NAME

GROUND RULES: This is a closed-book/closed-note exam, except that you are permitted one sheet of notes. Do your work on the paper provided. After the exam, staple your work to this exam sheet. Please be sure that your name is written on each page you submit. Also, please be sure that the problem number and your answer are clearly indicated.

The total score possible is 20 points, and the time allowed is 50 minutes. Use the time wisely. Good luck!

REMINDER: Read the questions **carefully**, and be certain you are responding appropriately.

HINTS:
(1) If you seem to be missing an important piece of information, assume a reasonable value, state your assumption, and proceed.
(2) Partial credit is granted, but only if your work can be understood (and your thinking is reasonable).
(3) The different parts of each problem are independent of one another and can be solved in any order.

Problem #1 (9 possible) ________

Problem #2 (5 possible) _______

Problem #3 (6 possible) ________

TOTAL SCORE (out of 20) [ ]

DATA AND RELATIONSHIPS (some of which may be useful):

ATOMIC MASSES (g/mol): H - 1, C - 12, N - 14, O - 16

APPROXIMATE COMPOSITION OF DRY ATMOSPHERE: N_2 - 79%, O_2 - 21%

IDEAL GAS LAW: $pV = nRT$ GAS CONSTANT: $R = 82.05 \times 10^{-6}$ atm mol^{-1} m^3 K^{-1}

CONVERSION FACTORS: pressure: 1 atm = 1.01325×10^5 Pa

volume: 10^{-3} m^3 = 1 L = 1000 cm^3 mass: 10^{-3} kg = 1 g = 10^3 mg = 10^6 µg

TWO-FILM MODEL: $J_{gl} = k_{gl} (C_s - C)$

BATCH REACTOR material balance: $d(CV)/dt = rV$

CMFR material balance: $d(CV)/dt = Q_{in} C_{in} - Q_{out} C + rV$

PFR material balance: $\partial C/\partial t = - U \, \partial C/\partial x + r$

RATE LAW, 1st-order decay: $r = - k C$

DYNAMIC EQUATION and SOLUTION:

problem statement: $dC/dt = S - L C$; $C(0) = C_o$; S,L constant

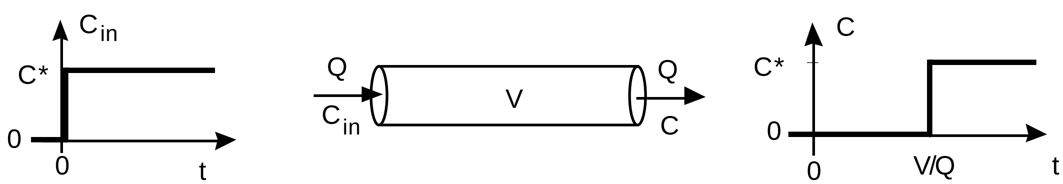
solution: $C(t) = C_o \exp(-Lt) + (S/L) [1-\exp(-Lt)]$

1. DYNAMIC RESPONSE OF REACTOR SYSTEMS (9 points; 3 points each)

Water flows at a constant rate Q (volume per time) through a reactor system. At the inlet, the concentration of a contaminant undergoes a time-dependent change. Three cases (a-c) are to be considered. For each case, the time-dependent inlet concentration, the reactivity of the contaminant, and the details of the reactor system are specified. S**ketch the time-dependent concentration of the contaminant at the reactor outlet**. Assume that the contaminant is absent from the reactor system at t = 0. Also assume that the reactors depicted are either ideal CMFRs or ideal PFRs. [*Hint*: For full credit, your answer should show the correct qualitative shape and have the concentration and time scales properly indicated, as in the example.]

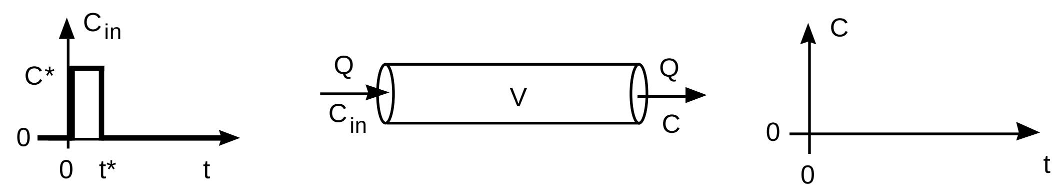
Example: Species is nonreactive

inlet reactor outlet



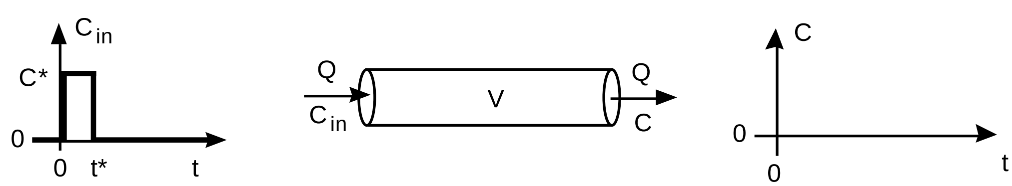
(a) Species is nonreactive.

inlet reactor outlet



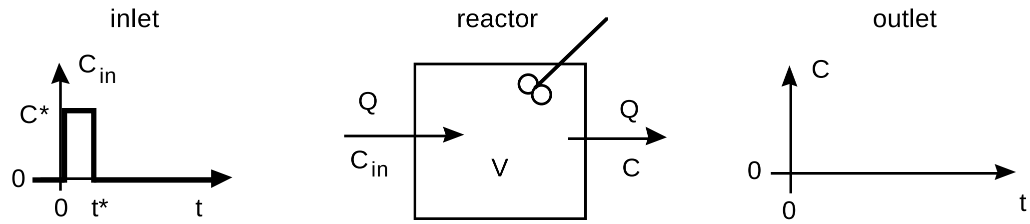
(b) Species undergoes first-order decay with rate constant = k.

inlet reactor outlet



(c) Species undergoes first-order decay with rate constant = k; t* >> V/Q.

inlet reactor outlet



---

2. ON WATER QUALITY ENGINEERING (5 points; 1 each)

Provide a brief answer to each of the following questions.

(a) Explain how coagulation and flocculation can improve the efficiency of a sedimentation basin.

(b) When would powdered activated carbon (PAC) be favored over granular activated carbon (GAC) in drinking water treatment?

(c) Before the development of a rapid-sand filter, slow-sand filtration was used. A rapid-sand filter is cleaned by backwashing. How is a slow-sand filter cleaned?

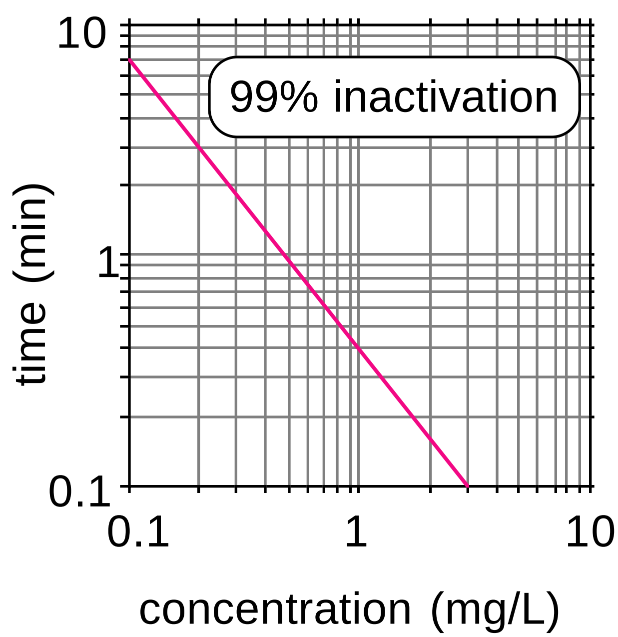
(d) Name two fundamentally different methods that can be used to remove unwanted organic compounds from drinking water.

(e) What is a NAPL?

3. PROCESSES ENGINEERING FOR WATER TREATMENT(6 points; 3 each)

(a) A conventional sedimentation basin is established to remove particles from water. In plan view, the basin is rectangular. Its dimensions are 40 m long × 10 m wide × 3.5 m deep. Water flows through (parallel to the long dimension) it at a linear velocity of 800 m d^{-1} = 0.93 cm s^{-1}. Assume that the water flow is ideal: laminar, and uniform with only a horizontal component throughout the settling zone. The figure on page 4 shows particle settling velocity as a function of particle diameter. What is the smallest particle diameter for which the removal efficiency in this device is 100%?

(b) The data in the figure below show the time required for 99% inactivation of *E. coli* by free chlorine in a batch reactor. Assume that Chick's law applies: $N(t) = N(0)\ e^{-kt}$. Consider the design of a disinfection stage of a drinking water treatment plant. The unit is to be configured as a PFR. The free chlorine concentration is 1 mg/L. The design goal for inactivation of *E. coli* is 99.999% removal. What contact time is required? [Reference: CN Haas, Disinfection, in *Water Quality and Treatment: A Handbook of Community Water Supplies*, 5th Edition, American Water Works Association, 1999.]



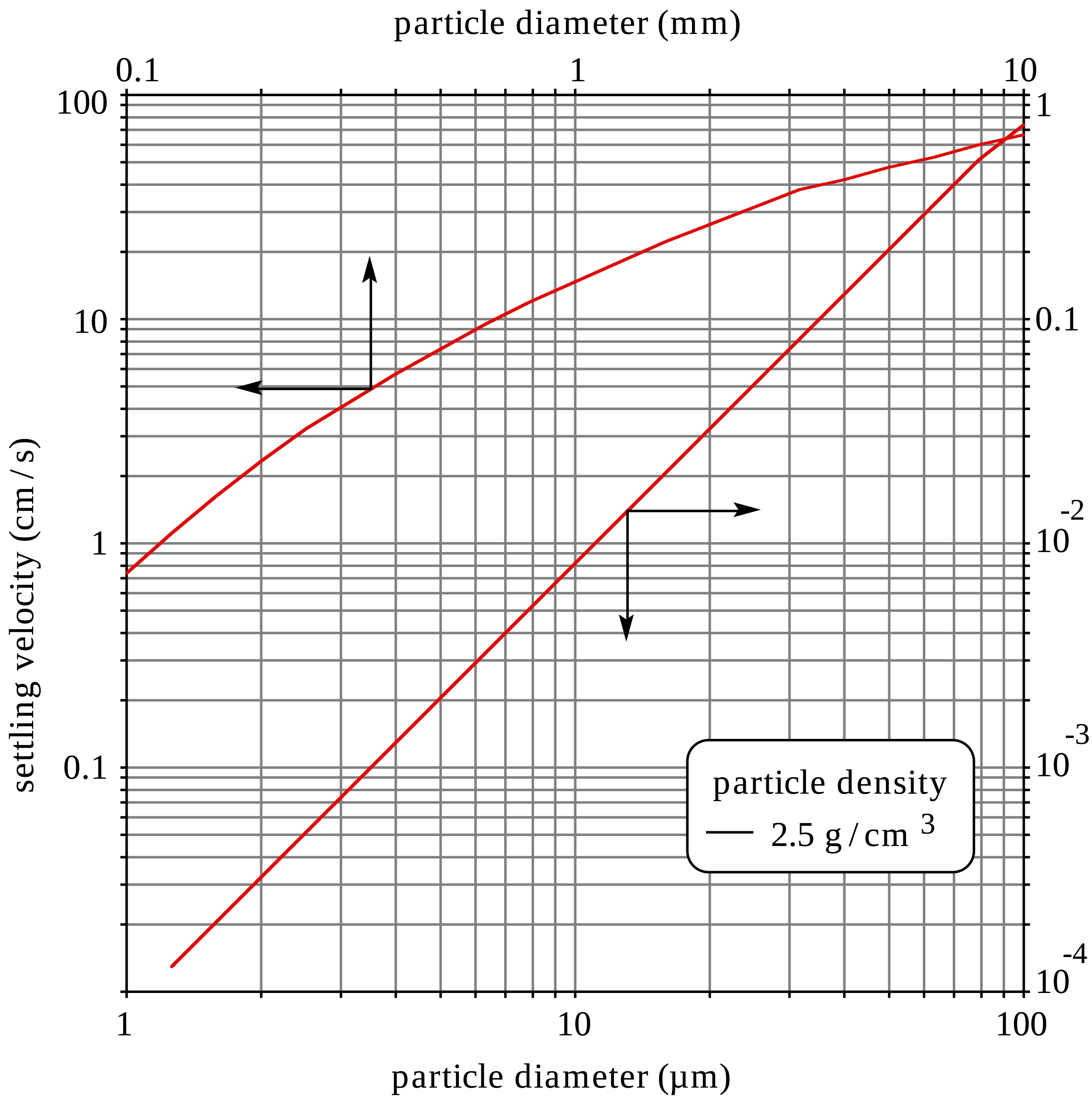


Figure for problem 3, part a. Terminal settling velocity of particles in water.