Rapid Mix Chamber Design Program

Rapid Mix Chamber Design Program

Rapid Mix Chamber Design Program

Abstract

The AguaClara plant design needed to be extended to accommodate high flow rates such as those at

Gracias (3000 L/min). One of the new design issues was that we could no longer rely on having the alum adequately mixed with the raw water in the pipe connecting the entrance tank to the flocculator. The design used for smaller flow rates does not generate enough large scale mixing to evenly distribute alum throughout the flow or enough energy dissipation to ensure that alum is mixed at the molecular level. Consequently, a new entrance tank was designed to accommodate a rapid mix chamber that could appropriately mix alum with raw water before flocculation. The entrance tank and rapid mix chamber were designed to be used in conjunction with the Nonlinear Chemical Dose Controller Fall08\-Summer09 between the maximum and minimum expected plant flow rates. The rapid mix chamber uses a combination of orifices and hydraulic drops to achieve desired even mixing.   For smaller flow-rates, the team is writing an algorithm to size orifices for smaller flow-rates and plot the design onto an AutoCADD: The Rapid Mix Orifice Sizing Algorithm .

Rapid Mix Chamber

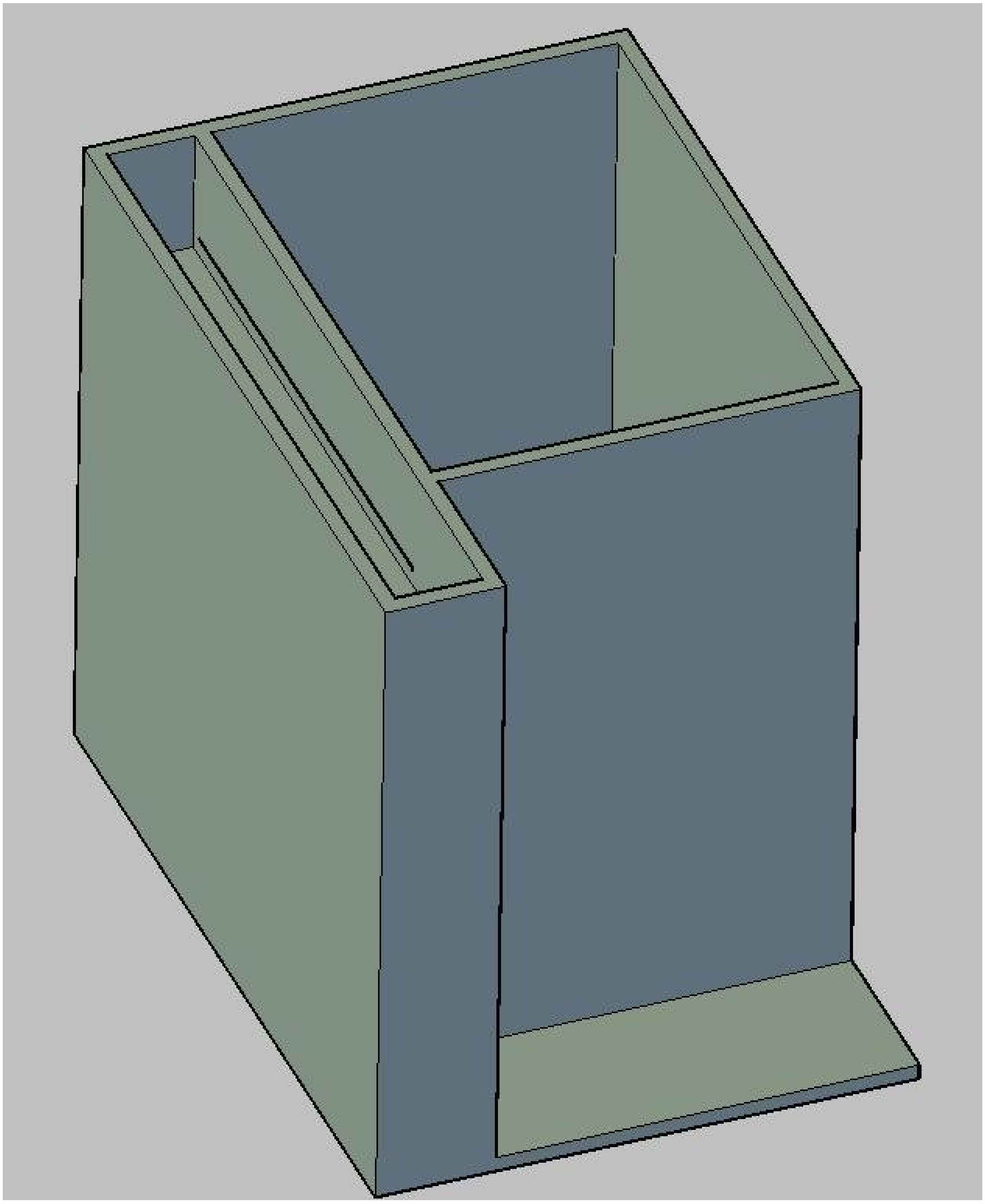

Figure 1: AutoCAD rendering of the rapid mix chamber

The rapid mix chamber is assumed to be made of concrete and attached to one side of the entrance tank. The water within the entrance tank enters the rapid mix chamber's orifice collector channel through the flow meter orifice. Once water passes through this orifice it travels to the end of the channel and then experiences a hydraulic drop. By the time the water reaches the bottom of the waterfall mixer, enough large scale mixing has occurred. Finally, as the water passes through the fine scale turbulence generating orifice of the rapid mix chamber, it experiences a contraction followed by an expansion. This expansion generates a high enough energy dissipation rate for turbulence to blend the solution to a small enough scale that molecular diffusion can finish the blending thereafter.

Design Assumptions and Specifications
Design Assumptions Design Program

Entrance Tank Dimensions
Entrance Tank Design Program

Flow Meter Orifice

The flow meter orifice is the rectangular orifice used to measure the plant flow rate. The flow meter orifice design is constrained by the maximum and minimum water height difference and the coefficient of discharge due to the vena contracta through the orifice. Taking these constraints into account and using the orifice equation the orifice area is calculated.

The plant's flow rate range is limited by the plant's lowest measurable flow rate, which occurs when the orifice is barely submerged. The flow rate ratio which is defined as the ratio of the minimum flow rate to the maximum flow rate ($Pi_{EtFlow} = Q_{min} / Q_{max}$) is related to the ratio of the height of the orifice to the head loss at maximum flow rate (heightratio = $W_{EtOrifice} / HL_{EtMax}$) through the following equation:

Where:

- $A_{EtOrifice}$ is the actual orifice area
- $Pi_{VenaContractaOrifice}$ is the coefficient of discharge due to the vena contracta
- g is the gravitational force
- $HL_{EtOrificeMin}$ is the water height at the minimum flow rate

Depending on the flow rate ratio desired the required head loss ratio can be determined as depicted in the graph (Figure 2).

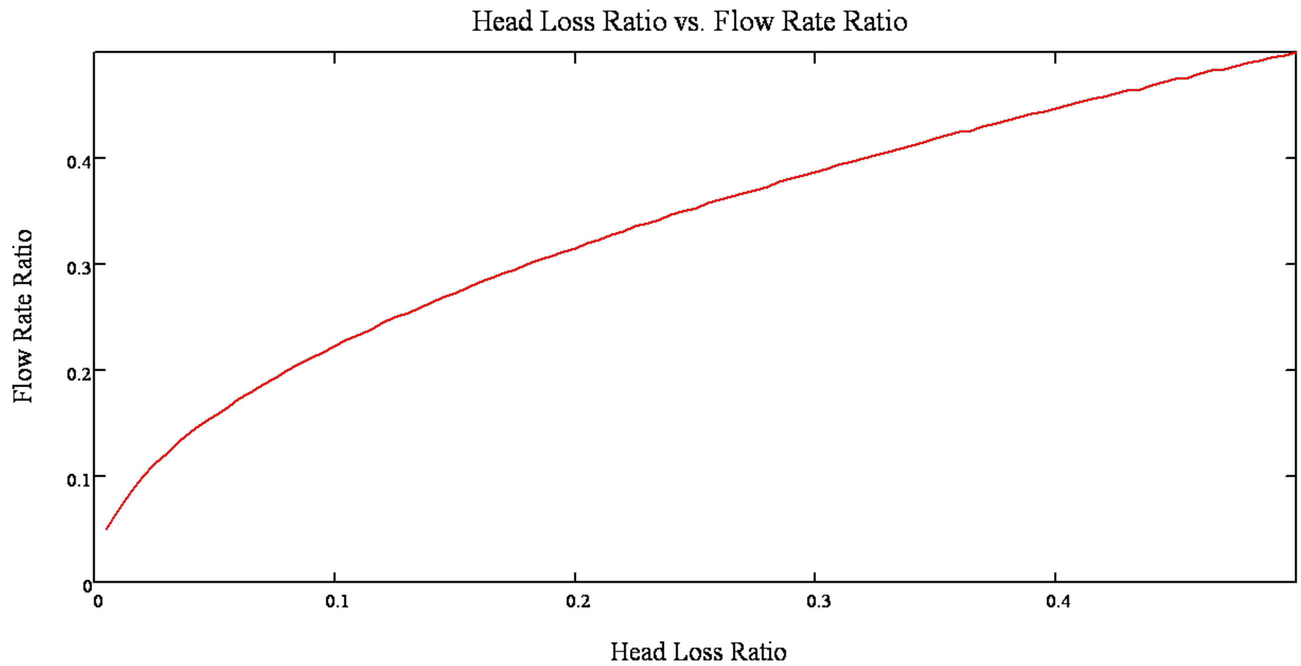

Figure 2: Head Loss Ratio vs. Flow Rate Ratio

Based on that head loss ratio the height of the orifice can be calculated:

and subsequently the length:

Where:

- $A_{EtOrifice}$ is the actual area of the orifice
- $W_{EtOrifice}$ is the width of the orifice

Orifice Collector Channel

The orifice collector channel is a channel that collects the water from the flow meter orifice. The orifice collector channel is modeled as an open channel flow conduit. The water enters through the flow meter orifice on the side of the channel and flows towards the hydraulic drop into the flocculator. The length of the channel is dependent on the length of the entrance tank orifice and the channel must be longer than this orifice. The height of water along the channel is iteratively solved for by using the direct step method described below.

The flow at the top of the hydraulic drop is critical- potential energy and kinetic energy are in balance and the height of water in the tank can be solved for using the equation:

Where:

- h_{crit} is the critical depth
- q is the flow per unit width
- g is the acceleration due to gravity

Given this initial height in the channel, the height of water in the rest of the channel can be determined. The energy equation for an open channel flow can be rearranged to give the relationship:

Where:

- S_o is the slope of the channel which is zero in this case
- S_f is the friction slope
- y is the depth along the channel
- x is the distance from the hydraulic drop to the end of the channel

The friction slope (Figure 3) was found using the equation:

Where:

- f is the friction factor
- V is velocity
- g is acceleration due to gravity
- R_h is the hydraulic radius defined as the cross sectional area over the wetted perimeter

Figure 3: Cross Sectional View of Orifice Collector Channel

Finally, to solve for the heights, the critical depth is used as the initial V_1 and a change in depth of 0.0001 cm is used to find V_2 . The modified energy equation is solved to find the corresponding distance upstream in the channel, given the calculated friction slope that corresponds to a change in water depth of 0.0001 cm. This process was repeated until the upstream end of the channel was reached and the height of water at the upstream end of the channel was found.

Waterfall Mixer

The waterfall mixer is a vertical conduit that has a small water surface elevation drop at the top and the flocculator entrance orifice. The waterfall mixer is the first mixing step after alum is added in the orifice collector channel. This hydraulic drop provides a region of energy dissipation for large scale mixing. The minor loss coefficient can be directly related to the mixing length and in this case it is assumed that a minor loss coefficient of 1.3 is adequate for large scale eddies to evenly mix the alum. The velocity can be found with the critical depth at the orifice collector channel exit and channel width. The equation for minor loss is then used to determine the height of the free fall necessary to obtain the desired minor loss:

Where:

- V is 1.07 m/s; the critical velocity of the drop
- K is 1.3; the minor loss coefficient
- g is acceleration due to gravity

Note: These values will change slightly with the square channel geometry.

First Baffle Section

The hydraulic drop deposits water into the first baffle section. The water level in this section is determined by the water level in the flocculator and the head loss through the flocculator entrance orifice(described below). The height of the channel includes the water level and the lower hydraulic drop height.

Flocculator Entrance Orifice

The flocculator entrance orifice is the orifice that delivers water into the flocculator from the waterfall mixer. The orifice that leads into the flocculator must provide enough energy dissipation so that turbulence will mix the alum with the water to a sufficiently small scale so that molecular diffusion can finish the mixing process in a few seconds. Therefore, energy dissipation rate from minor head loss has to be greater than diffusion requirements. The following equation is used to determine the minimum energy dissipation required to meet the diffusion requirements.

Where:

- pi $_{Dmix}$ is 2.4; the ratio between the diffusion length scale and the Kolmogrov length scale
- nu $_{water}$ is the kinematic viscosity of water
- D $_{m}$ is 0.673 cm ^{2} /s; the diffusion coefficient for aluminum hydroxide
- tau $_{diffusion}$ is 10s; time allowed for diffusion to finish the mixing process

Calculate the minimum energy dissipation to be used in the flocculator entrance orifice equation.

In order to design the dimensions of the flocculator entrance orifice, the velocity of the flow in the vena contracta is calculated. Once the flow through the vena contracta has been determined, the area of the flow through the vena contracta is calculated with the following equation.

Where:

- Q is the flow rate
- K $_{exp}$ is 1.3; the global mixing coefficient
- V is the velocity in the vena contracta

- &Theta& is the resonance time

Use the coefficient of discharge to calculate the area of the flocculator entrance orifice.

Alum Stock Tank

As with previous designs, the Gracias design calls for two alum stock tanks. This way, while one of the tanks is operating, the other tank may be filled with the appropriate amount of chemicals. Therefore, the tanks are designed to be big enough for the operator to have enough time to mix the chemical before the other tank has drained. It is assumed that a supply for 30 hours is adequate. The following formula is then used to determine what the maximum flow of alum out of the stock tank needs to be:

Where:

- $C_{FcmDoseMax}$ is 90 mg/L; the maximum concentration needed for flocculation
- $C_{FcmAlum}$ is 120 gm/L; the concentration of alum in the stock tank

From this equation, the maximum flow of alum is determined to be 2.25 L/min; and the volume required to sustain this flow rate for 30 hours is 4050 L.Higher alum concentrations of up to 500 g/L could potentially be used.