國立台灣科技大學九十七學年度碩士班招生試題

系所組別：化學工程系碩士班

科　　目：輸送現象與單元操作

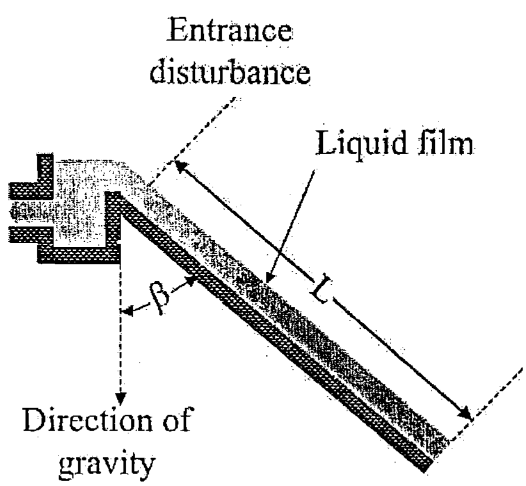
※總分100分

1. (6 points) Give the definition and physical meaning of the Prandtl number and Nusselt number in the heat transfer

2. (8 points) A room is constructed of an inner layer of 12 mm of pine, a middle layer of 140 mm of cork board, and an outer layer of 70 mm of concrete. The temperature of wall surface is -20°C inside the cold room and 27°C at the outside surface of the concrete. The conductivities for pine, cork and concrete are 0.15, 0.04 and 0.76 W/m K, respectively. Calculate the heat loss in W for 1 m^2.

3. Ammonia gas and nitrogen gas are diffusing in counter-diffusion through a straight glass tube 0.6 m long with a diameter of 25 mm at 300K and 101.32 kPa. Both ends of the tube are connected to large mixed chambers at 101.32 kPa. The partial pressure of NH_3 is constant at 20.0 kPa in one chamber and 6.67 kPa in the other. The diffusivity at 298 K and 101.32 kPa is 2.3×10^{-5} m^2/s.
   (a) (8 points) Calculate the diffusion of NH_3 in mol/s.
   (b) (3 points) Calculate the diffusion of N_2 in mol/s.
   (c) (4 points) Calculate the partial pressure at a point 0.3 m in the tube.

4. In the following figure, a Newtonian fluid with constant density ρ and viscosity μ flows at steady state on an inclined plate of length L and width W. The flow is a creeping, fully-developed and laminar flow.
   (a) (10 points) Show the velocity distribution in the falling film on the inclined plate. The thickness of falling film is assumed as δ
   (b) (4 points) Evaluate the average velocity of the falling film.
   (c) (4 points) Obtain the viscous force acting exerted by fluid on the inclined plate over the length L.



5. (8 points) A fluid, with density ρ and viscosity μ, approaches externally to a fixed solid body. The dimension of the body is L. The average velocity of velocity flow is v. The force F is exerted on the body by the fluid flow. By dimensional analysis, obtain the dimensionless groups formed from the variables given. Select v, ρ, and L are core variables.

國立台灣科技大學九十七學年度碩士班招生試題

系所組別： 化學工程系碩士班

科　　目： 輸送現象與單元操作

6. (15 points) A catastrophic eruption from a mountain spewed an ash plume into an altitude of 20 km. The winds then carried away these millions of tons of particles, consisting mainly of silica. One of your friends living 1000 km away from the mountain found that it started raining ashes just 50 hr after the eruption and that a 2-cm layer of ashes deposited around his house located on a small hill around 500 m high. After the eruption, the Environment Protection Agency warned that breathing silica particles smaller than 10 μm tends to cause silicosis. Your friend started to worry and collected some of the ashes to measure the density (2650 kg/m^3). Your friend recalled that both of you have learned the process of a solid spherical particle falling through stagnant fluids in the transport phenomena class, and showed you the notes taken in class.

   If m, d_{sph}, u and ρ_s are the mass, size, velocity and density of the particle, respectively, and ρ_g is the fluid density, and the F_d is the drag force, the force balance on the falling particle becomes

$$F_{\text{total}} = \frac{m}{g_c}\frac{du}{dt} = \left(\frac{\pi}{6}d_{sph}^3\right)(|\rho_s - \rho_g|)\frac{g}{g_c} - F_d$$

   and

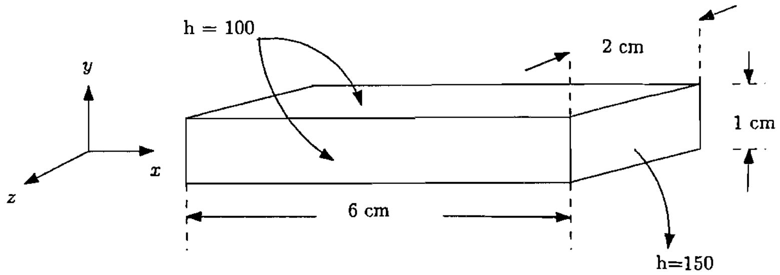
$$F_d = C_d \frac{\pi d_{sph}^2}{4}\frac{\rho_g u^2}{2g_c}$$

   where C_d is the drag coefficient.
   When the particle reaches its terminal velocity, the balance force becomes zero. And when the Reynolds number of the terminal velocity is less than one, the product of the drag coefficient and the Reynolds number is a constant.

   Please help your friend estimate the size of the particles by assuming that the particles are spherical, and let him know whether the erupted ashes could put his health in danger if the average atmospheric conditions from 500 m to 20 km are temperature = -30°C, pressure = 40 kPa, at which $\mu_{\text{air}} = 1.5 \times 10^{-5}$ kg/m s.
   Gas constant R = 8.314 J/mol K = 0.08206 liter atm/mol K = 8.314 m^3 Pa/mol K = 1.987 cal/mol K

7. A mixture contains 40 mole% isopentane, 30 mole% n-hexane, and 30 mole% heptane. If the mixture is separated by distillation in order to get a 98% recovery of n-hexane in the bottom and a 99% recovery of isopentane in the distillate. The feed is a two-phase mixture that is 40 % vapor, and the feed rate is 1000 kg moles/hr with a reflux ratio of 2.5.
   (a) (7 points) State your assumptions and estimate the distillate flow rate and bottom flow rate.
   (b) (4 points) Estimate the liquid flow rates in rectifying section and in stripping section by further assuming constant molal overflow.
   (c) (4 points) Estimate the vapor flow rates in rectifying section and in stripping section by further assuming constant molal overflow.

8. (15 points) You want to prepare some French fries by deep frying. When you measure the dimensions of the fries, you find that each strip is cut approximately 6 × 1 × 2 cm as shown below. You take the fries from a cooler at 0°C, and slip them into hot oil which is maintained at 180°C. Assuming that the heat transfer between each single fry and the oil can be regarded as an independent event, you want to know the centerpoint temperature of each fry after 5 minutes and how much heat taken up by each fry during this time.



You remember what you have learned in class. When a hot object is suddenly immersed into a cold liquid, it cools gradually. The cooling process can be described by the governing differential equation as follows.

$$\frac{\partial T}{\partial t} = \alpha \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right)$$

where α is thermal diffusivity and T is temperature at any point in the object.

Two dimensionless measures account for the cooling process. One is Fourier number, and the other is Biot number. Those two numbers are defined as $\frac{\alpha t}{L^2}$ and $\frac{hL}{k}$, respectively, where L is the characteristic length equal to half of the thickness of a slab, k is the thermal conductivity of the object, and h is the convection heat transfer coefficient. In 1975 Sucec proposed a simple relationship that can correlate the temperature at any point in a finite object with the corresponding temperature in the three mutually perpendicular infinite bodies whose intersections produce the object in question.

$$\left(\frac{\Delta T}{\Delta T_{\max}}\right)_{\text{object}} = \left(\frac{\Delta T}{\Delta T_{\max}}\right)_x \left(\frac{\Delta T}{\Delta T_{\max}}\right)_y \left(\frac{\Delta T}{\Delta T_{\max}}\right)_z$$

where the terms on the right are evaluated from the three mutually perpendicular infinite bodies in x, y, and z directions, respectively.

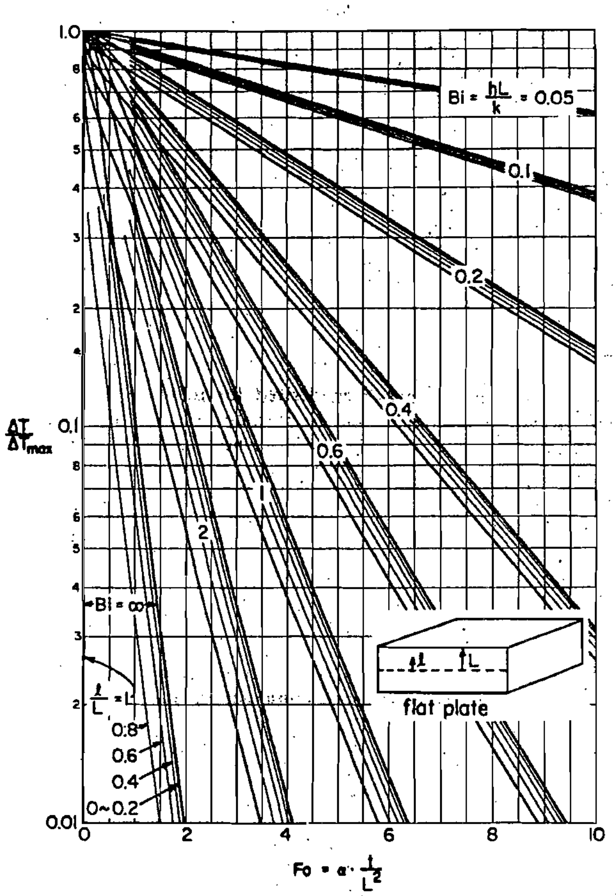
Similarly, the total heat loss from a finite object is related to the heat loss from the bounding infinite slabs by

$$\left(\frac{Q}{Q_{\max}}\right)_{\text{object}} = \left(\frac{Q}{Q_{\max}}\right)_x \left(\frac{Q}{Q_{\max}}\right)_y \left(\frac{Q}{Q_{\max}}\right)_z$$

Apparently you still need some physical properties to perform the calculation. One of your friends who works in a heat transfer laboratory kindly gives you the following data and the attached charts, hoping that you can finish the estimation of the centerpoint temperature of each fry and of how much heat taken up by each fry.

$\rho = 1050$ kg/m^3
$k = 0.5$ W/m K
$\alpha = 0.17 \times 10^{-6}$ m^2/s
$h = 150$ W/m^2 K for the two small end faces
$h = 100$ W/m^2 K for the four long faces

國立台灣科技大學九十七學年度碩士班招生試題
系所組別： 化學工程系碩士班
科　　目： 輸送現象與單元操作

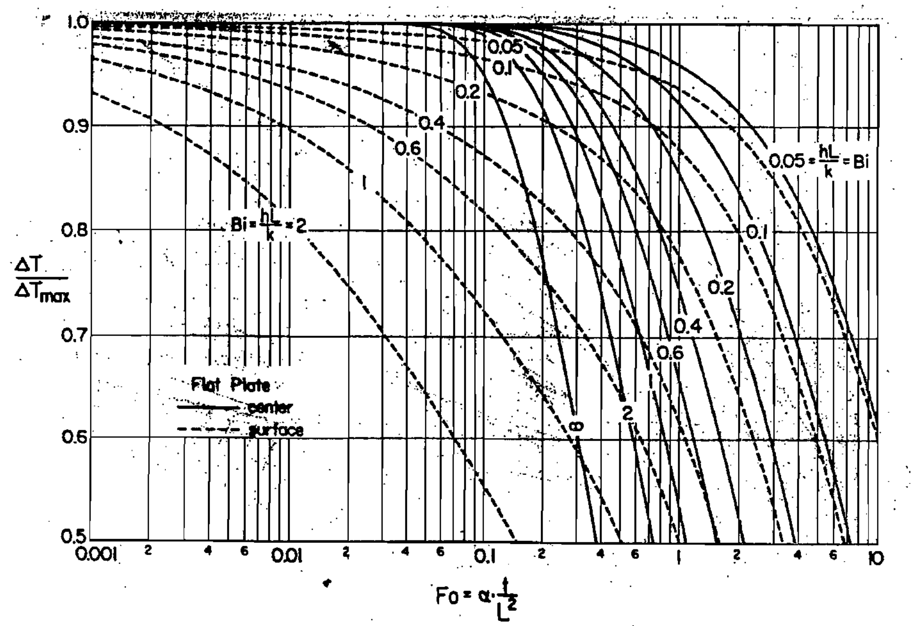


the temperature distribution within cooling infinite flat plates

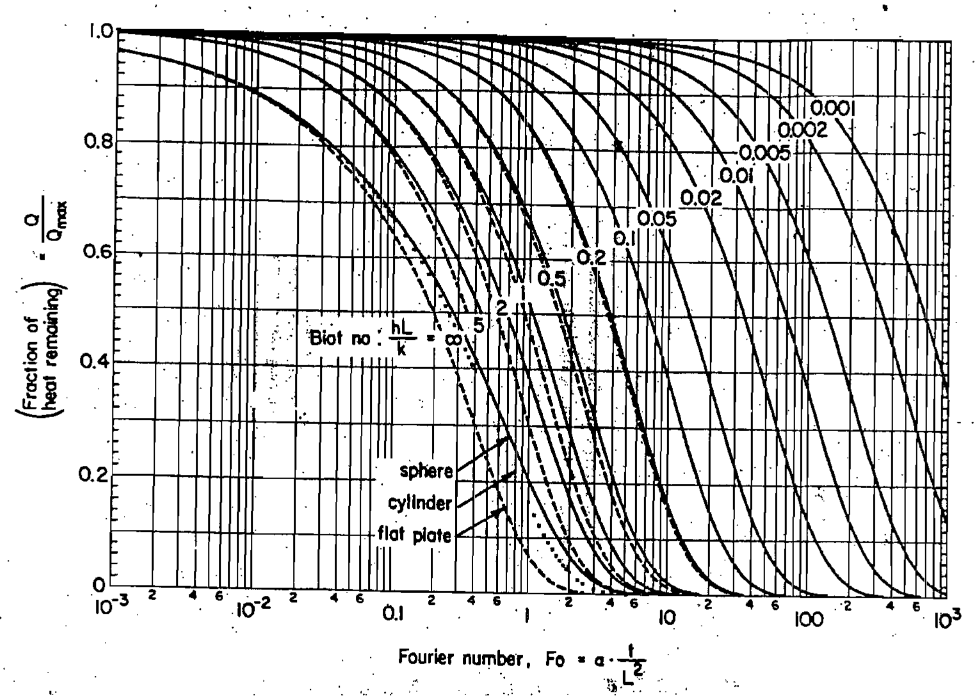
國立台灣科技大學九十七學年度碩士班招生試題

系所組別： 化學工程系碩士班

科　　目： 輸送現象與單元操作



the top left-hand corner of the previous figure



general representation of the heat loss within a cooling sphere, infinite cylinder and infinite flat plate