Title: Dissolved Organic Matter (DOM) Removal from Drinking Water with Polyaluminum Chloride (PACl), Clay, and Powdered Activated Carbon
Team: Dissolved Organic Matter, Spring 2023
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Abstract

The Spring 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 i) activated carbon and ii) clay concentration, 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 2022 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 (Campos et. al. 2000). 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

Fall 2022 Dissolved Organic Matter subteam aimed to vary coagulant dosage and observed flocculation in the sedimentation tank alongside influent and effluent turbidity. The schematics of the subteam's setups are as below:

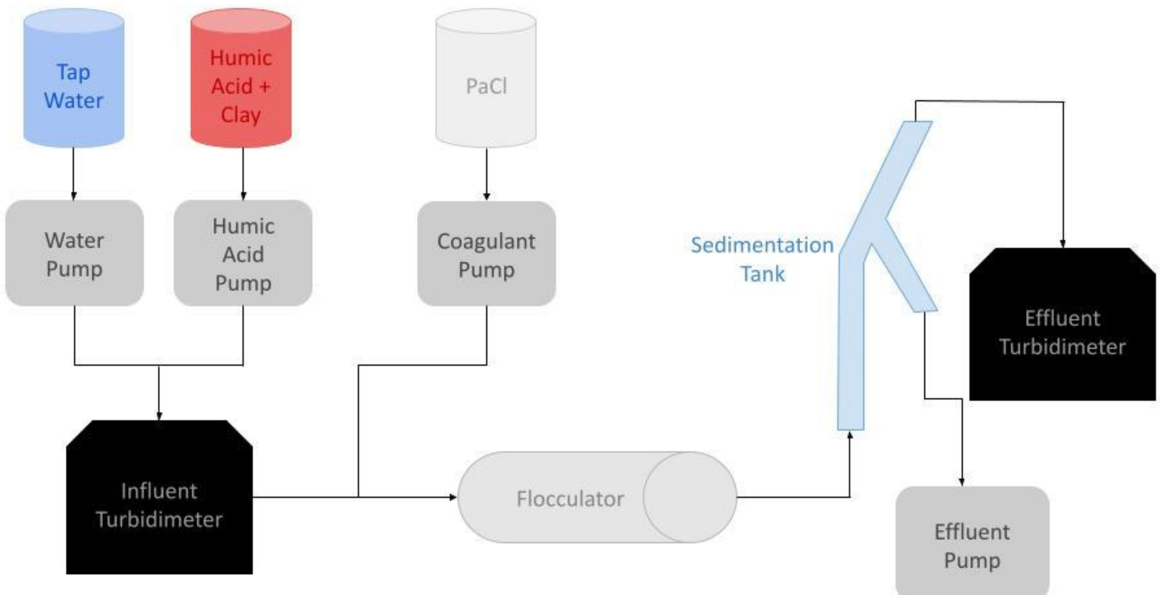

Figure 1. Schematic drawings of the experimental setup for testing varied kaolin clay, humic acid, and coagulant concentrations

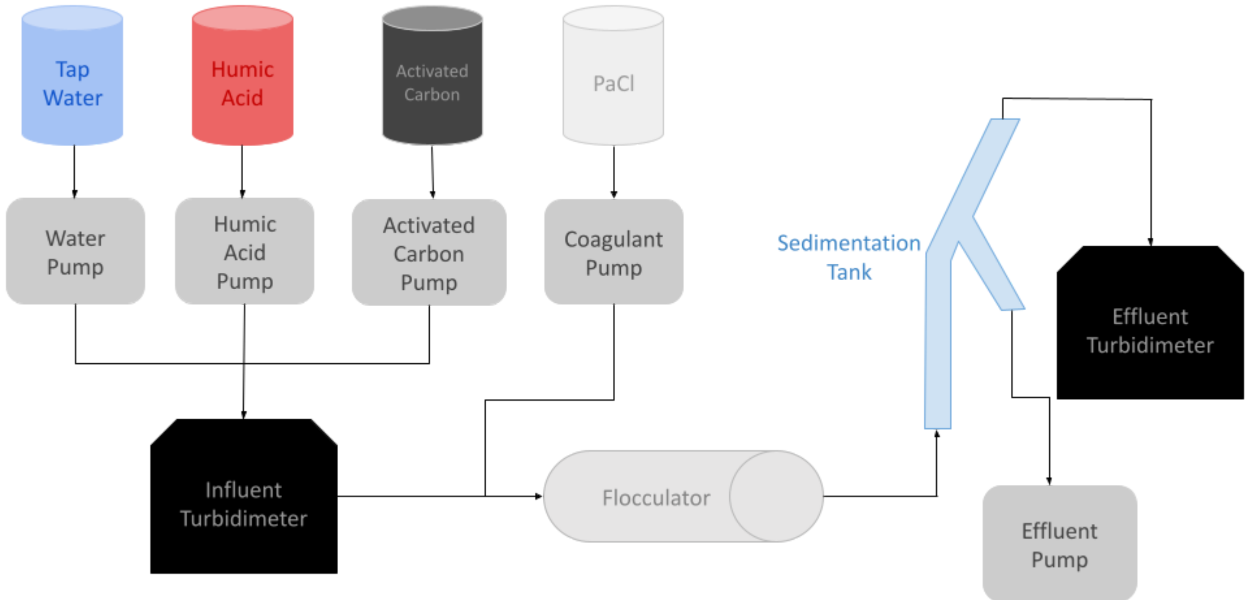

Figure 2. Schematic drawings of the experimental setup for testing varied activated carbon, humic acid, and coagulant concentrations

As in Figure 1, in previous semesters, kaolin clay was mixed with humic acid in the same stock solution with a view to reduce agglomeration between clay particles since humic acid can induce negative charge and, thus, cause the particles to repel. However, the experimental set up for Spring 2023 Dissolved Organic Matter requires the concentration of humic acid into the flocculator to be kept constant while that of kaolin clay to be varied with ProCoDA. Therefore, separate stock solutions for humic acid and clay, each connected to its own pump, needed to be prepared and modifications were made to the schematic.

In order to display the difference in flocculation that was found last semester, below are two photographs of floc formation which vary in effectiveness.

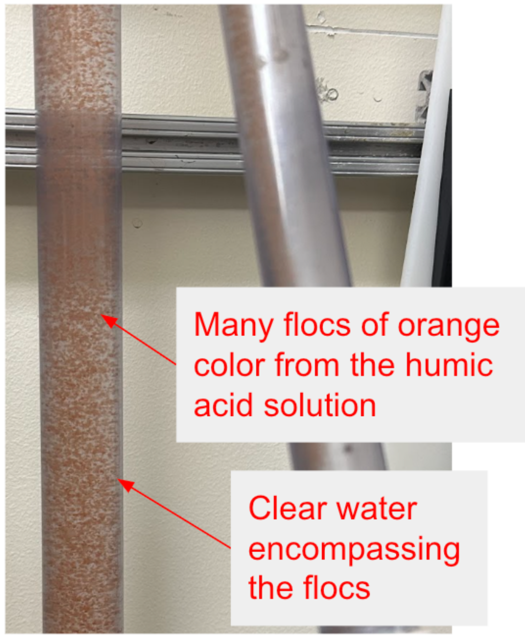

Figure 3. Image of sedimentation tank from experiments from Spring 2022

The figure above is representative of what the separation of flocs and water should look like—flocs should be clearly distinguishable from the surrounding water. To increase visibility for making qualitative observations, red dye was added to the humic acid solution. The dye adhered to the humic acid resulting in a multitude of red-colored flocs.

Figure 4. Run with 100 mg/L of PACl stock solution and 5 g/L of clay stock solution with 5 mg/L of humic acid stock solution from Fall 2022

Figure 4 starkly contrasts the previous figure, Figure 3, which had clear water and distinct, colored flocs in the sedimentation tank. Figure 4 shows murky reddish water, and it is difficult to clearly discern any flocs. This remained a continuing problem throughout the Fall semester–it was hard to tell whether humic acid was even forming flocs. It was speculated that the dye might not have been adhering to the flocs. To test this, the DOM subteam switched to a lab-grade dye, but still, the issue persisted. To test whether the white particles were flocs, the DOM team added more coagulants. Theoretically, if more coagulant was used, there should have been more flocs. The result of this experiment was the formation of more particles, which supported the theory that the white particles could be flocs. However, the water still remained murky and muddy in the sedimentation tank. It is important to note that the concentrations mentioned in Figure 4 are referring to the stock solution concentrations, not the concentrations in the sedimentation tank.

Methods

Last semester, the literature values of concentrations for coagulant, clay, and humic acid were thought to be regarding the stock solutions. However, the DOM subteam learned that these values actually referred to the concentrations of the respective chemicals in the sedimentation tank, which may explain why the water in Figure 4 was murky. Since this distinction was made clear, further labels and references to concentration should be made specifically referring to either the stock or flocculator concentration.

To streamline the testing process, a constant coagulant dosage (10 mg/L in the flocculator) was chosen because a) it is simpler to conduct experiments by varying just the clay and powdered activated carbon dosages, and b) plants in Honduras did not have one blanket coagulant dosage that they all used.

$$Mass\ Flow\ Rate\ =\ Concentration(Volumetric\ Flow\ Rate)\ =\frac{mg}{L}\left(\frac{L}{rev}\times\frac{rev}{time}\right)$$

The above equation for mass flow rate is an integral part of the setup for this experiment. Thus far, the concentrations of the stock solutions had been changed each time this subteam wished to change the mass flow rate. However, the DOM subteam was advised by Professor Monroe Weber-Shirk to instead change the volumetric flow rate on ProCoDA to vary the mass flow rates of clay and/or activated carbon in order to efficiently test their effects on humic acid flocculation. Breaking down the equation further, the L/rev factor should be constant for each pump because each pump setup should remain the same for the entirety of the experiment. This suggests that the true variable in this equation is the rev/time factor, which will need to be varied in order to test different dosages of clay and activated carbon.

In order to determine a suitable range of volumetric flow rate values to be varied on ProCoDA, it is first necessary to test each pump individually to ensure that their flow rates are running accurately (compared to the inputted values on ProCoDA) and make adjustments if necessary (e.g., replacing old tubing, changing flow rates, etc.). Through tracking the number of revolutions and volume pumped within a certain time limit, the team will be able to confirm the upper limit for the pump rotational speeds (50 rpm) and determine a suitable testing range for volumetric flow rates in ProCoDA.

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