Plate Settler Capture Velocity

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Abstract

The influence of plate settler capture velocity on performance of a sedimentation tank containing a floc blanket has not been well characterized. The current AguaClara design uses a plate settler capture velocity of 0.12 mm/s. The influence of this parameter on residual turbidity needs to be characterized to assess whether the capture velocity should be increased or decreased for optimal plant design. The influence of coagulant type (PACl or alum), turbidity, and natural organic matter, also need to be characterized.

Students 3

Skills fluid mechanics, process controller, data analysis

1 Introduction

The design of water treatment plants has not been optimized for reduction of water waste, minimization of chemical use, or minimization of overall carbon and ecological footprint. The design algorithms that have been generated as part of the AguaClara Design Tool facilitate the analysis of construction costs for a given design. The more complex optimization involves changing key expert input parameters. The goal of research with the floc/floc blanket/plate settler apparatus is to develop models that make it possible to characterize the influence of plate settler capture velocity on the overall operation of an AguaClara plant.

2 Equation development (a subset)

The velocity gradient, G, for the tube flocculator should be in the range of 30 to 100/s. The equations presented below can be used to assess the actual velocity gradients and corresponding energy dissipation rate in the flocculator. It may be desirable to change the tubing diameter if the resulting energy dissipation rate is far from the AguaClara design guidelines.

$$\overline{G} = \frac{64Q}{3\pi D^3} = \frac{16\bar{V}}{3D} \tag{1}$$

The relationship between velocity gradient and energy dissipation rate for laminar flow is

$$\bar{\epsilon} = \bar{G}^2 \nu \tag{2}$$

Thus the average energy dissipation rate can be calculated from the velocity and diameter of the tube flocculator. Note that this approach neglects the additional energy dissipation caused by using coiled tubing.

$$\bar{\epsilon} = \left(\frac{16\bar{V}}{3D}\right)^2 \nu \tag{3}$$

The maximum velocity gradient occurs at the wall of the tube.

$$G_0 = 8\frac{\overline{V}}{D} \tag{4}$$

The corresponding maximum energy dissipation rate for a tube flocculator is thus

$$\varepsilon_{Max} = 64\left(\frac{\overline{V}}{D}\right)^2 \nu \tag{5}$$

The ratio of maximum to average energy dissipation rate for laminar flow is thus

$$\alpha_\epsilon = \frac{\varepsilon_{Max}}{\bar{\epsilon}} = \frac{9}{4} \tag{6}$$

The AguaClara designs currently use 10 $\frac{mW}{kg}$ for the maximum energy dissipation rate. The corresponding $\overline{G}$ is

$$\overline{G} = \frac{2}{3}\sqrt{\frac{10\,\frac{mW}{kg}}{1\,\frac{mm^2}{s}}} = 67\,{}^1\!/\mathrm{s} \tag{7}$$

The required diameter of a laminar flow flocculator given a flow rate and a target maximum energy dissipation rate can be obtained by combining equation (5) with the continuity equation.

$$\varepsilon_{Max} = 64\left(\frac{4Q}{D^3\pi}\right)^2 \nu \tag{8}$$

$$D = \left(\frac{32Q}{\pi}\right)^{\frac{1}{3}} \left(\frac{\nu}{\varepsilon_{Max}}\right)^{\frac{1}{6}} \tag{9}$$

For a 10 cm diameter sedimentation tank with an up-flow velocity of 1 $\frac{mm}{s}$ the flocculator diameter should be $4.3\,mm$. This is smaller than the current laboratory setup and thus the laboratory setup may need to be revised.

The equations above do not account for the coiling of the flocculator tube. The Dean number, Π_{De} is used to characterize coiled tubing.

$$\Pi_{De} = \frac{VD}{\nu}\left(\frac{D}{2D_{Coil}}\right)^{\frac{1}{2}} \tag{10}$$

Liu and Masliyah's model (1993) for Dean numbers less than 5000 gives the ratio of the friction factor of curved versus straight tubing.

$$f_{ratio} = \frac{1 + \left[0.0908 + 0.0233\left(\frac{D}{D_{Coil}}\right)^{\frac{1}{2}}\right]\Pi_{De}^{\frac{1}{2}} - 0.132\left(\frac{D}{D_{Coil}}\right)^{\frac{1}{2}} + 0.37\left(\frac{D}{D_{Coil}}\right) - 0.2}{1 + \frac{49}{\Pi_{De}}} \tag{11}$$

Head loss in the tubing is proportional to the friction factor, f, and the energy dissipation rate is proportional to the head loss. The energy dissipation rate for a coiled tube is equal to the energy dissipation rate for a straight tube scaled by the f_{ratio}.

The design of the jet of flocculated water entering the bottom of the sedimentation tank should be reevaluated based on our latest understanding of the role of the maximum energy dissipation rate. We are currently using a maximum energy dissipation rate, ε_{Max}, of 10 $\frac{mW}{kg}$ in the design of the flocculator and inlet to the sedimentation tank.

$$\varepsilon_{Max} = \frac{\left(\Pi_{Jet}V_{Jet}\right)^3}{D_{Jet}} \tag{12}$$

where Π_{Jet} has a value of 0.4. Note that in the case of a tube discharging upward into the sedimentation tank that there is no vena contracta. The jet must be released at the bottom of a cone that collects all settled flocs and directs them toward the jet for resuspension.

The relationship between the jet energy dissipation rate and the diameter of the pipe that discharges the flocculator water into the sedimentation tank is highly dependent on the inlet geometry. For the case where the pipe discharges upward and there is no direction change (no vena contracta) as the fluid exits the pipe the equation is

$$D_{Pipe} = \left(\frac{Q_{Pipe}}{\epsilon_{Max}^{\frac{1}{3}}}\frac{4\Pi_{Jet}}{\pi}\right)^{\frac{3}{7}} \tag{13}$$

The maximum energy dissipation rate for the resulting jet is less than the energy dissipation rate in the pipe and thus it is likely that there is no additional constraint on the size of the jet exit. However, it is possible that a lower energy dissipation rate at the inlet to the floc blanket would help reduce floc breakup and reduce the residual turbidity.

3 Experiments

Conduct a series of experiments over a range of input turbidities and vary the capture velocity of the tube settler by varying the length of the tube settler. Use a tube settler with a similar velocity gradient to that used in the AguaClara designs or vary the tube settler flow rate. Varying the tube settler flow rate would be easier to automate, but it is necessary to show that the results are equivalent to changing the tube settler length. Varying the tube settler flow rate will vary the velocity gradient and hence there is the risk of floc roll up. The plate settlers for AguaClara are generally $60\,cm$ long and spaced $2.5\,cm$ apart. The vertical velocity component in the AguaClara plate settlers is approximately $1.1\,\frac{mm}{s}$. Consider using multiple tubes to increase the flow rate so that the residence time in the turbidimeter is negligible. This will reduce the required time for each parameter change.

We are using alum as our coagulant to facilitate the creation of flocs. Another option for the choice of coagulant would be PACl (polyaluminium chloride). PACl is currently used as a flocculant in a several water treatment plants in Honduras. It is not known if the coagulant type has a significant effect on the density of the resulting flocs or the relationship between capture velocity and residual turbidity.

The parameters to vary in these experiments are

- coagulant type
- coagulant dose
- capture velocity
- raw water turbidity
- humic acid concentration

Confirm that the results are similar regardless of whether the tube settler is shortened or the tube settler flow rate is increased. Assuming positive results set up the process controller to conduct 3-D scans over the parameter space of raw water turbidity, coagulant dose, capture velocity (table 1).

The 3-D scan would result in $3(turbidities) * 5(doses) * 7(velocities) = 105$ experiments. The entire 3-D scan should take less than 5 days operating continuously. Given the length of the experiment, take precautions to ensure that all reagents are continuously supplied, that the hydraulics are stable with no risk of leaks, that the process controller is programmed correctly to cycle through all of the variables in the correct sequence and that the appropriate stabilization times are provided when there are changes in coagulant dose or raw water turbidity.

Scans over multiple parameters can be created by thinking of this as nested while loops where each the exit condition for each while loop sends the process controller to a unique exit state that serves as the increment state for the next higher level while loop. Creating the program for these scans will require careful

Table 1: Suggested parameter ranges for 3-D scan of turbidity, coagulant dose, and capture velocity.

Parameter to vary	Parameter range
raw water turbidity (changes after cycle of coagulant dosages)	$5\,NTU$, $500\,NTU$, $50\,NTU$ (done in this order because the first two are harder to treat)
coagulant dose (changes after cycle of capture velocities)	$0.5\frac{mg}{L}$, $1\frac{mg}{L}$, $1.5\frac{mg}{L}$, $2\frac{mg}{L}$, $3\frac{mg}{L}$ of Al (abort the series if the residual turbidity is less than 0.5 NTU?)*
capture velocity (changes most frequently)	$0.05\,\frac{mm}{s}$, $0.075\,\frac{mm}{s}$, $0.1\,\frac{mm}{s}$, $0.125\,\frac{mm}{s}$, $0.15\,\frac{mm}{s}$, $0.2\,\frac{mm}{s}$, $0.3\,\frac{mm}{s}$

* It is possible that the coagulant dosages given here are too high. It is possible that a floc blanket with the very large collision potential that it offers will significantly reduce the required coagulant dose. If that is the case, it may be desirable to run a 3-D scan with a lower set of coagulant dosages.

thought and the program should be carefully constructed to be as simple and elegant as possible. The program can be tested by using artificially short times for the states to ensure that it cycles corrected through all of the states.

Each test would need to be run for two residence times of the tube settler. There would be additional time required for every coagulant dose change to allow the floc blanket to equilibrate. The required time for the coagulant dose to propagate through the floc blanket can be estimated based on the time required for the raw water solids to replace the floc blanket solids. Perhaps use two solids retention times as the basis of time required to replace the floc blanket solids. During the time after the coagulant dose is increased it would be useful to report the resulting residual turbidity as a function of time to see how long it takes for the effect of the new coagulant dose to begin influencing the residual turbidity. The major result of this experiment will be residual turbidity as a function of 3 variables that will enable the creation of models describing these relationships.

After preliminary data analysis to confirm that the experimental results are valid, prepare to repeat the 3-D scan using the second coagulant. Finally propose some experiments with variable dosis of humic acid to assess the influence of natural organic matter on flocculation/floc blanket/tube settler performance.

Prepare a series of graphs illustrating the many relationships obtained in this large set of data. Ideally develop mechanically-based models describing the results. If that is not yet possible, develop empirical fits that will be useful for modeling the performance of an entire water treatment plant.

Each experimental run for a single set of conditions will produce one data point and a standard deviation that is the residual turbidity after passing through the tube settlers. The data analysis method will need to be simplified and streamlined to extract the correct data sequence from the data file and then calculate the average and standard deviation. The entire data record for an experiment should also be graphed and evaluated to ensure that the turbidity was stable and that trends are consistent with expectations during the transitions between experimental conditions.

References

[1] Liu, S. and Masliyah, J.H. (1993). Axially Invariant Laminar Flow in Helical Pipes with a Finite Pitch. J. Fluid Mech. 251, 315-353.