Sedimentation Team Research Rationale2

Sedimentation Team Research Rationale

Background

An improved sedimentation tank design in AguaClara facilities could significantly improve effluent performance, reduce clean water waste (from frequent draining of current sedimentation tanks), and reduce particle loading to filters (for plants considering filtration). We believe that the formation of floc blankets in full-scale sedimentation tanks is integral to achieving these objectives. A floc blanket is a fluidized and highly concentrated bed of particles. Floc blankets facilitate particle removal through mechanisms of flocculation and differential sedimentation. In lab tests, floc blankets were shown to significantly improve particle removal. Furthermore, the sedimentation tank would be drained and cleaned less often because a floc weir constantly removes flocs from the top of the floc blanket, and flocs would no longer settle to the bottom of the tank. Our underlying goal is to understand how we can form floc blankets in a scaled model and to identify the geometric parameters of the sedimentation tank that enable floc blanket formation so that these benefits can also be implemented at our full-scale facilities.

Conceptually, during floc blanket operation, the average upflow velocity in the sedimentation tank must match the terminal settling velocity of the concentrated bed of particles. Furthermore, as currently designed, the jets from the inlet manifold have a horizontal velocity component, which generates a circular flow within the sedimentation tank, as well as dead zones (areas that are quiescent with respect to fluid movement). Dead zones can also result from geometry. The g eometry portion is ensuring that all particles reach an incline with an angle of repose sufficient to return all solids to the jet. We believe that our current design of the sedimentation tank has potential dead zones and we will be focusing on designs that could possibly reduce dead zone.

Dead zones and non-uniform upflow conditions could hinder the formation of a floc blanket by respectively preventing floc re-suspension in some areas of the sedimentation tank, and excessive turbulence in other parts of the floc blanket, disturbing the floc-water interface and diminishing the ability of the blanket to catch particles. There are two important aspects of the sedimentation tank design (and possibly more) that can facilitate floc blanket formation: downward-pointing jets with an appropriate velocity to re-suspend large floc particles, and steep sloping sides that transport particles that have settled out to the re-suspending jet. Vertical tubes extending downwards from the inlet manifold, which we call diffusers, direct jets to re-suspend flocs on the tank floor and also eliminate the horizontal component of the jet velocity. We expect this to generate a more uniform upflow velocity distribution in the sedimentation tank.

We plan to construct a small-scale sedimentation tank incorporating these new design ideas to form floc blankets quickly and reliably in the lab before scaling up our design to the full size plant. If we create uniform upward flow and form a floc blanket in our model, we expect scaling up to be feasible because our flocculator will generate floc sizes that match those created in full scale plants, and because our model sed tank is designed to have an upflow velocity equal to the settling velocity of flocs generated in full scale plants .

Tube Flocculation Design

We designed a tube flocculator to produce a supply of flocs for our model sedimentation tank. A mixture of coagulant and raw water with clay is mixed together before being pumped through a series of coiled tubes. Shear along the sides of the tube, as well as additional energy losses from secondary fluid motion due to the coiling causes appropriate fluid conditions that facilitate successful particle collision, producing

flocs. While non-laminar flow may also produce flocs, we design our system to be laminar so that the energy dissipation rate is easily controlled by the diameter of the tube and the flow rate. By adjusting the flow rate to 2000 mL/min distributed across four ” I.D. (inner diameter) tubes in parallel, the flow is laminar and produces an energy dissipation rate through the flocculator of ~10 mW/kg. Energy dissipation rates of this range have been shown to encourage floc growth, but is not so energetic as to cause substantial floc breakup.
The energy dissipation rate is given by the following equation:

$$ED_{Flocculator}(Q, D, v, \varepsilon) = \frac{f(Q, D\ v, \varepsilon)\dfrac{8\ Q^2}{g\pi^2 D^5}friction_{ratio}(Q, D\ v, R)\ g}{\dfrac{\pi D^2}{4\ Q}} \qquad (1)$$

where $f =$ friction factor in straight tube using the Swamee-Jain equation,

$Q =$ flow rate

$D =$ inner diameter of floc tube

$R =$ radius of curvature of floc tube

The friction ratio is the ratio of the friction factor for a curved versus straight tube, which is given by

$$friction_{ratio}(Q, D\ v, R) = \frac{1 + \left(0.0908 + 0.0233\sqrt{\dfrac{D}{R}}\right)\sqrt{De(Q, D\ v, R)} - 0.132\sqrt{\dfrac{D}{R}} + 0.37\dfrac{D}{R} - 0.2}{1 + \dfrac{49}{De(Q, D\ v, R)}} \qquad (2)$$

Plotting energy dissipation rate as a function of flow rate through a single tube flocculator of ” I.D. (inner diameter), we find that a flow rate of ~500 mL/min gives an energy dissipation rate of 10mW/kg.

Ass flocculator, the
size e of the tube
floc

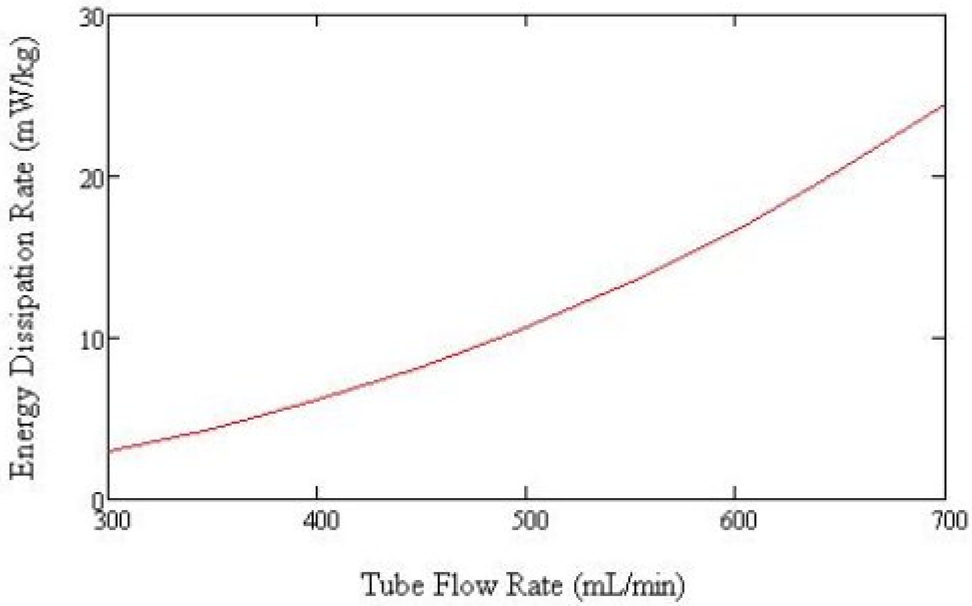


Figure 1: Graph illustrating the relationship between energy dissipation

A longer residence time allows for more collisions and hence larger flocs, barring floc break-up effects. We have chosen a length of tubing that gives a residence time of about 4 minutes, which has been shown in previous experiments to produce flocs that are comparable in size to those observed in the full-scale plant, which are on the order of millimeters. As the settling velocity of flocs is dependent on its diameter and density, we expect the flocs in our model to have similar settling velocities to those in the full-scale plant, that is roughly 1.2 mm/s.

With the optimum flow rate and residence time determined above, we calculated the length of tube required with the following equation, which gives us a total length of 112m of tubing.

$$L_{Tubefloc}(Q, D, \theta) = \frac{4\, Q\, \theta}{\pi\, D^2} \qquad (4)$$

Sedimentation Tank Design

1. Original Sedimentation Tank

We decided to work with the original sedimentation tank to use this as a control design to compare to the floc blanket formation in the modified sedimentation tank design. We will be adapting the current sedimentation tank design.

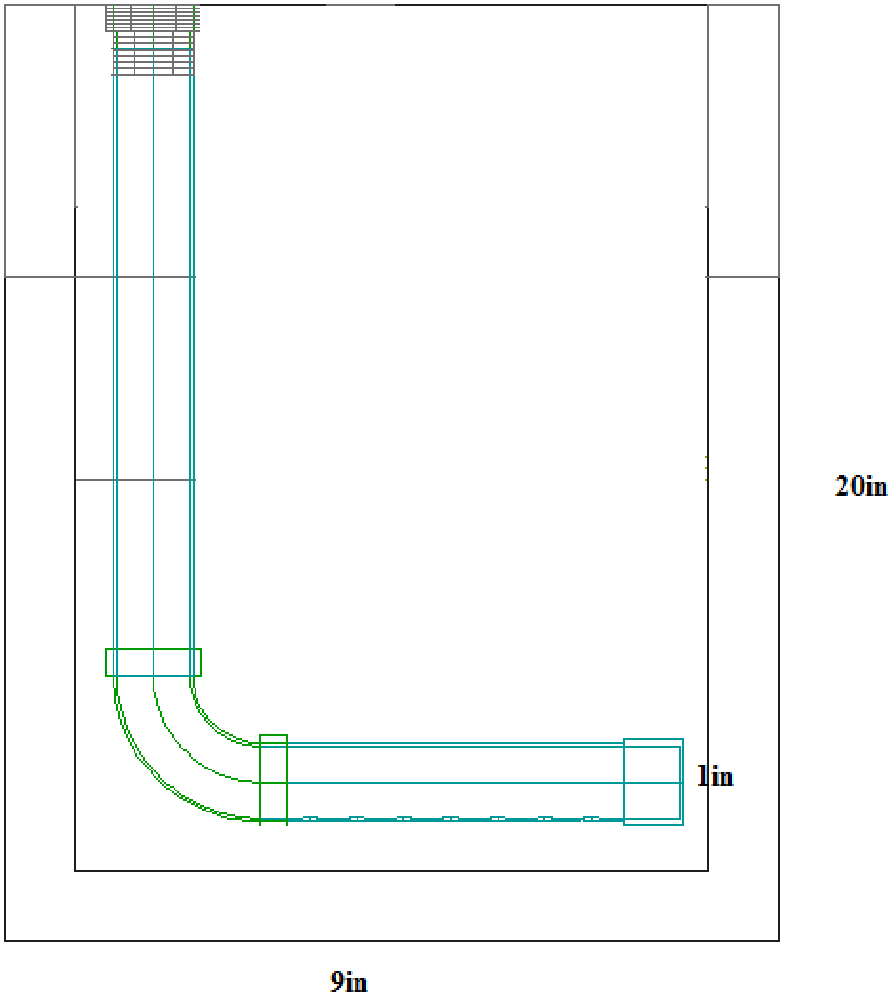


Figure 2: Schematic drawing of the front and side view of the original Sedimentation Tank

2. Modified Sedimentation Tank

We will be experimenting with two different manifold designs using a modified sedimentation tank. The manifold and diffusers are designed so that an energy dissipation rate of 10 mW/kg is not exceeded, and the velocity through the manifold is reasonable to prevent settling out of flocs. The dimensions of the sedimentation tank are in turn based on the length of the manifold, and an average upflow velocity of 1.2 mm/s. Other features are designed to maximize the active area of the sedimentation tank.

Manifold Design A:

Using the flow rate determined by the flocculator, we calculated the appropriate manifold diameter so that the energy dissipation rate through each orifice would not exceed 10 mW/kg:

$$D_{Pipe} \cong \left(\frac{Q_{Pipe}}{\varepsilon_{Max}^{\frac{1}{3}} \Pi_{vc}^{\frac{7}{6}}} \frac{4\alpha_{Jet}}{\pi} \right)^{\frac{3}{7}} \qquad (5)$$

where

$\square_{Max} \square\square 10 \frac{mW}{kg}$

D = diameter of the manifold

$Q = \frac{200mL}{min}$ = Flow through the manifold

$\pi = 0.61$ =venca contracta coefficient

We found that the diameter of the manifold must be at least 0.82 in to prevent floc break up at the orifices. The energy dissipation rate through the rest of the manifold was assumed, and later proven, to be less than that through the orifice so that floc break-up is prevented by this design.

We were also concerned about the velocity through the manifold being too small compared to the scour velocity of .15m/s (state department recommendation), which would result in the settling out of flocs in the manifold. Given a 1 in manifold diameter, the velocity was determined to be .066m/s, and seemed reasonable based on the high energy dissipation rate through the manifold. We are expecting that the vast majority of flocs will not settle out and instead enter the sedimentation tank.

After obtaining the diameter of the manifold, we found the diameters of the orifices so that the cross sectional area of the manifold equals the total area of the orifices. This constraint was made based on the conservation of mass balance-“what comes in must come out” during equilibrium. We set an arbitrary number of orifices to 10 and orifice spacing to 1 cm. The energy dissipation rate through the diffusers was then shown to not exceed the maximum energy dissipation rate. Using D.orifice, S.orifice and the number of orifices, we calculated the length of the manifold. With the length of the manifold determined, we calculated the length of the sedimentation tank to be the length of the manifold plus the length of the elbow.

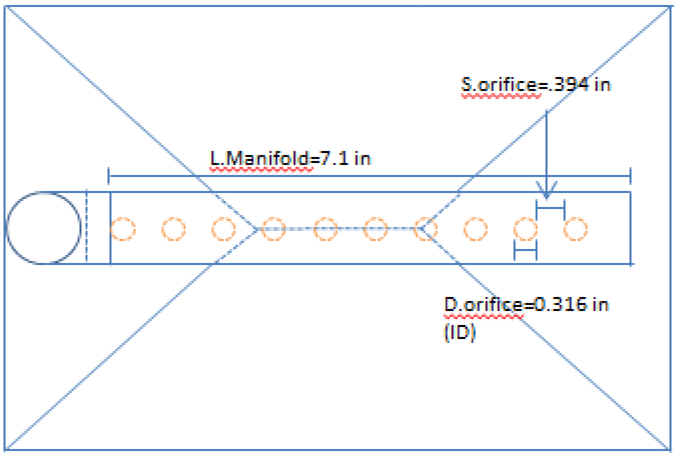
$L_{Manifold} \square\square n_{Orifices} \square D_{Orifice} \square S_{Orifice} \square n_{Orifices} \square \square 7.09 \square r$

$L_{Sed} \square\square L_{Elbow} \square L_{Manifold} \square 9.09 \square r$ The width of the tank was then det (6) maintain an upward velocity of 1.2mm/s

$$W_{Sed} \square\square \frac{A_{Sed}}{L_{Manifold}} \square 6.06 \square r \qquad (7)$$

Figure 3: Top view of inlet manifold and sedimentation tank

Where



L = Length of manifold

S = Spacing between each orifice

D = Diameter of orifice

Sloping inserts with an incline of 60° will be placed along the perimeter of the sedimentation tank. This will direct settling flocs towards the middle of the sedimentation tank where they can be re-suspended by the diffuser jets.

The inlet manifold will be located so that diffusers along the manifold are 5 cm above the bottom surface of the sed tank. This constraint is determined by previous sed tank experiments demonstrating that at 5 cm from the surface, jets are ideal for floc resuspension. The height of the manifold is designed so that the length of the diffusers falls within the range of 2-4 in, producing a range of head loss through the diffusers of 4.2 to 5.6 cm. Head loss calculation for different height of the diffuser is illustrated below:

$$H_{diffuser} := \begin{pmatrix} 2.37 \\ 6.39 \\ 3.94 \end{pmatrix} in$$

$$h_f(Q,D,L,\nu,\varepsilon) := f(Q,D,\nu,\varepsilon)\cdot\frac{8}{g\cdot\pi^2}\cdot\frac{L\cdot Q^2}{D^5}$$

$$K_{total} := K_{ent} + K_{exit}$$

$$h_e(Q,D,K) := K\frac{8}{g\cdot\pi^2}\cdot\frac{Q^2}{D^4}$$

$$h_l(Q,D,L,K,\nu,\varepsilon) := h_e(Q,D,K) + h_f(Q,D,L,\nu,\varepsilon) \qquad (8)$$

$$h_l\left(Q_{Plant},D_{Orifice},H_{diffuser},K_{total},\nu,\varepsilon_{PVC}\right) = \begin{pmatrix} 4.179 \\ 5.654 \\ 4.755 \end{pmatrix}\cdot cm$$

Based on the distance between the bottom of the tank and the manifold, and 60° slope, we calculated the length of bay. From past experiments in varying the slope of the inset, it was noted that 60° slope lead to easy resuspension of the flocs.

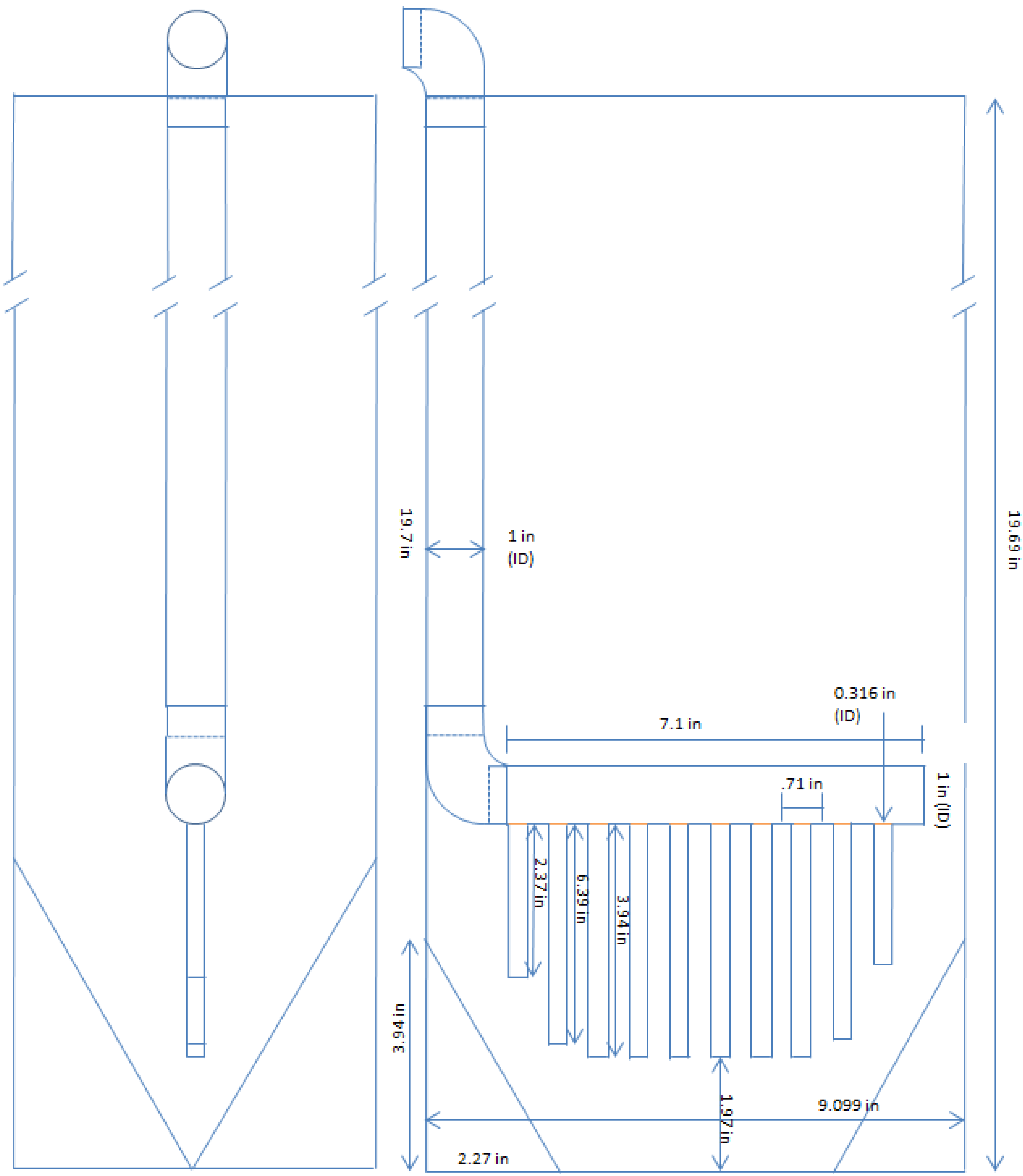


Figure 4: Schematic drawing of the front and side view of the modified Sedimentation Tank (to scale)

A f loc weir will be located 12 inches from the tank bottom and the overflow weir will be located 18 inches high from the bottom of the tank. Both weirs will be in the form of an orifice with a diameter of 0.5 in. This was determined considering the fact that the water is flowing through 1 inch manifold-an attempt to keep mass balance.

Manifold Design B:

Instead of having 1 cm spacing between the orifices, we are going to increase the spacing to around 10 (3.937 in) to test the spatial issues. For constructability purposes, it is desirable to find the minimum number of diffusers necessary to create uniform flow and floc resuspension. We want to explore the possible effects of the orifice spacing on the formation of floc blanket. We hypothesize that more concentrated jets from the orifice will form a floc blanket faster. The calculation for this design is not yet complete because we are aiming to build the initial sed tank and manifold first and to come up with different designs of the manifold to test its effect on floc blanket formation.

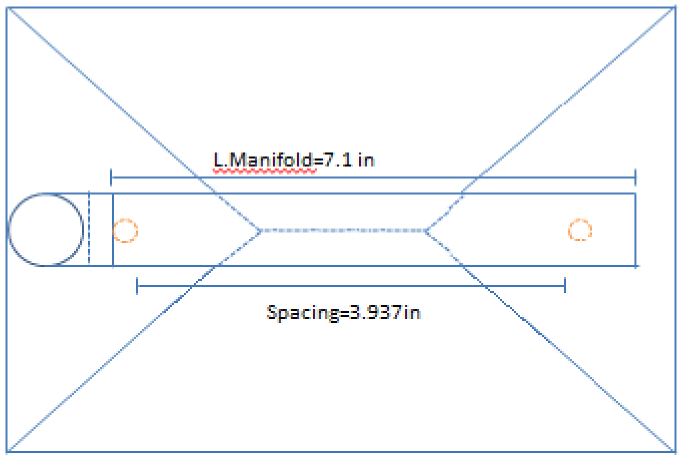


Figure 5: Schematic drawing of manifold design B

3. Sedimentation Tank based on High Velocity Jet Theory

Because constructing a manifold with diffusers is not simple, an improved sed tank design would be based on a single downward-pointing diffuser jet that causes floc re-suspension by imparting a velocity across the entire tank bottom that exceeds the scouring velocity of settled flocs.

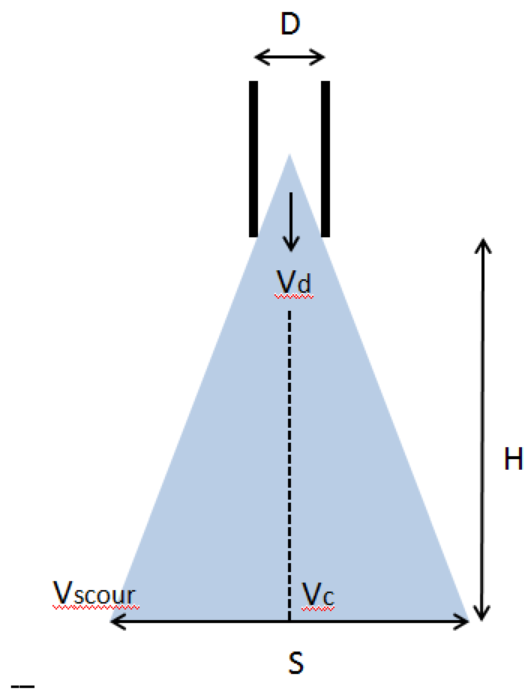


Figure 6: Schematic drawing of jet - based sedimentation tank

Based on a 2000ml/min flow rate and the same energy dissipation rate constraint, the diffuser diameter is determined to be 2.065 cm, by the calculation done for *Manifold Design A.* Based on this diameter we may plot diffuser height H.d, i.e. the distance between the diffuser and the tank bottom, and coverage diameter S.d as a function of a putative scouring velocity of settled flocs, which is unknown.

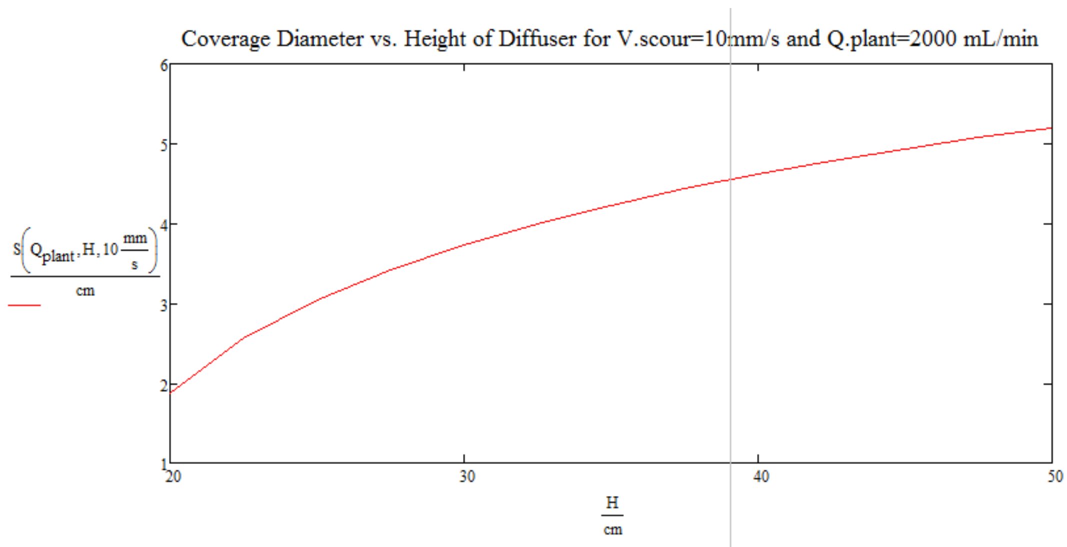


Figure 7: Plot illustrating the relationship between S.d and H.d.

10mm/s is a realistic choice for the scouring velocity based on the relative size of settled flocs and flocs initially leaving the flocculator and the 1.5 mm/s scouring velocity the smaller flocs. According to Figure 7, this choice is also reasonable, as coverage diameter is greater than the diffuser diameter for v.scour=10 mm/s and H.d greater than 20 cm.

The relationship between the height of the diffuser H.d and the coverage diameter S.d calculated for v. scour= 10 mm /s above is a generalization of the empirical relationship given by

$$v = .37\ v_c \quad (9)$$

for

$$S_d = 0.107 H_d \quad (10)$$

where v. is the centerline velocity at a distance H.d from the diffuser, and the centerline velocity at a distance H.d from the diffuser is related to the velocity leaving the jet v.d by

$$v_c = 6.2 v_d \frac{D_d}{H_d} \quad (12)$$

This generalization assumes a Gaussian distribution of flow. It can be seen in Figure 7 that a diffuser height of 25 cm covers a 3.43 cm tank length. From this value, the width of the tank was determined based on the desired upflow velocity, and the coverage area of the inserts may be determined.

The relationships here predicted are useful not only for general considerations when building a single-jet sedimentation tank, but for 1) single-jet experiments determining the true scouring velocity of settled flocs, and 2) designing the spacing of orifices of the first manifold design (Design A).

Materials List and Model Construction

Item	Quantity	Specifications	Source	Quote
Rapid Mix				
Coagulant (Alum & PAC)			AguaClara	
Raw Water			AguaClara	
Rapid mix stirrer	1		AguaClara	
Tube Flocculator				
PVC Floc Tube	~120m (400ft)	3/8 in diameter, 120m length	Clearpvcpipe.com: 3/8" ID x 9/16" OD non reinforced Clear PVC tubing	$140 ($0.35 /ft)
Cardboard tube	4	11.5 cm (4.5”) diameter	AguaClara	
Peristaltic pump	1	600rpm, 2300 mL/min maximum flow rate	AguaClara	
On/off valves	3		AguaClara	
Tube connectors	several	3/8in diameter	AguaClara	
Sedimentation Tank				
Glass tank	1	9” x 6” x 20”	Paul (see below)	~$200
PVC elbows	3	1in diameter	AguaClara	
PVC tube (floc weir)	~1m	1 in diameter	AguaClara	
PVC tube (drain)	1	1in diameter	AguaClara	
Insert material (foam/ wood)			AguaClara	
Manifold				
PVC pipe (manifold)	several	1 in diameter	AguaClara	
Diffuser (straws)	10	0.3 in diameter	AguaClara	
PVC glue			AguaClara	
Others				
Turbidimeter	2		Orbeco-Hellige Portable Turbidimeter, Model TB200 (0-1100 NTU) Hanna Instruments HI 93703C Portable Turbidity Meter (0-100 NTU)	$835 $674
High resolution webcam		3 megapixels, 496 x 658 resolution	Logitech Webcam C260	$40 (new) $17 (used)

Tank Material	Sizes	Area	Price Quote	Cost
Glass (1/2” tempered)	2 (21” x 10”) 1 (21” x 6”) 1 (6” x 9”)	600 sq in	$23/sq ft $0.16/sq in (Ithaca Glass)	$96

PVC (1/2")	1 (21" x 6")	126 sq in	$15.84 for ½" x 12" x 24" sheet (Freckleface.com)	$15.84
Other materials (eg. Metal for frame)			$100 (Paul)	$100
Total				**$211.84**

Experimental Apparatus and Set Up

In our experimental set up, an appropriate dose of coagulant (alum or PAC) will be mixed together with a raw water source containing clay particles. We will measure the influent turbidity to control the amount of clay entering the flocculator. This mixture is then pumped through four tube flocculators in parallel, during which the coagulant will help small clay particles in the raw water to clump together to form flocs. The flocculated water is then pumped into the inlet manifold and water exits through the diffusers to the bottom of the model sedimentation tank. Ideally, these jets will help to resuspend flocs that have settled at the bottom of the tank so that they will form a fluidized floc blanket above the manifold. The sedimentation tank consists of two weirs to control the floc blanket height and overall water level in the tank. These weirs comprise of a PVC elbow fitted through a hole in the side of the tank with an adjustable tube to control the draining height and flow rate. Samples of the water from the overflow weir will also be taken for turbidity testing. Figure 5 shows the schematic flow through the laboratory scale plant.

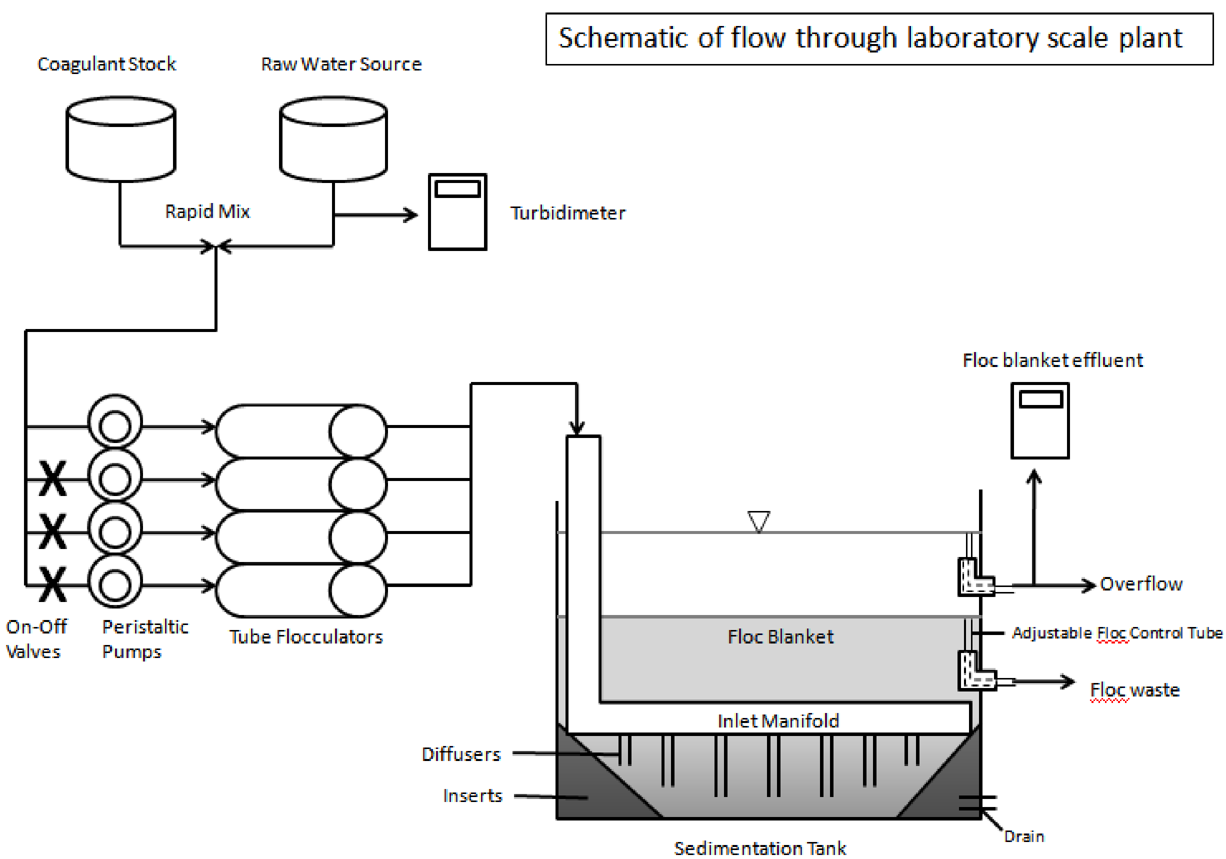


Figure 5. Schematic of flow through laboratory scale plant

Experiments and Data Collection

Experiments will be conducted in two phases to determine the extent of floc re-suspension and floc blanket growth for both the current design and alternative designs.

Phase 1

In Phase 1, we will first run experiments using the existing sedimentation tank geometry to observe flow through the sed tank and identify regions where dead zones may form. We will also assess the extent of floc re-suspension and floc blanket growth with the existing design. Some possible experiments and data collection methods are described below.

1. Dye test
   Purpose: To get a preliminary idea of flow through the tank and to identify the location of potential dead zones where sludge may form due to insufficient mixing.
   Description: While running clear water through the tank, inject dye into the inlet manifold. Visually observe the flow of dye through the sedimentation tank by using a high resolution webcam to take videos of the front and side of the tank. We expect dead zones to appear lighter in color, and well mixed areas to be darker in color.

2. Imaging the tank
   Purpose: To have a visual record of the stages of floc blanket formation.
   Description: While pumping flocculated water into the tank, use the LabVIEW program and a high resolution webcam to take a series of images of the front and side of the tank. Images will be taken until a clear floc-water interface is formed, and they will be analyzed to track and monitor the floc-water interface, the different stages of floc blanket formation, and the time taken for the floc blanket to form.

3. Slowly draining the tank after floc blanket has formed
   Purpose: To visually identify areas where sludge has formed on the tank bottom as the bulk solution will be less turbid (looking from top down) when the water depth is low.
   Description: Run the set up until the floc blanket has grown to the height of the floc weir. Carefully and slowly drain the floc blanket with the floc weir until the water level is about 5cm above the bottom of the tank, or until turbidity of the water is low enough to image the bottom of the tank. Do not disturb flocs that may have settled to the bottom. Image the tank from the top down or bottom up to identify areas where flocs have settled and formed sludge.

4. Estimate concentration of floc blanket
   Purpose: The concentration of flocs in the floc blanket is a useful parameter to quantify as it can be used in mass balance calculations to create a mathematical model for floc blanket formation.
   Description: After the floc blanket has formed, take water samples from the floc weir overflow, dry and weigh the suspended solids to determine the mass and concentration of flocs at the top of the floc blanket.

Phase 2

In Phase 2, we will make modifications to the design that we think can help to enhance floc blanket formation. The same four experiments as outlined in Phase 1 will be conducted on each modified set up. Some possible modifications include:

1. Changing the position and orientation of the inlet manifold
2. Changing the size and number of orifices in the manifold and the spacing between them
3. Changing the length of diffusers and their height above the bottom of the manifold
4. Changing the dimensions, position, angle and shape of the inclined inserts