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Structure and Settling of Freshwater Algae Flocs in a Shear Flow

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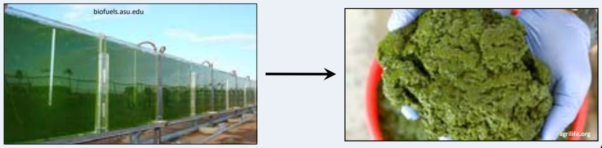
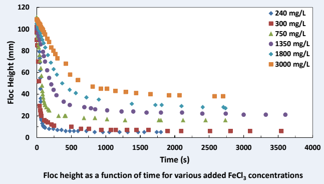
Introduction

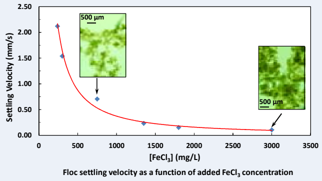
Algae have recently received much attention due to their potential as a source of clean biofuel. One of the key economic hurdles in the production of biofuel from algal feedstocks is the separation of algae cells from their growth media (harvesting). Flocculation, both natural and chemically induced, shows great potential for lowering the economic hurdle by providing a low energy, low cost method of separation. A sound understanding of the structure and settling characteristics of algae flocs under various environmental conditions is key to implementing flocculation strategies in an economical manner. Here we examine the effects of shear flows on the structure and settling of flocs of the freshwater algae *Chlorella zofingiensis* flocculated with ferric chloride. Settling velocities are also examined as a function of flocculant dose under quiescent conditions.



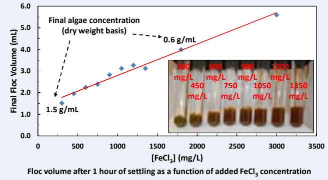
Quiescent Floc Settling Velocity



Floc height as a function of time for various added $FeCl_3$ concentrations



Floc settling velocity as a function of added $FeCl_3$ concentration



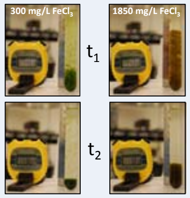
Floc volume after 1 hour of settling as a function of added $FeCl_3$ concentration

Increasing $FeCl_3$ concentration results in longer flocculation and settling times

Fastest flocculation obtained for lowest concentrations of $FeCl_3$ tested

Floc settling velocity decreases in a power law fashion with increasing $FeCl_3$ concentration

$$v_{settling} = 1890[FeCl_3]^{-1.24}$$



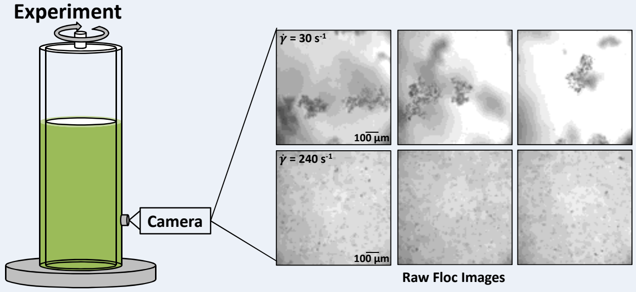
Final floc volume increases linearly with added $FeCl_3$ concentration.

Floc volume changes, but flocculation efficiency remains the same for similar pH conditions (i.e., cell counts in supernatant are the same for each sample)

Highest floc density (lowest floc volume) was obtained for lowest $FeCl_3$ concentration tested

Floc Size and Structure in a Shear Flow

Experiment



Raw Floc Images

Couette Flow Device

Couette flow device is used to establish a well controlled uniform shear flow field

C. zofingiensis is flocculated using FeCl3 and subjected to the shear flow – shear rates are varied from 30 s^{-1} to 240 s^{-1}

Floc structure is imaged using a high speed camera

Floc structure is analyzed via image analysis techniques (MATLAB) and quantified using fractal dimension

Floc size distributions are also calculated using image analysis techniques

Floc Structure Characterization – Fractal Dimension

Using the parameters of floc length (l), floc perimeter (P) and floc area (A), three floc fractal dimensions are calculated

Fractal dimension is used to quantify the irregular structure of flocs

Fractal dimension is important because floc properties such as density and settling velocity are a function of the fractal dimension

$$A \propto l^{D_2}$$

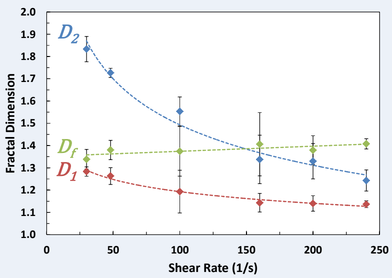
Smaller D_2 indicates elongation of the floc

$$P \propto l^{D_1}$$

Higher D_1 indicates more complex floc outlines

$$P \propto A^{D_f/2}$$

D_f values > 1indicate floc boundary becomes more convoluted as flocs grow

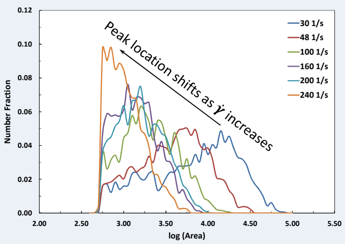


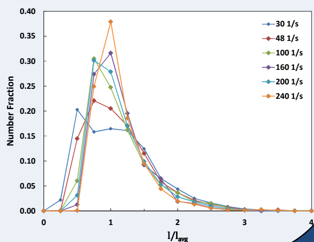
Floc Size Distribution

Average floc size decreases with increasing shear rate

Distributions for all shear rates collapse to a single master curve when the variable (area, length, perimeter) is normalized

- Shear has no effect on the normalized steady state size distribution (self preserving)
- If an estimate of one average floc variable is known, the entire distribution can be obtained



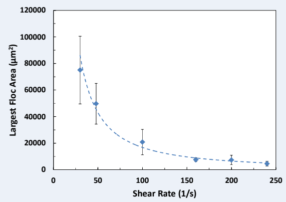


Distribution Characteristics

Size of the largest floc imaged decreases in power law fashion with increasing shear rate

Increase in shear rate results in increased shear stresses that break up larger flocs

Distribution becomes much more uniform in size at the highest shear rates

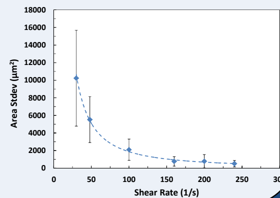


Area standard deviation decreases in power law fashion with shear rate

- Standard deviation gives information on the width of the distribution of floc areas

Error decreases as shear rate increases

- Flocs become much more uniform in size and structure



Conclusion

Floc Settling

Floc settling velocity decreases with increasing dose of ferric chloride Increased ferric chloride dose results in larger flocs that experience higher resistance to flow (drag)

Settled floc volume also increases with flocculant dose indicating a change in floc structure

Floc Structure

Average floc size decreases with increasing shear rate as additional shear stresses cause floc breakup

Fractal dimension decreases with increasing shear rate indicating elongated flocs with less complex outlines

Floc size distributions can be collapsed to a single curve, independent of shear rate, by normalizing by an average parameter

Floc size distributions narrow with increasing shear rate

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