國立中央大學105學年度碩士班考試入學試題

所別：化學工程與材料工程學系 碩士班 甲組(一般生)　　共3頁　第1頁

科目：輸送現象與單元操作

本科考試可使用計算器，廠牌、功能不拘　　＊請在答案卷(卡)內作答

1. (10%) Find the equivalent diameters for flow through an annulus, an annular region between two coaxial cylinders of radii κR and R（κ< 1）, and for flow through a square duct with length L on each side.

2. (25%) Find the velocity profile and the volumetric flow rate of the axial isothermal flow of a power-law liquid through a circular tube of radius R and length L under a pressure drop $P_0 - P_L$ (with R << L). For a power-law liquid,

$$\tau_{rz} = -m\left|\frac{dv_z}{dr}\right|^{n-1}\frac{dv_z}{dr}$$

Note: If you can't solve this problem for a power-law liquid, you can solve this problem for a Newtonian liquid with constant viscosity μ instead. However, you will not get full score for this problem.

3. (15%) Heat Conduction & Critical Radius

A long steam pipe with the length L and thermal conductivity k has the inner radius of r_i and the outer radius of r_o. The temperature of the inner surface of the pipe, T_i, and the temperature of the surrounding air, T_∞, are fixed. The heat loss per unit area from the outer surface is described by the Newton's rate equation, $q_r = h(T_o - T_\infty)$, where T_o represents the temperature of the outer surface and h the heat transfer coefficient.

(a) (8%) Obtain the radial heat flowrate Q_r of the pipe in terms of $(T_i - T_\infty)$, r_i, r_o, L, k, and h.

(b) (4%) Find the critical radius corresponding to the maximum heat transfer.
Hint: dQ_r/dr_o.

(c) (3%) Explain why there exists such a maximum heat loss. What is the implication in applications?
Hint: Think about the dual effect of varying r_o.

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4. (15%) Forced Convection & Thermal Boundary Layer Theory

(a) (6%) A fluid with a constant free-stream velocity v_∞ and temperature T_∞ flows past a heated plate. Derive the energy integral relation in terms of the thickness of the thermal boundary layer δ_t,

$$\frac{d}{dx}\int_0^{\delta_t} v_x(T_\infty - T)dy = \alpha\frac{\partial T}{\partial y}|_{y=0}.$$

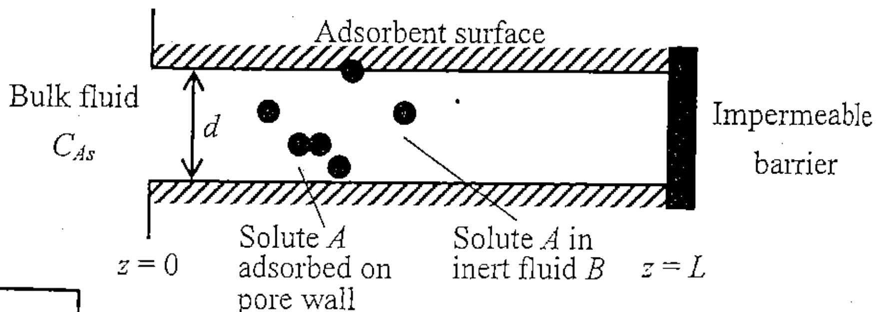
Hint: Leibniz integral rule

$$\frac{d}{dx}\int_0^{\delta_t} f(x,y)dy = \int_0^{\delta_t}\frac{\partial}{\partial x}f(x,y)dy + \frac{d\delta_t}{dx}f(x,\delta_t).$$

(b) (9%) Develop the expression for the local Nusselt number Nu_x in terms of the local Reynolds number Re_x for $Pr\approx1$, i.e. $Nu_x = f(Re_x)$.

Hint: Assume the velocity and temperature profiles of the form $v(x,y) = a+by$, $T(x,y) = \alpha+\beta y$ for the laminar boundary layer.

5. (25%) The adsorption isotherm of a solute A onto the pore wall of a solid sorbent can be described by the Langmuir isotherm: $q_A = \frac{q_{A,max}c_A}{K+c_A}$, where q_A is the amount of A adsorbed onto the surface in moles of A per cm^2 surface area, c_A is the local concentration of A right above the surface in moles of A per cm^3, K is the equilibrium constant in moles per cm^3, and $q_{A,max}$ is the maximum amount of A that can be adsorbed onto the surface also in moles A per cm^2 surface area. As solute A diffuses into the quiescent fluid space inside the pore space, it adsorbs onto the inner walls. The pore in question, initially filled with inert fluid B, can be considered cylindrical in shape, as depicted here with z as the positional vector (z = 0 is at the pore entrance and $z = L$ is at the end of the pore):



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(a) (5%) How can the adsorption isotherm be mathematically simplified in the high A concentration scenario? What about in the low A concentration case? List your assumptions and resulting isotherm form explicitly.

(b) (5%) What does the plot of the Langmuir isotherm q_A versus c_A look like for a physical system containing only A and B? Label your axes and clearly show the associated algebraic expression for maximum amount of solute A adsorbed (q_A) within the pore for the uppermost and lowest c_A regimes.

(c) (15%) You may now consider the concentration profile of solute A solely along the axial direction and disregard the radial direction. You may also assume that the process is dilute with respect to solute A and make the associated simplifications to the adsorption isotherm, and that the adsorption rates are extremely fast. Using the shell balance method, develop the differential forms of the general differential equation for mass transfer and Fick's flux equation, taking into account the adsorption of A onto the pore surface in the differential mass balance. Then combine the simplified forms of the two equations to arrive at a single differential equation for the transfer of solute A within the pores in terms of concentration c_A. State all of your assumptions, boundary conditions, and initial conditions as part of the analysis.

6. (10%) You are designing a packed tower specifically for absorbing carbon dioxide using an organic amine. CO_2 is to enter at 1.36 mol% with the entering gas and to leave at 0.08 mol% CO_2. On the other hand, the amine enters the tower pure, with no CO_2 content. You have determined that if the amine is in equilibrium with the entering gas, then it would contain 0.75 mol% CO_2. For the system, gas would flow at 2.0 gmol/sec while the liquid at 3.9 gmol/sec. The tower's diameter is 30 cm and the overall mass transfer coefficient times area per volume $K_y a$ is $4 \cdot 10^{-5}$ gmol/cm^{3}sec. Determine how tall this tower (l) needs to be to accomplish the desired carbon dioxide absorption.

Hint: $l = \frac{G}{K_y a}\left[\left(\frac{1}{1-\frac{mG}{L}}\right) ln\left(\frac{y_0 - m x_0}{y_l - m x_l}\right)\right]$