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

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1. The linear-momentum balance for a control volume can be expressed as follows:

$$\underbrace{\Sigma\vec{F}}_{\text{Term A}} = \underbrace{\iint_{c.s.} \vec{v}\rho(\vec{v}\cdot\vec{n})dA}_{\text{Term B}} + \underbrace{\frac{\partial}{\partial t}\iiint_{c.v.} \rho\vec{v}dV}_{\text{Term C}}$$

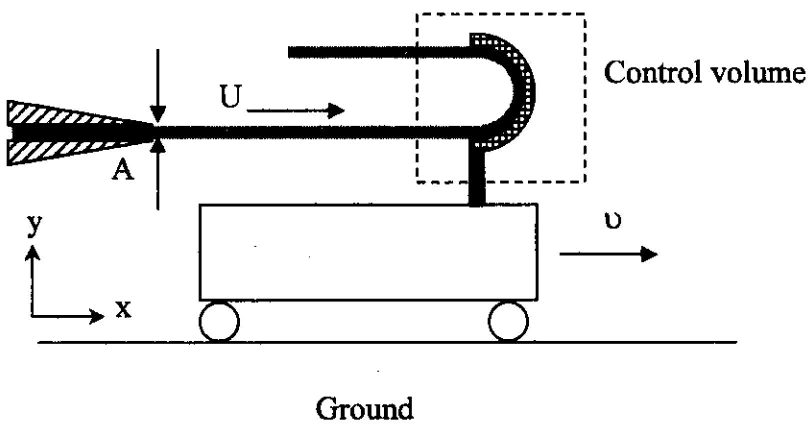
(a). What is the physical meaning for each term A, B, and C (3%)?

(b). **Write down each term** to find out the force exerted on the car due to the water jet (cross-sectional area: A; density: ρ) if:

(i). the xy coordinate system is moving at velocity υ to the right. (4%)

(ii) the xy coordinate system is fixed to the ground. (4%)

(iii) the xy coordinate system is moving at velocity υ to the left. (4%)



2. A Newtonian fluid with constant viscosity, μ, and density, ρ, is completely filled the region between two circular disks with radius, R. The bottom disk is fixed and a force, F(t), is applied onto the upper disk such that it moves very slowly toward the bottom disk at a constant speed, υ_0. The initial gap between two disks is H_0 ($H_0 \ll R$) and the instantaneous height of the upper disk is H(t). Having quasi-steady-state assumption and lubrication approximation,

(a).write down the equation of continuity and equation of motion for the problem. (5%)

(b).what are the boundary conditions? (5%)

(c).find the force F(t) to maintain the disk motion at speed υ_0. (5%)

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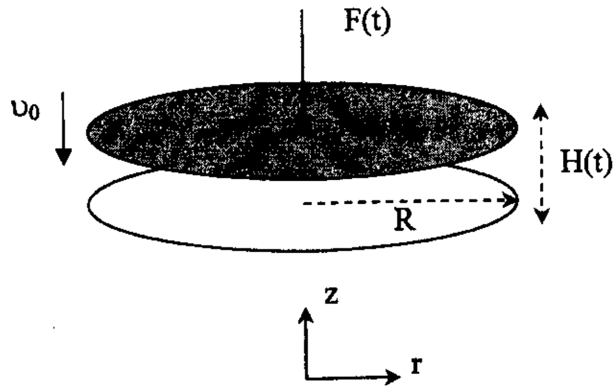

Equation of continuity (cylindrical coordinates)

$$\frac{\partial \rho}{\partial t}+\frac{1}{r}\frac{\partial}{\partial r}(r\rho\upsilon_r)+\frac{1}{r}\frac{\partial}{\partial \theta}(\rho\upsilon_\theta)+\frac{\partial}{\partial z}(\rho\upsilon_z)=0$$

Equation of motion for a Newtonian fluid (cylindrical coordinates)

$$\rho\left(\frac{\partial \upsilon_r}{\partial t}+\upsilon_r\frac{\partial \upsilon_r}{\partial r}+\frac{\upsilon_\theta}{r}\frac{\partial \upsilon_r}{\partial \theta}-\frac{\upsilon_\theta^{\,2}}{r}+\upsilon_z\frac{\partial \upsilon_r}{\partial z}\right)=-\frac{\partial P}{\partial r}+\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r\upsilon_r)\right)+\frac{1}{r^2}\frac{\partial^2 \upsilon_r}{\partial \theta^2}-\frac{2}{r^2}\frac{\partial \upsilon_\theta}{\partial \theta}+\frac{\partial^2 \upsilon_r}{\partial z^2}\right]+\rho g_r$$

$$\rho\left(\frac{\partial \upsilon_\theta}{\partial t}+\upsilon_r\frac{\partial \upsilon_\theta}{\partial r}+\frac{\upsilon_\theta}{r}\frac{\partial \upsilon_\theta}{\partial \theta}+\frac{\upsilon_r\upsilon_\theta}{r}+\upsilon_z\frac{\partial \upsilon_\theta}{\partial z}\right)=-\frac{1}{r}\frac{\partial P}{\partial \theta}+\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r\upsilon_\theta)\right)+\frac{1}{r^2}\frac{\partial^2 \upsilon_\theta}{\partial \theta^2}+\frac{2}{r^2}\frac{\partial \upsilon_r}{\partial \theta}+\frac{\partial^2 \upsilon_\theta}{\partial z^2}\right]+\rho g_\theta$$

$$\rho\left(\frac{\partial \upsilon_z}{\partial t}+\upsilon_r\frac{\partial \upsilon_z}{\partial r}+\frac{\upsilon_\theta}{r}\frac{\partial \upsilon_z}{\partial \theta}+\upsilon_z\frac{\partial \upsilon_z}{\partial z}\right)=-\frac{\partial P}{\partial z}+\mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \upsilon_z}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 \upsilon_z}{\partial \theta^2}+\frac{\partial^2 \upsilon_z}{\partial z^2}\right]+\rho g_z$$

3.(a) A dimensionless correlation is recommended for natural convection from spheres:

$Nu = 2 + 0.43\ Ra^{1/4}$

You may notice that, as Ra approaches zero, heat transfer from the surface to the surrounding medium is by conduction. Solve this problem to yield a limiting value for Nu equal to 2. (5%)

(b) Consider a large flat plate of uniform thickness L, having uniform initial temperature T_o, is placed in a new environment with its surfaces suddenly and simultaneously exposed to a fluid at temperature T_∞ .(1) What's the Biot modulus of the system? (1%) (2) Set up the differential equations for describing the time-dependent heat transfer processes according to $Bi \ll 1$, $Bi \doteqdot 1$, and $Bi \gg 1$, respectively. (9%)

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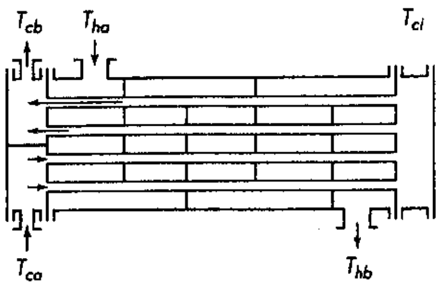
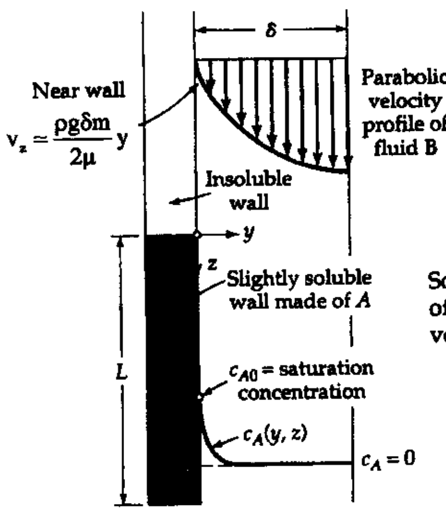
4.(a) Name the following shell-and-tube heat exchanger. (2%)

(b)Plot the temperature-length curves for the heat exchanger. (3%)



5. Liquid B is flowing in laminar motion down a vertical wall as shown in the following figure.



Solid *A* dissolving into a falling film of liquid *B*, moving with a fully developed velocity profile.

It is assumed that the velocity v_z of liquid B depends only on y for z > 0. In addition, the wall is made of a species A that is slightly soluble in B, thus for short distances downstream, species A will not diffuse very far into the falling film. That is, A will be present only in a very thin boundary layer near the solid surface. Therefore, the diffusing A molecules will experience a velocity distribution that is characteristic of the falling film right next to the wall, y = 0.

(a) (5%) The velocity profile is given by

$$v_z = \frac{\rho g \delta^2}{2\mu}\left[m\left(\frac{y}{\delta}\right) - \left(\frac{y}{\delta}\right)^2\right]$$

where δ is the film thickness, ρ and μ are the density and viscosity of the fluid, respectively. Please find the constant m in the above expression by the boundary condition at y = δ.

(b) (5%) Derive the governing equation (which is a partial differential equation) and the corresponding boundary conditions for $c_A(y,z)$, the concentration of A in B near the wall. (Do not solve the equations.)

(背面仍有題目,請繼續作答)

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(c) (7%) The molar flow of A across the entire mass transfer surface at y = 0 is given by

$$W_A = \frac{2D_{AB}c_{A0}WL}{1.1907}\left(\frac{a}{9D_{AB}L}\right)^{1/3} \quad ; \quad a = \frac{\rho g \delta}{\mu}$$

In the above expression, D_{AB} is the mutual diffusion coefficient of A and B, c_{A0} is the solubility of A in B, W and L are the width and length of the wall, respectively. Derive an expression for Sh_m (Sherwood number) in terms of L/δ, Re (Reynolds number) and Sc (Schmidt number) as in the following form

$$Sh_m = b\left(\frac{L}{\delta}\right)^c (Re\,Sc)^d$$

That is, derive the values of b, c and d in the above expression. The Sherwood number, Reynolds number and Schmidt number are defined, respectively,

$$Sh_m = \frac{k_m L}{D_{AB}} \quad ; \quad Re = \frac{L v_{max} \rho}{\mu} \quad ; \quad Sc = \frac{\mu}{\rho D_{AB}}$$

Here k_m is the mass transfer coefficient and v_{max} is the maximum velocity of the flow.

(d) (8%) Find the j-factor for mass transfer j_D, and friction coefficient f, as functions of Re and L/δ in this system.

6. A packed bed absorption tower is fed at the bottom with a gas containing 1 mol% ammonia and 99 mol% air. At the top of the column water is introduced, which contains 0.002 mol% ammonia. Other data are as follows:

Total pressure, 1 atm
Temperature, 25°C
The inlet gas flow rate, 5 moles/hr
The inlet liquid flow rate, 100 moles/hr
Cross-sectional area of the tower, 0.8 ft^2
Individual mass transfer coefficient for gas phase, $k_y a$ = 15 moles/hr ft^3
Individual mass transfer coefficient for liquid phase, $k_x a$ = 70 moles/hr ft^3
Equilibrium line, $y_e = 7x_e$

(a) Find the operating line if the ammonia concentration in the outlet gas reduces to 0.08 mol%. (5%)
(b) Determine the overall height of a transfer unit, H_{Oy}. (6%)
(c) Determine the height of packing. (7%)
(d) Determine the interface mole fractions corresponding to a gas phase mole fraction 0.005. (7%)