Fluidized Bed Flocculator

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Abstract

Novel methods of water treatment, that do not use electricity and only require basic construction materials, are in demand worldwide in remote regions without established centralized water treatment. Gravity-driven unit processes must be developed for these water treatment facilities. Current hydraulic flocculators use baffles with dimensions on the order of meters to generate turbulence and achieve particle aggregation. An alternative approach is to use sand grains, rather than large solid sheets, as flocculator baffles. A fluidized sand bed flocculator occupies much less plan view area, but generates much more head loss. Implementation will depend on a balance of the cost of land and materials against the available hydraulic head.

1 Introduction

Conventional hydraulic flocculators require significant plan view area for baffles to create desired turbulence, energy dissipation, and collision potential. The same energy dissipation may be created at a much smaller scale using particles of sand as baffles. The advantage of this approach is that the plan view area and materials required for construction are significantly less. Our team will design and fabricate a fluidized sand bed flocculator and compare its performance to a tube flocculator with a comparable energy dissipation rate.

2 Literature Review

Flocculation is a process that transforms a turbid suspension of tiny particles into a turbid suspension of larger particles. A gravity-driven hydraulic flocculator without mechanical agitation is an energy and cost efficient way to achieve flocculation. The flow through a hydraulic flocculator may include turbulent regions, which are caused by the expansion that results when the water changes direction as it flows around each baffle, or in this case, each grain of sand [1]. A fractal description of flocs, estimates of floc separation distances, and estimates of relative velocities of floc particles dependent on the relevant flow regime, provide an overall prediction of the required reaction time for formation of settle-able flocs based on influent turbidity, coagulant dose, and energy dissipation rate. Fluid viscosity is important for the beginning of flocculation where colloid sizes are smaller than the smallest fluid eddies. Turbulent eddies are shown to be significant for the final stage of flocculation. In turbulent flow, the collision potential, defined as the product of the hydraulic residence time (θ) and the cube root of the energy dissipation rate (ε), is expected to be a better predictor of flocculator performance than the commonly used product of hydraulic residence time and the velocity gradient Gθ [2].

A high energy dissipation rate is expected to increase collision frequency, creating larger flocs more quickly, but can also break up large flocs in the process. Ideally, the flocs would be less than the maximum (terminal) size reached in the flocculator so that they can grow by capturing other colloidal particles in the water, but not too small as to increase the residual turbidity of the water.

For hydraulic flocculation systems, low turbidity water is produced with minimal fluid shear. Low energy dissipation rates produced the fastest settling flocs and the lowest turbidity water. Because the lowest turbidity water can be produced using large flocs, the flocculator and the sedimentation tank must be designed to not break up large flocs. However, these conclusions have been drawn from laminar flow tube flocculators. While it is likely that the eddies in turbulent flow break up flocs in ways similar to that of laminar fluid shear, this concept has not been tested. Therefore, more research is required to test flocculator performance while adding zones with high energy dissipation rates to break apart and re-form flocs [3].

3 Methods

3.1 Design

3.1.1 Flocculator Design Calculations

The backwash porosity is given in equation 1.

$$\varepsilon_{FiSandBw} = \frac{\varepsilon_{FiSand} - 1}{\Pi_{FiBw}} + 1 \tag{1}$$

Where Π_{FiBw} is the filter expansion ratio defined as $\frac{H_{FiSandBw}}{H_{FiSand}}$, or the ratio of the expanded depth to the settled depth. The minimum approach velocity required to fluidize the bed is given by $V_{Fluidization}$.

$$V_{Fluidization} = \frac{\varepsilon_{Sand}^3 \cdot g \cdot D_{60}^2}{36 \cdot k_{Kozeny} \cdot \nu_{Water} \cdot (1 - \varepsilon_{Sand})} \left(\frac{\rho_{sand}}{\rho_{water}} - 1 \right) \tag{2}$$

The up-flow velocity may be used to calculate the residence time 3 and flow rate of the filter.

$$\theta = \frac{H_{FiSandBw}}{V_{Fluidization}} \tag{3}$$

$$Q_{Plant} = V_{Fluidization} \cdot \frac{\pi ID_{Fi}^2}{4} \tag{4}$$

3.1.2 Fluidized Sand Bed Flocculation

The head loss through an up-flow fluidized sand bed is given by equation .

$$h_l = H_{FiSand}\left(1 - \varepsilon_{FiSand}\right)\left(\frac{\rho_{sand}}{\rho_{water}} - 1\right) \tag{5}$$

With a sand density of $\rho_{Sand} = 2645\frac{kg}{m^3}$ and an unexpanded bed height of $H_{FiSand} = 1.0m$, the backwash head loss up through the filter is $h_l = 0.99m$. This head loss can be used to calculate the average energy dissipation rate and collision potential of the filter.

$$ED_\alpha = \frac{g \cdot h_l}{\theta} = 25.6\frac{mW}{kg} \tag{6}$$

$$\psi = \theta \cdot \sqrt[3]{ED_\alpha} = 110m^{\frac{2}{3}} \tag{7}$$

3.1.3 Settled Water Turbidity Measurement (SWaT)

Based on the AguaClara approach for plate settler design, the minimum spacing to prevent floc roll-up is 2.5 cm (or 0.984 in), so the minimum diameter for the tube is 1 inch [4]. With a target capture velocity of 0.17 mm/s, the length of the tube settler could be determined from equation 8, where S is the spacing or the diameter of the tube, L is the length of the tube, V_{Plate} is the vertical velocity going through the tank and alpha is the plate angle (set at 60 degrees) to get solids to slide down the incline. With these values, a length of 86 cm is required for the tube settler.

$$V_{Capture} = \frac{S{\cdot}V_{Plate}}{L \cdot sin(\alpha) \cdot cos(\alpha) + S} \tag{8}$$

Equation 9 was used to determine the flow rate. The minimum flow rate through the turbidimeter is 100 mL/min to prevent particles from settling in it.

$$Q_{Tube} = \frac{A_{Tube}}{sin(\alpha)} \cdot \frac{V_{Capture} \cdot (L_{Tube} sin(\alpha) \cdot cos(\alpha) + D_{Tube})}{D_{Tube}} \tag{9}$$

The specifications for the tube settler are given in the table 1 below. The SWaT system is located immediately following the flocculator and consists of a tube settler, turbidimeter and peristaltic pump.

Parameter	Value
Length	86 cm
Inner Diameter	1.049 in
Angle	60 degrees
Capture Velocity	0.17 mm/s
Flow Rate	100 mL/min

Table 1: Calculated Parameters of Tube Settler

3.2 Assembly

3.2.1 Clay Stock Tank and Constant Head Tank

A frame supporting a clay stock tank and constant head tank has already been assembled for the turbulent tube flocculator, and these stock solutions and tanks will be shared with the fluidized bed flocculator. Turbidity will be monitored in the head tank, and commensurate flow from the clay stock to the head tank will be controlled with a pinch valve. Temperature will also be monitored in the head tank, and commensurate flow of hot or cold water will be controlled with two solenoid valves. Finally, pressure will be monitored in the head tank to maintain the hydraulic grade line.

The setup is shown in figure 1. The tank on the top is the clay stock tank and the one underneath is the constant head tank. The blue boxes on the side are the solenoid valves, which are connected to the constant head tank.

Figure 1: Clay Stock Tank and Constant Head Tank

3.2.2 Sand Screens

Two screens are glued inline at either end of the filter to prevent sand from leaving. The screens are polyester mesh with 0.0148" openings. This diameter was chosen to be small enough that the sand will not pass through it, but large enough that any flocs created in the flocculator will.

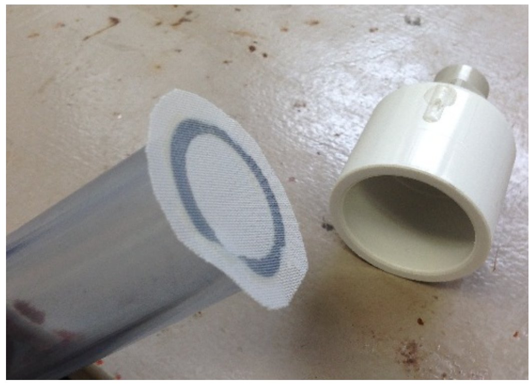

Figure 2: Inline Sand Screen

3.2.3 Waste Flow Tubing Elevation

The tubing coming down out of the end of the waste section of the apparatus is currently looped back up above the elevation of SWaT (taped to the ceiling). This is to ensure that the flow will not short-circuit and bypass SWaT. Settled flocs may collect in and clog this tubing, so a new method to prevent short-circuiting may need to be developed.

3.3 Experimental Control

Process Controller will monitor and regulate the water level, temperature, and turbidity of the constant head tank. Turbidity is controlled by metering in clay solution with a pinch valve, and water level and temperature are controlled using the process states depicted below.

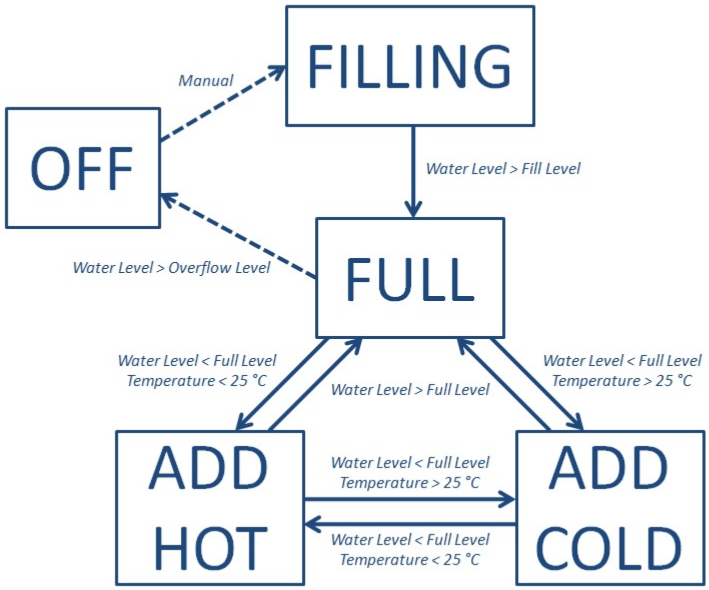

Figure 3: Water Level and Temperature Control States

4 Future Work

4.1 Sand Screen Check

Sand screens have been installed at the bottom and top of the sand column to prevent sand from escaping the column. However, the screen at the top of the column has the potential to shear flocs as they pass through it. Future teams should calculate the energy dissipation rate of the 0.0148" openings in the screen and verify that it is not too great.

4.2 Flow Rate Calibration

Influent raw clay solution will be pumped from the head tank into the sand column using a peristaltic pump. The flow through this pump must be set to achieve a 30% expansion of the sand column. The unexpanded bed height is 1 meter, so the expanded height will be 1.3 meters. A piece of red tape has been placed on the column to mark this target expansion height.

4.3 Connect Effluent Turbidimeter and Peristaltic Pump

The cable for the influent turbidimeter is already connected to a port on the back of the lab PC, allowing Process Controller to read that turbidity. The effluent turbidimeter still needs to be connected to the PC. A new port will likey have to be installed on the back of the PC to allow for the turbidity to be read over a separate COM. The peristaltic pump that pulls flow through SWaT also needs to be connected to the stamp box - either with an extension cord, a longer cord, or by repositioning the stamp box.

4.4 Process Controller

A process controller method file needs to be developed to run experiments. It can be modeled closely after the turbulent tube flocculator process controller method file from Spring 2014 since it will share all of the head tank and coagulant dosing apparatus and controls. It should maintain the three main operating states "Full", "Add HOT", and "Add COLD" to maintain pressure and temperature in the head tank. It will need new definitions for the influent raw water flow, effluent settled water flow, and effluent turbidity measurement.

Once the peripherals are all connected and process controller has been programmed, the team can troubleshoot the apparatus. Experiments will measure pC* for a range of influent turbidities and coagulant doses. Results can be compared with the turbulent tube flocculator, which has a comparable energy dissipation rate and collision potential.

References

[1] Weber-Shirk, Monroe. Flocculation Model. N.d. PowerPoint notes from CEE 4540. Https://confluence.cornell.edu/display/cee4540/Syllabus.

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[3] Tse, Ian C., Karen Swetland, Monroe L. Weber-Shirk, and Leonard W. Lion. "Fluid Shear Influences on the Performance of Hydraulic Flocculation Systems." Water Research 45.17 (2011): 5412-418.

[4] Weber-Shirk, Monroe. Sedimentation. N.d. PowerPoint notes from CEE 4540. Https://confluence.cornell.edu/display/cee4540/Syllabus.