CBE 30356 Transport II
Problem Set 11
Due via Gradescope, 11:55 PM 4/20/23

1). You are assigned the task of stripping out trichloroethylene from groundwater (55°F) using an air-water stripping tower. Your tower is loaded with 1 inch metal Raschig Rings, and is to be operated at a water superficial flow rate of 26 gpm/ft^2 and air superficial flow rate of 48 cfm/ft^2.

a. To calculate mass transfer coefficients you will need to get the diffusivities of trichloroethylene in both water and air (at 55°F). This can be done using a number of empirical correlations, and a nice summary specific to trichloroethylene in air and water is found on p. 7 & 8 of the reference:

https://dtsc.ca.gov/wp-content/uploads/sites/31/2018/01/tce.pdf

Note that while this is a government publication, it actually has an error in it! For their diffusivity in water expression they forgot to include the dependence of viscosity on temperature – not huge, but not insignificant either! When using this correlation, be sure to also use the correct viscosity at our operating temperature!

b. For these conditions, calculate k_L, k_G, and $K^o{}_L a$. You will find table 4 on p. 75 of Staudinger's thesis to be of use to get the Henry's Law coefficient. A typical surface/volume ratio for this size Raschig Ring is 216 m^2/m^3.

c. It is desired to use the above conditions to reduce the concentration of trichloroethylene from 1 ppmw to 10 ppbw. How tall should the tower be for these flow rates?

2. Consider an equimolar counter-diffusion / first order reaction Thiele modulus problem such as was covered in class. If the reaction is fast (e.g., you are severely diffusion limited) it is more appropriate to solve the problem in the boundary layer limit: We define $y = R – r$ and examine reaction and diffusion in this "flat Earth" limit. Show that the problem formulated in this way is just a simple exponential for the concentration distribution, and solve for the flux at the surface and resulting effectiveness factor. Compare your result to the asymptotic limit derived in the notes and show that they agree.

3. The Taylor dispersivity limit is reached only after solute molecules have a chance to diffuse across streamlines so that they sample the different convective velocities. In this problem we examine this transition. While this can be done analytically, the problem is more than a bit messy – so we will do it using a MC simulation.

a. Simulate the dispersion of an initially focused solute slug in a circular tube of radius a with diffusivity D and average velocity U. After rendering the problem dimensionless, show (via simulation!) that at long times the variance grows as 2Kt where $K = 1/48\ U^2a^2/D$ (e.g., Taylor's classic result).

b. Subtracting this asymptote off, determine the (dimensionless) time (or distance, same thing!) with which the steady state is achieved.

For this problem it is useful to do your random walk diffusity in both the x and y directions (e.g., Cartesian coordinates), where $r = (x^2+y^2)^{1/2}$. Reflection at the tube wall is pretty simple: your new radius would be rnew = min(r,2-r), and your new x and y positions would be scaled by the new radius (e.g., x = x*rnew/r). It's just a couple of lines of code. As was done in the class simulations, use TR to get the displacement in the flow direction. Ignore diffusion in the axial direction, as that would be very small at large Pe. Your initial distribution can be set up in a square box (using the rand command to get it uniform) and then you just trim out the tracers which fall outside the circle of radius 1.