

Demonstration Plant

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Abstract

The AguaClara program needs appropriate teaching and publicity aids. The team developed a demonstration plant several years ago that illustrated the early flow control module, the baffled flocculator, and a sedimentation tank with plate settlers. In the intervening years we have developed a dose controller that tracks the plant flow rate, sedimentation tanks designed to include floc blankets, and stacked rapid sand filters. The next generation of the AguaClara demonstration unit should illustrate as many of these concepts as possible.

The demonstration plant will be used as a portable demonstration unit to advertise the AguaClara technologies. The AguaClara POU will be a centerpiece of the EPA P3 competition in April of 2012.

Students 3 (this team size could be expanded given the broad scope of the project)

Skills fluids, AguaClara water treatment processes, process controller, fabrication

1 Introduction

The AguaClara POU will be an excellent educational tool and demonstration unit as well as a device that can be used in households.

This team can begin learning the complexities of small scale water treatment by setting up a bench scale water treatment plant using the ENGR1 1131 apparatus. As the team is setting up the bench scale model they can also begin designing components of a new demonstration plant, DP, that incorporates as many of the AguaClara concepts as are feasible. The DP flow rate should be as low as possible to reduce the need for large storage tanks for the raw water. The minimum flow rate may be set by the sedimentation tank or by the stacked rapid sand filter, SRSF.

2 Design Strategy

Create a detailed Mathcad worksheet with design equations for each unit process. Create equations for all relevant dimensions. Some of the equations can be

borrowed from the AguaClara design tool files. However, care must be taken for flocculator design to account for the laminar flow. The design tool files assume turbulent flow for the flocculator.

2.1 Flow measurement and dose control

Explore the possibility of using a linear flow orifice meter, LFOM, to measure the raw water flow into the DP. It is possible that the required hole saw for an LFOM would be too small to be practical. If that is the case, use a long laminar flow tube to generate a linear relationship between flow through the DP and elevation of water in the DP entrance tank. Explore the possibility of using a chemical dose controller for the coagulant (Poly aluminum chloride, PACl, or aluminum sulfate, alum). It would be excellent if this demonstration plant could fully illustrate how a chemical dose controller works. The dose controller will require significant elevation. Full scale plants use 20 cm of elevation change in the entrance tank. Perhaps the elevation change in the entrance tank could be reduced slightly. However, if the elevation is reduced too much surface tension will cause large errors in dosing.

2.2 Tube Flocculator

Design a tube flocculator to be as short as possible given the maximum flow rate predicted above. The velocity gradient, G , will likely be in the range of 30 to 100/s. Explore the relationship between G and maximum floc size to determine the optimal value for G .

$$\bar{G} = \frac{64Q}{3\pi D^3} \quad (1)$$

The equation for G (equation 1) can be used to determine the optimal diameter of the flocculator.

The collision potential for a laminar flow flocculator is proportional to the product of the velocity gradient and the residence time, θ . The collision potential is a measure of the ability of the flocculator to cause flocs to collide.

$$G\theta = \frac{16L}{3D} \quad (2)$$

The fractal flocculation model predicts that for 50 NTU water that $G\theta$ of 1400 would be adequate to produce 70 μm flocs and those flocs should be able to settle out with a capture velocity of 0.12 mm/s. Thus for demonstration purposes where we would generally use very turbid water it may be adequate to use a relatively short residence time. Equation 2 can be solved for the length of the flocculator.

2.3 Sedimentation Tank

The sedimentation tank should include a floc blanket, floc weir, floc hopper, and plate settlers. The plate settler will likely be replaced with a simple tube

settler. The floc blanket will require a section of the reactor that has vertical walls and an up flow velocity of $1 \frac{mm}{s}$. Previous efforts to create a floc blanket at very small scales have failed. It is very possible that the floc blanket failure mode is related to the energy dissipation rate of the incoming jet of flocculated water. Given the same jet velocity, the energy dissipation rate is higher for small diameter jets than for large diameter jets. The incoming jet does break up flocs and it is very likely that the high energy dissipation rate of a small diameter incoming jet causes the flocs to be broken into such small fragments that an excessively high fraction of the fragments end up being carried out of the top of the sedimentation tank.

The relationship between the jet energy dissipation rate and the diameter of the pipe that discharges the flocculator water into the sedimentation tank is

$$D_{Pipe} = \left(\frac{Q_{Pipe} 4\alpha_{Jet}}{\epsilon_{Max}^{\frac{1}{3}} \pi} \right) \quad (3)$$

where Q_{Pipe} is the volumetric flow rate in the pipe, ϵ_{Max} is the maximum energy dissipation rate produced by the jet, and α_{Jet} has a value of approximately 0.5. The relationship between the energy dissipation rate and G in the tube flocculator is

$$\bar{\epsilon} = \bar{G}^2 \nu \quad (4)$$

The relationship between average energy dissipation rate, $\bar{\epsilon}$, and maximum energy dissipation rate in a jet is

$$\epsilon_{Max} = \alpha_{\epsilon} \bar{\epsilon} \quad (5)$$

where α_{ϵ} is the ratio of maximum to average energy dissipation rate and has a value of about 2 for jets. The maximum floc size was measured by Ian Tse with a tube flocculator.

$$D_{Floc} = 75 \mu m \left(\frac{\bar{\epsilon}}{\frac{W}{kg}} \right)^{\frac{-1}{3}} \quad (6)$$

It should be possible to combine equations 3 to 6 to solve for the required pipe diameter given a target floc diameter. Ideally the flocs would have a sedimentation velocity that matches the up flow velocity in the floc blanket to ensure that they aren't carried up and out of the sedimentation tank. Or perhaps they only need to have a sedimentation velocity that matches the tube settler capture velocity. The previous attempts at producing a floc blanket with 2.5 cm diameter sedimentation tanks did not include tube settlers and thus it is possible that this floc breakup problem will not occur if tube settlers are in place to return flocs that they capture. Floc sedimentation velocity is given by

$$V_t = \frac{gd_0^2}{18\Phi\nu_{H_2O}} \frac{\rho_{Floc0} - \rho_{H_2O}}{\rho_{H_2O}} \left(\frac{d}{d_0} \right)^{D_{Fractal}-1} \quad (7)$$

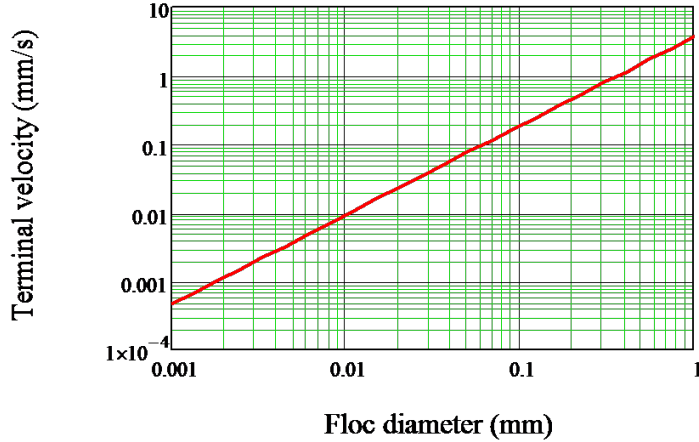


Figure 1: Floc sedimentation velocity as a function of size.

where d_0 is the diameter of the primary particles, d is the floc diameter, Φ is a fluid drag correction factor for the non spherical flocs, ν_{H_2O} is the kinematic viscosity of water, ρ_{Floc_0} is the density of the primary particles, ρ_{H_2O} is the density of water, and $D_{Fractal}$ is the fractal dimension of the flocs. The graph of equation 7 is shown in Figure 1. The flocs in the floc blanket may grow in size to be several mm in diameter and thus have very high sedimentation velocities. The up flow velocity in the floc blanket is 1 mm/s and the capture velocity in AguaClara plate settlers is set to 0.12 mm/s.

The floc weir will set the maximum level of the floc blanket. The floc blanket should probably have a depth between 30 and 60 cm. Floc blanket particle capture efficiency improves with depth, but the goal for the demonstration plant is to keep the unit processes small and to sacrifice performance if necessary.

2.4 Stacked Rapid Sand Filter

The stacked rapid sand filter is a hydraulically complex system that would be incredibly useful to be able to demonstrate at bench scale. A full scale unit has a depth of about 3.7 m based on 6 20 cm filter layers and then the elevation required for the fluidized bed and backwash head loss. This will require scaling the depth of the filter layers down significantly to make a bench top model. One possibility will be to reduce the filter layer depth to approximately 2 cm. The plumbing dimensions will also have to be carefully considered. The vertical drop tubes on the inlet side of the filter need to be large enough to allow counter current flow of air and water. That constraint requires a tubing ID of about 9 mm. It would also be beneficial if the vertical drop tubes had a small angle away from the vertical to making it easier for water to flow down the bottom of the tube and air to flow up on the top side of the tube.

The inlet and outlet manifolds could be custom manufactured stainless steel tubes with tiny orifices. As many components as possible should be transparent to facilitate direct observation of the hydraulics.