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 0307 節次 1

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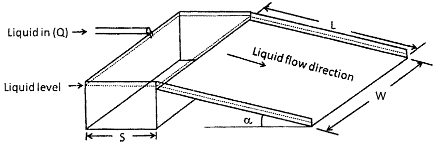
1 The figure shows a Newtonian liquid with constant density ρ and viscosity μ flows into an open rectangular tank and then the fluid flows over the lower edge of the tank onto an inclined-plane surface. As the fluid flows down the inclined plate, it entrains a liquid film with a constant thickness δ. The flow is steady and fully developed. Assume L >> δ, S >> δ, and W >> δ. Also neglect edge and entrance effects.

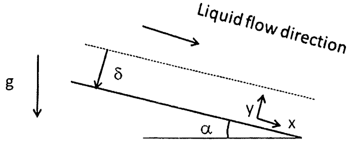
(a) (8 %) For the liquid on the inclined plate, write down the differential mass balance. Also write down the differential momentum balance in the x direction.

(b) (6 %) For the liquid on the inclined plate, derive the liquid velocity υ_x and the shear stress τ_{yx}.

(c) (6 %) Please derive the inlet mass rate of flow Q in order to maintain the liquid level and the liquid film with a constant thickness δ.



Side view



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2. (5 %) The friction loss, h_L, in pipe flow can be expressed as follows.

$$h_L = f\frac{L}{D}\frac{\upsilon^2}{2g}$$

where L is the pipe length and g is the acceleration due to gravity f is a dimensionless coefficient depends on the average velocity υ of the pipe flow, the pipe diameter D, the fluid density ρ, the fluid viscosity μ, and the average pipe wall unevenness e (length). Using Buckingham π theorem with the core group of υ, D and ρ, find a dimensionless function for the coefficient f

3 A liquid flows upward in a 100 m long, vertical tube with reducing diameter. The diameter at the inlet is 8 times larger than that at the outlet. If the average velocity at the inlet is 1 m/s, the pressure difference between the inlet and the outlet is 4 kPa, the density is 1 g/cm^3, and the heat added to the liquid is 15 J/g,

(a) (2 %) write down the integral relation for the conservation of energy

(b) (8 %) if the specific heat of the liquid is 4.2 J/(g-K), what is the change in liquid temperature?

4. (a) (12 %) The temperatures at the inner and outer surfaces of a plane wall of thickness d are held at the constant values T_0 and T_d, respectively, where $T_0 > T_d$. The wall material has a thermal conductivity k that varies linearly according to $k = k_0 (1 + \beta T)$, k_0 and β being constants. At what point will the actual temperature profile differ most from that which would exist in the case of constant thermal conductivity?

(b) (4 %) Consider laminar forced convection in a circular tube. Will the heat flux be higher near the inlet of the tube or near the exit? Why?

(c) (4 %) Many heat exchangers are designed to transfer heat from cylinders subjected to cross flow. Please explain why the Reynolds analogy, which permits the calculation of heat transfer from the skin-friction factors, does not apply in such cases.

5 A spherical droplet of a pure liquid is held stationary in a large volume of still air. The liquid evaporates, and the drop radius R decreases with time t. Develop a quasi-steady model from which the radius may be found as a function of time. Assume that the external phase controls the mass transfer (i.e., the evaporation rate) and that the Sherwood number is 2 (Sh = 2).

(a) (8 %) Present a differential equation for R(t). State clearly any assumptions you made.

(b) (6 %) Solve the differential equation to find R(t).

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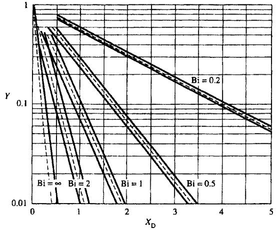
6. (6 %) A droplet of a non-volatile viscous liquid, at a uniform temperature of 300 K, and with a uniformly distributed initial concentration of a solute, is suddenly exposed to a large volume of air containing none of the volatile solute. The droplet has an initial diameter D of 173 μm, and it is suspended in the air under such conditions that the Sherwood number is 2. The diffusion coefficient D^{air} of the volatile species in the surrounding air is 0.3 cm^2/s. The diffusion coefficient of the volatile species in the viscous liquid, D_{AB} is 3×10^{-5} cm^2/s. Please estimate the time required for the concentration of the solute, at the center of the droplet, to fall to 1% of its initial value. The Gurney-Lurie chart of Y vs. X_D for transient diffusion (or conduction) in a sphere is given in the following. Here Y, the dimensionless concentration, and X_D, the dimensionless time, are defined as

$$Y=\frac{C_A-C_A^\infty}{C_A^0-C_A^\infty} \quad , \quad X_D=\frac{D_{AB}t}{D^2}$$

where C_A and C_A^0 are the concentration and initial concentration of species A in the droplet, respectively, C_A^∞ is the concentration of solute in the air, and t is the time. In the plot, for each value of the Biot number (Bi), a set of three lines is shown. The upper line is the value of Y at the center of the sphere. The dashed line is the value of Y averaged over the volume. The lower line is the value of Y at the surface.



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7 A feed consists of two components is separated into a distillate and bottom product in a distillation column with ideal trays. The following are the steady-state compositions of the more volatile component in the column.

$x_D = 0.957$	
$x_0 = 0.890$	$y_1 = 0.911$
$x_1 = 0.745$	$y_2 = 0.842$
$x_2 = 0.604$	$y_3 = 0.776$
$x_3 = 0.497$	$y_4 = 0.684$
$x_4 = 0.382$	$y_5 = 0.521$
$x_5 = 0.237$	$y_6 = 0.421$
$x_6 = 0.172$	$y_7 = 0.282$
$x_B = 0.062$	

Here, x and y denote the mole fraction in liquid and vapor respectively, x_B is the mole fraction in bottom product, x_D is the mole fraction in overhead product, x_n is the mole fraction in liquid from plate n, and y_n is the mole fraction in vapor from plate n. The system being separated has a constant relative volatility The molar ratio of the top product to the feed is 0.545

(a) (4 %) What determines the theoretical maximum extent of separation for a distillation column?
(b) (3 %) What is the composition of the feed?
(c) (3 %) Is a total or partial condenser being used? Why?
(d) (3 %) What is the value of the relative volatility?
(e) (3 %) What is the reflux ratio being used?
(f) (3 %) Assume q is the moles of liquid to stripping section of column per mole of feed. What is the q value for the feed?
(g) (2 %) What is the feed condition?
(h) (4 %) Find the feed line.