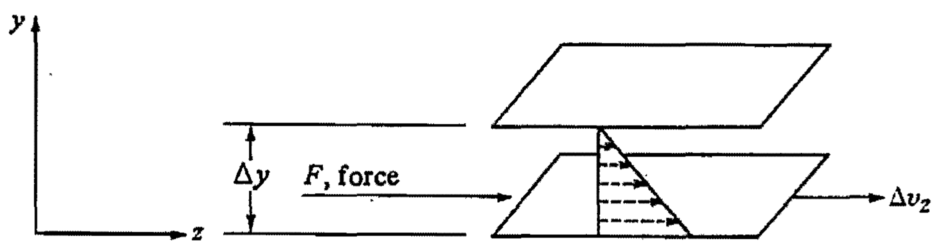
國立雲林科技大學
100學年度碩士班暨碩士在職專班招生考試試題
系所：化材系
科目：單元操作與輸送現象

1. Whole milk at 293 K having a density of 1030 kg/m^3 and viscosity of 2.12 cp is flowing at the rate of 0.605 kg/s in a glass pipe having a diameter of 63.5 mm.
   (a) Calculate the Reynolds number. Is this turbulent flow? (10%)
   (b) Calculate the flow rate needed in m^3/s for a Reynolds number of 2100 and velocity in m/s. (10%)

2. Using the below figure, the lower plate is being pulled at a relative velocity of 0.40 m/s greater than the top plate. The fluid used is water at 24°C (viscosity of 0.9142×10^{-3} Pa・s).
   (a) How far apart should the two plates be placed so that the shear stress τ is 0.30 N/m^2? Also, calculate the shear rate. (10%)
   (b) If oil with a viscosity of 2.0×10^{-2} Pa・s is used instead at the same plate spacing and velocity as in part (a), what are the shear stress and the shear rate? (10%)



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3. A fluid flowing in laminar flow in the x direction between two parallel plates has a velocity profile given by the following

$$v_x = v_{x\,\max}\left[1 - \left(\frac{y}{y_0}\right)^2\right]$$

where $2y_0$ is the distance between the plates, y is the distance from the center line, and v_x is the velocity in the x direction at position y. Derive an equation relating $v_{x\,av}$ (bulk or average velocity) to $v_{x\,max}$. (10%)

4. Consider a steam pipe of length L= 30 m, inner radius r_1= 6 cm, outer radius r_2= 10 cm, and thermal conductivity k=20 W/m.℃. The inner and outer surfaces of the pipe are maintained at average temperatures of $T_1 = 180$℃ and $T_2 = 60$℃, respectively. (12% all)

(a). Assume: one-dimensional heat conduction in the r direction only, i.e. $T = T(r)$, steady-state, and there is no heat generation. The heat equation can be can be derived as:

$$\frac{d}{dr}\left(r\frac{dT}{dr}\right) = 0$$

Together with the following boundary conditions:

$$T(r_1) = T_1 \quad \text{and} \quad T(r_2) = T_2$$

Derive that the temperature distribution inside the pipe is:

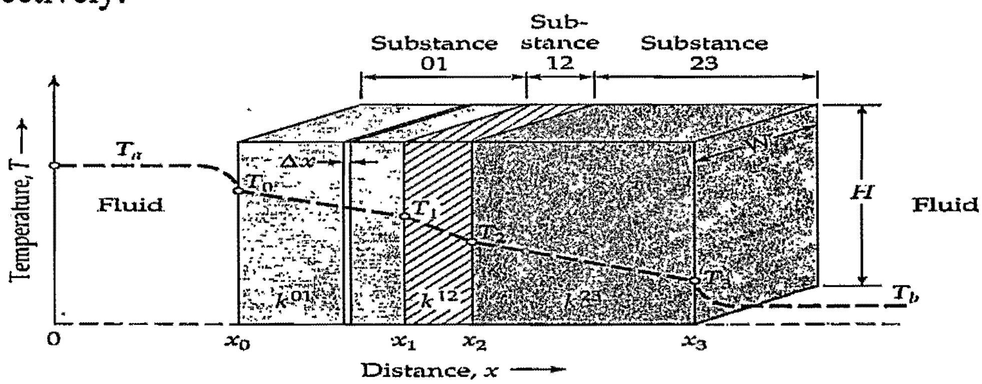
$$T(r) = \frac{(T_2 - T_1)}{\ln(r_2/r_1)}\ln(r/r_1) + T_1 .$$ 4%

(b). ***Calculate*** the heat flux at $r = 8$ cm. 4%

(c). ***Calculate*** the rate of heat conduction through the pipe. 4%

5. ***Heat conduction through composite walls*** (14% all)

(a). As shown in the following figure, a composite wall is made up of three materials of different thicknesses, $x_1 - x_0$, $x_2 - x_1$, and $x_3 - x_2$, and different conductivities k_{01}, k_{12}, and k_{23}. At $x = x_0$, substance 01 is in contact with a fluid at temperature T_a, and at $x = x_3$, substance 23 is in contact with a fluid at temperature T_b. The convective heat transfer coefficients at the boundaries $x = x_0$ and $x = x_3$ are h_0 and h_3, respectively.



BIRD: *Transport Phenomena, 2e*
Fig. 10.6-1 W-150

Assume: one-dimensional heat conduction in the x direction only, i.e. $T = T(x)$, steady-state, and there is no heat generation. ***Derive that*** the heat flux can be calculated by:

$$q_0 = U(T_a - T_b)$$

where U, called the "overall heat transfer coefficient," is given by:

$$\frac{1}{U} = \frac{1}{h_0} + \frac{x_1 - x_0}{k_{01}} + \frac{x_2 - x_1}{k_{12}} + \frac{x_3 - x_2}{k_{23}} + \frac{1}{h_3}$$ 5%

Hint:

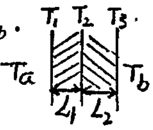
The energy balance equation $\frac{d}{dx} q_x = 0$ and the Fourier's law $q_x = -k\frac{dT}{dx}$.

(b). Now, consider only two layers. A composite wall is made up of two materials of different thicknesses, $L_1 = 0.004$ m and $L_2 = 0.01$ m, different conductivities $k_1 = 0.78$ W/m.℃ and $k_2 = 0.026$ W/m.℃, and same surface areas $A = 1.2$ m^2. The temperatures of the two fluid streams are $T_a = 30$℃ and $T_b = 0$℃. The convective heat transfer coefficients at the boundaries are $h_a = 10$ W/m^2.℃ and $h_b = 40$ W/m^2.℃. ***Calculate***:

(i). The overall heat transfer coefficient U and the heat flux q_0. 4%

(ii). The temperatures at the boundaries of the two materials T_1, T_2, and T_3. 5%

Note: The temperatures are in the order of $T_a \to T_1 \to T_2 \to T_3 \to T_b$.



6. Air at 70 °F (T_{b1}) and 1 atm is to be pumped through a straight 2-in (D) i.d. tube at a rate of 70 lb$_m$/hr (w). A section of the tube is to be heated to an inside wall temperature of 250 °F (T_O) to raise the air temperature. The heated length is 20 ft (L). The physical properties of air are as follows: viscosity μ =0.05 lb$_m$/hr-ft, specific heat C_p =0.242 Btu/lb$_m$-°F, and thermal conductivity k = 0.018 Btu/hr-ft-°F. ***Calculate***: (12% all)

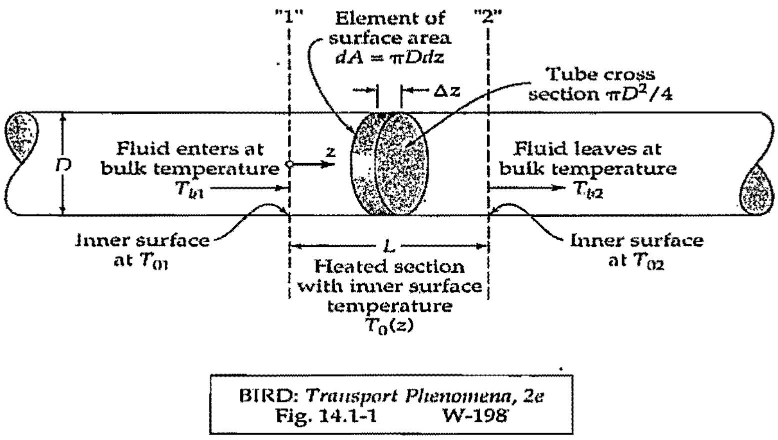
(a). The logarithmic mean heat transfer coefficient $h_{\ln}$. 4%

(b). The bulk temperature of air at the exit of the heated region T_{b2}. 4%

(c). The rate of heat flow Q. 4%

Hint:

As shown in the following figure, a fluid flows through a circular tube of diameter D, in which there is a heated wall section of length L and varying inside surface temperature $T_O(z)$, going from T_{O1} to T_{O2}. The bulk temperature T_b of the fluid increases from T_{b1} to T_{b2} in the heated section.



The logarithmic mean temperature difference $\Delta T_{\ln}$ and the logarithmic mean heat transfer coefficient $h_{\ln}$ are defined as:

$$Q = h_{\ln}(\pi D L)\Delta T_{\ln}$$

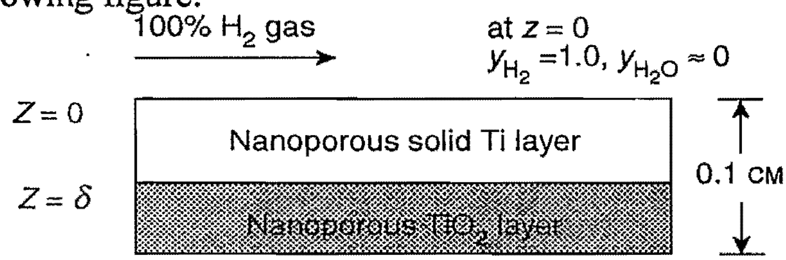
$$\Delta T_{\ln} = (T_0 - T_b)_{\ln} = [(T_{01} - T_{b1}) - (T_{02} - T_{b2})]/[\ln(T_{01} - T_{b1}) - \ln(T_{02} - T_{b2})]$$

where the rate of heat flow Q can also be calculated by:

$$Q = wC_p(T_{b2} - T_{b1})$$

$h_{\ln}$ can be estimated by the following correlations: for highly turbulent flow ($\mathrm{Re} > 20{,}000$), $Nu_{\ln} = 0.026\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{1/3}$ and for laminar flow, $Nu_{\ln} = 1.86(\mathrm{Re}\,\mathrm{Pr}\,D/L)^{1/3}$. The dimensionless parameters are defined as: $\mathrm{Pr} = C_p\mu/k$, $\mathrm{Re} = D\,v_b\,\rho/\mu = 4w/(\pi D\mu)$, and $Nu_{\ln} = h_{\ln}D/k$.

7. As part of the manufacturing process for the fabrication of titanium-oxide-based solar panels, a layer of nonporous titanium oxide must be reduced to metallic titanium, Ti, by hydrogen gas as shown in the following figure: <u>(12% all)</u>



The reaction at the Ti/TiO_2 boundary is given by:

$$TiO_2(s) + 2H_2(g) \rightarrow Ti(s) + 2H_2O(g)$$

Let species A represent H_2 (g) and species B represent H_2O (g). Further assume: (1). The non-homogeneous reaction occurs only at the TiO_2/Ti surface, i.e. there is no reaction occurring when species A (H_2) diffuses in the Ti layer (R_A=0)；(2) The diffusion of species A (H_2) is under steady state and one-dimensional (z-direction) conditions.

(a). Using the following boundary conditions: $z=0$, $y_A=1.0$ and $z=\delta$, $y_A=0$, ***derive that*** $N_{A,z}=\dfrac{cD_{AB}}{\delta}$. 6%

Where c, D_{AB} are the gas phase concentration and diffusivity, respectively.

(b). Further consider a pseudo steady-state condition for the growth of the Ti layer (thickness δ). Using the following boundary conditions: $t=0$, $\delta=\delta_1$ and $t=\theta$, $\delta=\delta_2$, ***derive that*** $\theta=\dfrac{\rho_{Ti}/M_{Ti}}{cD_{AB}}(\delta_2{}^2-\delta_1{}^2)$. 6%

Where ρ_{Ti}, M_{Ti} are the density and molecular weight of Ti, respectively.

Hint:

The general differential equation for mass transfer of species A：

$$\frac{\partial c_A}{\partial t}+\left[\frac{\partial N_{A,x}}{\partial x}+\frac{\partial N_{A,y}}{\partial y}+\frac{\partial N_{A,z}}{\partial z}\right]=R_A$$

Fick's equation of species A：

$$N_{A,z}=-cD_{AB}\frac{dy_A}{dz}+y_A(N_{A,z}+N_{B,z})$$