometry

We ran experiments with asymmetrical bottom geometries, as opposed to the symmetric geometries previously used, to observe an experiment where the jet does not

Figure 9: Asymmetric bottom geometry

split. With this configuration, the jet will have twice the cross sectional area, and therefore twice the momentum, that can potentially be used for floc resuspension.

In this configuration, the jet enters the reactor at an angle of 60 degrees, following the angle of the incline. A single semi-circle deflects the jet upwards. Flocs falling down the two slopes will enter the jet stream both in the direction of the jet flow (these should enter the jet stream), and into the flow of the jet stream.

The experiment resulted in adequate floc resuspension and minimal sludge buildup. The floc blanket formed evenly across the tank since there was no jet in the center of the tank to provide an obstruction.

To test the performance of the asymmetric bottom geometry, we produced a floc blanket in the reactor and slowly turned down the flow rate by 30 mL/min per tube (60 mL/min total), beginning at the typical flow rate of 228 mL/min (456 mL/min total), until failure was observed. Failure is defined as flocs passing the jet stream and entering the bottom geometry. Failure was observed at a flow rate of 30 mL/min (60 mL/min total), approximately 13 percent of the plant flow rate (figure9). As the flow rate was decreased, the jet was deflected from its original path parallel to the incline to a purely vertical path at the time of failure, validating our hypothesis that the jet does deflect if the dynamic pressure is too low. Jet deflection is a sign of scouring and entrainment of solids, as the hydrostatic pressure of the built up solids will divert the path of the jet. Jet deflection can therefore be used as a parameter to indicate failure.

Although the asymmetric bottom geometry works well compared to the other bot-

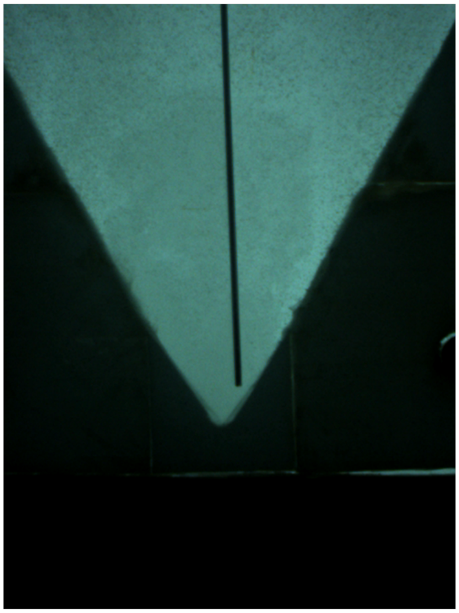


Figure 10: Asymmetric jet position

tom geometries, as shown by the experiment previously described, its fabrication in an AguaClara plant will be difficult to implement and design.

Tolerance of Asymmetry

It is important that the bottom geometry is tolerant of slight asymmetries since perfect symmetry during fabrication will prove difficult. Slight deviations of the jet location relative to the center of the tank typically results in preferential flow, uneven distribution of flocs, and large eddies. The design must be able to avoid failure and maintain a functioning floc blanket under these conditions.

To mimic conditions of slight asymmetry in a single semi-circle geometry, the jet was positioned approximately 3 cm to the right of the trench center (figure10). The position of the jet to the right of the trench resulted in a large clockwise recirculating eddy (figure10). Flocs were carried upwards on the left side of the tank, crossing to the right side, and settling down towards the jet. The flocs crossed under the path of the jet, resulting in significant floc breakup. These conditions made floc blanket formation difficult and significantly increased floc blanket formation time. However, a floc blanket did form, illustrating that a single semi-circle geometry is tolerant of slight variations in jet location. In the actual plant, we do not expect the variation in jet position to be as large as 3 cm.

To create more evenly distributed flow in cases with less tolerance of asymmetry, such as the double semi-circle bottom geometry, a solution would be to split the

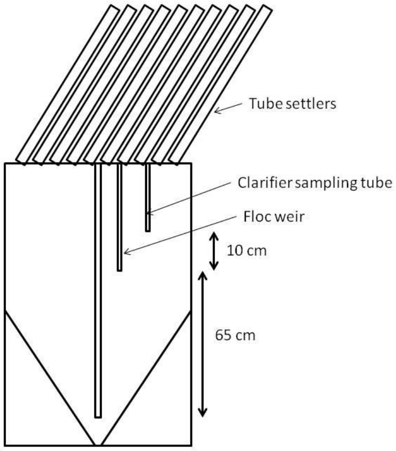


Figure 11: Reactor set-up for performance studies

flow into two tubes. Placing an orifice or another device that leads to energy loss in the inlet will ensure more evenly distributed flow in each tube because energy dissipation resulting from flow from an orifice is much more significant than head loss throughout the tank, which is typically the cause of uneven flow. However, the addition of an orifice or another device will lead to floc breakup because of larger energy dissipation that shears flocs.

Quantitative Analysis of Data

To quantitatively measure the effectiveness of various bottom geometries, several parameters can be measured, including the turbidity of the clarified water above the floc blanket, the turbidity after lamellar sedimentation, floc blanket growth rate, and floc blanket concentration.

New Methodology

To take the turbidity measurements, the reactor was set up with a tube placed 60 cm above the jet inlet to waste flocs from the floc blanket at a constant rate of 50 mL/min, resembling a floc weir located at this height. A tube was placed in the reactor at a height of 70 cm, 10 cm above the floc weir to draw water from above the floc-water interface at a rate of 50 mL/min and measure the clarified effluent turbidity. 10 tubes were set up above the reactor to resemble plate settlers (figure11). Turbidity measurements were taken of the effluent after lamellar sedimentation by sampling the water leaving the tube settlers.

Floc blanket concentration and growth rate were measured using image analysis software on MasterProgram. Code was written in LabVIEW to determine the concentration of flocs at each point in the reactor by comparing the light intensity of the image to the light intensity of the background image. The floc blanket height could be quantitatively determined by measuring the concentration of flocs throughout a vertical region of interest, determining the concentration of flocs with respect to height, and determining the height where the second derivative of the concentration is equal to zero, or where there is the greatest change in concentration with respect to height occurs. This point represents the floc-water interface.

To take more precise and accurate measurements, 10 cm by 10 cm bottom geometries for the center of the reactor were constructed from 1.27 cm (0.5 inch) thick slabs of polyvinyl chloride (PVC). PVC is less malleable than the foam inserts previously used for bottom of the reactor and can be more precisely cut to the desired specifications.

Quantitative Analysis

One experiment was performed using 1.5 cm radius double semi-circle bottom geometry. A plot of floc blanket height vs. time is given below. Since the floc blanket height data is taken by determining the position of the floc-water interface, this data can be used to determine the time of floc blanket formation, which is the time when the floc blanket height data gives a relatively constant value. In this experiment, the floc blanket formation time was approximately 2000 seconds, or approximately 0.5 hours. From this point, the floc blanket grows almost steadily with time. The time between 7000 and 9000 seconds where the floc blanket blanket height remains approximately constant may represent a period of floc blanket concentrating, where flocs entering the blanket contribute to increasing density instead of height growth. Additional trials should be run to examine the extent and the effects of floc blanket concentrating.

The pC* of the system over time can be used as a measurement of the particle removal efficiency of the floc blanket and the tube settlers. pC* is defined as the negative log of the ratio of effluent to influent turbidity. Data for pC* vs. time are given in the chart below (figure13). pC* for both the influent raw water to the clarified effluent and for the influent raw water to tube settlers. The pC* was initially low, indicating a lower particle removal. After approximately 5 hours, the floc blanket reached a steady state, with a pC* of slightly greater than 2, or slightly greater than 99% removal efficiency. The pC* from the raw water to the clarified effluent at steady state is negative, indicating a greater turbidity in the clarified effluent than in the raw water. The additional flocs in the clarified effluent may be due to the particles captured by the tube settlers. These particles will fall back into the floc blanket by passing through the clarified effluent, and will be taken in the turbidity readings of the clarified effluent. Additional experiments should be run against a control to see the relationship between clarified effluent turbidity and tube settler turbidity with and without a floc blanket.

The pC* data for raw water to the clarified effluent and tube settlers over the first 4 hours of the experiment was plotted to see the relationship between clarified effluent and tube settler turbidity before the floc blanket reached steady state (figure14).

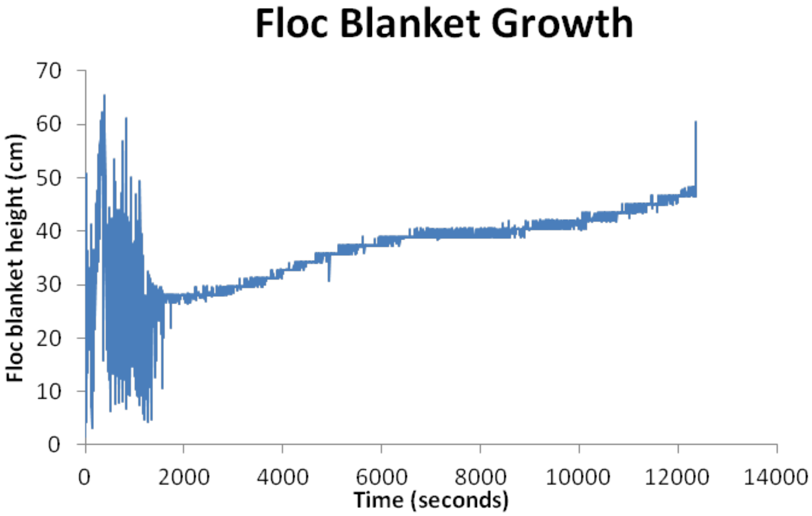


Figure 12: Floc blanket height vs. time

The pC* of both the clarified effluent and tube settlers drops during the first 0.5 hours as the floc blanket is forming. The pC* of the water taken from the clarified effluent sampler drops because a floc blanket has not yet formed and the amount of flocs in the sedimentation tank is steadily increasing. Once the floc blanket forms, the pC* of the raw water to the tube settlers steadily increases in direct proportion to the floc blanket height. The pC* of the raw water to clarified effluent, however, drops to less than zero. As previously mentioned, the high clarified effluent turbidity is due to the particles captured by gravity during lamellar sedimentation that fall back into the floc blanket.

Conclusion

Experiments run with the current bottom geometry (single 10 cm semi-circle) have illustrated the presence of fluid entrainment in the jet stream, which ultimately leads to a lower dynamic pressure. A double semi-circle bottom geometry presents the best solution to this problem, as of yet, because it minimized fluid entrainment where the jet comes in contact with the bottom. Extending the two circles beyond 180 degrees and allowing the jet to leave the geometry at an angle allows the jet to undergo a better vena contracta. The vena contracta decreases the cross sectional area of the jet stream, increasing the jet velocity and the hydrodynamic pressure. However, a single semi-circle with a small radius of curvature has advantages in its tolerance for asymmetry, a factor that must be taken into account since it will be difficult to achieve perfect symmetry during fabrication. A quantitative analysis of floc blanket data can provide further insight into the effectiveness of various geometries.

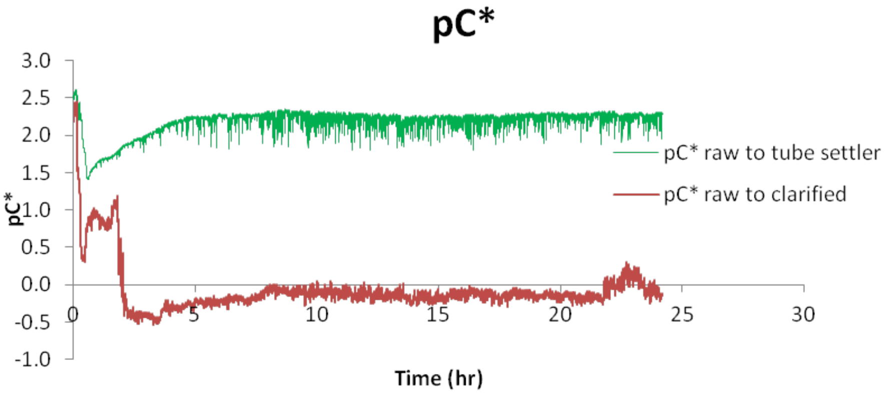


Figure 13: pC* vs. time from raw water to tube settlers and clarified effluent

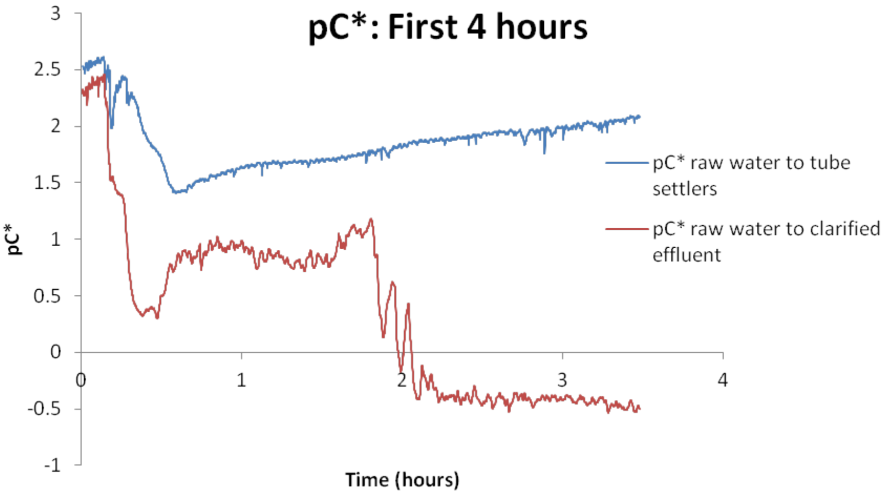


Figure 14: pC* from raw water to tube settlers and clarified effluent during first 4 hours.

Ultimately, the best bottom geometry will be the geometry that provides the lowest effluent turbidity and meets the objectives mentioned above.

Future work

Performance Studies

We will now use a quantitative analysis to determine the optimal bottom geometry based on our design objectives. We can use the methods described previously to determine floc blanket formation time, clarified effluent turbidity and tube settler turbidity for several bottom geometries for a more methodical approach at determining the optimal bottom geometry given a certain objective.

Measuring Hydrostatic Pressure

We want to quantitatively measure debris flow on the incline to determine the effects of hydrostatic pressure due to solids built up on the incline. Quantifying the hydrostatic pressure will allow us to find a relationship between hydrostatic pressure and dynamic pressure, and connect this relationship to bottom geometry failure.

Designing a Floc Weir

We are also working on preliminary designs for a floc weir, which will keep the floc blanket at a constant height (figure15). Previous teams have confirmed that this design functions as a floc weir. After the floc blanket forms, the blanket grows until it reaches the height of the floc weir, and flocs will then fall over the weir and into the hopper.

We need to determine the appropriate height of the floc weir. Based on previous research by Matthew Hurst, the overall particle removal efficiency improves with increasing floc blanket depth up to 45cm. This can be the initial height of our floc weir, which will ensure the highest possible removal efficiency for the smallest floc blanket, thereby saving space in the sedimentation tank. The floc weir should also be higher than the height of the floc blanket when it first forms.

Another important parameter of the floc weir design is the rate of sludge removal from the floc weir. This rate can be determined by performing a mass balance around the reactor, assuming that the floc blanket is at steady-state, so that the rate of flocs entering the tank is equal to the rate of flocs being removed.

$Q_{inlet}c_{inlet} = Q_{waste}c_{compression}$

where Q is the flow rate and c is the concentration of flocs. The concentration of flocs in the inlet can be determined using the image analysis software, and the concentration of compressed flocs in the floc hopper can be determined by image analysis software or a total solids test after baking a fixed volume of flocs in the model sedimentation tank. Regarding waste removal in AguaClara plants, we must

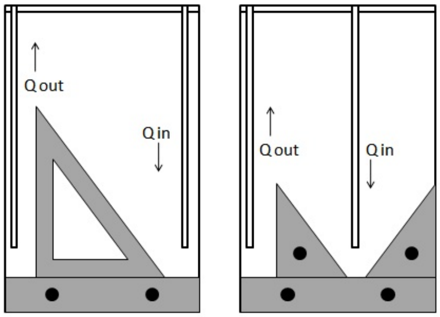


Figure 15: Proposed floc weir design

consider the size of an orifice to be used as well as manual removal at given intervals compared to continual draining.

References

[Hurst et al., 2010] Hurst, Matthew. ”Parameters Affecting Steady State Floc Blanket Performance.”

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