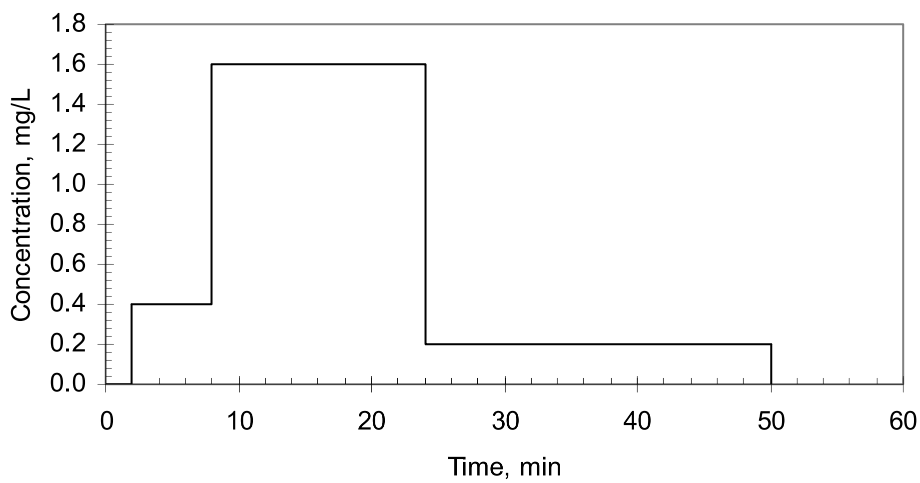
Environmental Engineering Comprehensive Exam
CE211A – Environmental Physical-Chemical Processes

You are interested in modeling the oxygen concentration in a continuous flow non-ideal reactor that is used to treat wastewater with a low oxygen concentration. Assume that the only reaction that oxygen undergoes is gas transfer at the water surface. Answer the following questions. You must show all of your work to receive full credit.

a. A pulse of conservative tracer was injected into the non-ideal reactor at $t = 0$ and the effluent concentration is shown in the figure below. The reactor has a volume of 20 L and the flow rate was 1.5 L/min.
   i. Calculate the mass of tracer recovered.
   ii. On the same graph, draw an E(t) curve for the reactor. Label the values of E(t) on the second y-axis.
   iii. Calculate the mean hydraulic retention time of the reactor.
   iv. Does the reactor have any dead space? Explain your answer.
   v. What fraction of the influent spends more than 24 min in the reactor?



b. Next you must determine the rate at which oxygen is transferred from the gas to liquid phase. The following rate expression describes the transfer rate of oxygen:

$$\frac{dC}{dt} = -k_L a\left(C - C^*\right)$$

where C^* is the aqueous concentration of oxygen in equilibrium with the gas phase (in this case $C^* = 9$ mg/L). You set up a simple experiment in which you fill a beaker with water, measure the oxygen concentration ($C_o = 1.8$ mg/L), let the beaker sit for 30 min, and then measure the oxygen concentration again ($C_{30} = 8.8$ mg/L). Calculate the value of k_La for this system.

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c. Calculate the steady-state oxygen concentration in the non-ideal, continuous flow reactor in part a using the k_La from part b (use $k_La = 0.1$ min^{-1} if you aren't sure about your answer).

d. For comparison, calculate the steady-state concentration of oxygen in an ideal PFR and an ideal CFSTR with the same hydraulic retention time as the non-ideal reactor (use $t_d = 30$ min and $k_La = 0.1$ if you aren't sure about your answer). Assume that the influent water has an oxygen concentration of 1.8 mg/L.

e. Do you think it is reasonable to use the value of k_La determined for the batch reactor in part b to model oxygen transfer in the other reactors (the non-ideal reactor and the ideal CFSTR and PFR)? Why or why not?

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Geosmin is a chemical produced by cyanobacteria (blue-green algae), which can give water an unpleasant taste and odor. In drinking water storage reservoirs, the production of geosmin is seasonal, coinciding with the occurrence of algae blooms. Thus, many drinking water treatment plants must have the capability to remove geosmin periodically, but not year-round. In this problem, you will explore whether it is more efficient to use particulate activated carbon (PAC) or granular activated carbon (GAC) for removal of the geosmin by adsorption. The adsorption of geosmin onto the PAC/GAC can be described by a Freundlich isotherm (assume the same isotherm applies to both the PAC and GAC, so basically they have the same surface area per mass):

$$q = kC^n$$

a. From these experimental data, determine k and n for the PAC/GAC (adapted from Ng et al., 2002):

C (μg/L)	q (μg/g)
1.00	0.25
0.32	0.16
0.10	0.10
0.02	0.04

b. The configuration for PAC treatment is that the PAC is added to a well-mixed reactor (CFSTR), where it is in contact with the water for a period of time. After this reactor, the PAC is removed by sedimentation. Develop an expression for the dose of PAC (mass of PAC per volume of water treated) as a function of the influent and effluent concentrations of geosmin (C_{in} and C_{out}), and q (absorption density). You may assume that adsorption equilibrium is reached. (Hint: write a mass balance around the CFSTR).

c. The configuration for GAC treatment is in a fixed bed, column reactor. You may assume that the Mass Transfer Zone (MTZ) is very thin, such that breakthrough occurs instantaneously. Develop an expression for the dose of GAC (mass of GAC per volume of water treated) as a function of influent concentration, C_{in} and q. Assume that all of the GAC is at equilibrium when breakthrough occurs. (Notice that C_{out} does not appear in your equation, because the effluent concentration is zero until breakthrough occurs).

d. Which configuration is more efficient (which requires less PAC/GAC) if 50% removal of geosmin is required? If 99% removal of geosmin is required?