※ 考生請注意：本試題可使用計算機。　請於答案卷(卡)作答，於本試題紙上作答者，不予計分。

1. In a creeping flow, the fluid with a known viscosity μ approaches a sphere with a radius R with a constant velocity, υ_∞. The flow is laminar and steady. The drag force, F_{drag}, acting on the sphere by the fluid is $6\pi\mu R\upsilon_\infty$.
   (a) Please describe the physical meaning of drag coefficient C_D. (3%)
   (b) Please determine the drag coefficient C_D for the sphere. (4%)

2. In cylindrical coordinates, an incompressible and irrotational Newtonian fluid flows at r and θ directions. Answer the following questions.
   (a) This fluid flow can be described by the Laplace's equation of stream function, Ψ . Please prove it by mathematical derivation. (8%)

$$\nabla^2\Psi = \frac{\partial^2\Psi}{\partial r^2} + \frac{1}{r}\frac{\partial\Psi}{\partial r} + \frac{1}{r^2}\frac{\partial^2\Psi}{\partial\theta^2} = 0$$

   (b) Please explain the physical meaning of stream function. (3%)
   (c) An incompressible and irrotational Newtonian fluid approaches a stationary cylinder of radius a with a uniform, steady velocity, υ_∞. Assume the flow is laminar and steady. Ignore the gravitational force. Derive the stream function. (12%)
   Hint: The method of separating variables can be applied to solve the derived PDE.

Equations

In cylindrical coordinates, the divergence of velocity, vorticity and Laplace's equation of Ψ.

$$\nabla\bullet\vec{\upsilon} = \frac{1}{r}\frac{\partial}{\partial r}(r\upsilon_r) + \frac{1}{r}\frac{\partial\upsilon_\theta}{\partial\theta} + \frac{\partial\upsilon_z}{\partial z},\ \nabla\times\vec{\upsilon} = \left(\left(\frac{1}{r}\frac{\partial v_z}{\partial\theta} - \frac{\partial v_\theta}{\partial z}\right)\vec{e}_r + \left(\frac{\partial v_r}{\partial z} - \frac{\partial v_z}{\partial r}\right)\vec{e}_\theta + \left(\frac{1}{r}\frac{\partial}{\partial r}(rv_\theta) - \frac{1}{r}\frac{\partial v_r}{\partial\theta}\right)\vec{e}_z\right),$$

$$\nabla^2\Psi = \frac{\partial^2\Psi}{\partial r^2} + \frac{1}{r}\frac{\partial\Psi}{\partial r} + \frac{1}{r^2}\frac{\partial^2\Psi}{\partial\theta^2} + \frac{\partial^2\Psi}{\partial z^2} = 0 \qquad \upsilon_r = \frac{1}{r}\frac{\partial\Psi}{\partial\theta} = \frac{\partial\phi}{\partial r},\ \upsilon_\theta = -\frac{\partial\Psi}{\partial r} = \frac{1}{r}\frac{\partial\phi}{\partial\theta},$$

3. Explain the following:
   (a) Economy (which is used to describe the performance of an evaporator) (3%)
   (b) Stefan-Boltzmann law in thermal radiation (3%)
   (c) Number of heat transfer unit (for a heat exchanger) (3%)
   (d) For pool boiling in water on a horizontal wire, why does the heat flux decrease when boiling passes right after the nucleate boiling regime? (3%)

4. A long wire with 0.5 cm in diameter is immersed into a water bath at temperature 330 K. The average temperature of the wire increased from 285 to 310 K after 20 seconds. Please estimate the average surface conductance, h. The density of the wire is 8000 kg/m^3, the specific heat of the wire is 300 J/kg · K and the thermal conductivity of the wire is 500 W/m · K. (hint: lumped-parameter analysis) (13%)

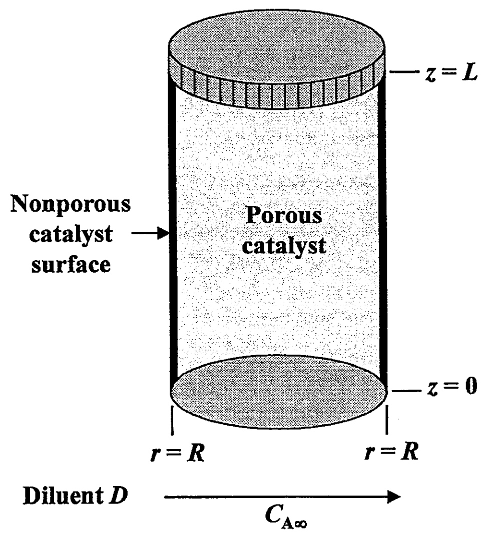
5. Consider the catalytic reaction process occurred in a tubular reactor. The reactor exhibits two catalytic zones, including a porous catalyst that fills the reactor, and a nonporous catalyst surface on the shell of the reactor ($r = R$). Reactant A, with the effective diffusion coefficient D_{Ae}, diffuses into the porous catalytic material through the bottom of the reactor ($z = 0$), and is converted to product B according to the first-order reaction with the rate constant k_1. Reactant A can also diffuse to the nonporous catalyst surface, and is converted to product C according to the first-order surface reaction form with the surface reaction rate constant k_s. The source for reactant A is well-mixed flowing fluid of constant concentration $c_{A\infty}$. Reactant A in the source is diluted in inert carrier fluid D. Therefore, the reactor contains four species: A, B, C, and inert diluent D. The top side ($r = 0$ to R, $z = L$) of the catalytic zone is impermeable to reactant A, products B and C, and diluent fluid D.

(a) State reasonable assumptions for the mass-transfer processes associated with reactant A that allow for appropriate simplification of the general differential equation for mass transfer, and Fick's flux equation. (4%)

(b) Develop the differential forms of the general differential equation for mass transfer and Fick's flux equation for reactant A within the process. Combine the general differential equation for mass transfer and Fick's flux equation to obtain a second-order differential equation in terms of concentration $c_A(r,z)$. (10%)

(c) Specify all relevant boundary conditions on reactant A for a steady-state process. (4%)

(d) Specify the units of k_1 and k_s. (2%)



6. An aqueous solution containing 3% (mole percent) of ammonia (NH_3). The ammonia is stripped by counter current contact with air to remove 90% of the ammonia. The equilibrium relationship of ammonia concentration in the gas (y) and liquid (x) is y_e**=0.8** x_e. Please answer the following questions:

(a) To remove 90% NH_3, what is the **minimum flow rate** of air input (V) per 100 mole of liquid feed (L), and what is the ideal plate required in this operation condition? (5 %).

(b) If the air input (V) is 1.5 times of the liquid input (L), determine the required number of ideal stage. (10 %)

(c) If the striping is carried out in a sieve plate column, and the Murphree efficiency of the plate is η_M**=0.7**, how about the stage required for problem (b). (10 %)

Kremser equation: $$N = \frac{\ln\left[(y_b - y_b^*)/(y_a - y_a^*)\right]}{\ln\left[(y_b - y_a)/(y_b^* - y_a^*)\right]}$$