Determining an Effective Alum Dose

Abstract

Coagulation is the process of chemically destabilizing solutions whereby electrolytes are added into solution so as to reduce the charge on the colloidal particles, thus facilitating their close approach and aggregation. In water treatment processes, the primary electrolyte introduced into solution as the primary coagulant is aluminum sulfate (Al2(SO4)3), also known as Alum. Flocculation is the subsequent process whereby particles collide and form large aggregates, or flocs. Flocculation involves producing collisions between suspended particles that are strong enough to overcome the repulsive potential barrier between particles, but that will not simultaneously break up the flocs already in suspension. Improving the effectiveness of coagulation and flocculation will greatly enhance the efficiency of small-scale water treatment systems, which will drive down costs and make the technology more feasible and attractive to communities.

One of the important contributors to the formation of flocs is the chemical coagulant aluminum sulfate (Alum). When dissolved in water, alum dissociates and the multivalent aluminum ions (Al3+) form various species that have an average positive charge. Since most suspended colloidal matter in surface waters has an overall negatively charged surface, the dissolved Al species will adsorb onto the surfaces of these particles and reduce its net surface charge, thus lowering the barrier for floc formation. The appropriate amount of alum required to facilitate total particle removal via the sedimentation of flocs is dictated by a couple key parameters: the concentration of clay particles and other natural organic matter (specifically the chemical properties of these contaminants and their reactivity with the dissolved Al species) will effect how much alum is needed. The alkalinity of the water will also effect how well the coagulant will perform.

In the current laboratory flocculator experimental setup, there are several parameters that control the flocculator process. Our main objective in conducting research with the lab flocculator is to be able to isolate each of the parameters in order to understand their specific roles in the flocculation process and to optimize overall flocculator efficiency. While the need to fully understand the mechanism by which alum coagulates particles was not immediately pressing, it was important for our research to determine the most effective alum dose for various levels of turbidity in order to temporarily remove alum dosing as a variable in our later experiments. In order to isolate and temporarily remove alum as a variable, a relationship between alum dose and influent turbidity must be determined. For a given influent turbidity, there is, theoretically, an optimal amount of alum that should be added to the influent in order to form the greatest amount of flocs and thus producing the lowest effluent turbidity. This optimal alum dose should, therefore, change with different influent turbidities. The objective of our first experiment was to determine the optimal alum dose for various influent turbidities.

While finding this relationship is integral to our later experiments, the empirical values would not necessarily apply to vertical flocculators used in water treatment plants designed for Honduras. First, differences in flocculator design, and thus intensity and quality of mixing, could greatly affect the appropriate alum dose for various turbidities. Moreover, the levels of contaminants in the waters in Honduras will have very different dissolved matter in it that will react to alum much differently than in our experiments. However, the purpose of our investigating optimal alum dose is not to give operators in Honduras a alum dosing guide, but to develop a control method in our experiments that will render alum dosing a temporary non-variable. Future experiments may need to be performed to determine whether the effects of alum can vary with different mixing intensities or other variables.

After determining the optimal alum dose for different influent turbidities, we proceed to run experiments with other variables, such as velocity gradient (G) and Gtheta, an indicator of the cumulative extent of mixing experienced after one pass through a reactor.

Methods

The flocculator setup was used in this experiment.

In order to isolate alum dose as the only variable in our experiment, we must maintain mixing at a constant. If we maintain both flow rate and flocculator length (hence residence time) constant, we can keep mixing constant. The length of the tube was inherited from the summer team, as our team did not replace the tube that had already been attached to the set up. The calculation for the length of the tube was done by measuring
the outer diameter of the cylinder around which the tube was wrapped (plus adjustments for the thickness of the tube itself) and multiplying that by \( \pi \) to give the circumference and then multiplying the circumference by the number of times the tube wrapped completely around the cylinder. The effective diameter was 42 cm and the tube wrapped around the cylinder approximately 15.5 times, giving a total length of approximately 20.45 meters.

Given that the flocculator length is fixed, we must select and hold constant a flow rate that is will cause adequate amount of mixing but that will not break up flocs. From observations of past experiments and reports done by past lab floc teams, a Gbar (average velocity gradient) of roughly 40 sec\(^{-1}\) was selected as the Gbar that will be used in every run of this particular alum dose experiment. The equations relating Gbar to the flow rate Q for laminar pipe flow are as displayed below. Note that the transition between laminar flow to turbulent flow in long smooth pipes occurs at a Reynolds number of roughly Re = 2300. This translates to a flow rate of roughly 9.69 mL/sec through the 0.42m diameter pipes used in this experimental setup. Since the pumps are unable to pump fluid through the pipes at those speeds, it is valid to assume that the flow in the pipes will be laminar for our experiments. The flow rate at which all our experiments will be run is Q = 1.33 mL/sec which produces a Gbar = 42 sec\(^{-1}\).

The alum stock had not been used up at the start of our experiments, but we noticed that contaminants in the form of dust and lint had fallen and aggregated at the bottom of the alum stock tank. These aggregated contaminants had the potential to clog up the very narrow feed tubes that led out of the alum stock container. Furthermore, while fine tuning the Process Controller methods, we noticed that the current concentration of 5000 mg/L, a dose of 5 mg/L could not be produced by the peristaltic pump. While Process Controller read a value of 5 mg/L for the alum dose, the pump was not spinning and thus not pumping the amount indicated by Process Controller. The solution to this problem was to dilute the alum to a lower concentration (1500 mg/L in our case) so that a higher alum flow rate would be required to obtain a particular influent concentration than when it was at 5000 mg/L.

To determine the optimal alum dose needed for an influent water turbidity of 100 NTU, we set up a special program in Process Controller. We varied the alum dose added to the influent stream from 0 mg/L to 45 mg/L in increments of 5 mg/L for an influent turbidity of 50, 75, 100, and 150 NTU. This range in alum doses was selected based on previous observations that 40 mg/L of alum produced best results at a turbidity on the order of 100 NTU.

Results

After running a set of alum incremented experiments on influent turbidities of 50, 75, 100, 150 NTU, we extracted the data for analysis. Normally, a Mathcad program developed by the previous teams would have been utilized to gather, parse, and extract relevant data recorded throughout the experimental runs; however, our team had not been introduced to the software at the time of this report’s submission and had to parse and analyze the data with Microsoft Excel.

Figure 1: Settling curves for various alum doses at an influent turbidity of 50 NTU.
Figure 2: Settling curves for various alum doses at an influent turbidity of 75 NTU.

Figure 3: Settling curves for various alum doses at an influent turbidity of 100 NTU.
Figure 4: Settling curves for various alum doses at an influent turbidity of 150 NTU.

Figures 1-4 display the time series plots of turbidity during the settle state in which flocculated particles are allowed to settle in a quiescent environment inside the modified glass cylinder of the effluent turbidimeter. The effectiveness of alum is measured by the size of flocs after flocculation. Since we do not have the equipment needed to observe and measure the sizes of flocs formed after each experiment, we can only observe the rate at which flocs settle under quiescent conditions and the final settled turbidity. Since the experiments were run under identical conditions, the mechanisms creating the flocs are identical from run to run; therefore, the composition of the flocs (their shape and density) should be relatively uniform. This fact allows us to directly relate the settling rate of the flocs to the size of the flocs, while neglecting factors such as electrostatic interactions and porosity (which would affect drag coefficients and densities.) Final turbidity is a measure of whether or not much suspended particles were not affected by the alum—a high final turbidity would indicate that an inadequate amount of alum was introduced compared to the amount of contaminants in solution. Therefore, the optimal alum dose should be indicated by the curve with the quickest settling rate and final turbidity.

The 100 NTU figure (Figure 3) is missing curves for the experiments run at 0 mg/L and 5 mg/L because the data obtained for those two runs were interrupted by the interference of the 7kPa pressure sensor going in and out of voltage range. The data was omitted from the figure because of those errors. The 100 NTU experiments were the first experiments to be run, so the error was fixed and eliminated. The subsequent experiments at 100 NTU are correct as well as the runs for 50, 75, 150 NTU.

For the 50 NTU experiments (Figure 1) a general trend can be seen that indicates final turbidity decreases as alum dose increase. There is an unexpected anomaly in the relationship between the 0 mg/L curve and the 5 mg/L curve. Contrary to expectations, it appears that the quality of the final water was worse off after adding 5 mg/L of alum as opposed to having no alum present. The cause of this discrepancy is unclear, but it appeared to be an isolated occurrence as the experiments run with 75 (Figure 2) and 150 NTU (Figure 4) were consistent with expectations.

Another general observation deduced from comparing each of the figures is that the settling rate of flocs increases dramatically between the alum dose of 5 mg/L and 10 mg/L. This trend occurred across all turbidities (this observation is less obvious in the 100 NTU run, but the data does not necessarily oppose this observation) and is a phenomena that may be of significance in understanding alum effectiveness. A second observation deduced from comparing each of the figures is that the marginal effectiveness (measured in both final turbidity and initial rate of settle) of increasing alum dose decreases significantly after about 25-30 mg/L of alum. It is expected that a point will be reached at which additional alum addition will not significantly reduce turbidity, and it is in the proximity of this alum dose that we suspect the optimal alum dose will be. More experiments should be run to obtain better data resolution at the alum doses between 25-55 mg/L. The largest alum dose used in these experiments was 45 mg/L, and while the curves show that the marginal benefit gained by adding more alum in the 40-45 mg/L range is minimal, extending the alum dose range will give more definitive evidence that we have indeed reached a critical value in alum dose.

The lowest turbidity reading reached in each of the four turbidity experiments were in the 10 NTU range. Additionally, it appears that for the higher alum doses, the curve flattened out at approximately the same elapsed time in each of the four influent turbidity experiments. This indicates that at higher influent turbidities (higher particle concentrations), particle aggregation becomes easier and therefore effluent flocs are generally bigger and settle out faster.
Discussion

The experiments proved that the addition of alum into turbid waters prior to flocculation improves particle aggregation, leading to higher settling velocities and cleaner effluent water. The experiments do not show conclusive evidence of where the optimal alum dose is for the different levels of turbidity. The fact that the curves are so similar in all four figures suggests that the optimal alum doses changes only slightly for this range of turbidity values. More experiments should be done to refine the data resolution of the 25-55 mg/L alum dose range for each of the 4 turbidities.