Title: Dissolved Organic Matter (DOM) Removal from Drinking Water with Poly-aluminum Chloride (PACl), Clay, and Powdered Activated Carbon
Team: Dissolved Organic Matter, Fall 2023
Names: Zachary Kwon, Rachel Lai, Henry Lin, Nhi Nguyen
Date: 20 October 2023

Abstract

The Fall 2023 Dissolved Organic Matter subteam aims to compare the effectiveness of implementing polyaluminum chloride with clay and/or powdered activated carbon to remove humic acid from drinking water. To ascertain the optimal amounts of activated carbon and clay concentrations, ProCoDA will be utilized to introduce various flow rates of the different solutions into the system, which allows for higher efficiency testing and more control over what amounts of solutions are in the system at a given run.

Both clay and activated carbon are predicted to increase the density of flocs, so this subteam plans to determine which is more effective and efficient at producing high-density flocs to get the maximum floc removal in the sedimentation tank. Through performing research regarding the optimal concentration of clay and/or activated carbon, the DOM subteam hopes to improve the capability of AguaClara water treatment plants.

Introduction

Dissolved organic matter, a natural transparent water contaminant, is present in unusually high amounts in AguaClara's plant in Gracias, Honduras. DOM is created from the decomposition of organic matter, such as feces and decaying leaves. When DOM reacts with coagulants like PACl, the contaminants clump together into flocs, which are more easily removed in the filtration process.

However, to remove DOM by means of flocculation, it is essential that flocs form with a relatively high density, preferably higher than that of water. If the reverse is the case, flocs float to the surface of the water, leading to difficulty in floc blanket formation and filtration in subsequent steps.

One method to achieve high density flocs is through pre-combining kaolin clay with coagulant solution prior to the flocculation step (Wu et al., 2020). Clay can be used to simulate the turbidity of influent water and promote coagulation by adhering to the surface of coagulant and attracting DOM by means of collision aggregation.

An alternative to kaolin clay in the flocculation process is powdered activated carbon, which can be combined with humic acid and water prior to the introduction of coagulant for denser floc formation (Tafvizi et al., 2021). Due to its porous surface, activated carbon particles, having been bound onto coagulant particles, have the capability to adsorb a large amount of dissolved organic matter onto its surface. This ability helps to increase the effectiveness of the coagulant, reduce coagulant dosage, and create heavier flocs.

This semester, the Dissolved Organic Matter subteam is investigating the effectiveness of implementing coagulant with clay and/or powdered activated carbon in removing humic acid from influent water. Future steps in this experiment include examining the optimal dosage of coagulant with clay and/or activated carbon and the financial trade-offs between the two.

Literature Review

Clay is important in modeling the removal of dissolved organic matter in water due to its ability to produce turbidity. In a 2021 article by Saxena et al., researchers modified a model for hydraulic flocculators and tested for a sludge blanket clarifier by running experiments using synthetic water samples consisting of humic acid and kaolin clay, and PACl as a coagulant. The reasoning behind the use of clay in the procedure of removing dissolved organic matter is that it is a major contributor to inorganic turbidity in surface waters due to the fact that it is larger than PACl nanoparticles. Since turbidity is measured by the amount of light scattered or blocked by suspended particles in a water sample, large particles such as clay will be able to produce turbidity readings since they will most likely be able to block light through the sample in the turbidimeter. The researchers also found that the coverage of PACl on clay increases for the same dose of PACl as the input turbidity decreases meaning that there will be greater coverage of the clay particles by coagulant when there is less clay. Thus, the Fall 2023 team will monitor how much clay is added in order to maintain high coagulant coverage while providing turbidity readings for analysis.

Like clay, activated carbon has been researched in its potential role for removing dissolved organic matter from drinking water. In a 2021 study by Biswas et al., researchers collected waters from a non-wastewater-impacted reservoir at Big Elk Meadows, CO to test how activated carbon adsorbed the different types of DOM (e.g., humic, aromatic, polyphenol, etc.) within the waters. The results were measured through fluorescence spectroscopy, UV-absorption, and size exclusion chromatography. According to the paper, peaks associated with humic acid were shown to adsorb with activated carbon through fluorescence spectroscopy, indicating that activated carbon should flocculate with humic acid to create dense flocs which will be easily removed from drinking water.

Another variable to take into account when exploring activated carbon's effectiveness in the flocculation process is the effect of varying activated carbon flow rate on its adsorption efficiency. According to Campos et. al. in a 2000 study, for a fixed dosage of activated carbon, decreasing the carbon retention time resulted in a reduction of activated carbon absorption efficiency. Thus, careful considerations must be made when deciding on process flow rates during experimental trials since varying the residence time in the upflow blanket reactor may result in a less desirable activated carbon absorption efficiency.

It is also important to factor in the environmental and health effects of a coagulant when determining which is the best flocculant. Activated carbon is classified as an inorganic chemical flocculant, while kaolin clay is classified as a natural coagulant. The use of chemical coagulants, both inorganic and organic, can cause adverse environmental and health problems. Activated carbon specifically is known to have residual aluminum which is neurotoxic and carcinogenic to humans (Aljuboori et al., 2015). This detail should be kept in mind when discussing the trade-offs between the clay and activated carbon in the drinking water flocculation process.

Previous Work

Flow Rate Tests for Each Pump's Volume/Revolution

In order to properly implement ProCoDA in the experimental procedure, the volume per revolution values for each pump setup needed to be experimentally determined. Through tracking the number of revolutions and volume pumped (with an electronic balance) for each pump within a certain time limit, the values for each pump's volume per revolution could be calculated. Once this test was performed for all of the pumps in the system, the calculated values were inputted into the ProCoDA method file for more accurate results on future experiments.

Automated Testing with ProCoDA

To implement timed trials using ProCoDA, the Spring 2023 DOM team updated the old method file to include the automated testing necessary for experimenting with different clay/activated carbon dosages (Kwon et al., 2023). This process involved working through Dr. Monroe Weber-Shirk's ProCoDA tutorial and adjusting his values to reflect that of this experiment. Specifically, this involved changing set points in the "Rules and Outputs" tab to reflect Run, Warmup, and OFF states for that cycle after a set time interval. All the set points that control flow rates were modified to be variables, whose values could be incrementally adjusted using the ProCoDA mathematical functions. Desired clay flow rates were set through adjusting constant set points such that a new geometric series was generated with different base and coefficient values. The waste flow was also changed from a constant to a variable where it was set equal to a certain percentage (e.g., 30%) of the total incoming flow of the system. For this experiment, clay flow rate increments were based on the geometric series:

$$\mathbf{0.5 * 3^{x} \text{ for } x = 0, 1, 2, 3, 4 \text{ (in rpm)}}$$

with base (3) and coefficient (0.5) values chosen and set as constant on ProCoDA. Geometric series were chosen instead of arithmetic, on the basis that the increase in clay dosage is more significant between intervals for geometric series. This allows for a wider range of clay dosages for analysis. In addition, the ProCoDA built-in math function for geometric series – "Increment by factor rep" – was more easily accessible and faster to implement than other series. The total run time for each run was set to be 25 minutes to allow for clay/activated carbon dosages to fully take effect in the flocculator and sedimentation tank.

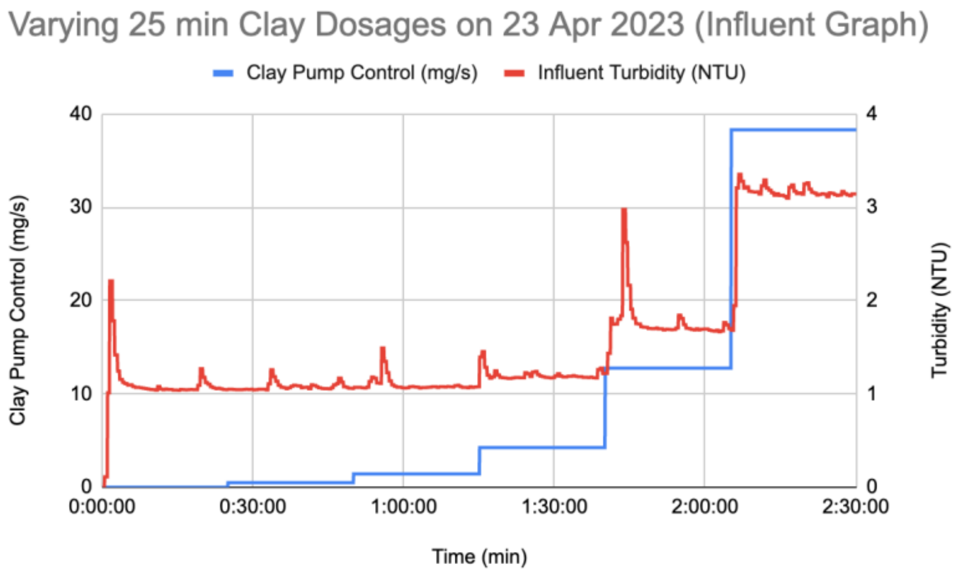

Figure 1. Graph of Influent Turbidity vs Time after Varying Clay Dosages

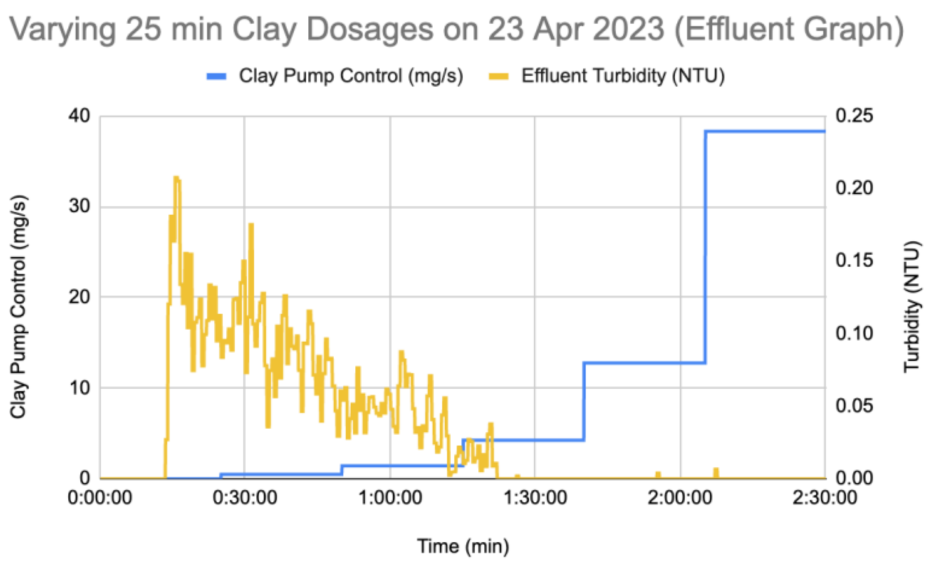

Figure 2. Graph of Effluent Turbidity vs Time after Varying Clay Dosages

Methods

Calculating Upflow Velocity and Flow Rates

The optimal upflow velocity for the system needed to be determined by running trials with only humic acid, coagulant, and water. By increasing the upflow velocity in the sedimentation tank, the system would reach failure and serve as a control group to verify the effectiveness of adding clay and/or activated carbon into the system. The purpose of this experimentation process is to provide a contrast between a system with and without clay/activation carbon through creating an environment where flocs are unable to form when only humic acid and coagulant are supplied. Calculations for the flow rates necessary to determine the optimal upflow velocity were made with Deepnote.

To determine the humic acid and coagulant dosages with Deepnote, it was necessary to determine their respective concentrations in the system. Based on the data from Du et al. (2019) in Figure 3, a value of 25 mg/L for system humic acid concentration and values between 2-3 mg/L for system coagulant concentration were chosen for this experiment.

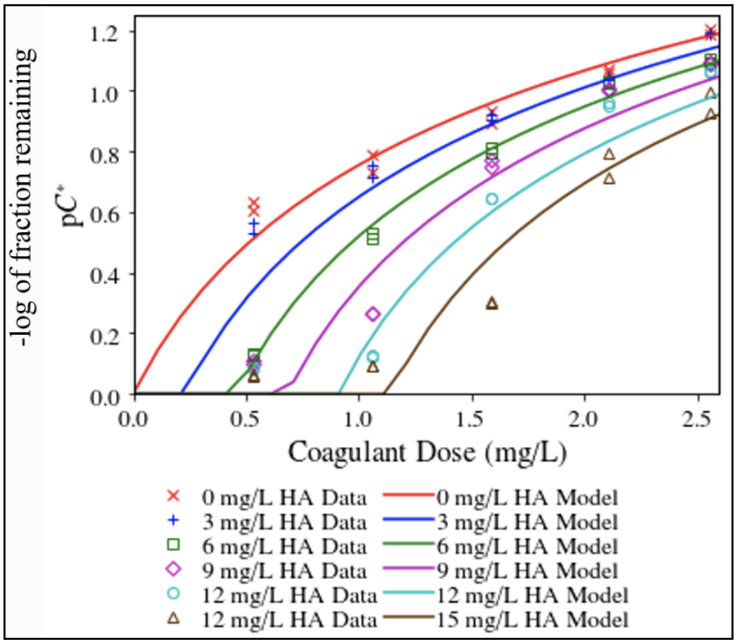

Figure 3. Flocculation performance as a function of coagulant dose and humic acid concentration

<u>Preparation of New Sedimentation Tank</u>

When testing the upflow velocity, several additional adjustments were made to the system as well to accommodate for the discrepancy of the testing. One of the main adjustments was the preparation of a new sedimentation tank. The new sedimentation tank was cut to reduce the time for the system to travel through the sedimentation tank and prevent the formation of a floc blanket. The tank was cut using an electric reciprocating saw at roughly ~9 cm below the bent portion of the tank. The new shorter sedimentation tank was installed to the right of the original tank and secured at a 60° angle from horizontal for effective separation of flocs. The 60° angle adjustment was made to ensure that there is a large enough planar area for the flocs to settle on and eventually enter the lower arm, thus leaving the system.

Turbidimeter Calibration + Replacing Desiccant

At the start of the semester, both turbidimeters were calibrated using an NTU kit to ensure that the turbidimeters measured accurate readings as part of system maintenance for the start of the semester.

During the upflow velocity testing, unusual turbidity readings were observed throughout a series of experiments, so the turbidimeters were recalibrated again to check to ensure the turbidimeter readings were accurate. The turbidimeters were also displaying DESC, indicating that the internal mechanisms of the turbidimeter contained excess moisture. The desiccants were replaced in each turbidimeter to prevent moisture build up and condensation from forming on the vial, which would disturb the turbidimeter readings.

Replacing Y/B Tubing

During the experimentation process, the influent turbidity repeatedly decreased substantially during multiple runs. After consulting with Dr. Monroe Weber-Shirk about these unexpected trends, he advised that this phenomenon was likely due to an issue with the pump tubing. Upon inspecting the Y/B tubings on the six-roller pumps, they were noticeably compressed and deformed from overuse. This issue was resolved by replacing the tubing and a note was made for tubings to be replaced at the start of each semester as part of system preparation and maintenance for future experimentation.

References

Aljuboori, A. H. R., Idris, A., Al-joubory, H. H. R., Uemura, Y., Abubakar, I. (2015). Flocculation behavior and mechanism of bioflocculant produced by Aspergillus flavus, *Journal of Environmental Management*, 150, 466-471.

Biswas, S., Fatema, J., Debnath, T., & Rashid, T. U. (2021). Chitosan–Clay Composites for wastewater treatment: A state-of-the-art review. *ACS ES&T Water*, 1(5), 1055–1085. https://doi.org/10.1021/acsestwater.0c00207

Campos, C., Snoeyink, V. L., Mariñas, B., Baudin, I., & Lainé, J. M. (2000). Atrazine removal by powdered activated carbon in floc blanket reactors. *Water Research*, 34(16), 4070–4080. https://doi.org/10.1016/s0043-1354(00)00169-x

Du, Y., Pennock, W. H., Weber-Shirk, M. W., & Lion, L. W. (2019). Observations and a Geometric Explanation of Effects of Humic Acid on Flocculation. *Environmental Engineering Science*, 36(5), 614-622. http://doi.org/10.1089/ees.2018.0405

Kwon, Z., Nguyen, N., Paykin, B., & Lin, H. (2023). 2023SP DOM Final Report. Retrieved from https://github.com/AguaClara/Dissolved-Organic-Matter/blob/main/Spring%202023/2023SP%20DOM%20Final%20Report.pdf

Saxena, K., Brighu, U., & Choudhary, A. (2021). Experimental investigation and modeling the effect of humic acid on coagulation efficiency for sludge blanket clarifier. *Chemosphere*, 266, 128958. https://doi.org/10.1016/j.chemosphere.2020.128958

Tafvizi, H., Chowdhury, S., & Husain, T. (2021). Low cost activated carbon for removal of NOM and dbps: Optimization and comparison. *Water*, 13(16), 2244. https://doi.org/10.3390/w13162244

Wu, Z., Zhang, X., Pang, J., Zhang, X., Li, J., Li, J., & Zhang, P. (2020). Humic acid removal from water with pac-al30: Effect of calcium and kaolin and the Action Mechanisms. *ACS Omega*, 5(27), 16413–16420. https://doi.org/10.1021/acsomega.0c00532