Floc Modeling

Developing a mathematical model that describes flocculation and clarification.

https://github.com/AguaClara/floc_modeling

Agenda

- Clarification Mechanisms
- Methodology
- Dye Selection
- Results & Discussion
- Future Work

Clarification Mechanisms

What is Clarification?

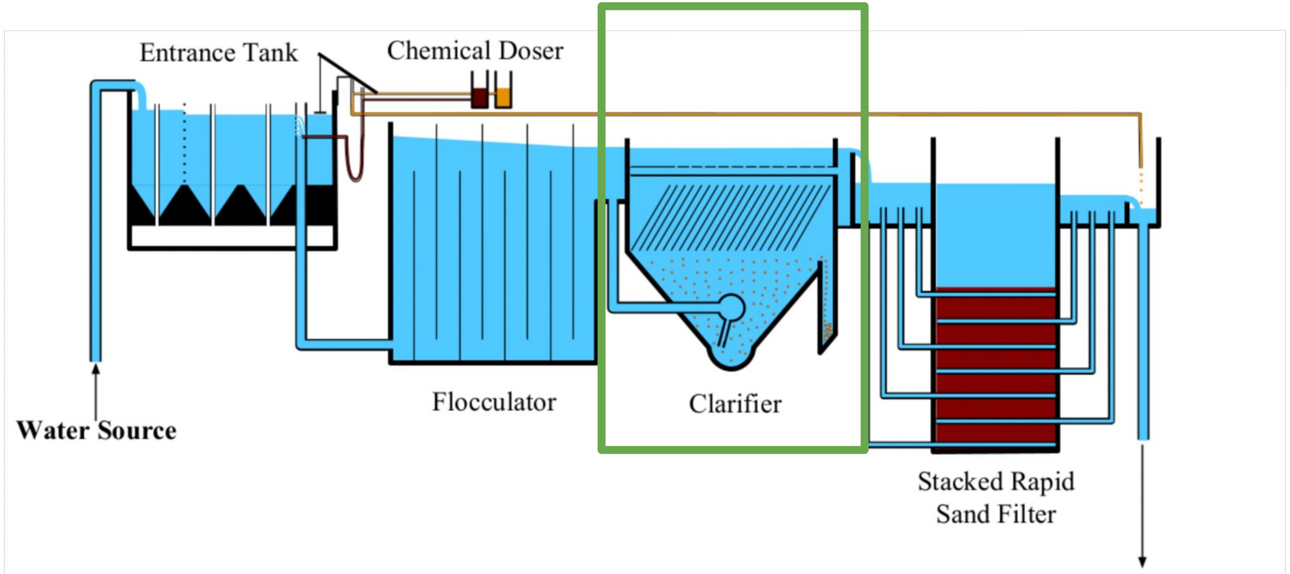


Figure 1. AguaClara treatment process.

Clarification is the process of removing suspended solids from water following flocculation.

What Makes AguaClara Clarifiers Unique?

AguaClara treatment plants use **lamella clarifiers** with a **floc filter**

- A lamella clarifier uses parallel plate settlers to maximize the surface area where particles can settle
- The floc filter uses suspended flocs to filter out smaller primary particles
  - Floc filters are not a conventional water treatment technology in the US

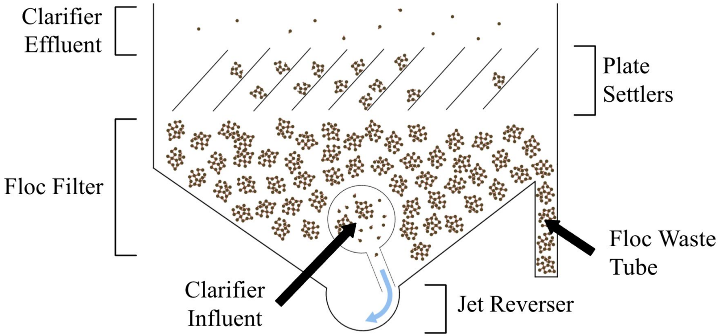


Figure 2. AguaClara clarifier diagram. The clarifier is divided between the floc filter and the plate settlers.

Clarification Mechanisms

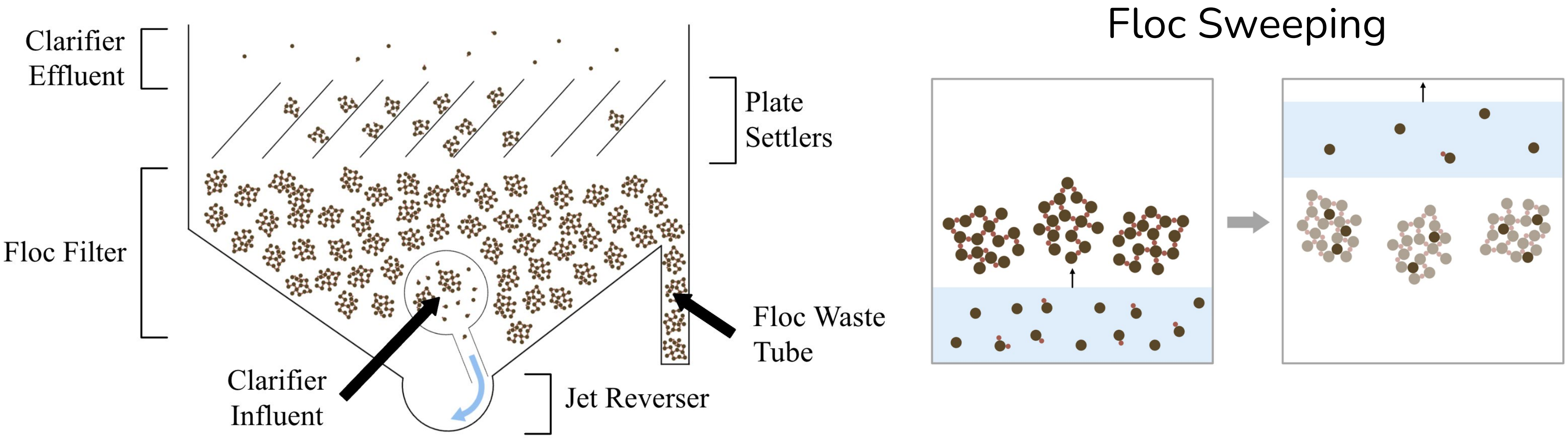


Figure 3. Clarifier diagram and primary particle removal mechanism within the clarifier.

Floc Saturation

$$\textbf{Floc Saturation} = \frac{\text{primary particles captured by a floc}}{\text{maximum number of particles the floc can capture}}$$

- Increases as a floc captures primary particles and its pores fill
- Saturated flocs have reduced capture efficiency

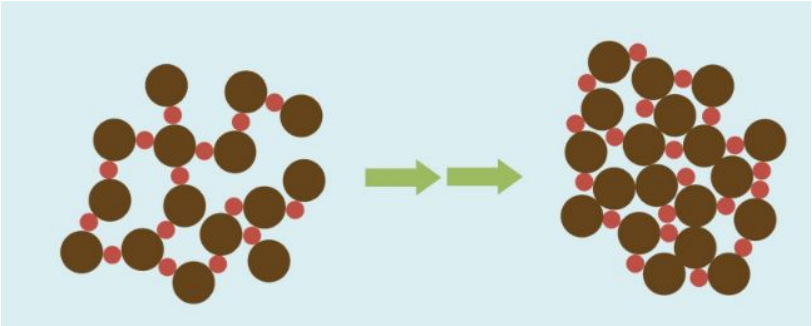


Figure 4. An unsaturated floc vs. a saturated floc.

Floc Concentration

$$\textbf{Floc Concentration} = \frac{\text{number of flocs}}{\text{volume of floc filter}}$$

- Units: $(\text{Volume})^{-1}$
- Distinct from **floc saturation**
- Previous work by Swetland et al. (2014) focused on measuring variation in floc concentration throughout floc filter

Distribution of Floc Saturation

Open question: ***how is floc saturation distributed within the floc filter?***

- Current clarification model assumes floc saturation is uniformly distributed
- Floc saturation may vary spatially within clarifier
  - Ex: Flocs could be more saturated towards the bottom of the floc filter because this is where most primary particles are captured
- Wasting the most saturated flocs from floc filter first could improve performance efficiency

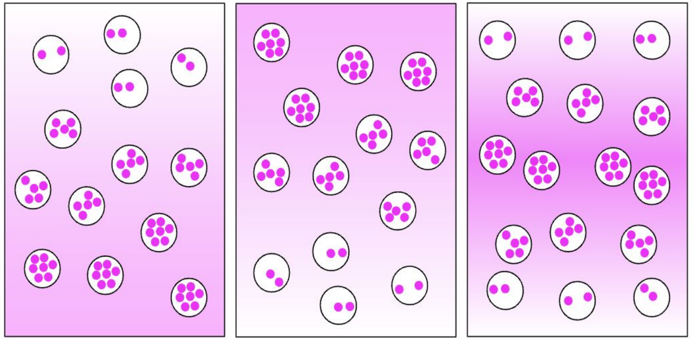


Figure 5. Examples of possible floc saturation spatial distributions.

Methodology

How can we measure floc saturation in the floc filter?

Previous Idea

Previous Idea: Use colored primary particles to visualize distribution of floc saturation

Problems: Primary particles did not significantly change the color of floc filter for measurement.

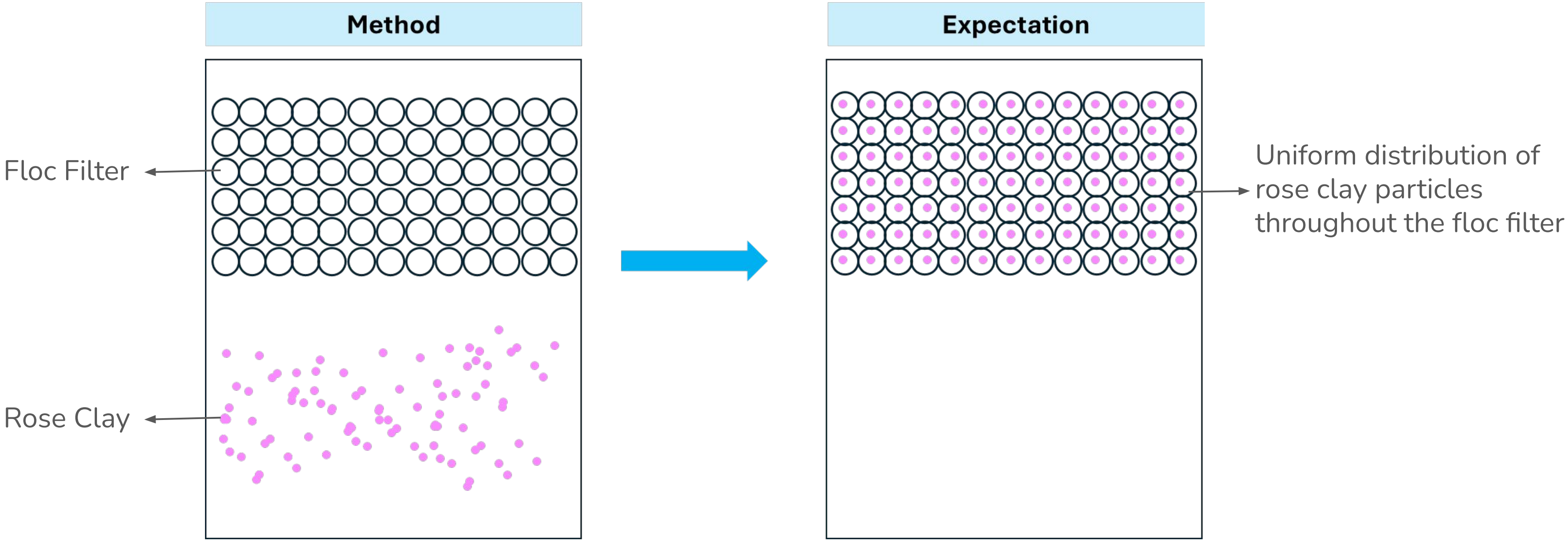


Figure 8. Rose clay addition in floc filter.

New Method

New Method: Using Red-40 colored flocs to track movement of flocs to determine if the floc filter is well mixed. Thus, floc saturation is uniform.

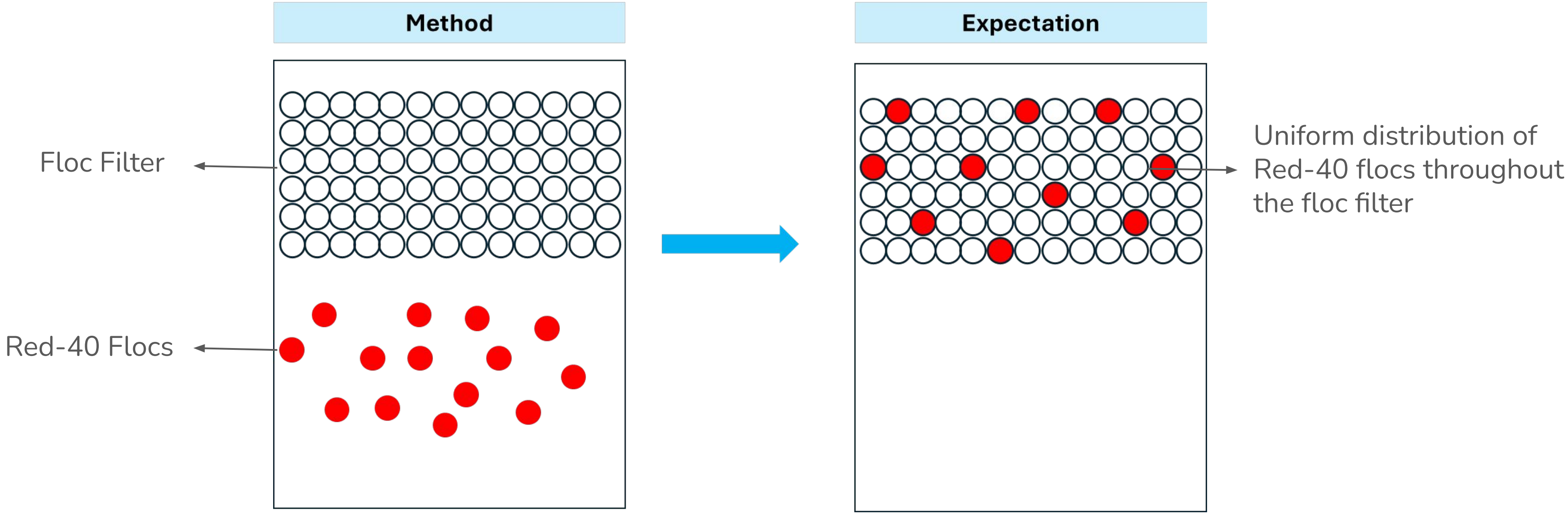


Figure 9. Red-40 floc addition to floc filter

Well-Mixed

Definition: Given a particle starting at position x, after a small time step, the particle has equal probability of being found at any position y in the system. In a well-mixed system, any perturbation or addition is almost instantaneously reflected across the system.

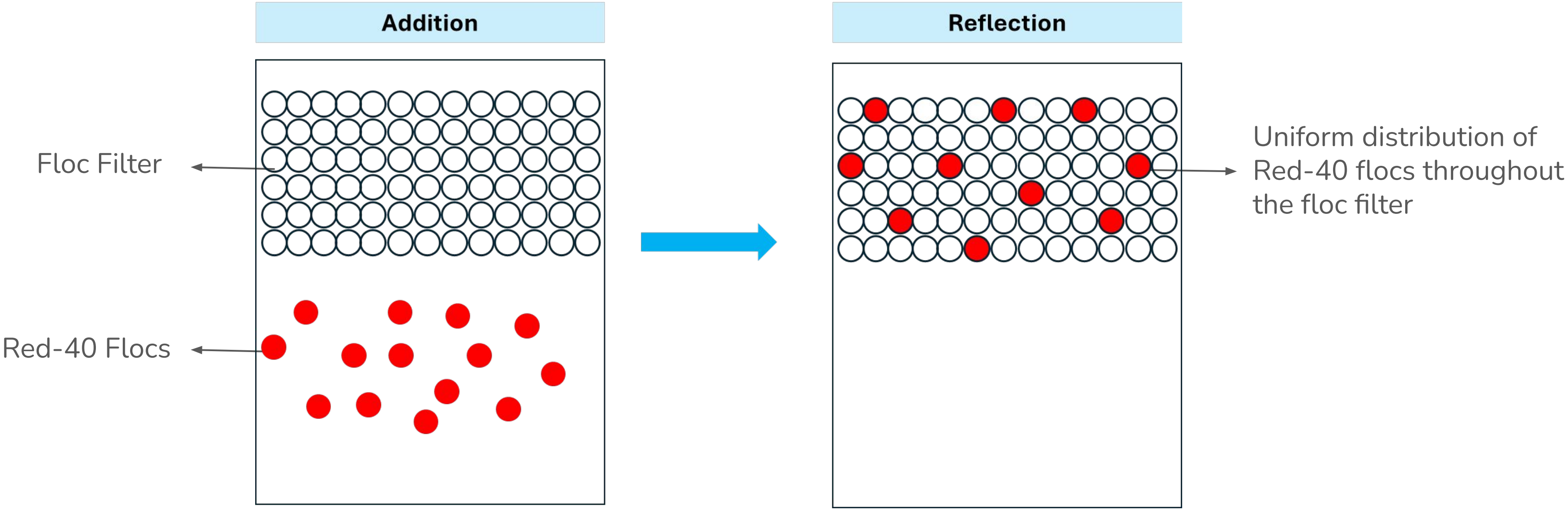


Figure 10. Reflection of perturbation in a well mixed system

Mini Clarifier Schematics

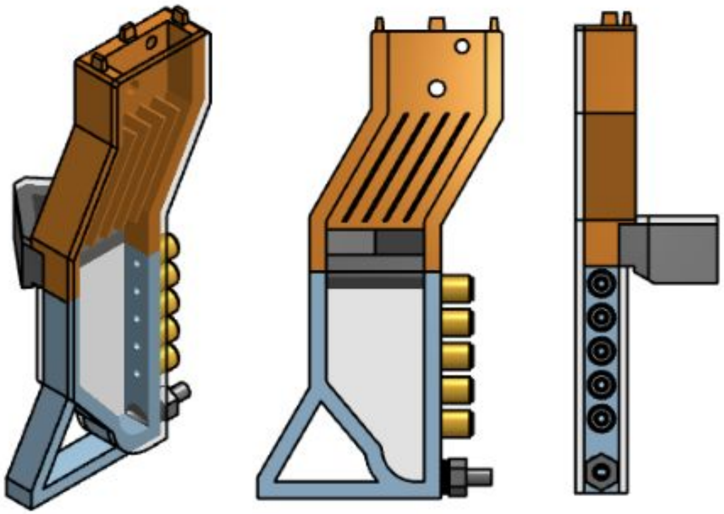


Figure 11. Miniature clarifier CAD from three different angles.

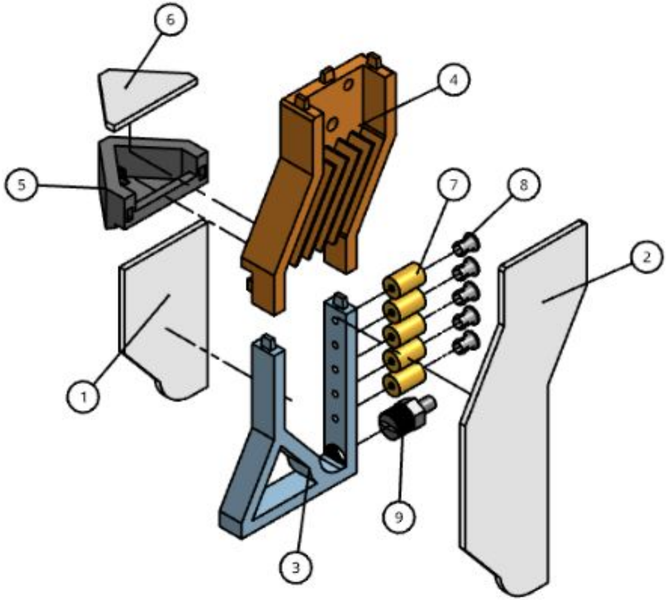


Figure 12. Exploded view of miniature clarifier CAD.

Method

1. Form floc filter using uncolored flocs composed of white kaolin clay and coagulant
2. Form a small number of colored flocs using white kaolin clay, Red-40, and coagulant
3. Add colored flocs to clarifier and track movement of flocs throughout floc filter

Dye Selection

Lit Review on Red 40

Objective: Proof-of-concept for Red-40 adsorption onto coagulant

- Existing literature focuses on Red-40 adsorption on chitosan
- Protonated amino group in chitosan has **strong electrostatic interactions** with negative sulfonate group in Red-40

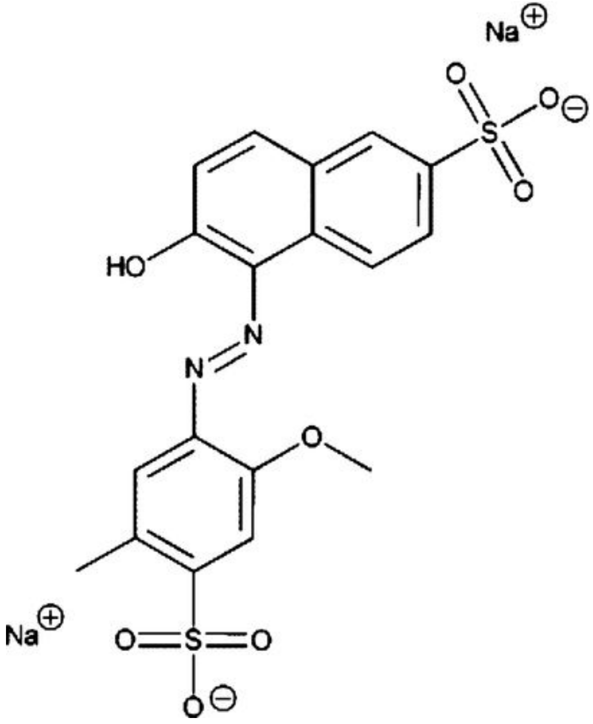


Figure 6. Chemical structure of Red-40.

Chitosan - PACl Coagulant Similarities

- Chitosan has positive surface charge in acidic to near-neutral pH
- NH_2 (chitosan) and $Al(OH)^{2+}$ interact similarly with Red-40 sulfonate

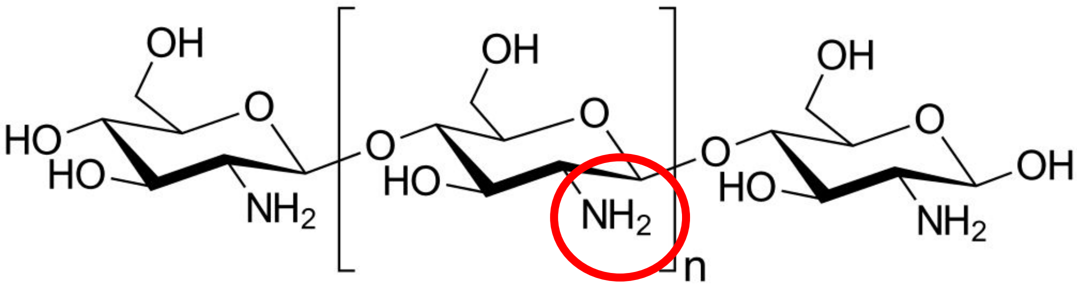


Figure 7. Chemical structure of chitosan.

Results

Formation of Dyed Flocs

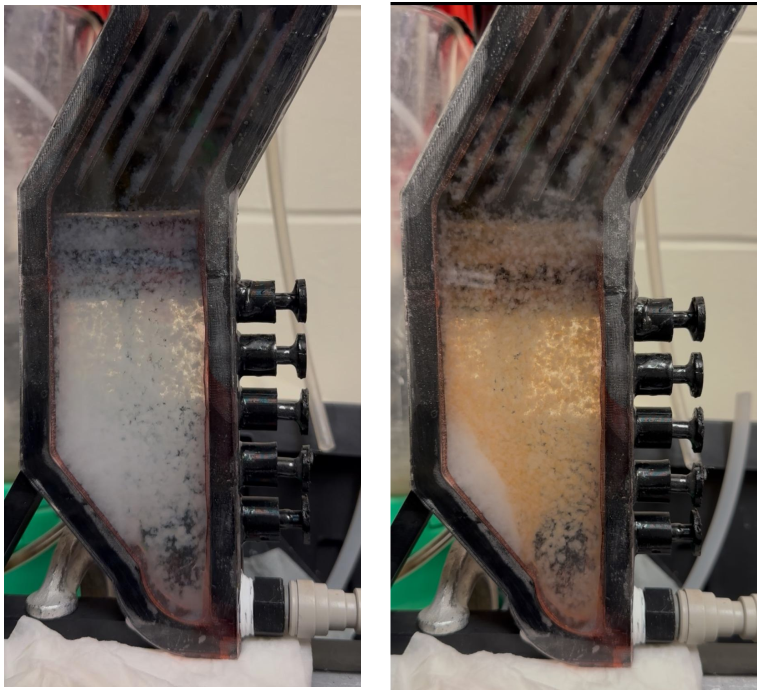
- Red-40 and PACl were successfully flocculated into red flocs
  - Larger amounts of residual, unflocculated Red-40
  - Redness of surrounding water made flocs difficult to distinguish
- Using majority white kaolin clay and small amount of Red-40 also successfully formed red flocs
  - Less vibrant, but significantly reduced amount of residual Red-40

Figure 13. Floc filter formed from only Red-40 and PACl.

Video of Red-40 Flocs

Using Dyed Flocs as Tracers

- Adding dyed flocs to clarifier caused coloration to diffuse throughout floc filter
    - Dyed flocs became indistinguishable from undyed flocs
    - Change in coloration occurred rapidly
- Adding more undyed flocs without additional Red-40 did not affect color



Figures 14, 15. Floc filter before and after addition of dyed flocs.

Video of Dyed Flocs

Discussion

Discussion

- Dyed flocs need to stay distinguishable from undyed flocs for method to be effective
- ***Hypothesis:*** Residual dissolved Red-40 that had not been flocculated was adsorbed onto undyed flocs
- Maybe due to overly high concentration of Red-40
    - Unfortunately, there will likely always be some residual unflocculated Red-40 in solution

Future Work

Future Work

- Repeat experiments using lower concentration of Red-40
  - Avoid large amounts of residual Red–40 dye in surrounding water
- Return to colored clay for experimentation
  - More stable, avoid unintentional color diffusion
  - Forming flocs entirely from colored clay → sufficient color variation
- Consider using hydrophobic dyes
  - Oil based dyes would not dissolve into water, but could still bond to clay to create dyed flocs

Thanks for Listening!
Questions?

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References

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