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Equations:

The shear stress components in cylindrical coordinates

$$\tau_{r\theta} = \tau_{\theta r} = \mu\left[r\frac{\partial}{\partial r}\left(\frac{\upsilon_\theta}{r}\right) + \frac{1}{r}\frac{\partial \upsilon_r}{\partial \theta}\right]$$

$$\tau_{z\theta} = \tau_{\theta z} = \mu\left[\frac{\partial \upsilon_\theta}{\partial z} + \frac{1}{r}\frac{\partial \upsilon_z}{\partial \theta}\right]$$

$$\tau_{zr} = \tau_{rz} = \mu\left[\frac{\partial \upsilon_z}{\partial r} + \frac{\partial \upsilon_r}{\partial z}\right]$$

Problems:

1. For a flowing fluid, it was found that the substantial derivative of the density equals to zero.
   (a) Is it possible that the partial derivative of the density is nonzero? Explain. (3%)
   (b) Is this fluid incompressible? Explain. (3%)

2. An incompressible Newtonian fluid flowing through a horizontal pipe with radius of R and length of L. The pressure gradient between the two ends is $-\left(\frac{dP}{dz}\right)$. The fluid filling the pipe has density ρ and viscosity μ. The flow is laminar and fully developed. Neglect the entrance and exit effects. The derived velocity was found to be

$$\upsilon_z = -\left(\frac{dP}{dz}\right)\frac{R^2}{4\mu}\left[\frac{3}{2} - \left(\frac{r}{R}\right)^2\right]$$

   (a) Is no-slip condition applied in this case? Explain. (2%)
   (b) Determine the net rate of linear momentum efflux for a defined control volume. (3%)
   (c) Derive the average velocity, υ_{avg}, in terms of the maximum velocity. (3%)
   (d) Determine the shear stresses on the wall ($r = R$). (4%)
   (e) Derive the Fanning friction factor, f_f, in terms of Reynolds number. (5%)
   The head loss for a given fitting is $h_L = 2f_f\frac{L}{D}\frac{\upsilon_{avg}^2}{2g}$ and D is the diameter of the pipe ($2R$).
   (f) What is the physical meaning of Fanning friction factor? (2%)

3. An engineer installed a pump in order to transfer one fluid from a tank to a reactor. The tank was installed several meters above the pump. In commissioning, the engineer found that the pump created noise and assessed that cavitation occurred. Explain why this happened and propose one approach to resolve the problem. (5%)

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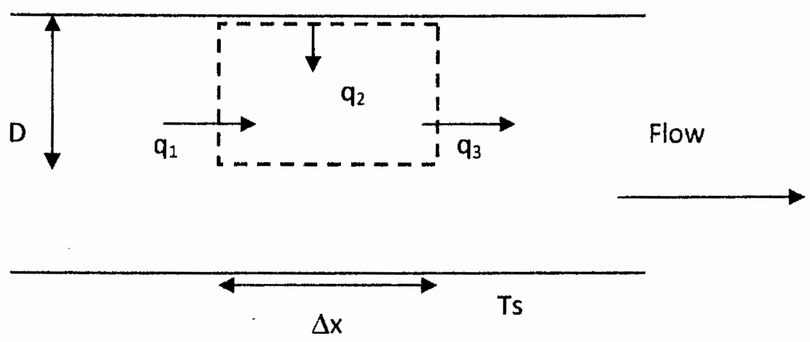
4. Consider a liquid flowing through a heat-exchanger tube shown as follows. The tube diameter is D and the wall temperature is Ts. The density and specific heat of the liquid are ρ and C_p, respectively. The heat transfer coefficient is *h* and the flow velocity is v_x.

   (a) If the liquid temperature is T(x), evaluate the heat transfer rates q_1, q_2, and q_3 in and out of the control volume (note: q_2 is the heat transfer rate by convection). (4%)

   (b) If the length of the tube is L and the temperature at the entrance is To, find the exit temperature T_L. (7%)

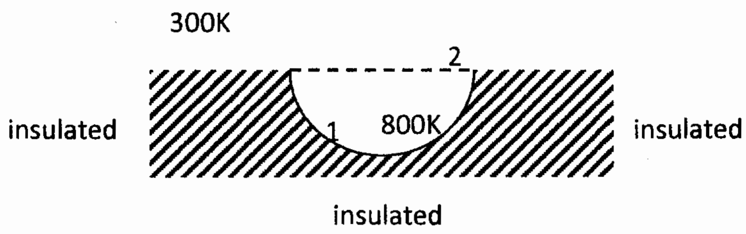
   (c) If To=60°C, Ts=250°C, D=2cm, L=100cm, and the friction factor is 0.0042, estimate T_L using the Reynolds analogy. (4%)



5. The black surface of a hemispheric cavity is maintained at 800K as shown in the following figure. The radius of the hemisphere is 50 cm. If the surface radiates uniformly and the surroundings are considered to be black at 300K,

   (a) What is the view factor F_{12}? (4%)

   (b) Find the heat loss to the surroundings. The Stefan-Boltzmann constant: 5.676×10^{-8} W/(m^2.K^4) (6%)



6. A two components mixture is to be separated by a distillation column shown below. The feed is a saturation vapor (y_F) fed from the bottom of the column. The concentrations of the products in the upper and lower parts of the column are X_D and X_B, respectively.

   (a) For using McCabe – Thiele method, please derive the operation line and the end points for this system. (3%)

   (b) For constant (y_F)and (X_D), how to obtain the **minimum reflux ratio** (R_{Dm}) for this system. Please describe your answer with the help of a figure. (3%)

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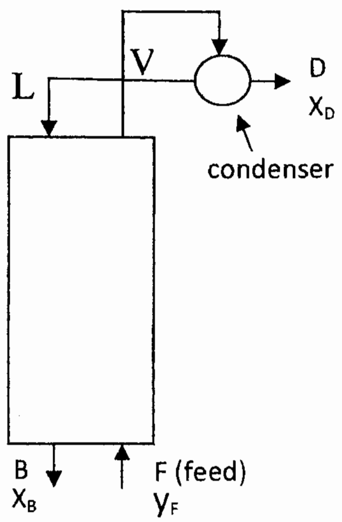
(c) If the reflux ratio is zero, how about the number of idea stage at this condition? (2%)

(d) In the distillation column with constant ideal plate and feed concentration (y_F), when the reflux ratio is increased, how about the variation of the following parameters in response to the increase of R_D. (i). temperature of the top plate, (ii). B and F, (iii). required cooling water. (4%)



7. In a laundering process, 15 kg surfactant solution was retained by 100 kg dry clothes. Pure water is used to remove the surfactant from the tissue by leaching. It is known that the mass of liquid retained on the clothes is independent of the surfactant concentration (i.e. 15 kg solution per 100 kg dry clothes).

(a) By the method of cross-contact stage and 100 kg water is allowable for the leaching, how many percentage of the surfactant can be removed in a single ideal stage? (4%)

(b) As in problem (a), only 100 kg water is allowable, how can you operate by cross-contact process to remove 90% surfactant from the clothes? (4%)

8. The enzyme-catalyzed reaction A→B is to be carried out under steady-state conditions with the enzyme immobilized in a membrane. The membrane has two purposes: to prevent loss of the expensive enzyme, and to help separate any residual reactant from the product. Consider the arrangement shown ablow. One surface of the membrane (at x = L) has a thin coating that permits rapid diffusion of A from the feed stream to the membrane, such that $C_A(L) \approx C_0$. A key feature of the system is that the coating restricts (but does not eliminate) the passage of B. With negligible B present in the feed stream, the flux of B across the coating is described by

$$N_{Bx}(L) = k_c C_B(L),$$

(背面仍有題目，請繼續作答)

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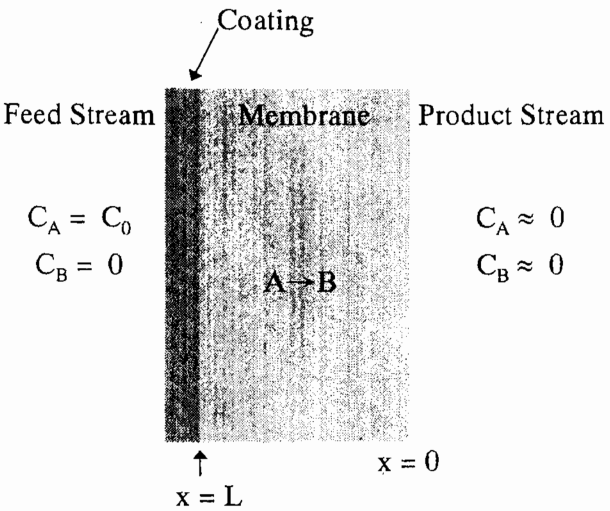
where k_c is the permeability coefficient of the coating for B (similar to a mass transfer coefficient). For simplicity, assume that the concentrations of A and B in the product stream are maintained at low levels and that the diffusivities in the membrane are equal, $D_A = D_B = D$. The first-order, homogeneous reaction rate constant in the membrane is k_r.



(a) Starting from a mole balance within a control volume, state the equations governing the concentrations of reactant and product in the membrane. (6%)

(b) Use the following dimensionless quantities to re-write the molar-equivalent equations: (4%)

$$\eta \equiv \frac{x}{L},\quad \Theta_A \equiv \frac{C_A}{C_0},\quad \Theta_B \equiv \frac{C_B}{C_0}$$

$$\lambda \equiv \left(\frac{k_r L^2}{D}\right)^{1/2} = Da^{1/2},\quad \gamma \equiv \frac{k_c L}{D}$$

(c) What is the physical meaning of λ? (3%)

(d) Determine $\Theta_A(\eta)$ and $\Theta_B(\eta)$. (6%)

(e) Two measures of reactor performance are the purity of the product stream,

$$\phi_1 \equiv \frac{N_{Bx}(0)}{N_{Ax}(0) + N_{Bx}(0)},$$

and the fractional recovery of B in the product stream,

$$\phi_2 \equiv \frac{N_{Bx}(0)}{N_{Bx}(0) - N_{Bx}(L)}.$$

Derive general expressions for ϕ_1 and ϕ_2, and determine the limiting values of both quantities for very fast or very slow reactions (large or small λ, with fixed γ). (6%)