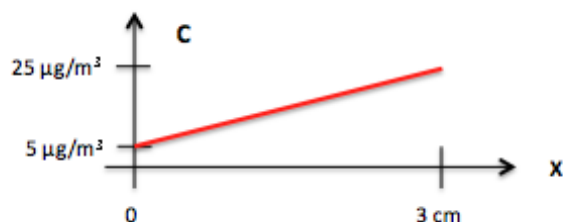


**ANSWERS****1. Elementary kinetics in batch and flow reactors**

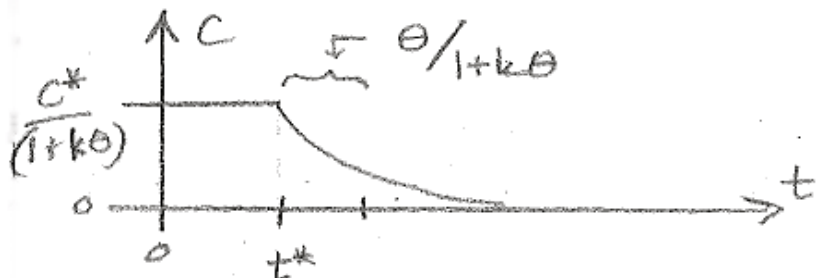
- (a) For first-order decay,  $[A](t) = A_0 \exp(-kt)$ . At  $t = 1$  h,  $[A] = 1.82$  mM. By stoichiometry, the decrease in  $[A]$  equals the increase in  $[B]$ , so at  $t = 1$  h,  $[B] = 2 + 1.18$ , or  $[B] = 3.18$  mM.
- (b) For steady-state conditions in a CMFR, given first-order decay, the outlet concentration of the decaying species is  $[A] = A_{in}/(1+k\theta)$ , so in this case,  $[A] = 3 \text{ mM}/1.5$  or  $[A] = 2$  mM. The reaction changes A to B, but doesn't change the sum  $[A] + [B]$ . Therefore, by stoichiometry, the loss of  $[A]$  must equal the gain of  $[B]$ . So,  $[B] = 3$  mM.
- (c) Think of batch reactors on a conveyor belt. This problem is essentially identical to part (a) except that  $A_{in}$  plays the role of  $A_0$  and likewise for  $[B]$ . We can write the answer directly:  $[A] = 1.82$  mM and  $[B] = 3.18$  mM.

**2. Diffusion as an environmental transport process**

- (a) Net diffusion will occur from the high concentration to the low concentration. The steady-state concentration profile will be linear, decreasing from  $25 \mu\text{g}/\text{m}^3$  at one end of the tube to  $5 \mu\text{g}/\text{m}^3$  at the other. The magnitude of the flux will be  $D \Delta C/\Delta x = (0.2 \text{ cm}^2/\text{s}) \times 20 \mu\text{g}/\text{m}^3 \times (10^{-2} \text{ m}/\text{cm})^3 \div 3 \text{ cm} = 1.3 \times 10^{-12} \text{ g}/\text{cm}^2 \text{ per s}$ . So,  $J_d = 1.3 \text{ pg cm}^{-2} \text{ s}^{-1}$ . [That's a mass flux!]
- (b) See sketch below. Note that the profile is linear and that the boundary conditions are met:  $C(0) = 5 \mu\text{g}/\text{m}^3$  and  $C(3 \text{ cm}) = 25 \mu\text{g}/\text{m}^3$ .

**3. Transient response of a CMFR**

- (a) Clearly, for very large  $t$ , with the contaminant no longer being supplied at the inlet, the outlet concentration will be zero:  $C(\infty) = 0$ .
- (b) Approach: Write a governing time-dependent material balance equation for the reactor and extract the loss-rate coefficient  $L$ . The characteristic time is  $\tau \sim 1/L$ .  
 Material balance:  $d(CV)/dt = Q C_{in} - Q C - k C V \Rightarrow dC/dt = (Q/V) C_{in} - (Q/V + k) C$ .  
 Characteristic time:  $\tau \sim 1/(Q/V + k)$ , or  $\tau \sim \theta/(1+k\theta)$  where  $\theta = V/Q$ .
- (c) See sketch below.



#### 4. Sedimentation for particle control: CMFRs in series

Approach: Write a material balance for particles in each reactor and solve for outlet to inlet concentration in steady state. Then apply three times to determine overall outlet concentration in relation to inlet concentration. Obtain efficiency from definition:  $\eta = (C_{in} - C)/C_{in} = 1 - (C/C_{in})$ .

Material balance for particle settling in a single CMFR, where  $C_1$  is the outlet concentration of the first reactor:

$$d(C_1 V)/dt = Q C_{in} - Q C_1 - [d(C_1 V)/dt]_{\text{settling}}$$

The last term is obtained from the flux relationship:

$$[d(C_1 V)/dt]_{\text{settling}} = -J_s A$$

Here,  $A = V/H$  = area of the bottom of the tank and  $J_s = v_s C_1$  is the flux associated with settling.

Substitute and divide both sides by  $V$  to obtain this expression:

$$dC_1/dt = (Q/V) C_{in} - [(Q/V) + (v_s/H)] C_1$$

Solve for relationship in steady state:

$$C_1 = C_{in} / [1 + (v_s \theta/H)]$$

The key group here is  $v_s \theta/H$ , where  $\theta = V/Q = 0.5$  h. So, for this problem that group has value  $1.2 \text{ m/h} \times 0.5 \text{ h}/3 \text{ m} = 0.2$ .

We find, then, that  $C_1/C_{in} = 1/1.2 = 0.833$  and that  $C/C_{in} = 0.833^3 = 0.58$ . Consequently, the efficiency is  $1 - (C/C_{in})$  or  $\eta = 0.42$ .