Subsurface Biosphere Initiative
Research and education focused on life below Earth's surface.

OSU Oregon State University

Effect of Aggregate Morphology on Low-Pressure Membrane Fouling:

Development of a Bench-Scale System and Improved Analytical Techniques

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Introduction

The technological advancements in low-pressure membrane processes for drinking water treatment have greatly expanded over the past decade, resulting in decreased cost and increased implementation. However, with the benefits of these processes come difficulties in maximizing efficiency and effluent quality; membranes are susceptible to fouling from the accumulation and attachment of unwanted particles and organic matter. This causes diminished output, increased energy use and higher costs for the process. Chemical pretreatment is vital for controlling adsorptive and particulate fouling of membranes, as well as minimizing the formation of disinfection byproducts (DBPs). However, pretreatment conditions are rarely optimized with these multiple goals in mind. The overall goal of this project is to further understand the capabilities and effectiveness of coagulation as a means of pretreatment for reducing both membrane fouling and DBP formation. With respect to particulate fouling, we are interested in the influence of pretreatment conditions on aggregate morphology and subsequent cake formation.

Background

Membrane Fouling

Microporous membranes are prone to fouling by the adsorption of dissolved constituents on the interior of pores and the formation of a cake layer of deposited particulate matter on the surface; fouling increases the resistance of fluid flow through the membranes resulting in a decreased yield, a greater need for harsh chemicals for cleaning, and a significant reduction in efficiency.

Aggregate Morphology

Morphology, describing the structure of aggregates, likely plays a role in controlling particulate fouling of membranes. Aggregates can be characterized by their fractal dimension, which is correlated with porosity. In Euclidean geometry, $V \propto L^3$ and $A \propto L^2$ where V is volume, A is projected area and L is characteristic length. In Fractal geometry, $V \propto L^{D_3}$ and $A \propto L^{D_2}$ where D_3 and D_2 are the 3-D and 2-D fractal dimensions, respectively. As fractal dimensions decrease (from the Euclidean limits), the structures are more open and porous. Plotting a log-log graph of projected area versus length gives fractal dimension. Thus a plot of log(Area) vs log(Length) of Euclidean spheres would yield a slope of two. However a plot of the same traits for aggregates would produce a slope (and fractal dimension) less than two. In this work, an aggregate's Feret's diameter (the distance between the maximum tangent lines formed from opposite sides of an object) was used as the characteristic length.

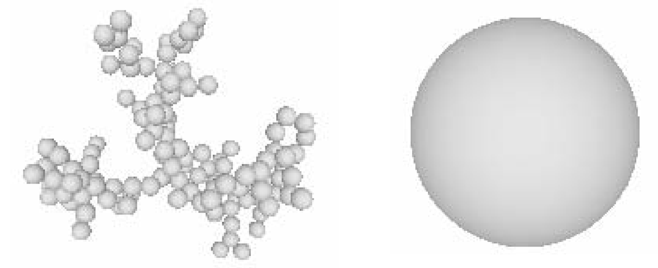

Figure 1: Fractal aggregate (left) compared to a Euclidean sphere (right)
<http://www.aanda.org/articles/aa/full/2006/03/aa3212-05/img43.gif>

Objectives

The overall goal of this project is to further understand the capabilities and effectiveness of coagulation as a means of pretreatment for reducing both membrane fouling and DBP formation through the use of a model filtration system and fractal dimension analysis. Specific objectives are to:

- Develop, build, and test bench-scale membrane filtration systems (Figure 2) consisting of small hollow-fiber membrane modules and the necessary pumps, piping, valves, and gauges. Published literature and input from a local engineering firm with previous experience will guide these efforts.
- Investigate the use of 2-D fractal dimension as determined by digital imaging of floc as a method for characterizing floc morphology.

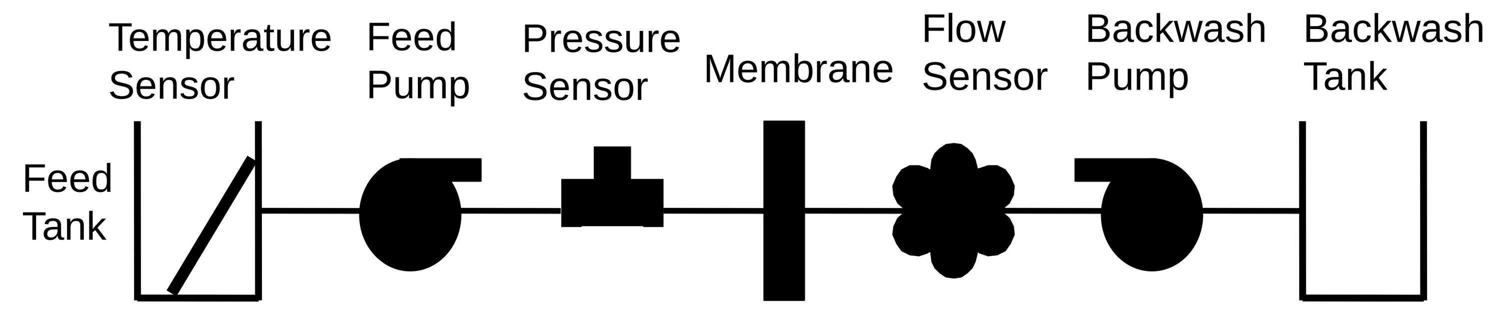

Figure 2: Schematic of the basic components in filtration system

Bench-Scale Model

This filtration system shown above was designed with these points in mind:

- Bench-scale design and short run times
- Reasonable and controllable flow rates
- Ability to automate and control system
- Automated collection of data (temperature, pressure, flow)

When considering the materials to be used in the bench-scale model (Table 1), industrial examples and published experiments were used as starting points. Common permeate flux rates for pressurized systems range from 30-170 L/m²*h [1]. Furthermore, recent research examining NOM fouling of low-pressure membranes used a flux rate of 109 L/m²*h [2]. To simplify calculations, a rate of 100 L/m²*h was used to specify suitable equipment.

Table 1: Acquired and proposed materials for the bench-scale model

Component	Manufacturer	Specifications
Data Acquisition NI USB-6211	National Instruments	16-Bit, 250 kS/s
Pump Drive EW-07551-00	Cole-Parmer	0.006 – 3400 mL/min
Pump Head HV-77201-60	Cole-Parmer	0.06 – 2300 mL/min
Tubing HV-06424-14	Cole-Parmer	0.21 – 210 mL/min maximum 25 psi
Temperature Probe TMP-BTA	Vernier	-40 – 135° C
Pressure Sensor PX26-005DV	Omega	+/- 5 psi differential
Membrane	Pall	To be decided
Flow Meter	Unneeded for first phase of tests	

Characterization of Floc Morphology

Methodology

To analyze the morphology of the aggregates, a digital particle analyzer (DPA) was used to produce 2-D pictures (Figure 3) that were digitally analyzed. The system produced data of each aggregate with traits such as equivalent circular diameter, area, perimeter, aspect ratio, and Feret's Diameter. These characteristics were then used in calculations for fractal dimension. A calibration run of several sizes of latex microspheres was conducted to show accuracy with the DPA (Figure 4).

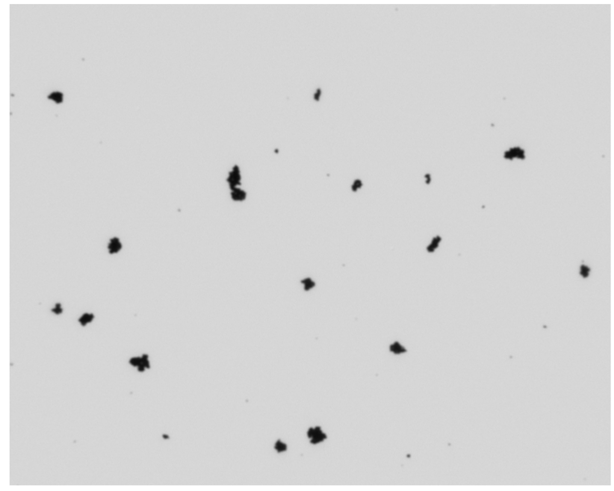

Figure 3: Image of latex aggregates from the DPA used in the experiment summarized by Table 2.

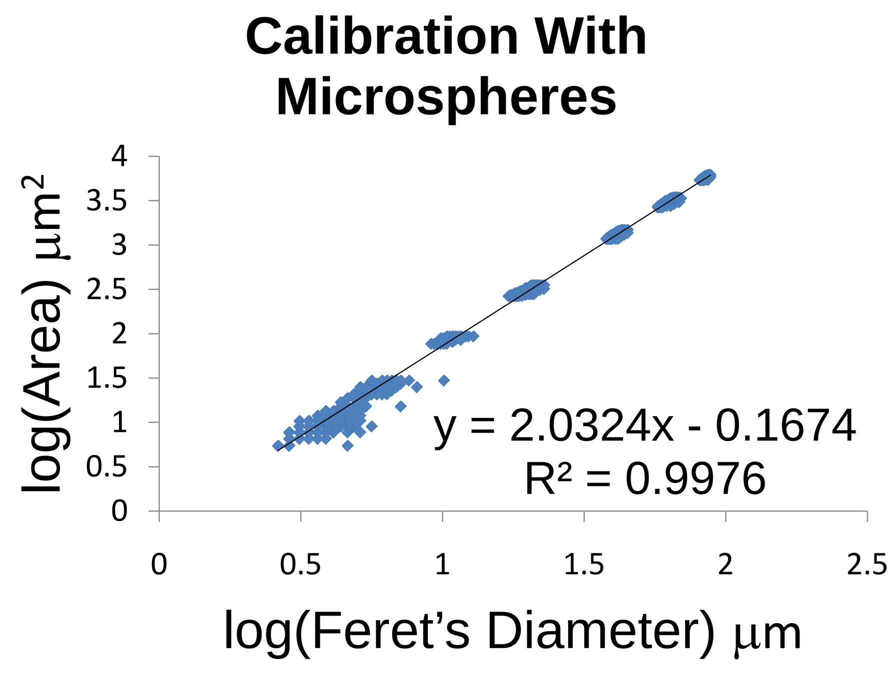

Figure 4: Calibration run of latex microspheres of varying sizes to show that they follow Euclidean geometry (i.e., slope = D_2 = 2).

Results

Data from an extended aggregation experiment performed by a previous M.S. student in Dr. Nason's lab was re-examined using the 2-D fractal dimension methodology. The experiment consisted of aggregating 2 μm latex microspheres in a high ionic strength electrolyte. The original work characterized the 3-D fractal dimension using a Coulter Counter and the DPA. As shown in Table 2 below, both fractal dimensions show decreasing trends over time, translating to increased porosity. According to theory, if the D_3 value is less than D_2, then $D_3 = D_2$. The two fractal dimensions produce comparable results, suggesting they are complimentary measurements but further experimentation is required to evaluate the accuracy of either calculation.

Table 2: Data comparing fractal dimensions from experimentation on aggregates over extended periods of time

	D_2		D_3	
	Feret's Diameter Cutoff			
Mix Duration	32-50 μm	> 50 μm	32-50 μm	> 50 μm
7 Hours	1.71	1.57	2.27	1.21
24 Hours	1.55	1.35	1.98	1.17
48 Hours	1.41	1.17	1.86	1.04
144 Hours	1.30	1.14	1.53	1.28

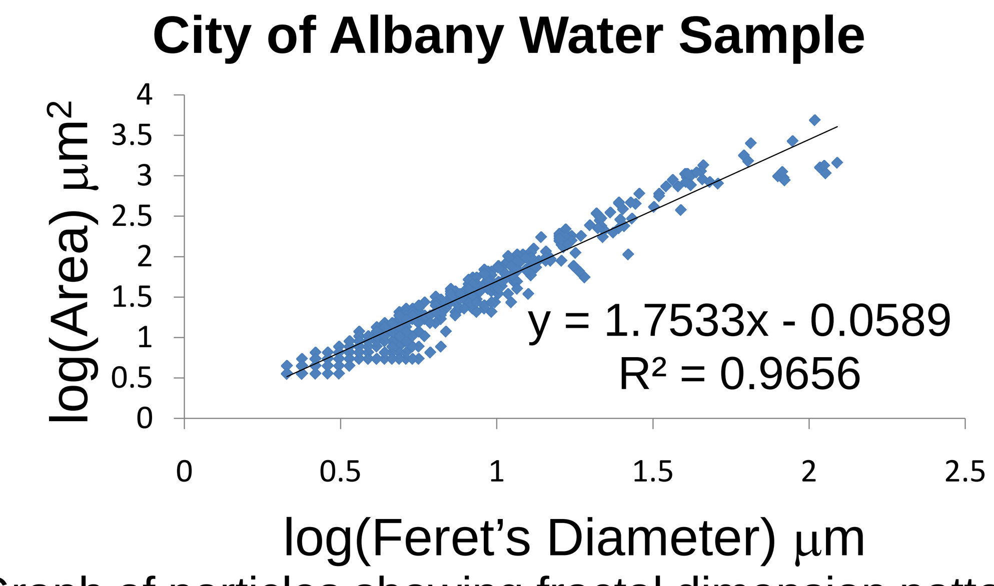

Figure 4: Graph of particles showing fractal dimension patterns from water for a City of Albany project analyzing river water samples. The particles are non-Euclidean with a D_2 fractal dimension of 1.75

Future Work

- Order remaining needed parts, build and test bench-scale model.
- Continue developing methods for characterizing floc morphology based on preliminary results.
- Perform jar testing of water samples from the Santiam River to determine the effect of aluminum chlorohydrate (ACH) dose and pH on the removal of dissolved organic carbon (DOC) and turbidity.
- Use a DPA and a Coulter Counter to characterize the particle size distribution that forms during the jar testing, noting the size, concentration, and morphology of aggregates that form during coagulation.
- Conduct bench-scale microfiltration experiments on raw water and pretreated water subjected to optimal and sub-optimal coagulation conditions to evaluate the influence on membrane fouling.

References

1. Crittenden, John; Trussell, Rhodes; Hand, David; Howe, Kerry and Tchobanoglous, George. Water Treatment Principles and Design, Edition 2. John Wiley and Sons. New Jersey. 2005.
2. Huang, Haiou;Lee, NoHwa; Young, Thayer; Gary, Amy; Lozier, James C; Jacangelo, Joseph G. Natural organic matter fouling of low-pressure, hollow-fiber membranes: Effects of NOM source and hydrodynamic conditions. Elsevier Ltd. 2007.
3. Maguire, Ian. The Effect of Coagulation Conditions on Floc Size Distribution and Morphology: Implications for Downstream Treatment Processes. Oregon State University. 2009.

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