Series of Orifices Design

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Summary

Another proposed design was to use a series of orifices within a tube that supplies the alum stock to the untreated water. Given the head loss that these orifices would provide, we needed to determine if the resulting alum flow would be slow enough to dose the water appropriately. To do this, we allowed a 20-percent error (since the dose was not intended for flocculation) and looked at the range of flow given this allowable error and the constant decrease in alum solution level. Unfortunately, we found that the resulting flow of alum from this design was too large for our purposes.

Calculations

Download the Series of Orifices Design MathCAD file here.

The head loss in the tube was determined using the equations for major and minor losses. The equations used in these calculations were found in online AguaClara notes and in Frank M. White's Fluid Mechanics (6th Edition).

$$Re(Q,D,\nu) := \frac{4 \cdot Q}{\pi \cdot D \cdot \nu}$$

Equation for reynolds number

$$f(\varepsilon, D, Re) := \begin{cases} \dfrac{64}{Re} & \text{if } Re < 2100 \\ \dfrac{.25}{\left(\log\left(\dfrac{5.74}{Re^{0.9}} + \dfrac{\varepsilon}{3.7 \cdot D}\right)\right)^2} & \text{otherwise} \end{cases}$$

Equation for friction factor

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

Equation for Major Loss

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

Equation for Minor Loss

$$h_t(h_f, h_e) := h_f + h_e$$

Total Head Loss = Major Head Loss + Minor Head Loss

The flow through the alum doser exit tubing was determined given user-defined parameters for the dimensions of the alum stock tank, such as height of tank (and thus, height of alum level) and diameter of exit orifice (and thus, diameter for the attached plastic tubing). These calculations were completed by simplifying the system to a "hole-in-the-bucket" situation.

$Re_{Tubing} := Re(Q_{Tubing}, D_{Tubing}, \nu) = 1.243 \times 10^4$

$f_{Tubing} := f(\varepsilon_{PVC}, D_{Tubing}, Re_{Tubing}) = 0.029$

$L_{Tubing} := 7in$ **user input**

$L_{TubingEffective} := L_{Tubing} - (N_{Plates} \cdot L_{Plate}) = 6.6 \cdot in$

$Major_{LossesTubing} := h_f(Q_{Tubing}, D_{Tubing}, f_{Tubing}, L_{TubingEffective}) = 18.966 \cdot mm$

Equivalent to shear losses.

$K_{Tubing} := 0$ no elbows

$Minor_{LossesTubing} := h_e(K_{Tubing}, Q_{Tubing}, D_{Tubing}) = 0$

$Total_{LossesTubing} := h_t(Major_{LossesTubing}, Minor_{LossesTubing}) = 18.966 \cdot mm$

$Total_{LossesSystem} := Total_{LossesPlates} + Total_{LossesTubing} = 1.21 m$

Next, using the previously determined flow through the exit tubing, the flow through one orifice plate can be easily determined. The calculations for flow assumes that flow through the tube was constant and neglects the effect of gravity on the flow. We assumed that the flow was fast enough to support this neglection.

$D_{Orifice} := 3mm$ set parameter: min. diameter for orifice

$$A_{Orifice} := \pi \cdot \left(\frac{D_{Orifice}}{2}\right)^2 = 7.069 \cdot mm^2$$

$$V_{Orifice} := \frac{Q_{Tubing}}{A_{Orifice}} = 17.536 \frac{m}{s}$$

$$Q_{Orifice} := A_{Orifice} \cdot V_{Orifice} = 123.956 \frac{mL}{s}$$

Total head loss through the orifice plates were calculated given user input for width and number of orifice plates. These calculations utilize the fluids functions found at the top of this page. Essentially, the head loss through one orifice plate was determined. The total head loss through the plates was then found by multiplying the number of plates by the head loss through one plate only. It should be noted that the head loss through these plates are purely cause by shear forces and thus experience major losses only.

$\nu := 1 \times 10^{-6} \frac{m^2}{s}$ set paremeter: kinematic viscosity

$Re_{Orifice} := Re(Q_{Orifice}, D_{Orifice}, \nu) = 5.261 \times 10^4$

$\varepsilon_{PVC} := .0015mm$ set parameter: roughness of pvc material

$f_{Orifice} := f(\varepsilon_{PVC}, D_{Orifice}, Re_{Orifice}) = 0.022$

$L_{Plate} := 0.1in$ **user input**

$Major_{LossesPlate} := h_f(Q_{Orifice}, D_{Orifice}, f_{Orifice}, L_{Plate}) = 297.765mm$

Equivalent to shear losses.

$K_{Plate} := 0$ no elbows

$N_{Plates} := 4$ **user input**

$Minor_{LossesPlate} := h_e(K_{Plate}, Q_{Orifice}, D_{Orifice}) = 0$

$Total_{LossesPlate} := h_t(Major_{LossesPlate}, Minor_{LossesPlate}) = 297.765mm$

$Total_{LossesPlates} := N_{Plates} \cdot (Total_{LossesPlate}) = 1.191m$

Head loss through the external tubing was then calculated given user input for the the desired length of the tubing. The calculations were similar to those above. The total head loss through the system then can be defined as the summation of the head loss through the orifices plates and the head loss through the wider, encompassing tubing.

$$Re_{Tubing} := Re(Q_{Tubing}, D_{Tubing}, \nu) = 1.243 \times 10^4$$

$$f_{Tubing} := f(\varepsilon_{PVC}, D_{Tubing}, Re_{Tubing}) = 0.029$$

$$L_{Tubing} := 7in$$ **user input**

$$L_{TubingEffective} := L_{Tubing} - (N_{Plates} \cdot L_{Plate}) = 6.6 \cdot in$$

$$Major_{LossesTubing} := h_f(Q_{Tubing}, D_{Tubing}, f_{Tubing}, L_{TubingEffective}) = 18.966\,mm$$

Equivalent to shear losses.

$$K_{Tubing} := 0$$ no elbows

$$Minor_{LossesTubing} := h_e(K_{Tubing}, Q_{Tubing}, D_{Tubing}) = 0$$

$$Total_{LossesTubing} := h_t(Major_{LossesTubing}, Minor_{LossesTubing}) = 18.966\,mm$$

$$Total_{LossesSystem} := Total_{LossesPlates} + Total_{LossesTubing} = 1.21m$$

Using this information, the necessary flow of alum from the doser based on dimensions given above is determined. Using a required dose concentration of 1.5 mg/L in the untreated water, the necessary stock concentration located in the alum doser can be calculated.

$$Q_{AlumDose} := \left[\pi \cdot \left(\frac{D_{Orifice}}{2}\right)^2\right] \cdot \left[VenaContracta \cdot \left[2 \cdot g \cdot (Total_{LossesSystem} + H_{StockLevel} + L_{Tubing})\right]^{\frac{1}{2}}\right] = 23.888 \frac{mL}{s}$$

$$C_{AlumDose} := 1.5 \frac{mg}{L}$$ set parameter: required dose concentration

$$D_{Filter} := 4in$$ **user input, found in other MathCAD file**

$$V_{Approach} := 4 \frac{mm}{s}$$ set parameter: approach velocity in filter column

$$A_{Filter} := \pi \left(\frac{D_{Filter}}{2}\right)^2 = 12.566\,in^2$$

$$Q_{Filter} := V_{Approach} \cdot A_{Filter} = 0.032 \frac{L}{s}$$

$$C_{AlumStock} := \frac{Q_{Filter} \cdot C_{AlumDose}}{Q_{AlumDose}} = 2.036 \frac{mg}{L}$$

The following section calculates the flow of alum given varying alum stock heights (of 5 inches to 25 inches). The final graph depicts results showing that if alum stock height varies greatly, the flow remains generally within the acceptable flow error. This error stems from the fact that we are not using alum for flocculation. Flocculation requires precision whereas merely dosing for improved performance leaves room for some error.

$$Q_{Alum}(\Delta h) := VenaContracta \cdot \left[\pi \cdot \left(\frac{D_{Orifice}}{2}\right)^2\right] \cdot \sqrt{2g \cdot (Total_{LossesSystem} + L_{Tubing} + \Delta h)}$$

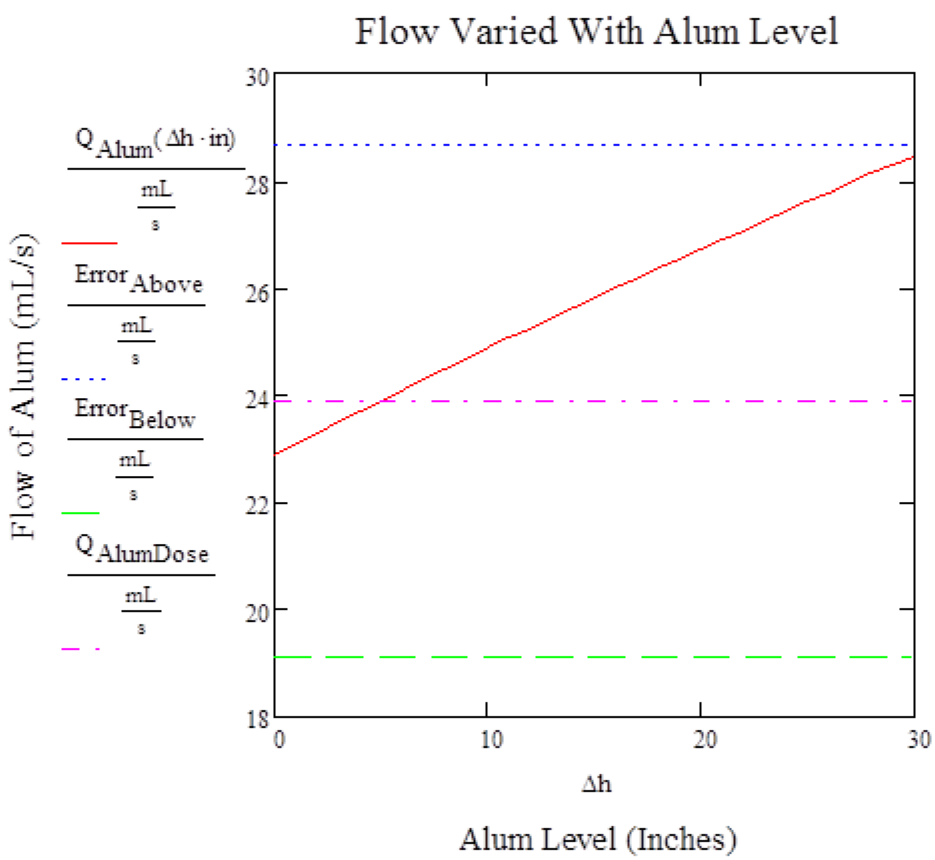
$$\Delta h := 0..30$$

$$\varepsilon_{allowed} := 0.2$$

set parameter: acceptable error

$$Error_{Above} := (1 + \varepsilon_{allowed}) \cdot Q_{AlumDose} = 28.666 \cdot \frac{mL}{s}$$

$$Error_{Below} := (1 - \varepsilon_{allowed}) \cdot Q_{AlumDose} = 19.11 \cdot \frac{mL}{s}$$



These results prove that the design will not work well with our point-of-use unit. By playing with the dimensions of the tubing, orifice plates, alum doser itself, and more, the lowest average flow we could obtain was around 12 mL/s which is extremely high for our desired system. Given this value, 1,037 L of alum stock would be used per day.