Rapid Mix Tube

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Abstract

During the fall 2009 semester, the main focus of the Rapid Mix Tube subteam was the development and design of a rapid mix tube system to provide adequate large and small-scale mixing of alum with the raw water source entering the plant. The system developed in the fall 2009 semester is designed for the Agalteca plant, but the ultimate design can be modified to fit into future AguaClara plants and even fit into existing plants to improve rapid mix . The design of the system evolved multiple times throughout the semester, and the current system was developed to improve upon the main problem of those initial designs: access to the small scale rapid mix orifice to clean it in case of clogging. The design of the tube was thus tailored to fix this problem, and a MathCAD file calculating orifice sizes and head loss through the system was developed. A built prototype model of the rapid mix tube was also constructed to provide a model for the construction of the rapid mix tube system, and a series of experiments (to be run using FReTA) was also designed to test the effect of the rapid mix tube system on the effluent water turbidity and to determine the need for the rapid mix tube system.

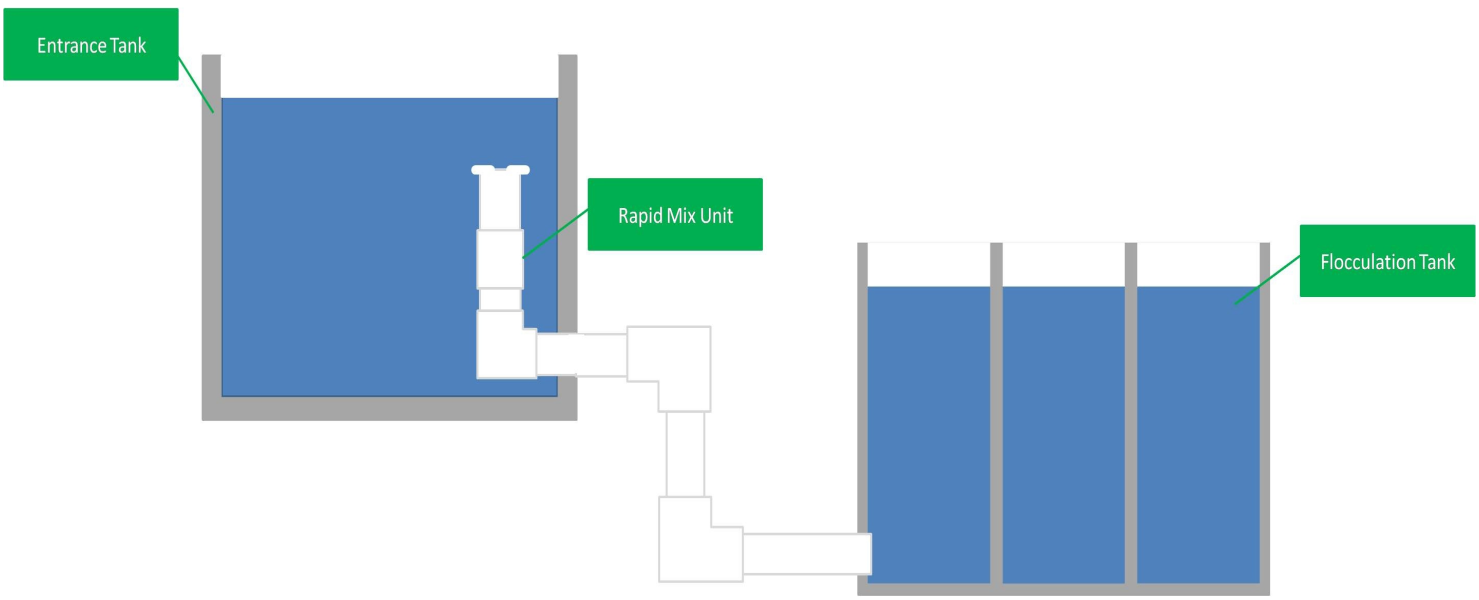

Figure 1. Overview of the plant flow from the entrance tank through the rapid mix tube, out into the flocculation tank.

Rapid Mix Tube Design Process

Initial Rapid Mix Design

The initial rapid mix system proposed for the Agalteca plant was much different than the system designed this semester. As can be seen in Figure 2, water from the entrance tank flows into a pipe that carries it into the flocculation tank.

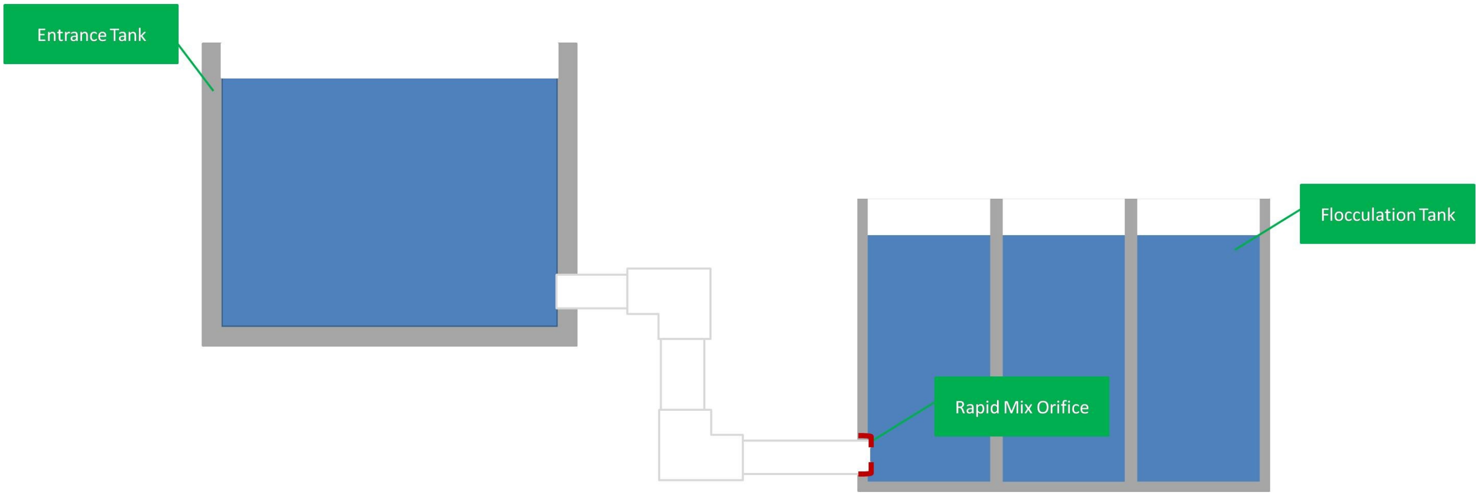

Figure 2. Initial Rapid Mix system design and integration into the plant. As indicated, the Rapid Mix Orifice in this design is completely submerged and accessed through the flocculation tank.

Rapid mix is achieved in this system when the water flows through an orifice at the end of the pipe leading into the flocculation tank, allowing small-scale mixing of the aluminum sulfate with the raw water to occur before reaching the flocculation tank. One of the main problems with this system is the location of the rapid mix orifice; it is submerged in the bottom of the flocculation tank, making it very difficult to reach or remove. Flow to the plant would have to be stopped and the flocculation tank drained at least partially to remove and clean this orifice if it ever clogged or needed to be replaced or exchanged. Another problem with this design is that the exit tube taking water from the entrance tank to the flocculation tank is flush with the side wall of the entrance tank and is located quite deep in the tank. Thus, for flow to the plant to be stopped, the entrance tank would have to be emptied completely.

Current Rapid Mix Tube Design Deveopment

The current design for the rapid mix tube was developed to address the problems created by the initial design. A schematic of the new design is shown in Figure 3. This new rapid mix tube system consists of two separate 'stages,' a large-scale mixing process in the first portion of the system, and small-scale mixing process in the second portion. The tube protrudes up into the entrance tank to help regulate flow through the plant-flow through the plant will cease once the water level in the entrance tank reaches the top of the rapid mix tube, allowing the water already in the tank to be stored if there is low source flow or the plant needs to be cleaned.

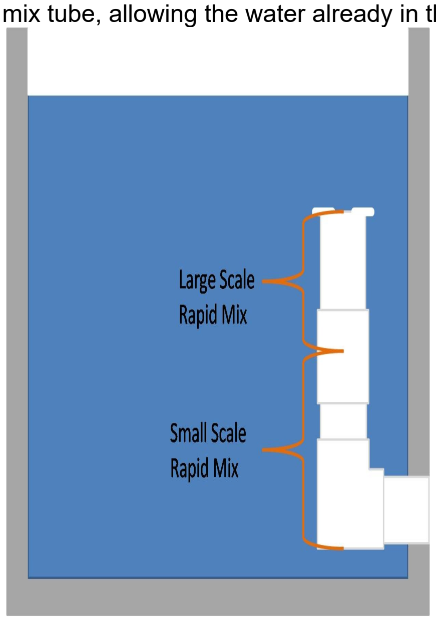

Figure 3. Schematic of the current Rapid Mix Tube system.

Large-Scale Mixing Orifice Design

Water enters the top of the tube through the large-scale mixing orifice, where it is dosed with the aluminum sulfate and begins the rapid mix process. This orifice is in place to create large scale mixing in the first section of the tube. The design of this orifice size is based on the exit loss coefficient through the orifice, K. The target K value for this orifice is 2, which provides the best mixing in the first section of the tube for large-scale rapid mix. To calculate the necessary area and diameter of the large scale mixing orifice, the following equation was used:

$$K_{ex}\left(A_{out}, A_{in}\right) = \left(\frac{A_{out}}{A_{in}} - 1\right)^2$$

Solving for A.in, which will be the area of the stream of water entering the tube through the orifice, we obtain:

$$A_{in}\left(A_{RapidMixOrifice}, Pi_{VC}\right) = A_{RapidMixOrifice} * Pi_{VC}$$

In this equation, A.in is taken to be the area of contracted flow through the orifice, which is the area of the large-scale mixing orifice multiplied by the vena contracta coefficient, which accounts for the contraction of flow through an orifice. The equation the describes this is as follows:

$$A_{RMOrificeLS}\left(A_{out}, K_{ex}, Pi_{VC}\right) = \frac{A_{out}}{Pi_{VC} * \left(1 + \sqrt{K_{ex}}\right)}$$

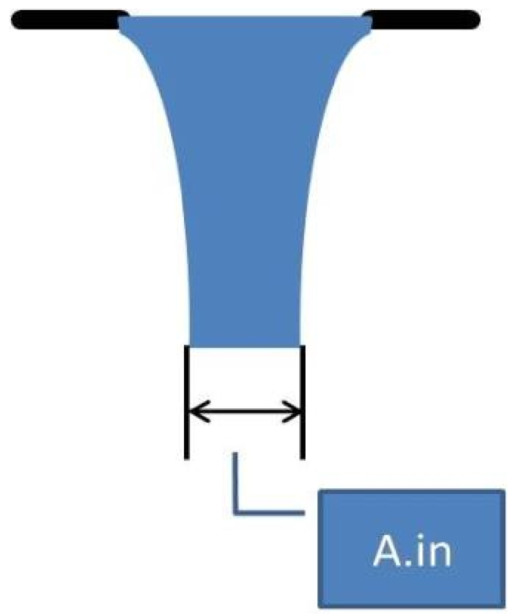

Figure 4 illustrates the effect of the water contraction flowing through an orifice.

Figure 4. Diagram showing the area used for A.in in the Exit loss coefficient equation.

A.out in the above equations is taken to be the area of the pipes used in the system since the water is allowed to outlet freely into these pipes.

Water flows down the pipe after entering through the large-scale mixing orifice, then flows down the length of the pipe, which should be at least as long as several diameters of the pipe to provide adequate mixing. The Agalteca plant will be using 0.152 m (6-in.) diameter PVC pipes, and thus the length of the large-scale rapid mix tube will be between 0.457 m and 0.762 m (18-in. to 30-in.) to provide enough diameters of length for large scale mixing.

Small-Scale Mixing Orifice Design

After water flows into the rapid mix tube and through the top section of the pipe to achieve large-scale mixing, it reaches the small-scale mixing orifice. The area of the small-scale mixing orifice is designed to achieve a target head loss, providing a mechanism to measure the level of water in the plant to assist in the correct dosing of the plant's raw water source with aluminum sulfate. The equation used to calculate the area of the small-scale mixing orifice is as follows:

$$A_{RMOrificeSS}\left(Q, \Delta h\right) = \frac{Q}{K_{vc}\sqrt{2g\Delta h}}$$

In this equation, Q signifies the flow rate of water through the plant, K.vc is the vena contracta coefficient as discussed above in the large-scale orifice design section, and Δh is the target head loss for which the plant is being designed; this design value can be varied based on the desired characteristics of each plant. K.vc is used here again because the flow of water through the small-scale mixing orifice is also a flow contraction, and the area of the water stream entering the pipe following is a fraction of the area of the orifice.

The area of the small scale orifice can be either cirucular or rectangular in shape, again depending upon the plant flow rate, desired energy dissipation rate, and desired head loss through the small-scale orifice. A diagram of some possbile orifice configurations is shown below in Figure 5.

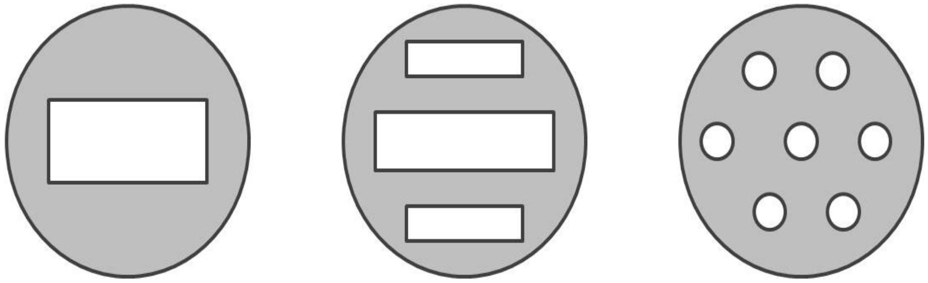

Figure 5. Possible configurations for the small scale rapid mix orifice. Which is chosen depends upon the specific plant for which the rapid mix system is being designed.

Each of these designs is preferred in different cases depending on the plant flow rate, pipe diameter, desired head loss, and desired energy dissipation rate. Tentatively, the Agalteca plant will feature a small-scale orifice featuring the multiple round orifices, which will best serve this plant in evenly mixing the aluminum sulfate dosed to the raw waste, as well as achieving the desired energy dissipation rate through the orifice. To calculate the dimensions of the round orifices that will occur in the small-scale mixing orifice, the following equation in used:

$$Width\left(\Delta h, \varepsilon\right) = \frac{\left(2g\Delta h\right)^{1.5}}{20\varepsilon}$$

Here, ε is the value of the maximum energy dissipation rate for the plant, and the orifice is thus designed to achieve this value. Δh is the same target value for the head loss from the small-scale orifice design equation. This equation thus calculates the maximum minimum dimension of a rectangular orifice. This dimension can be adapted to the proposed Agalteca design with multiple small orifices, however, because of the presence of many small orifices in entire small-scale mixing orifice. The dimension calculated in this equation will then be used as the diameter of the multiple orifices that must be put into the small-scale mixing orifice. Figure 6 provides a schematic of the rapid mix tube as well as the placement of the two orifices and a detail of the multiple-orifice small scale mixing orifice that will likely be used in the Agalteca plant.

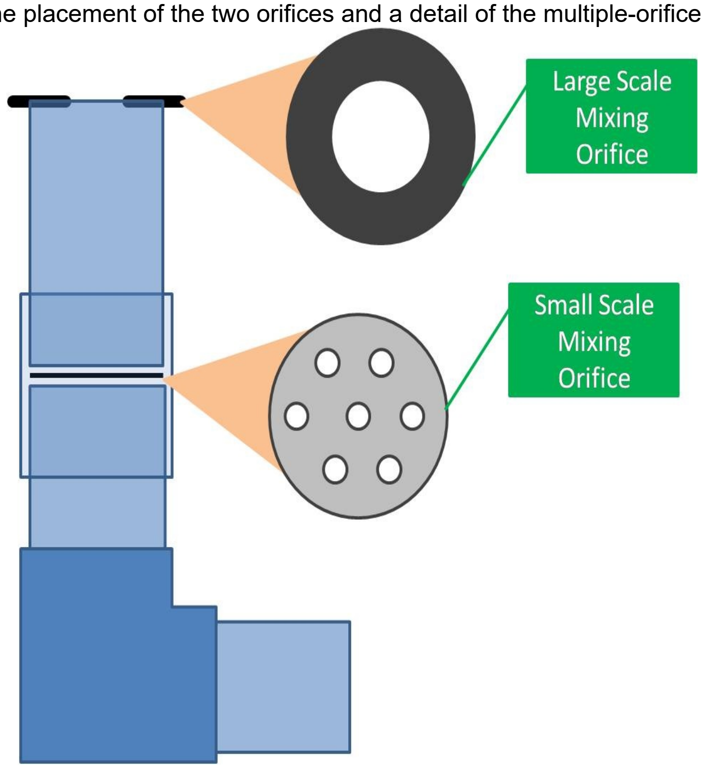

Figure 6. Proposed schematic for the rapid mix tube showing orifice placements and design for the small and large scale mixing orifices.

Headloss Calculations and Significance

The total headloss through the system is comprised of minor losses, caused by water flow through the orifices and through pipe fittings such as elbows, and major losses due to friction on the pipe walls. The equation used to calculate total headloss through the system is:

$$HL_{system} = HL_{LargeScaleMixing} + HL_{SmallScaleMixing} + HL_{PipeFittings} + HL_{PipeFriction}$$

Here, HL.LargeScaleMixing and HL.SmallScaleMixing refer to the minor losses through the large and small scale mixing orifices, respectively. HL.PipeFittings and HL.PipeFriction are caused by minor losses through the pipe fittings and major losses sue to shear along the pipe walls.

Flow through both the large and small scale orifices is modeled as an expansion; as the water flows through the orifices, the flow is contracted and then expands on the other side of the orifice. Thus, head loss can be calculated using the equation for head loss in a flow expansion:

$$h_{ex}\left(Q_{plant}, A_{pipe}, K_{ex}\right) = \frac{Q_{plant}}{2g\left(A_{pipe}\right)^2} * K_{ex}$$

The calculation of the headloss through the system is important because the headloss through the rapid mix tube system partially determines the change in height of the water in the entrance tank when the plant flow changes. The nonlinear chemical doser is designed to change the flow rate of alum with the flow rate of the plant, and it is thus very important to calculate the headlosses through the rapid mix tube system and the sections of the plant following it in order to correctly design the chemical doser to maintain a constant concentration of alum in the raw water source despite changing flow rates.

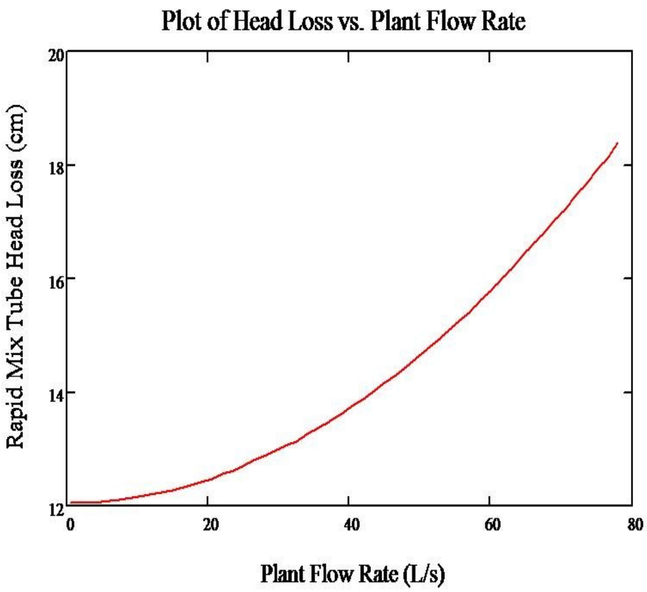

Figure 7. Plot of the rapid mix tube system head loss. vs. plant flow rate for a given target head loss through the small scale rapid mix orifice. As plant flow rates increase, the total head loss through the rapid mix system increases despite a constant small scale orifice head loss due to the increase in head loss from the pipe fittings and pipe friction, as well as through the large scale mixing orifice.

Full-Scale Rapid Mix Tube Model

In order to aid the construction of the Rapid Mix Tube system and orifice design, a full-scale prototype model of the Rapid Mix Tube was constructed using 4-inch PVC pipe and fittings. The fully constructed tube can be seen in Figure 8 below.

Figure 8. Photo of the full constructed rapid mix tube system.

The large scale mixing orifice was constructed using a 4-inch PVC cap; a hole saw was then used to create the large scale mixing orifice diameter. The diameter of the large scale orifice was slightly smaller than calculated, due to available hole saw sizes, and the tube head loss and exit loss coefficients were adjusted accordingly.

Next, an 18-inch length of PVC pipe was capped with the large-scale orifice cap and fitted on the other end with a coupling. The small scale orifice was inserted into the system between the large scale mixing tube section and the lip of the coupling, holding the orifice in place in the center of the coupling. The other end of the coupling was then fitted with a small length of 4-inch PVC pipe, and 90 degree elbow was attached to the other end. Another small length of 4-inch PVC pipe was attached to the elbow outlet to model the outlet of the rapid mix tube into the pipes carrying the raw water mixed with alum to the flocculation tank.

Figure 9. Photo of the rapid mix tube in sections. The tube in constructed by fitting all pieces of the system together in the series as shown.

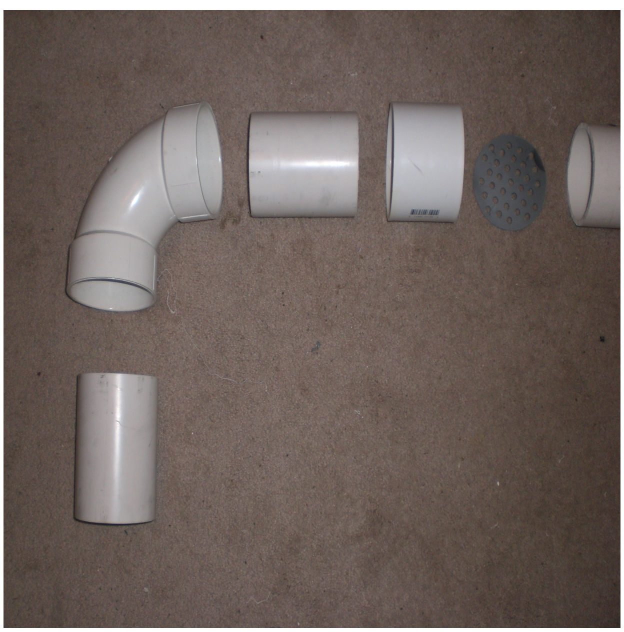

Figure 10. Photo of the lower sections of the tube, showing the location of the small scale mixing orifice.

The small scale mixing orifice was constructed using a bucket lid; a circular piece of the lid matching the inner diameter of the PVC piping was cut out using box cutters. The bucket lid materials provides a good potential material for the rapid mix tube small scale orifice. It is a strong material, and will not corrode if submerged for long periods of time. It is also very easy to cut and drill, making construction a relatively simple process. Using a 5-16" drill bit, approximately 34 orifices were drilled into the orifice material to create a model of the small scale orifice. 

Figure 11. Photo of the final, drilled small scale mixing orifice for the 4" PVC pipe rapid mix tube model.

This built model is not a direct model for the Agalteca plant; the Agalteca plant is built to use 6-inch PVC pipe, and thus the placement and number of orifices in the small scale mixing orifice will have to be adjusted, but this built model provides a good prototype from which to work and show the basic construction of the system.

Proposed Rapid Mix Tube Experiments

Towards the end of the Fall 2009 semester, the Rapid Mix Tube subteam developed a set of experiments to test the effect of rapid mix on the turbidity of effluent water through the FReTA test apparatus, as well as the effectiveness of the current rapid mix tube design. These experiments will be started at the end of the Fall 2009 semester or used as a starting point for the Rapid Mix Tube subteam at the start of the Spring 2010 semester.

First, the alum dosing system was re-designed to eliminate the 'pulse-dosing' effect created by dosing alum directly to the test system with a peristaltic pump. The drive behind this change is the thought that the pulsing peristaltic pump dosing may be creating pockets of raw water that have very little exposure to the dosed aluminum sulfate, creating pockets of dirty water that negatively affect the turbidity of the effluent water. To eliminate this problem with the pump dosing, an accumulation chamber was designed. This chamber sits between the peristaltic pump and the dosing tube, allowing alum to accumulate and flow into the system through an orifice. This orifice was designed to create enough head loss to allow for a constant flow rate of alum through the orifice and, as a result, a more uniform flow of alum into the raw water, allowing a more even mixture of alum with the raw water before rapid mix occurs. The FReTA system will be run using this new alum accumulation chamber to test the effects of the addition of the accumulation chamber to the dosing system. The acquired data will be compared to existing FReTA data run under the same flow rate and flocculation tube lengths to determine the effect, if any, of the addition of the alum accumulation chamber.

Following the alum accumulation chamber experiments, the next set of experiments run will be to test the effect of the new rapid mix tube design on the effluent water turbidity in the FReTA test system. There are two possibilities here for the rapid mix tube system. First, a scaled-down version of the rapid mix tube can be constructed, creating the large and small scale mixing orifices and using small-scale elbows and PVC piping. This system would be replacing the current rapid mix section present in FReTA, which is simply a coil of tubing. Second, a straight-line version of the rapid mix tube could be constructed, simply by inserting the two orifice into a line of tubing, the second small scale orifice creating a turbulent jet of water in the tubing, allowing for greater small scale mixing. With either of the above two rapid mix substitute design, the scaled-down rapid mix system will be inserted into the FReTA system between the alum dosing and flocculation tubing, allowing us to test the effects of the new rapid mix tube design compared to the old coiled tubing mix system. The results of this experiment will tell us how important and effective rapid mix is to the effluent turbidity of the water, and will direct the course of experiments following.

If the rapid mix system addition shows positive effects upon the effluent water turbidity, a third set of experiments will be run to test if inadequate rapid mixing is having adverse effects on effluent turbidity. A stream of untreated raw water will be introduced to the system after rapid mix to test the effect of poor rapid mix on the system.

The results of this set of experiments will give us insight into the importance of rapid mix in the AguaClara water treatment plants. If rapid mix is shown to have a significant effect upon the effluent water turbidity, further research can be done into rapid mix tube design.

Before the experimental design can be completed and run, however, the rapid mix team must first collaborate with the tube flocculator team to determine multiple parameters for the FReTA apparatus such as water and alum feed flow rates, raw water NTU, length of the flocculation tubes, and current and target energy dissipation rates in the rapid mix section as well as throughout the remainder of the system.

Future Work

Work throughout the rest of the fall 2009 semester and the beginning of the spring 2010 semester will focus on finalizing and running the experimental design for the alum accumulation chamber and rapid mix tube mixing, and measuring the effect of these variations on the effluent water turbidity. The rapid mix subteam will also build another 6-inch PVC full-scale model of the system in order to provide a better model of the Rapid Mix Tube system for the Agalteca plant.

Deliverables

- MathCAD file detailing the Rapid Mix Tube design specifications including orifice sizes and head losses through the system
- MathCAD file detailing the rapid mix tube experimental design and calculations for the alum accumulation tank, scaled-down rapid mix systems, and experimental schemes to be run
- Schematic drawing of the Rapid Mix Tube system as well as how it fits into the greater plant design
- A prototype of the Rapid Mix Tube system constructed of PVC piping and fittings to test the feasibility of the design as well as the effectiveness of the chemical mixing

No labels

1 Comment