系所組別： 化學工程學系甲組

考試科目： 單元操作與輸送現象

考試日期：0219，節次：1

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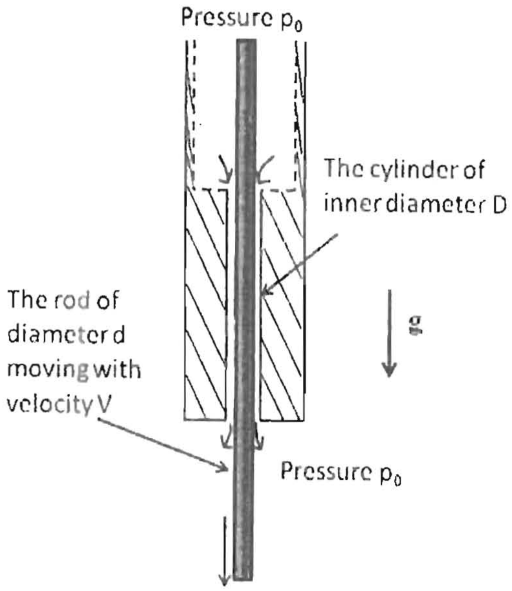
1. Please briefly describe an experimental procedure to determine the viscosity of an unknown fluid using a reference fluid with known viscosity, a capillary tube, and a timer. (7%)
(Hint: Deriving an equation is needed. Based on it, the viscosity of an unknown fluid can be determined.)

2. Consider a vertical wire-coating process as shown below, in which the cylindrical rod is being moved with a velocity V. The rod is at the center of the cylindrical die. The fluid filling the space between the rod and the inner cylinder wall has density ρ and viscosity μ. Assume the flow is laminar and steady. No-slip condition is applied on the surface of the cylinder and rod.
(a) Derive the differential momentum balance in the z direction. (6%)
(b) Derive the fluid velocity distribution in the space between the rod and the inner cylinder wall. (7%)
(c) Derive the shear stress acting on the surface of the rod. (5%)




where the shear stress components

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

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

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

(背面仍有題目,請繼續作答)

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3. Write down the description, definition or expression for the following:
   (a) Newton's law of cooling (or the Newton rate equation). (2%)
   (b) Nusselt number. (2%)
   (c) Heat exchanger effectiveness. (2%)
   (d) Economy of an evaporator. (2%)
   (e) Stefan-Boltzmann law for energy emitted from a black surface. (2%)

4. A thin slab is subjected to microwave radiation that causes volumetric heating to vary according to:

$$\dot{q}(x) = \dot{q}_0\left[1-\left(\frac{x}{L}\right)^2\right]$$

where $\dot{q}_0$ has a constant value of 40 $kW/m^3$. The thickness of the slab, L, is 0.12 m and its thermal conductivity, k, is 0.6 W/(m.K). The boundary at x=L is perfectly insulated, while, at x=0, the temperature $T_0$ is maintained at 300 K.
   (a) Determine an expression for T(x) in terms of x, L, k, $\dot{q}_0$ and $T_0$. (11%)
   (b) Where will the maximum temperature occur in the slab? (2%)
   (c) What is the value of $T_{max}$? (2%)

5. A 3 mm diameter air bubble is introduced into pure water from the bottom of a container of depth 0.5 m. Assume it rises at the terminal velocity $v_t$ and the water temperature is 20°C. The viscosity of water at 20°C is 1 cp.
   (a) Estimate the terminal velocity $v_t$. (5%)
   (b) Estimate the amount of oxygen absorbed by water from the single bubble. It is assumed that the pressure inside the bubble is 1 atmosphere. Henry's constant (H) of oxygen in water and the diffusion coefficient ($D_L$) of oxygen in water at 20°C are given as follows (8%)

$$H = 40100 \text{ atm}, \qquad D_L = 2.08\times10^{-9}\ m^2/s$$

In addition, the mass transfer coefficient k can be estimated by

$$k = \sqrt{\frac{4D_L v_t}{3\pi D}}$$

where D is the diameter of air bubble.

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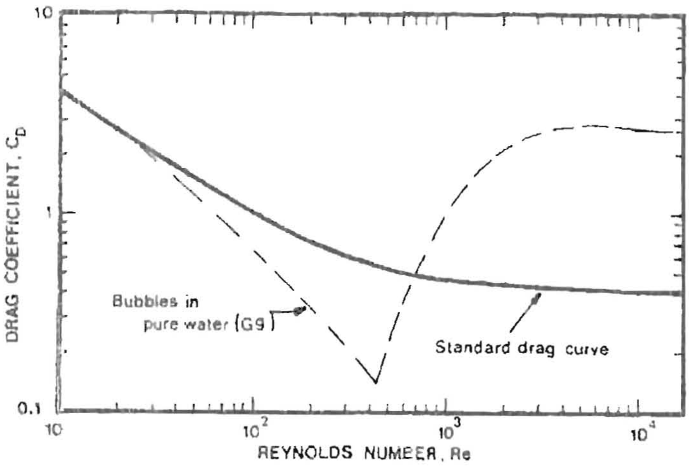


**FIG.** Drag coefficient for bubbles in water. Standard drag curve is for rigid spheres.

6. A solid sphere of substance A is suspended in a liquid B in which it is slightly soluble, and with which it undergoes a first-order chemical reaction with rate constant $k_1$, i.e., $R_A = -k_1 C_A$, where $C_A$ is the molar concentration of A in the liquid. At steady state, the diffusion is exactly balanced by the chemical reaction. To simplify the analysis, it is assumed that the bulk flow induced by the diffusion process can be neglected.

   (a) Derive the governing equation and appropriate boundary conditions for species A to describe the diffusion-reaction process in the liquid phase. State your symbols and assumptions clearly. (4%)

   (b) Solve the above equation to get the concentration profile of A. (8%)

   The following information may be useful.

   The solution to the differential equation $x^2 y'' + 2xy' - a^2 x^2 y = 0$ is $y = \frac{C_1}{x} e^{ax} + \frac{C_2}{x} e^{-ax}$

   The solution to the differential equation $x^2 y'' + 2xy' + a^2 x^2 y = 0$ is $y = \frac{C_1}{x} \cos ax + \frac{C_2}{x} \sin ax$

   Equation of Continuity of Species A $\frac{\partial \rho_A}{\partial t} + \nabla \bullet \mathbf{n}_A = r_A$ ; or $\frac{\partial C_A}{\partial t} + \nabla \bullet \mathbf{N}_A = R_A$

   Laplacian of a scalar s $(\nabla^2 s) = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \frac{\partial s}{\partial r}\right) + \frac{1}{r^2 \sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta \frac{\partial s}{\partial \theta}\right) + \frac{1}{r^2 \sin^2\theta}\frac{\partial^2 s}{\partial \phi^2}$

7. Nitrogen is used in a packed column to strip $SO_2$ from water. The entering water contains 0.4 mol% $SO_2$ and a 90% removal of $SO_2$ is desired. The liquid flow rate is 10 mol/s and the cross-sectional area

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of the column is 5 $m^2$. The equilibrium relationship may be taken as $y_e = 10x_e$, where $x_e$ and $y_e$ denote the equilibrium mole fraction in liquid and gas respectively.

(a) What is the difference between absorption and stripping? (2%)

(b) What is the minimum gas flow rate ($G_{min}$) required for achieving the desired stripping? (4%)

(c) If G (gas flow rate) = $1.2G_{min}$, what is the mole fraction of $SO_2$ in the outlet nitrogen? (3%)

(d) Using the gas rate G from part (c) and knowing that the individual phase mass transfer coefficients are constant values of $k_xa = 0.03$ mol/$m^3$s and $k_ya = 0.01$ mol/$m^3$s for this system, calculate the overall height of a transfer units, $H_{Oy}$, for the column. (3%)

(e) What would be the overall height of packing required for the desired separation using the gas flow rate from part (c). (5%)

(f) At the point in the column where the liquid phase mole fraction is 0.0015 in the bulk, what are the interfacial gas and liquid mole fractions? (5%)

(g) If there is a novel column packing claimed a reduction in the operation cost by increasing the interfacial $SO_2$ concentration in the nitrogen relative to the water, would you consider the packing as a superior separation material? Why or why not? (3%)