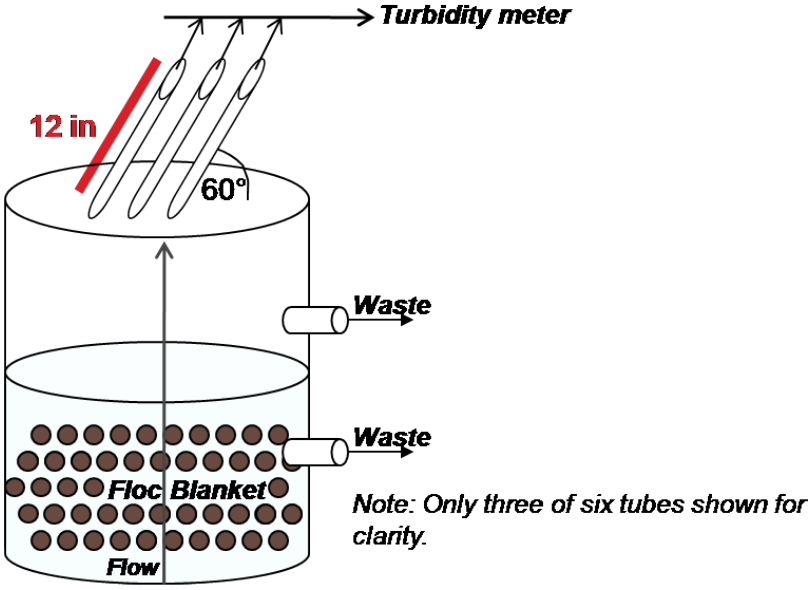
Plate Settler Spacing Research Fall 2008

Sedimentation

The sedimentation process, which occurs directly after flow through the floc blanket, is the final separation technique in our water purification system. By the time the water enters the tube settlers, uniform flow has been established and the floc blanket has already dramatically reduced the water turbidity. The design of the sedimentation section of the apparatus requires serious consideration of flow rates, tube geometry, and other parameters.

The design of our column allows for independent control of the flow rates through the floc blanket and the tube settlers. The independence of these flow rates is maintained by the additional waste outlet located above the floc blanket (see figure below). The water flows up through six tube settlers and a manifold, through a turbidity meter (where turbidity data is collected by process control), and is then wasted. The same pump circulating alum to the system controls this flow. In order to maintain a steady flow, a buffer may be utilized.



The flow rate (Q) through the tube settlers is calculated based on a desired upflow velocity (Vup) of 100 m/day through the tube settlers. We note here that the tube settlers are angled at the standard sixty-degrees from the horizon in order to optimize floc settling and accessibility for cleaning. We also note that flow through the tubes is assumed to be laminar, resulting in a parabolic velocity profile with the maximum velocity (Va) occurring at the center of the tubes.

Below are the equations used to calculate the flow rate, regulated by a pump, through the tube settlers:
Upflow Velocity

Velocity through tube settlers

Flow rate through tube settlers

Where Ased is the cross-sectional area of one tube.

As seen above, the flow rate is based on the inner diameter of the tube settlers, upflow velocity, tube length, and angle. Additionally, the critical velocity (Vc) is dependent on the inner diameter of the tube settlers (see equation below). The critical velocity is the velocity of the flow that facilitates particle settling.

For these experiments, a modified Vc equation is used that takes into account the circular geometry of the tube settlers
K is the efficiency factor: 1.33 for circular tubes according to Shultz and Okun.
Lu (the effective relative depth where laminar flow can first be considered) is defined by the following equations

Lr: relative depth
Lt: 12 in length of settling tubes
b: tube diameter
Re: Reynolds number (~280) (Shultz and Okun)

Evidently, analysis of the inner diameter of the tube settlers is important to understanding other key parameters of the system such as flow rate and critical velocity. Due to the codependency of these and other parameters, determination of the optimal diameter is multi-faceted.

First of all, the ratio of the vertical height of the tube to the tube diameter must be at least twenty-four in order to allow enough distance for the flocs to settle out of the flow (this value is based on the critical velocity and tank dimensions). In addition, a decrease in diameter allows for a decrease in plate length and, consequently, a decrease in sedimentation tank depth. However, if the diameter is too small, the resultant shear force may rupture the flocs. Also, previous research (see Summer 2008 above) indicates that various problems that are difficult to identify and quantify, such as clogging, exhibit at small diameters.

Since flow through the tube settlers is laminar, the shear stress is greatest at the tube surface where Va is zero. Below is a calculation of the minimum diameter based on the shear stress at the tube surface. We assume that floc integrity begins to suffer under shear stresses of 1 Pa.

The velocity gradient equation:

yields the equation for maximum shear stress:

Substituting the head loss equation:

into the maximum shear stress equation yields:

Since substituting our parameters into this equation yields an unreasonably small minimum diameter of 20 µm, shear stress is not the limiting factor for tube settler diameter. Therefore, the diameters tested in this experiment are based on floc size, the length/diameter ratio of twenty-four mentioned above, and material availability. The minimum diameter was set to be at least twice the diameter of a floc (estimated at 2 mm), and the length of the tubes was set to be 0.304 m. The table below lists the parameters of the tube settler apparatus for this experiment.

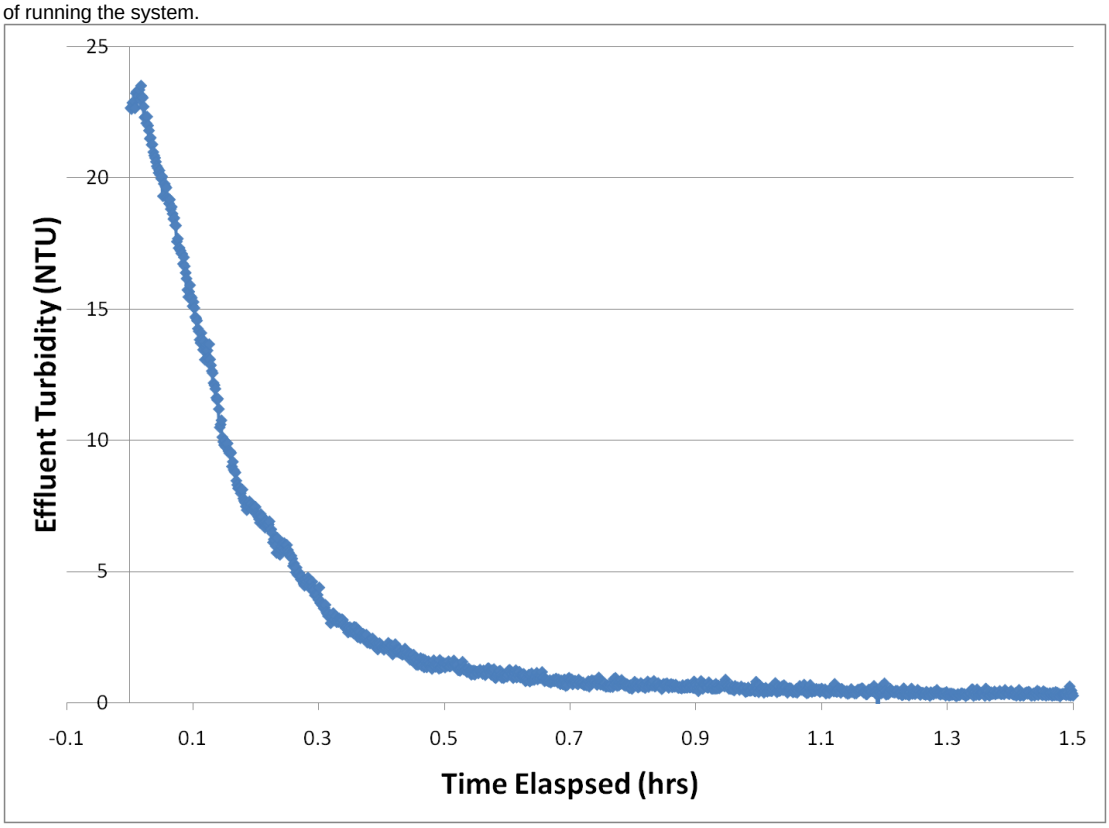
Diameter of Tube (b)	Flow Rate (Q)	Critical Velocity (Vc)	L/b (where L =.305m)
12.7 mm	45.7 ml/min	8.78 m/day	24
9.50 mm	25.6 ml/min	6.72 m/day	32
4.00 mm	4.53 ml/min	2.94 m/day	76

Results and Discussion

The results gathered from the above method are indicative of a system that is capable of producing consistent and quality data. However, more trials must be run and the system must be made more robust for the data to be as credible as possible. At this point, we offer discussion regarding the data gathered up to this point and the current design of the experiment.

Although the interest of these experiments is to determine the impact of plate settler spacing on effluent turbidity, floc and floc blanket formation are crucial elements for attaining the low effluent turbidities that are desired. Both floc and floc blanket formation are priorities of this system and must be discussed briefly. One improvement that was made to this system after the earliest trials was to ensure that the alum solution is introduced to the system by its own pump (it had previously been run on the same pump as the sedimentation tubes). This independence facilitates increased control over both the effluent and alum flow rates. Also, the rapid-mix chamber, discussed in the apparatus setup section above, and the over twenty-seven meter long flocculator help to ensure optimal floc formation. Another adjustment made to guarantee floc blanket formation was the removal of the mesh (placed in the bottom of the column to hasten flow distribution in the column) because it was ripping apart the flocs.

The graph below illustrates the importance of the floc blanket in attaining low effluent turbidity. The graph is the effluent turbidity for the first hour and a half of running the system.



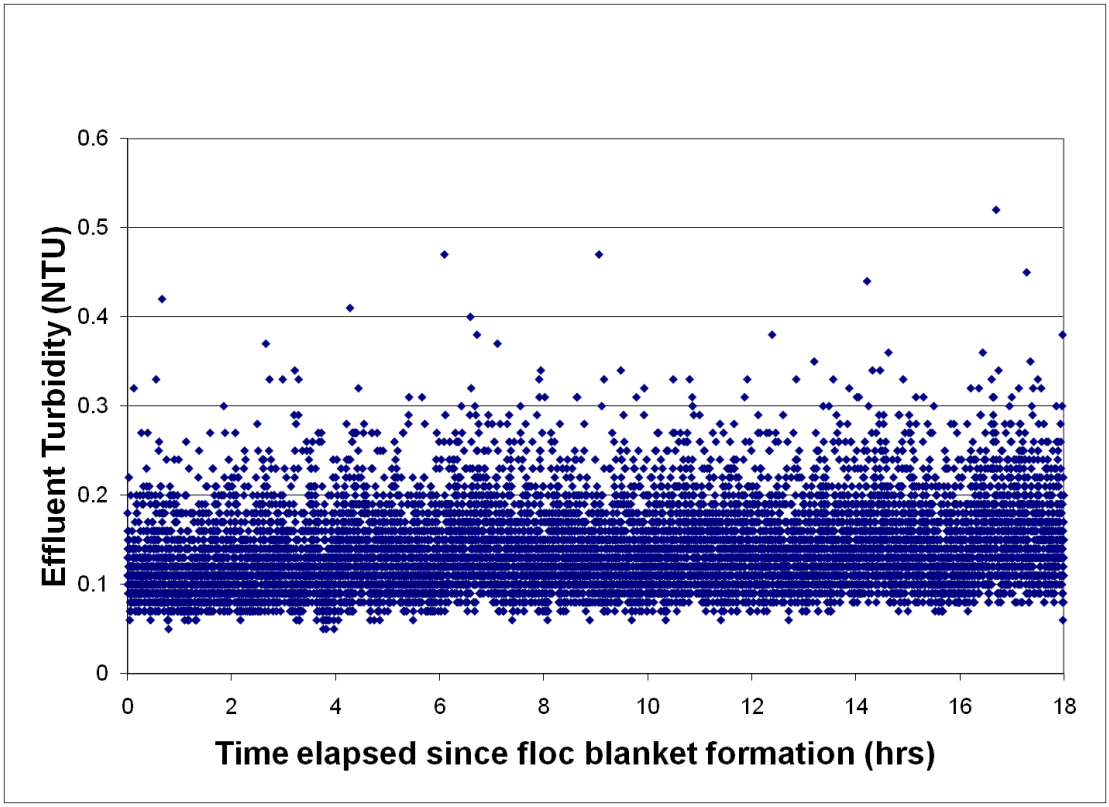
Graph 1. Effluent turbidity with 12.7 mm inner diameter tube settlers before floc blanket is fully developed.

The drop in turbidity as the floc blanket forms correlates with previous findings by Matt Hurst that the floc blanket is important for attaining a low effluent turbidity.

The floc blanket depth is regulated by a flow-control weir, as discussed previously in the apparatus setup section. Thus far, the floc blanket has been maintained just above the weir control outlet and about 10cm below the sedimentation tubes. The top of the floc blanket is about 53 cm above the cone that is located at the bottom of the column. Presumably, the floc blanket extends into the cone.

During the first experimental trials, great attention was paid to floc blanket depth. Though the data below are based on the top of the floc blanket sitting below the sedimentation tubes, we observed that when the openings of the 12.7 mm tubes were immersed in the floc blanket, effluent turbidity remained under 1 NTU. This persistently low turbidity was visually dramatic since the tubes immersed in the floc blanket were significantly more filled with flocs than the tubes located above the floc blanket. More tests would need to be run in order to draw conclusions about the effect of tube/floc blanket location on effluent turbidity. However, these preliminary observations are noteworthy.

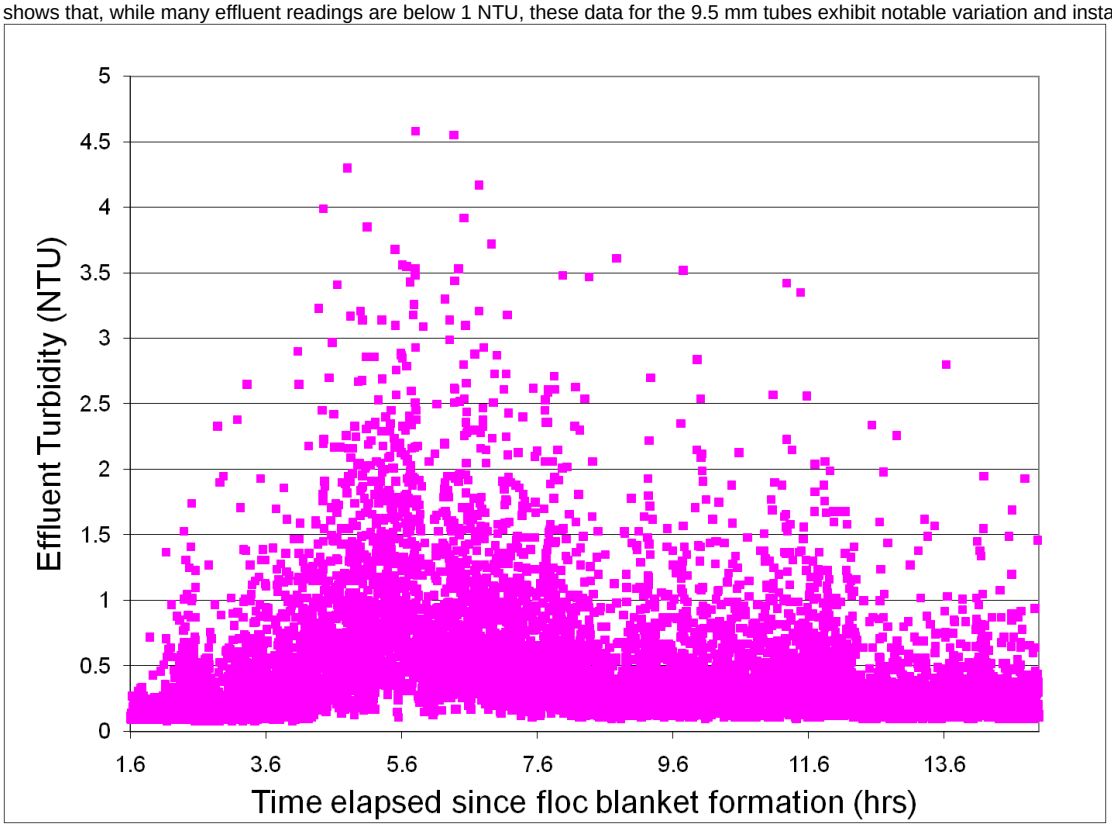
We now turn to the sedimentation tubes and the data gathered thus far. Below is a graph of the effluent turbidity over time of sedimentation tubes with 12.7 mm inner diameter.



Graph 2. Effluent Turbidity: 12.7 mm inner diameter tube settlers.

Graph 2 above shows incredibly low turbidity of the effluent from the sedimentation tubes. In fact, most readings were below 0.3 NTU. Such a low effluent turbidity is promising because it reflects a system that is capable of achieving very low turbidity water. This low turbidity for the 12.7 mm inner diameter tubes is expected since 12.7 mm is a fairly large spacing and does, therefore, provide more horizontal distance over which the flocs may settle-out than do smaller diameter tubes. Also worthy of brief mention here is the influent turbidity versus effluent turbidity. The data from all of the tests run so far show that even with a twenty-NTU variation in the influent turbidity, effluent turbidity remains constant. This indicates that the flocculation and sedimentation parts of this system are resistant to shifts in influent turbidity.

The two recent trials of 9.5 mm inner diameter tubes have revealed more variability and more turbid effluent than the 12.7 mm tubes. The graph below shows that, while many effluent readings are below 1 NTU, these data for the 9.5 mm tubes exhibit notable variation and instability.



Graph 3. Effluent Turbidity: 9.5 mm inner diameter tube settlers.

For example, there seems to be a subtle increase in effluent turbidity around 5.6 hrs. However, there is no immediate reason for this peak. Something may have happened to the system that was not documented, or maybe flocs collected around the tops of the tubes and were pushed into the manifold around that time. In fact, the flocs were observed to collect in the 9.5 mm tubes. In the 12.7 mm tubes, nearly all of the flocs settle down the tube. However, in the 9.5 mm tubes, flocs are more likely to rest stably on the tube surface without settling down the tube. The picture below illustrates immobilized flocs on the sides of the 9 mm tubes:

This may occur because the smaller diameter allows flocs to collect, coagulate, and form a greater mass. Consequently, this greater mass may be unable to settle down the tube as easily as lighter, more independent flocs.

A final comparison between the 12.7 mm and 9.5 mm tubes is their different critical velocity values. Recall that critical velocity is dependent on tube diameter:

where Lu is a function of the tube diameter b.

This means that when all parameters in the equation above are held constant except for tube diameter, the critical velocity will vary according to tube diameter. Therefore, the critical velocity through a narrower tube will be smaller than the critical velocity through a wider tube. This means that flocs should settle out of the 9.5 mm tubes more readily than they settle out of the 12.7 mm tubes. The data do not corroborate this hypothesis.

Conclusion

The current data does not support the hypothesis that the partile removal of the settle tubes improves as the critical velocity decreases. There is not enough supporting data, however, to make any conclusions about the effluent turbidity and its correlation to critical velocity. From observations it is clear that both the 12.7 and the 9.5 mm tubes were able to remove the particles effectively. However, the 9.5 mm did not drain as well as the 12.7 mm tubes at the same Va. This could lead us to limiting parameter in the performance of smaller tube settler spacings.

Varying the velocity could better show how the Va though the system effects the performance, thus further testing the predicted critical velocities. This experiment along with several others to be performed next semesters are disscused in the section below.

Some of the other success of the semester were the formation of a stable floc balnket, control of the floc blanket height using the flow control weir, the development of a system that produces consistant and accurate results, and consistant effluent turbidities of less than 1 NTU, with 0.07 being the lowest consitant value.

The final working system provides much opportunity for experimentation as we attempt to determine the optimal plate settler spacing.

Future Work

Continued Data collection

Data collection is still in the preliminary stages. The settling tubes with the smallest diameter, 4mm, have yet to be tested. The experiment as explained above should continue based on the observations and preliminary data collected.

Additional Experiment

- Jet dissipation
  It is still not clear what is happening in the cone as far as mixing and jet dissipation. Determining the fluid mechanics of this system could improve floc blanket formation. With the mesh the floc blanket formed quicker, however, the mesh resulted in the breaking up of flocs due to the low hole diameter of 0.5 cm. A mesh should be made with hole diameter of 1 cm to test the jet dissipation and floc maintenance. In addition to the mesh experiment, Several experiments can be performed solely on optimizing the jet dissipation.

- Tube spacings
  The velocity of the affects the particle removal, as previously mentioned. Varying the flowrates on each of the tube size could result present some interesting data. To collect these values one would only have to use the process controller increment method to vary the flowrate of the water pulled off the top of the settling column (pump 2).
  It would also be worthwhile to vary the floc blanket depth using the floc blanket height flow control unit. This should include testing the particle removal of settling tubes with the tubes submerged in the floc blanket.

Changing the alum dosage may also provide some interesting data concerning floc blanket performance.

Improvements to the System

- Making the system more robust
  Certain parts of the system are fragile, difficult to fix or correct and could use some design improvement. For example, the tube settler could use a more stable connection.
  One of the most unstable parts of the setup are the flocculators that sit on the table. They are very susceptible to being knocked over and have been several times! Next semester the team should speak with Paul in the shop and try to design some sort of structure to hold and stabilize the flocculators. This structure would also include some sort of support for the two bubble release tubes currently attached to the ceiling.

The goals and challenges for next semester are outlined in the Spring 2008 Challenges section.