CEE 483 Winter 2009 Final Exam Solutions

1. In a CMR, the influent is immediately diluted to a lower concentration, and the water throughout the reactor contains that concentration. In a PFR, no dilution occurs, and water in all parts of the reactor has a concentration that is larger than in the effluent. Since the rate of reaction generally increases with concentration, the average rate of reaction in a PFR is greater than in a CMR receiving the same influent, so a greater reaction efficiency is achieved.

2. The data imply that, during the first 36 minutes of settling, 60% of the particles have an average velocity of at least 1.0 m/36 min, or 0.0278 m/min. During the first 54 minutes of settling, 60% of the particles have an average velocity of at least 1.5 m/54 min, which also corresponds to0.0278 m/min. Therefore, the particles are falling at a constant velocity, implying that they are not flocculating; i.e., they are characterized by Type I settling.

3. The phrase "filter to waste" refers to the practice of diverting the water that exits from a granular media filter at the beginning of a filter run to a waste stream, rather than distributing the water to consumers. This is necessary because the water quality is often poor at the beginning of a run. It improves when the filter "ripens," i.e., when previously collected particles begin collecting influent particles, so that the overall removal efficiency increases.

4. If the headloss criterion is reached long before particle breakthrough, the captured particles are almost all in the portion of the bed nearest the influent, and the media near the effluent end remains clean. Thus, the capacity of the bed is not being well-utilized, and energy is being wasted as clean water is passing through clean media.

5. When Ca^{2+} is removed from a water supply, the justification is usually aesthetic or economic. Ca^{2+} binds to soap molecules, forming a precipitate that is not useful in cleaning (so more soap must be used to accomplish a given cleaning task) and that can remain on fabrics, making them look dirty. Also, in water heaters, Ca^{2+} can combine with carbonate species to coat the heating elements with $CaCO_3$(s), thereby decreasing the heat transfer efficiency. Finally, if $CaCO_3$(s) is supersaturated, the solid can precipitate on the pipes in the distribution system, potentially reducing their capacity to carry water to consumers.

6. Samples for Cu and Pb must be taken in the home, because the source of these metals is primarily the plumbing in the home. Even if water at the treatment plant or in the distribution system has very low concentrations of the metals, the concentrations in the tap water might exceed the action levels.

7. Enhanced coagulation removes natural organic matter (NOM) from the water. This is the material that reacts with disinfectants to generate DBPs. By removing the NOM prior to the disinfection step, the opportunity for DBP formation is reduced.

8. Ozone does an excellent job of killing organisms as long as it remains in the system, but it is unstable and rapidly disappears, so that no residual disinfectant remains after a

few minutes. In order to provide long-lasting disinfection throughout the distribution system, a disinfectant that does not auto-decay rapidly, such as OCl species, must be added.

9. The Langmuir isotherm is based on the assumption that all surface binding sites are equivalent. Correspondingly, the non-linearity in the isotherm is ascribed to the gradual loss of available sites as the adsorption density increases. By contrast, the Freundlich isotherm is based on the assumption that the surface has sites with a wide range of affinities for the adsorbate. As the adsorbate concentration increases, the high-affinity sites fill first, so subsequent adsorption is onto lower-affinity sites, and the curvature in the isotherm is attributed to this decline in affinity.

10. The rate of reaction is $r = -kc$. The value of k is given as $0.12\,\text{min}^{-1}$, and the concentration in the reactor (where the reaction is occurring) is 7.3×10^{-6} mol/L. The rate of reaction is therefore the product of these values, or -8.8×10^{-7} mol/L-min.

(b) The mass balance of interest is for the reactor during the upset, which is a non-steady-state condition. That mass balance is:

$$\frac{d\left(Vc_{r,up}\right)}{dt} = Qc_{in,up} - Qc_{out,up} - kc_{r,up}V$$

11. Particles that had an average settling velocity of 0.5 cm/min (i.e., 30 cm/h) would have fallen 90 cm in three hours. The corresponding point on the graph would fall on an isopleth of ~76% removal, indicating that 76% of the particles fell at average velocities greater than or equal to 0.5 cm/min during the test. Thus, 24% of the particles fell at velocities less than 0.5 cm/min.

12. The molar concentrations of Ca^{2+} and SO_4^{2-} in the feed to the RO unit are:

$$\left(\text{Ca}^{2+}\right) = \frac{30\text{ mg/L}}{40,000\text{ mg/mol}} = 7.5\text{x}10^{-4}\,\frac{\text{mol}}{\text{L}}$$

$$\left(\text{SO}_4^{\ 2-}\right) = \frac{60\text{ mg/L}}{96,000\text{ mg/mol}} = 6.25\text{x}10^{-4}\,\frac{\text{mol}}{\text{L}}$$

The highest concentrations of Ca^{2+} and SO_4^{2-} will develop at the outlet of the RO system, when the largest fraction of clean water has been extracted. We can compute the concentrations at that location as follows. Both solutes are rejected with 97% efficiency by the membrane system, so their concentrations in the permeate are 3% of the feed values, or $2.25\text{x}10^{-5}$ and $1.875\text{x}10^{-5}$ mol/L, respectively. The water recovery achieved by the system is 80%, so for each liter of feed, 0.8 L of permeate and 0.2 L of concentrate are generated. Thus, a mass balance on 1.0 L of feed is as follows:

$$c_f\left(1.0\text{ L}\right) = c_p\left(0.8\text{ L}\right) + c_c\left(0.2\text{ L}\right)$$

c_f and c_p are known for each constituent of interest, so c_c can be computed. The result is that the concentrations of Ca^{2+} and SO_4^{2-} in the concentrate are 3.66x10^{-3} and 3.05x10^{-3} mol/L, respectively. The product of these concentrations is:

$$Q_{so} = \left(\text{Ca}^{2+}\right)\left(\text{SO}_4{}^{2-}\right) = \left(3.66\text{x}10^{-3}\right)\left(3.05\text{x}10^{-3}\right) = 1.12\text{x}10^{-5} = 10^{-4.95}$$

The computed value of Q_{so} at the RO outlet is less than K_{so}, so no precipitation will occur, and $CaSO_4$(s) will not foul the membrane.

13. The Langmuir isotherm is:

$$q = q_{max}\frac{K_{Lang}c}{1+K_{Lang}c}$$

In the current case, q_{max} and K_{Lang} are given, and the final concentration is specified to be 10 μg/L. The adsorption density in equilibrium with the treated solution is therefore:

$$q = \left(400\,\frac{\mu\text{g}}{\text{g}}\right)\frac{\left(0.3\text{ L}/\mu\text{g}\right)\left(10\ \mu\text{g/L}\right)}{1+\left(0.3\text{ L}/\mu\text{g}\right)\left(10\ \mu\text{g/L}\right)} = 300\,\frac{\mu\text{g}}{\text{g}}$$

The concentration of adsorbate (Pb^{2+}) that must be collected by the adsorbent is (60 – 10), or 50 μg/L. At the equilibrium adsorption density, the concentration of adsorbent required to adsorb this much Pb^{2+} is:

$$c_{solid} = \frac{c_{adsorbed}}{q} = \frac{50\ \mu\text{g/L}}{300\ \mu\text{g/g}} = 0.167\,\frac{\text{g}}{\text{L}} = 167\,\frac{\text{mg}}{\text{L}}$$

The fractional utilization of adsorbent sites is just q/q_{max}, or 300/400, i.e., 75%.

14. The value of C used to compute the CT product is the disinfectant concentration in the effluent of the reactor, and the value of T is the time when 10% of the mass of a spike tracer input has exited the system. T can be read directly from the graph as the time when the value on the x axis is 0.1, i.e., T = 60 min. Therefore, to achieve a CT product of 140 mg-min/L, C must be:

$$C = \frac{CT}{T} = \frac{\left(140\,\frac{\text{mg}}{\text{L-min}}\right)}{60\text{ min}} = 2.33\,\frac{\text{mg}}{\text{L}}$$

In a PFR, the effluent concentration of a constituent undergoing a first-order reaction is:

$$C_{out} = C_{in}\exp\left(-kt\right)$$

Thus:

$$
\begin{aligned}
C_{in} &= C_{out}\exp\left(kt_d\right) \\
&= \left(2.33\frac{\text{mg}}{\text{L}}\right)\exp\left(\left[0.35\text{ hr}^{-1}\right]\left[\frac{70\text{ min}}{60\text{ min/hr}}\right]\right) \\
&= 3.51\frac{\text{mg}}{\text{L}}
\end{aligned}
$$

where C_{in} is the concentration at the inlet to the PFR. The instantaneous demand of Cl_2 is 1.2 mg/L, so the required dose is (3.51+1.2), or 4.71 mg/L.