Rapid Mix Orifice Sizing Program

Rapid Mix Orifice Sizing Algorithm

Introduction

The AguaClara team is revising a design for smaller flow rates (under 50 L/s). This page documents and describe the current changes in the Rapid Mix system. The rapid mixer system sizing algorithm is presented. We are working toward including AutoCAD images for the entrance tank and rapid mixer in our designs. Figure 1 shows a layout of the design.

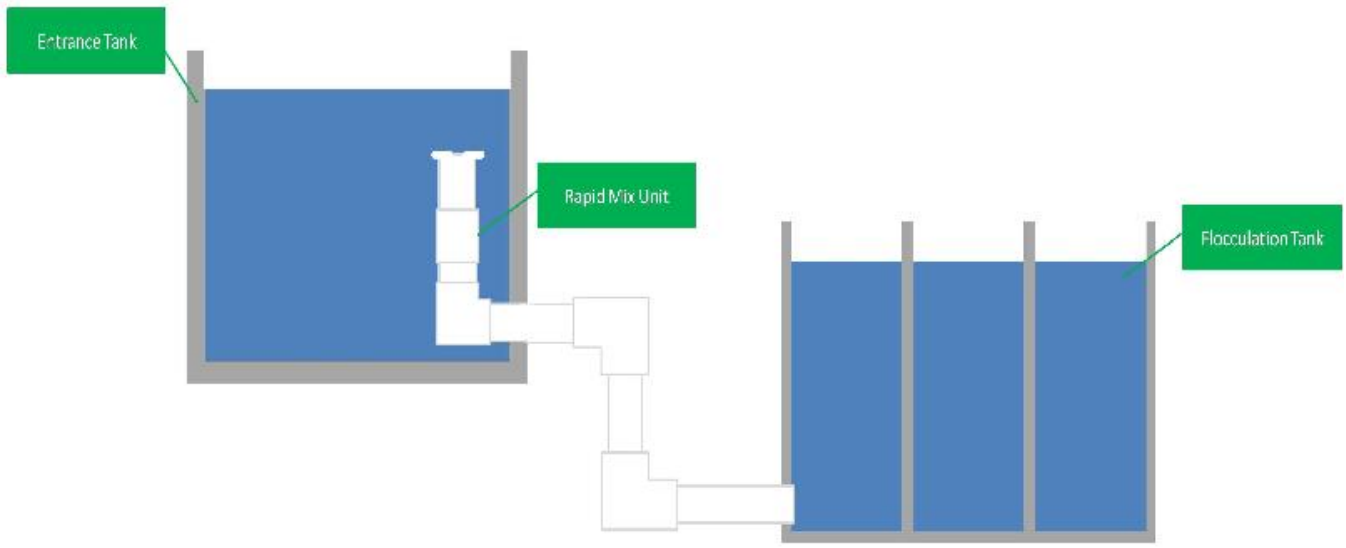


Figure 1: Design Layout of Rapid Mix System. **Chemical Doser Team**

The suspended particles in the water are removed through a process known as sedimentation. The effectiveness of sedimentation is increased with larger particles. A process known as flocculation is used to stick the particles together, and this results in the creation of larger particles that are easily settleable. A coagulant or chemical that can help stick the particles together is needed. The coagulant used in AguaClara plants is alum. To ensure the effectiveness of alum in flocculating the particles together, we need to have the alum distributed evenly to the molecular level. This is done through the rapid mixer.

The rapid mix system is designed to accomplish this. The rapid mix design consists of piping leading from the entrance tank to the flocculator entrance. The piping contains two orifices. The orifices decrease the cross sectional area of the flow allowing for a higher velocity and thus turbulence. Turbulence, measured in energy dissipation rate, is associated with the formation of eddies which mix the alum to the length scale at which viscosity overrides the formation of eddies with a larger energy dissipation rate being associated with a smaller eddies. The length scale at which the eddies can mix the alum to is known as the Kolmogorov length scale.

$$L_k = \left(\frac{\nu^3}{\varepsilon} \right)^{\frac{1}{4}}$$

Where:

L.k: Kolmogorov Length Scale

: Kinematic Viscosity

: Energy Dissipation Rate

The two different orifices in the rapid mixer are for the two types of mixing that occur. One is for macro-mixing and the other is for micro-mixing. Macro-mixing mixes the alum to the length scale at which micro-mixing can start. Micro-mixing distributes the eddies to the length scale where molecular diffusion can finish the task.

Design Algorithm

In the current design, we have two circular orifices on the same pipe segment. Originally, the micro-mixing orifice was after the first pipe bend. However we have decided to change that to allow facility of removal when cleaning is required. The micro-mixing orifice is two pipe diameters below the macro-mixing orifice. This ensures adequate mixing time for macro-mixing to take effect. The orifices for both equations are sized using the equations of minor loss coefficient for a submerged orifice.

$$K_{eorifice} = \left(\frac{d_{pipe}^{2}}{K_{vc} d_{or}^{2}} - 1 \right)$$

Where:

K.e.orifice: Minor loss Coefficient
K.vc: Vena Contracta Coefficient
d.pipe: Pipe Inner Diameter
d.orifice: Orifice Diameter

The equation for head loss is shown below:

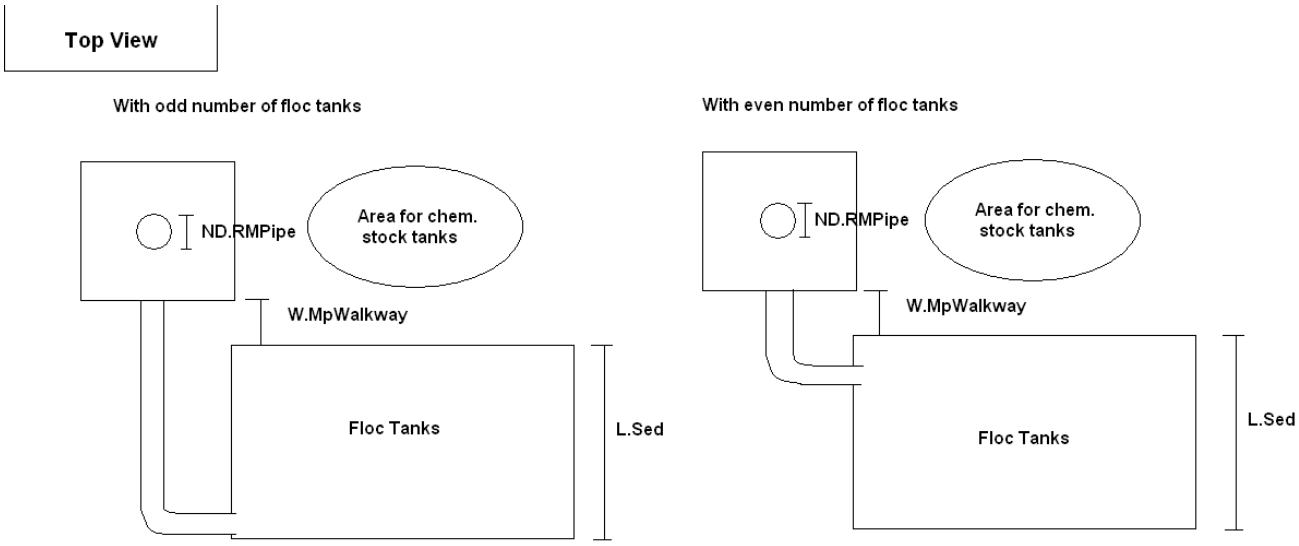
$$h = K \frac{V^2}{2g}$$

Where:
h: Head Loss
K: Minor Loss Coefficient
V: Velocity of Fluid
g: Gravitational Constant

The equation for minor loss coefficients for a submerged orifice shown above is used to find the orifice diameter needed.

In the case of macro-mixing, we are setting the minor loss coefficient to 1.3. This value is assumed to be adequate to allow for macro-mixing. The total head loss through the rapid mixer accounts for a total head loss of 40 cm throughout the entire plant, with most of the head loss in the rapid mix system belonging to the micro-mixer. This will be needed for the dose controller that will be integrated into the system. The dose controller uses a flow measurement device which relates head loss to flowrate (See Lectures on Rapid Mix). From the equation for a submerged orifice, it can be seen with the design assumption of K = 1.3, each pipe size will allow for one macro-mixing orifice size.

A pipe size/macro-mixing combination can be used for a range of flowrates. An increase in flowrates will result in a higher head loss for the macro-mixing orifice. This can actually result in the macro-mixing orifice having a higher head loss than the micro-mixing orifice. Due to this, the user can select a constraint value for head loss (usually 2 to 10 cm, currently set at 5 cm) that will cap how high the macro-mixing head loss can be. This is done by selecting a larger pipe size and larger macro-mixing orifice. In figure 2, the results for head loss through the macro-mixer are shown below. At high flow-rates, macro-mixing head loss becomes higher than micro-mixing head loss.

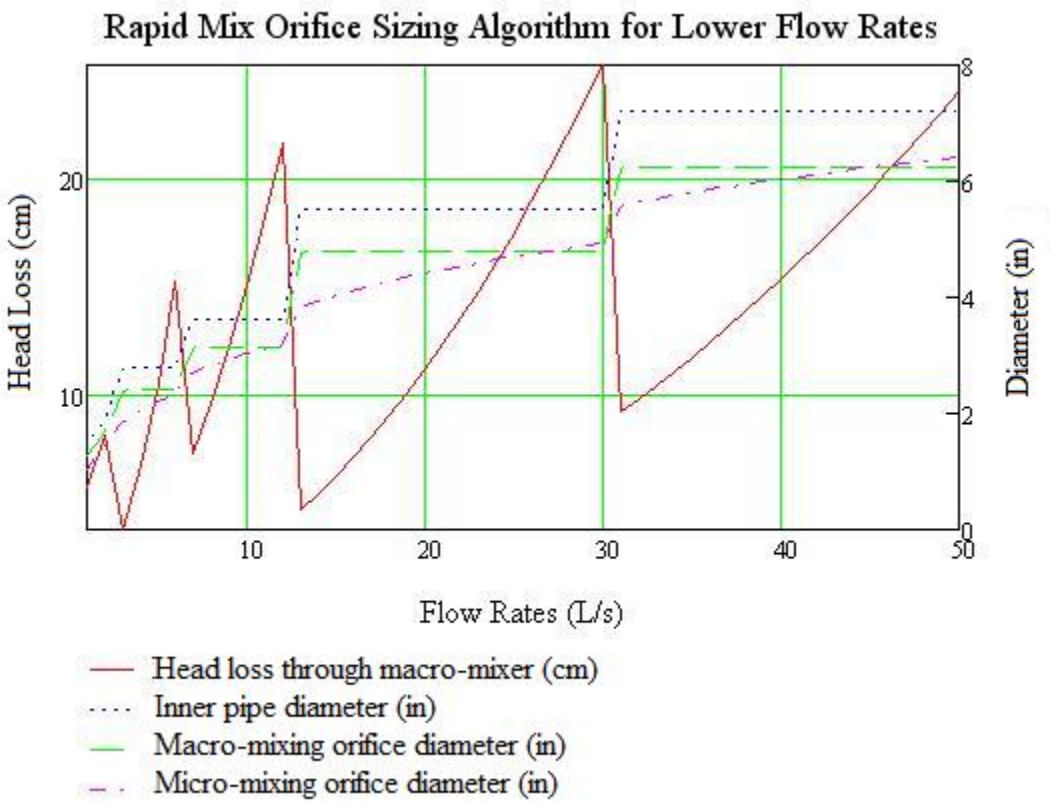


$$L_{RMPipe} := \begin{cases} \left[L_{Sed} + W_{MpWalkway} + L_{PipeInTank} + 2\left(ElbowRadius\left(ND_{PltWeir}\right) + innerD\left(ND_{PltWeir}, EN_{PipeSpec}\right)\right) + \frac{W_{Et}}{2}\right] & \text{if } mod\left(N_{FlocChannels}, 2\right) = 1 \\ \left[W_{MpWalkway} + L_{PipeInTank} + 2\left(ElbowRadius\left(ND_{PltWeir}\right) + innerD\left(ND_{PltWeir}, EN_{PipeSpec}\right)\right) + \frac{W_{Et}}{2}\right] & \text{otherwise} \end{cases}$$

L.RMPipe accounts for length of the piping and elbows of the entire rapid mix system. This length is needed to determine the nominal diameter of the pipes and elbows in the system based on a necessary head loss throughout the entire plant.

With the head loss of the entire plant and the entire system accounted for the constraint on the macromixer headloss (MacroMHConstraint = 5 cm) the size of the nominal diameter of the pipe, the diameter of the macromix orifice and the size and number of micromix orifices can be determined.

Figure 2: Rapid mix sizing algorithm for lower flow rates with 20 cm through micro-mixer and no constraints



The results show that above that with each pipe size and macro-mixing size, we have high head losses through the macro-mixing orifice which will increase to levels greater than 20 cm and hence give most of the head loss through the micro-mixing orifice.
The algorithm can be summarized in these following steps:
1. Determine the inner pipe size given the flowrates, maximum pressure drop (20 to 50 cm), total minor loss coefficients, and the available pipe sizes. The user also sets a constraint or limit for the macro-mixing orifice head loss.

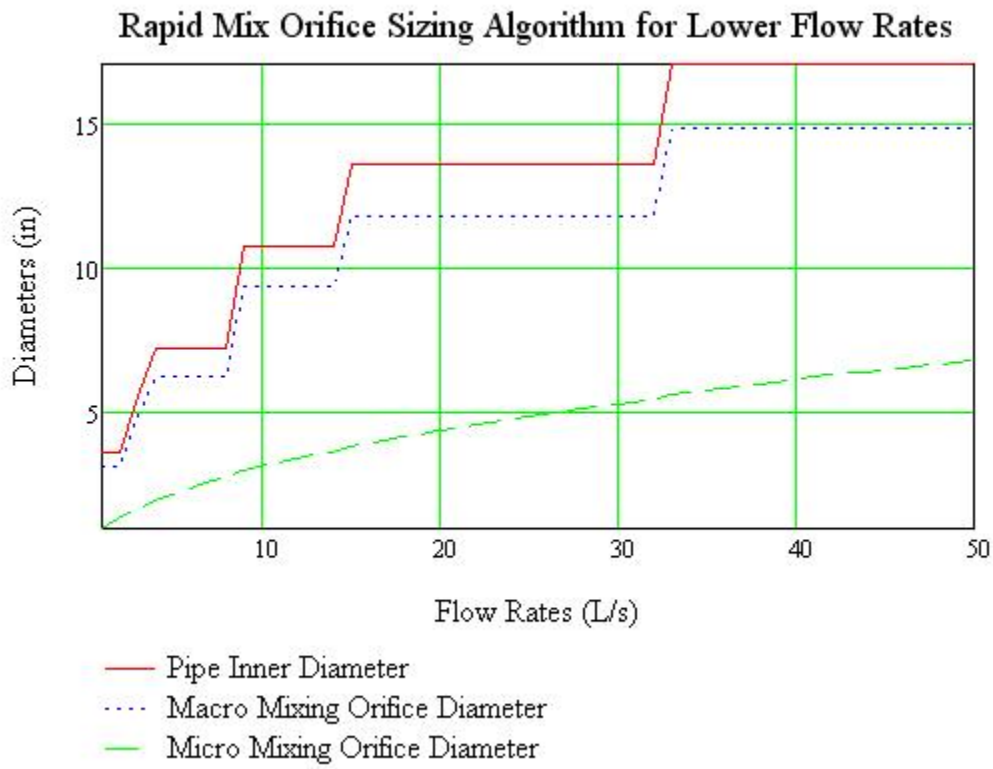
2. Using the pipe size given, determine the orifice diameter of the macro-mixing orifice. This is determined using the equation for minor loss coefficients for submerged orifices

3. If the head loss through the macro-mixing orifice exceeds the user-set constraint, then move up to the next pipe available and recalculate the orifice size. This step is repeated until the head loss is less than the constraint value.

4. Use the assigned total head loss value (calculated to provide 40 cm of loss in the entire system) and maximum flow rate to determine the minor loss coefficient needed for the micro-mixing orifice. Using the equation for minor loss coefficients for submerged orifices to determine the orifice diameter for the micro-mixing orifice. The number of orifices that can fit the area of the micro-mixing interface is returned based on the micro-mixing diameter.

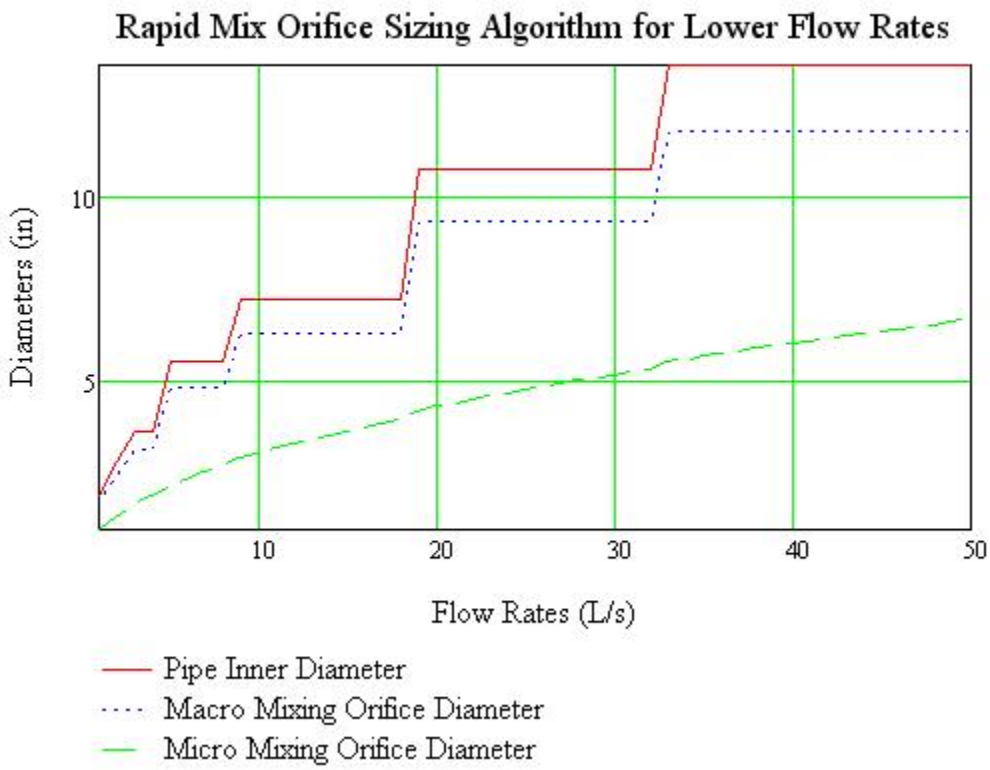
Running this algorithm for flow-rates under 50 L/s gave the following results as shown below on Figure 3.

Figure 3: Rapid mix sizing algorithm for lower flow rates with 50 cm maximum head loss and 2 cm constraint on macro-mixer



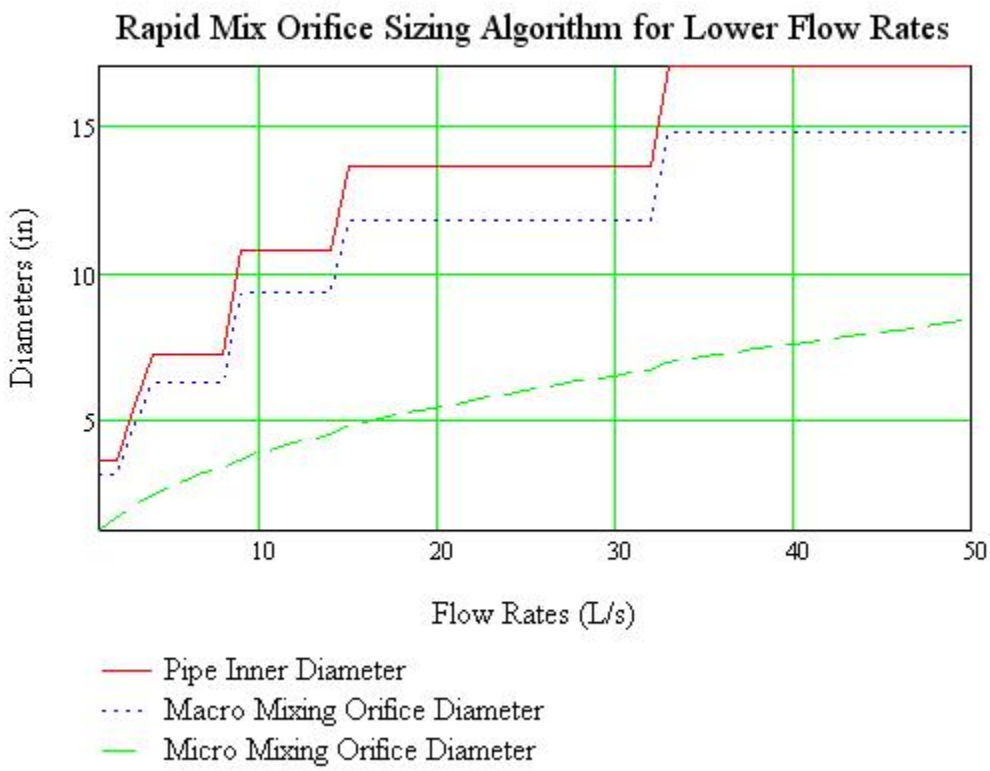
We also did runs where the constraint was raised to 10 cm head loss through the macro-mixing orifice.

Figure 4: Rapid mix sizing algorithm for lower flow rates with 50 cm maximum head loss and 10 cm constraint on macro-mixer



With this lower constraint, we find much smaller pipe sizes used. The micro-mixing orifices are also larger. We can also change the results to see what happens when we want a 20 cm head loss through the rapid mixer with our 2 cm constraint through the macro-mixer.

Figure 5: Rapid mix sizing algorithm for lower flow rates with 20 cm maximum head loss and 2 cm constraint on macro-mixer



The results for the pipe sizing and and macro-mixer sizing are not changed but we have larger orifices.

Figure 6: Rapid mix sizing algorithm for lower flow rates with 40 cm maximum head loss throughout plant and 5 cm constraint on macro-mixer

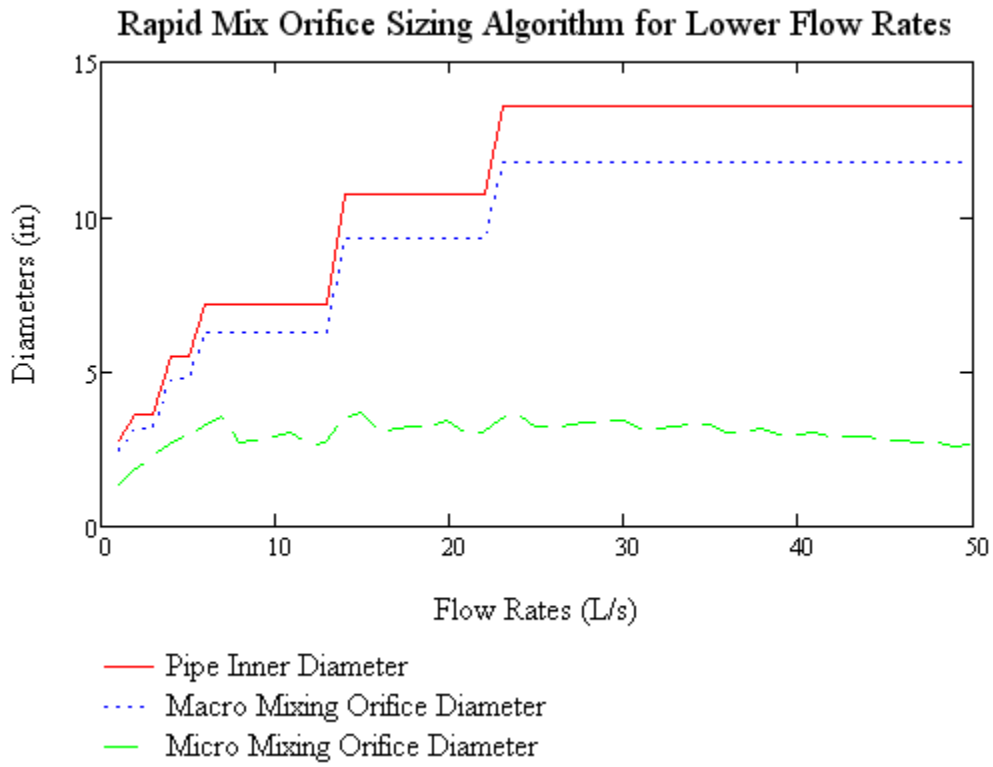


Figure 7: Number of micro-mixing orifices for lower flow rates with 40 cm maximum head loss throughout plant and 5 cm constraint on macro-mixer

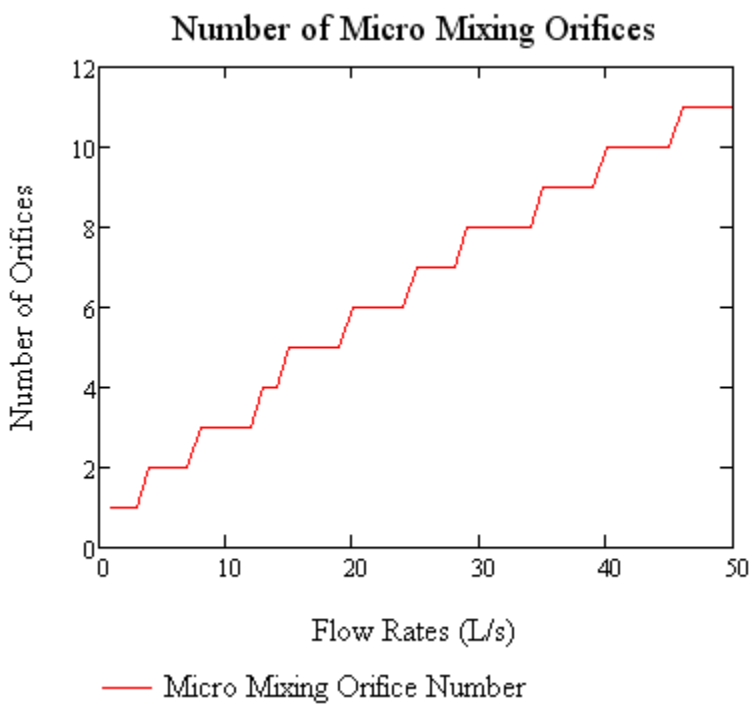
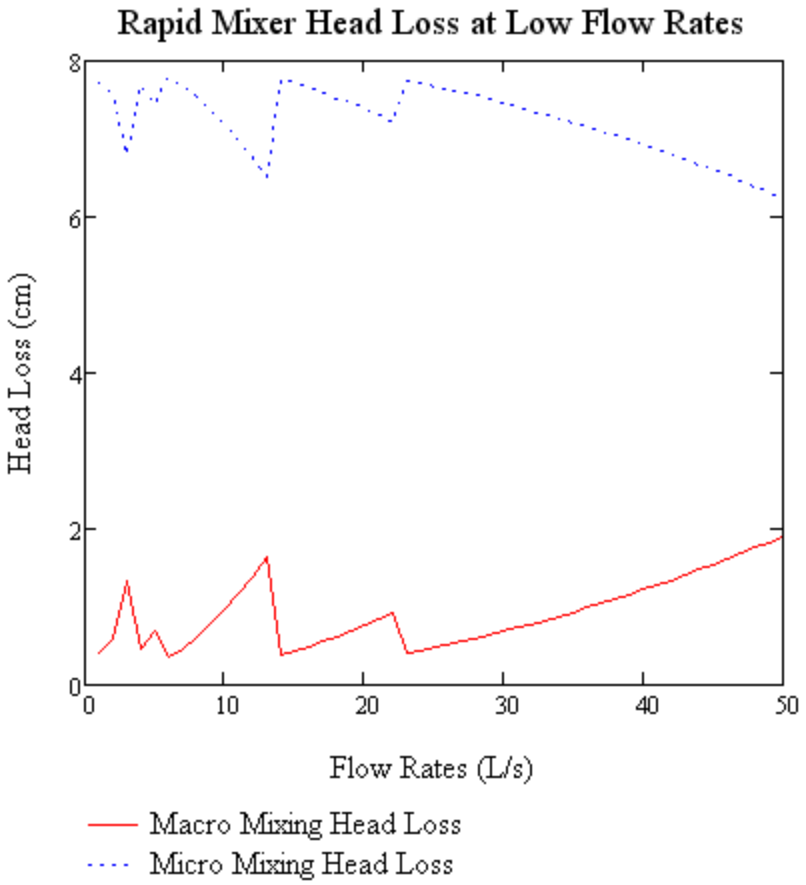


Figure 8: Head loss in macro and micro-mixing orifices for lower flow rates with 40 cm maximum head loss throughout plant and 5 cm constraint on macro-mixer



The next task is to use this code in developing an AutoCAD image of the entrance tank and rapid mixer.