ENV 6438: Physical & Chemical Processes for Drinking Water Treatment
Department of Civil & Environmental Engineering
University of South Florida

Cunningham **Spring 2020**

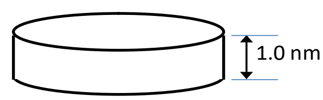
Homework #3 Due Wednesday, Feb. 12

Topic: Particles in water; Coagulation

1. (50 pts) *adapted from a problem written by Paul Roberts, Stanford University*
A city pulls water from a nearby river for its source of drinking water. After a rainfall event, there is a lot of runoff of clay and silt particles into the river, and the water gets pretty turbid. The city analyzed the particle-size distribution and obtained the following data:

particle size range (μm)	ΔN (particles/mL)
0.5 – 1	1.8×10^{11}
1 – 2	1.6×10^{10}
2 – 8	4.3×10^{8}
8 – 32	3.35×10^{6}
32 – 128	2.6×10^{4}

The particles are flaky in shape. The shape can be approximated by a flat elliptical cylinder with thickness 1.0 nm, as in the figure shown at right. The particle sizes given in the table above correspond to the major axis of the ellipse; the minor axis is approximately half as long. The density of the particles is 2.2 g/cm^3 = 2200 kg/m^3.



a. For each of the five size ranges, compute the *sphericity*, ψ, of the particles. The sphericity is the ratio of the surface area of a sphere to the surface area of the particle, given that the sphere has the same volume as the particle. A sphericity of 1 means that the particle is a perfect sphere. Which size class is "most spherical"? Which is least? Do you think it would be acceptable to treat these particles as spheres? Hint: each size class spans a range of particle sizes and therefore does not correspond to just one exact size; you can use the *geometric mean* particle size as a good representative size for each size range.

b. If you ran a test for total suspended solids (TSS) on this water, what concentration (mg/L) would you expect to measure? Which size class dominates the TSS measurement?

problem 1 continues →

1. continued

   c. Estimate the total *surface area concentration* for the particles in units of m^2 of surface area per L of water. Which size class dominates the surface area concentration?

   d. Suppose that the city wants to remove 99% of the particle mass during drinking water treatment. How much of each size class would have to be removed? Hint: large particles are more easily removed than small particles of the same density, so start by removing 100% of the largest size class, and then work your way down the size classes until you meet the goal of 99% overall removal.

   e. Estimate the dose (in units of mg/L) of alum that would be required to destabilize this particle suspension. Assume that destabilization requires 50% of the particle surface area to be covered by aluminum precipitate. Assume that the aluminum precipitate is in the form of spheres of hydroxoaluminum polymers, that these spheres have a molecular formula $(Al_6(OH)_{15})^{3+}$, and that the diameter of these spheres is 2.5 nm. [The aluminum precipitate is probably not really spherical particles, but let's just use that here to get a decent estimate.]

   f. How much alkalinity (expressed as mg/L of $CaCO_3$) would be consumed by the alum dose you found in part e?

   g. For the given particle size distribution, estimate the empirical parameters A and β for the particle-size-distribution model

$$\frac{dN}{dx} = Ax^{-\beta}$$

   where x is the particle size as indicated in the table above. Specify the units of A. Hint: use the data in the table to estimate dN/dx for each value of x, then graph the relationship, and ask Excel for a trendline. Or, if you like to do things the old-fashioned way (i.e., how we used to do it before Excel could give us a trendline), linearize the equation by taking logarithms, and then perform linear regression on the log-transformed equation.

2. (30 pts) Answer any three of problems 9-1, 9-2, 9-3, and 9-4 in the text book. In problems where you need to assume a temperature of the water, use 25 °C.

3. (20 pts) The city of Tampa uses ferric sulfate, $Fe_2(SO_4)_3$, as its coagulant at the David Tippin drinking water plant (the city's main treatment plant). I believe it is also the coagulant used at the Surface Water Treatment Plant operated by Tampa Bay Water.

   a. (10 pts) Answer question 9-5 in the Crittenden text book.

   b. (10 pts) Assume that the $Fe_2(SO_4)_3$ is added from a stock coagulant chemical that is 50% $Fe_2(SO_4)_3$ by mass and has a specific gravity of 1.45. Calculate the molar concentration of Fe in the stock solution and the required coagulant feed rate (in L/min). Assume a flow rate of 60 million gallons per day (realistic for the Tippin plant).