**1. (5%)** Regarding the Hagen-Poiseuille equation for flows in circular pipes, answer "**True**" or "**False**" to each of the following statements. **Each 1%.**

(a) Applicable to flows at a steady state only.
(b) Applicable to non-Newtonian fluids.
(c) Applicable to flows in a pipe that is held fixed only.
(d) Applicable to flows with $Re < 0.1$.
(e) Applicable to flows that are driven purely by pressure drops.

**2. (5%)** Let's consider an incompressible and Newtonian fluid. Its flow is at a non-steady state with a Reynold's number of approximately 0.05 (Re=0.05). Answer "**Yes**" or "**No**" to each of the following equations that can be used to describe the flow system. **Each 1%.**

(a) Equation of continuity.
(b) Equation of motion in terms of viscous force.
(c) Navier-Stokes equation.
(d) Euler equation.
(e) Steady Stokes (creeping) flow equation.

**3. (5%)** Followings are statements associated with adsorption, absorption, and related processes. Answer "**True**" or "**False**" to each of the following statements. **Each 1%.**

(a) Both adsorption and absorption can be purely physical processes or involving chemical reactions.
(b) The stripping process is a reverse operation of absorption.
(c) The adsorption process is commonly used to remove trace moisture in air to produce dry air.
(d) Co-current flow arrangements are most commonly used in absorption processes to obtain a higher mass transfer rate than counter-current flow.
(e) In absorption, solute molecules diffuse from the bulk of a gas phase to the bulk of a liquid phase, while for adsorption, molecules diffuse from the bulk of the fluid to the surface of the solid adsorbent forming an adsorbed phase.

4. **(5%)** Followings are statements associated with transport and related processes. Answer "**True**" or "**False**" to each of the following statements. **Each 1%.**

(a) The Schmidt number for mass transfer is analogous to the Prandtl number for heat transfer.
(b) The thermal diffusivity, mass diffusivity, and momentum diffusivity (kinematic viscosity) all have the same dimensions.
(c) For gaseous substances at a pressure below 10 atm, the thermal diffusivity, mass diffusivity, and viscosity are all independent of pressure.
(d) In the cooling tower, the reduction of water temperature comes mainly from evaporation. It is therefore required that the ambient web-bulb temperature is above that of the water temperature.
(e) The heat transfer coefficient in the nucleate boiling regime is higher than that in the film boiling regime.

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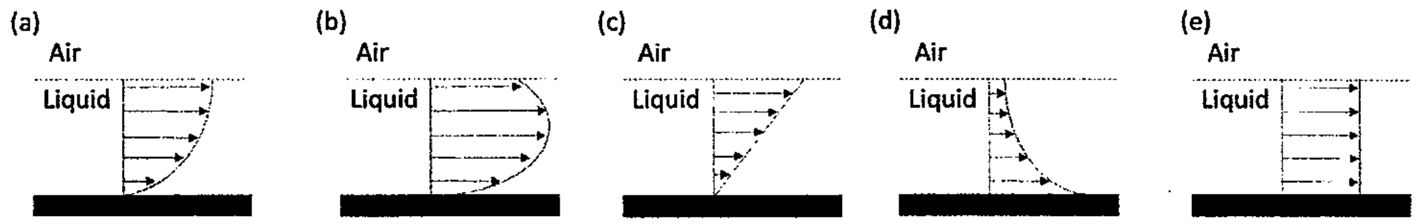
**5. (5%)** The flow shown below is a Newtonian and incompressible fluid sitting on top of an infinitely large plate that may be moving or fixed. Also, the flow may or may not be influenced by gravitational force along the flow direction. Answer "Yes" or "No" to each of the profiles shown below to indicate it is physically possible. **Each 1%.**




**6. (10%)** For an incompressible and Newtonian fluid (density and viscosity: $\rho$ and $\mu$, respectively) in a cylindrical container that is initially at rest. There is a sudden motion applied to rotate the container at an angular velocity. The time-dependent velocity profile along the $\theta$ direction ($v_\theta$) in this system using cylindrical coordinates can be determined by the following partial differential equation:

$$\rho \frac{\partial v_\theta}{\partial t} = \mu \frac{\partial}{\partial r}\left[\frac{1}{r}\frac{\partial}{\partial r}(r v_\theta)\right]$$

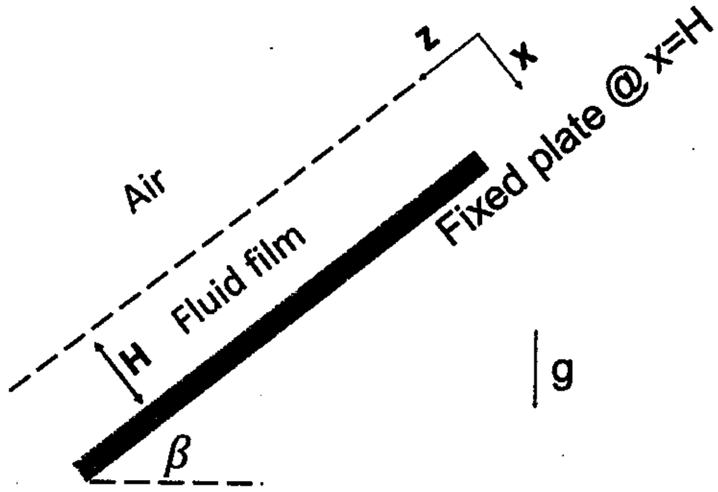
**(a) (5%)** Perform a dimensional analysis to express the above PDE in terms of dimensionless variables ($\tilde{r}, \tilde{v}_\theta, and\ \tilde{t}$). Use $l_o$ and $v_o$ as the characteristic length and velocity, respectively. With these, you can then define a reasonable characteristic time accordingly.

**(b) (2%)** Define Reynold's number (Re) from your analysis in (a) above.

**(c) (3%)** Assuming that you place the same fluid in two containers (A and B) of different sizes (i.e., $R_A$=R and $R_B$=3R in radius) and the Container A rotates at an angular velocity of $\Omega$. What should the angular velocity of the Container B be in order to maintain the dynamic similarity between the two systems? Let's choose $l_o$ and $v_o$ to be the container's radius and rotating speed, respectively.

**7. (10%)** Consider a liquid film of Bingham and incompressible fluid (density $\rho$) on an inclined and infinitely large plate with a thickness of H. If the fluid flows down the inclined plate, the flow is steady-state and laminar without any edge effects. The system's coordinates have been defined as schematically illustrated on the right. **You are NOT allowed to define a new coordinate system otherwise 0 pts.**

For the Bingham fluid in this system, its stress-strain relationship is shown below:

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$$\frac{dv_z}{dx} = 0 \;\; ; \; if\ |\tau_{xz}| < \tau_o$$

$$\tau_{xz} = \tau_o - \mu\frac{dv_z}{dx} \;\; ; \; if\ |\tau_{xz}| \geq \tau_o$$

In this system, the tilted angle ($\beta$) of the plate is considered as a controllable variable; you are asked to develop a criterion in terms of $\beta$ for determining when the fluid will flow down the plate.

*You may find the following equations (in cartesian coordinates) potentially useful:

**Equation of continuity:** $\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho v_x) + \frac{\partial}{\partial y}(\rho v_y) + \frac{\partial}{\partial z}(\rho v_z) = 0$

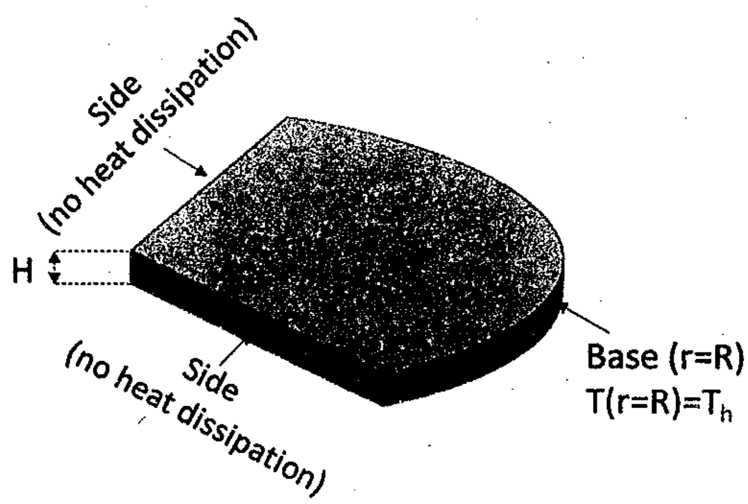
**Equation of motion in terms of $\tau$:**

$$\begin{cases} \rho\left(\frac{\partial v_x}{\partial t} + v_x\frac{\partial v_x}{\partial x} + v_y\frac{\partial v_x}{\partial y} + v_z\frac{\partial v_x}{\partial z}\right) = -\frac{\partial p}{\partial x} - \left[\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z}\right] + \rho g_x \\ \rho\left(\frac{\partial v_y}{\partial t} + v_x\frac{\partial v_y}{\partial x} + v_y\frac{\partial v_y}{\partial y} + v_z\frac{\partial v_y}{\partial z}\right) = -\frac{\partial p}{\partial y} - \left[\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z}\right] + \rho g_y \\ \rho\left(\frac{\partial v_z}{\partial t} + v_x\frac{\partial v_z}{\partial x} + v_y\frac{\partial v_z}{\partial y} + v_z\frac{\partial v_z}{\partial z}\right) = -\frac{\partial p}{\partial z} - \left[\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}\right] + \rho g_z \end{cases}$$

**Navier-Stokes equation:**

$$\begin{cases} \rho\left(\frac{\partial v_x}{\partial t} + v_x\frac{\partial v_x}{\partial x} + v_y\frac{\partial v_x}{\partial y} + v_z\frac{\partial v_x}{\partial z}\right) = -\frac{\partial p}{\partial x} + \mu\left[\frac{\partial^2 v_x}{\partial x^2} + \frac{\partial^2 v_x}{\partial y^2} + \frac{\partial^2 v_x}{\partial z^2}\right] + \rho g_x \\ \rho\left(\frac{\partial v_y}{\partial t} + v_x\frac{\partial v_y}{\partial x} + v_y\frac{\partial v_y}{\partial y} + v_z\frac{\partial v_y}{\partial z}\right) = -\frac{\partial p}{\partial y} + \mu\left[\frac{\partial^2 v_y}{\partial x^2} + \frac{\partial^2 v_y}{\partial y^2} + \frac{\partial^2 v_y}{\partial z^2}\right] + \rho g_y \\ \rho\left(\frac{\partial v_z}{\partial t} + v_x\frac{\partial v_z}{\partial x} + v_y\frac{\partial v_z}{\partial y} + v_z\frac{\partial v_z}{\partial z}\right) = -\frac{\partial p}{\partial z} + \mu\left[\frac{\partial^2 v_z}{\partial x^2} + \frac{\partial^2 v_z}{\partial y^2} + \frac{\partial^2 v_z}{\partial z^2}\right] + \rho g_z \end{cases}$$

**8. (15%)** Consider a thin cylindrical wedge, as schematically shown on the right, that has a constant thermal conductivity $k$, thickness $H$, radius $R$, and angle $\alpha$. The base of the wedge has a constant temperature of $T_h$ (i.e., $T(r=R)=T_h$), and its surfaces except the two sides dissipate heat to the air that is at a temperature of $T_a$ with a heat transfer coefficient of $h$ (i.e., following Newton's law of cooling). The entire system is at a steady state.




(a) **(4%)** Define Biot number (Bi). Also, should the system have a large or small Bi number such that it can be considered as an one-dimensional system? That is, the temperature profile is only a function of r (i.e., T=T(r)). Briefly state your reason.

(b) **(11%)** Derive the temperature profile T(r).
Hint: for a 2nd order ODE in a form of $x^2y'' + xy' - \lambda^2 y = 0$, its general solution is $y = c_1 I_o(\lambda x) + c_2 K_o(\lambda x)$ where $I_o$ and $K_o$ are the modified Bessel functions of the first and second kind of an order 0, respectively. It is also known that $K_o(0) = \infty$.

*You may find the following equations (in cylindrical coordinates) potentially useful:

**Fourier's law of heat conduction:** $\begin{cases} q_r = -k\frac{\partial T}{\partial r} \\ q_\theta = -k\frac{1}{r}\frac{\partial T}{\partial \theta} \\ q_z = -k\frac{\partial T}{\partial z} \end{cases}$

**Equation of energy for non-moving materials with constant $\rho$ and $k$:**

$$\rho\widehat{C_p}\frac{\partial T}{\partial t} = k\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2} + \frac{\partial^2 T}{\partial z^2}\right]$$

9 **(10%)** For a spherical particle flowing in a fluid, the friction factor is $\left(\sqrt{24/Re} + 0.54\right)^2$ for Re below 2000, and is 0.44 for Re in the range between 2000 and 100000. Answer the following questions. Note: if the required quantities are not given, you may clearly define and use them.

(a) (5%) Calculate the terminal velocity for a ping-pong ball 2 gram in weight and 4 cm in diameter falling in air at 300 K. The air viscosity is $2*10^{-5}$ Pa.s.

(b) (5%) For a sedimentation process of dilute suspensions operated at 300 K, calculate the terminal velocity of the suspension particles. The particle and fluid densities are 1.1 and 1 g/cm$^3$, respectively, the viscosity of the fluid is 0.02 poise and the suspensions are spherical particles with a diameter of 0.07 mm.

10 **(10%)** A 0.5-mm-thick square silicon chip is mounted to a 2-mm-thick aluminum plate with a thin layer of glue in between. The width and length of the chip and the aluminum plate are both 2 cm. Both sides of this sandwiched system are exposed to the flowing air at 25°C with the convection coefficient of 100 W/m$^2$.K. The thermal conductivity of silicon and aluminum are 150 and 240 W/m.K, respectively. The chip dissipates $10^4$ W/m$^2$ under normal condition. If the heat transfer is one-dimensional and the chip is isothermal, answer the following questions. Note: if the required quantities are not given, you may clearly define and use them.

(a) (5%) Find the thermal resistance of the thin layer of glue required for the steady state chip temperature to be not greater than 80°C.

(b) (5%) One engineer states that the thickness of the aluminum plate is very critical to the wafer steady-state temperature. Do you agree? State your reason.

11 **(20%)** A benzene-toluene mixture containing 50 mol% of benzene at a feed rate of 100 kmol/hr is to be separated using a fractionating column. The top and bottom products contain 90 and 10 mol% of benzene, respectively. The vapor leaves the column is with reflux and product and is condensed but not cooled. The T-xy diagram for benzene and toluene mixture at 1 atm is shown below. Answer the following questions.

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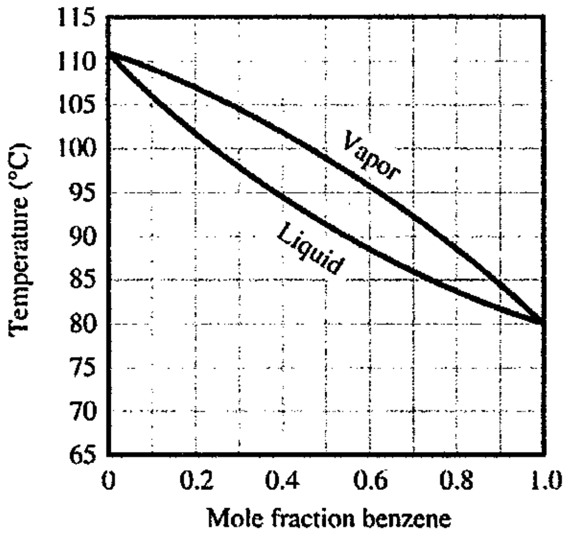
(a) (5%) Find the flow rate of the top and bottom products.

(b) (5%) Find the minimum reflux ratio if the feed enters the column at its boiling point.

(c) (5%) If feed enters the column is 50% of saturated liquid, find the relative volatility.

(d) (5%) Show that the slope of the operating line in the stripping section is greater than one.




**試題隨卷繳回**