國立清華大學 106 學年度碩士班考試入學試題

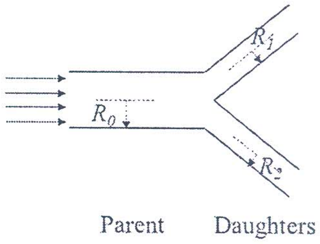
系所班組別：化學工程學系碩士班

考試科目（代碼）：輸送現象及單元操作（1001）

Problem 1 (20%)

Vascular network is part of the circulatory system that transports blood throughout the human body. In 1926, Murray presented an optimal principal called "Murray's law" to describe the minimal energy required for pumping blood through vessels. The theory was generated based on the few assumptions including Poiseuille's law. (Each sub-question is 2%) (Pick only one answer for each problem.)

1. Which is Poiseuille flow?
   (A) A flow is driven by pressure gradient with periodic variation.
   (B) A flow is transported in the direction of wave propagation
   (C) A flow is incompressible, Newtonian, steady state and laminar.
   (D) A flow has swirling current that differs from normal direction.
   (E) A flow with various shear rate from zero at the center and to a maximum at the wall.
2. If blood vessel can be described as a cylinder tube with radius R and length L, and the blood has a constant viscosity μ with pressure drop ΔP, the flow rate Q in Poiseuille equation is:
   (A) $\frac{\pi \Delta P R^3}{8\mu L}$, (B) $\frac{\pi \Delta P R^4}{8\mu L}$, (C) $\frac{\pi \Delta P R^3}{16\mu L}$, (D) $\frac{\pi \Delta P R^4}{12\mu L}$, (E) $\frac{\pi \Delta P R^2}{16\mu L}$.
3. Thus, the power P_f to maintain the viscous flow of blood is:
   (A) $\frac{8\mu L Q^2}{\pi R^3}$, (B) $\frac{12\mu L Q^2}{\pi R^4}$, (C) $\frac{16\mu L Q^2}{\pi R^2}$, (D) $\frac{8\mu L Q^2}{\pi R^4}$, (E) $\frac{16\mu L Q^2}{\pi R^3}$.
4. If the metabolic power required in a blood vessel is $P_m = k_m L \pi R^2$, where k_m is metabolic coefficient, the total power P_t required to maintain the blood flow is $P_t = P_f + P_m$. Based on this relationship, we can know that under a fixed flow rate Q, the minimum power required to maintain the blood flow is when:
   (A) $Q = \pi \sqrt{\frac{k_m}{16\mu}} R^3$, (B) $Q = \pi \sqrt{\frac{k_m}{24\mu}} R^3$, (C) $Q = \pi \sqrt{\frac{k_m}{24\mu}} R^{7/2}$,
   (D) $Q = \pi \sqrt{\frac{k_m}{12\mu}} R^3$, (E) $Q = \pi \sqrt{\frac{k_m}{16\mu}} R^{5/2}$
5. As we know, the vessels have branched structures. To simplify the model, a bifurcation geometry is used to describe a division of a main, parent, branch with radius R_0 into two daughter branches R_1 and R_2. These branches have the circular cross section. If we assume the two daughter branches have the same radius $R_1 = R_2$, based on the previous answer from sub-question 4, the $\frac{R_1}{R_0}$ will be:
   (A) 0.73, (B) 0.76, (C) 0.79, (D) 0.82, (E) 0.85 .



6. If the radius of parent branch R_0 is equal to 50 μm and flow rate in parent branch Q_0 is equal to 6 μL/min, the Reynolds number of blood in parent branch is:(assume blood has a constant viscosity and density equals to 3.5 cP and 1.025 g/cm^3, respectively)
   (A) 0.18, (B) 0.37, (C) 0.93, (D) 1.11, (E) 1.67 .
7. Reynolds number of blood in daughter branch is:
   (A) 0.09, (B) 0.15, (C) 0.24, (D) 0.85, (E) 1.27 .
8. To fabricate circular geometry of micro-level channel sometimes is limited by using current technology. Therefore, observation of blood flow in a rectangular microchannel is another compensation way to study fluid mechanics of blood. If we assume the width and height of rectangular channel is *w* and *h*, respectively, the hydraulic radius R_h can be:

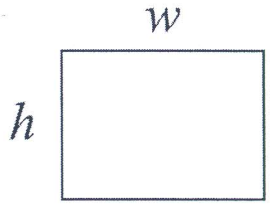
   (A) $\dfrac{2(w+h)}{w\times h}$

   (B) $\dfrac{(w+h)}{w\times h}$

   (C) $(w\times h)^{1/2}$

   (D) $\dfrac{w\times h}{(w+h)}$

   (E) $\dfrac{w\times h}{2(w+h)}$



9. Based on the previous concept, if we want to keep the same Reynolds number in parent channel like in sub-question 6, the width of parent channel will be:(assume the flow rate Q_0 is the same, channel height *h* is 50 μm)
   (A) 12 μm, (B) 50 μm, (C) 108 μm, (D) 221 μm, (E) 275 μm.
10. Again, if we want to have the same Reynolds number in daughter channel like in sub-question 7, the width of daughter channel will be:(assume the flow rate Q_1 is the same, channel height *h* is 50 μm)
    (A) 10 μm, (B) 32 μm, (C) 50 μm, (D) 72 μm, (E) 145 μm.

Problem 2 (20%)

(Pick only one answer for each problem.)

11. What is the SI unit of thermal conductivity?
    (A) W/(m K), (B) W/(m^2 K), (C) W/(cm^2 K), (D) m^2/s.

12. What is the SI unit of heat transfer coefficient?
    (A) 1/m, (B) W/(m K), (C) W/(m^2 K), (D) dimensionless.

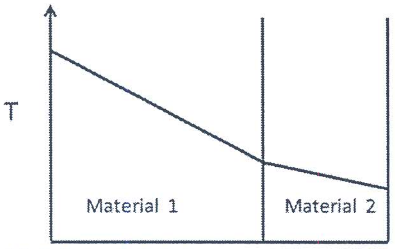
13. For the following materials, (a) H_2 at 1 atm and 273 K, (b) air at 1 atm and 273 K, (c) H_2 at 1 atm and 373 K, and (d) H_2 at 10 atm and 373 K, place them in the order of increasing thermal conductivity.
(A) (b)(a)(d)(c), (B) (b)(a)(c)(d), (C) (a)(b)(d)(c), (D) (a)(b)(c)(d).

14. What is the order of magnitude of the Prandtl number of air at 1 atm and 373 K?
(A) << 1, (B) >> 1, (C) ~ 1, and (D) ~ -1.

15. Consider an electric wire of radius R. The electric current generates heat at a rate per unit volume of Se. The surface of the wire is coated with an insulating material of thickness d and thermal conductivity k. The surface of the wire is maintained at temperature T_0. What is the rate of outflow heat at the surface of the insulating material (for a length of L) at steady state?
(A) $(k\,d/T_0)\,\pi R^2 LSe$, (B) $(T_0/k\,d)2\pi RLSe$, (C) $\pi R^2 LSe$, (D) $2\pi RLSe$.

16. Consider the viscous heating of a Newtonian fluid of constant density and viscosity, flowing between two large plates separated by a distance b. The temperature of the lower plate (located at x=0) is maintained at T_0 and that of the upper plate at T_b (located at x=b). The temperature distribution in the fluid domain can be derived to be $\left(\frac{T-T_0}{T_b-T_0}\right)=\frac{1}{2}Br\frac{x}{b}\left(1-\frac{x}{b}\right)+\frac{x}{b}$. Here, Br is the Brinkman number. Under what conditions will there exist a maximum temperature in the fluid domain? (A) Br=0, (B) Br<0, (C) Br>10, (D) any Br.

17. Consider the following steady state temperature profile in a laminated system. Which of the following statements is true?



(A) Material 1 is more thermally conductive than material 2.
(B) The normal heat flux of material 1 at the interface is greater than that of material 2.
(C) The normal heat fluxes are continuous at the interface.
(D) The normal heat flux of material 1 at the interface is less than that of material 2.

18. The equation of change for temperature in terms of the heat flux vector, $\underline{q}$, and the viscous momentum flux tensor, $\underline{\underline{\tau}}$, is given as the following.

$$\rho \hat{C}_p \frac{DT}{Dt} = -\underline{\nabla} \cdot \underline{q} - \underline{\underline{\tau}} : \underline{\nabla} \underline{v} - \left(\frac{\partial \ln \rho}{\partial \ln T} \right)_p \frac{Dp}{Dt},$$

where ρ is the density, $\hat{C}_p$ the heat capacity per unit mass, T the temperature, $\underline{v}$ the velocity vector, and p the pressure of the fluid. The symbol t is for time. All physical properties are considered constant. If Fourier's law of heat conduction applies, what form will the above equation be reduced to for heat transfer in a solid domain? (k is the thermal conductivity of the fluid.)

(A) $\rho \hat{C}_p \frac{DT}{Dt} = k\nabla^2 T + \frac{Dp}{Dt}$, (B) $\rho \hat{C}_p \frac{DT}{Dt} = k\nabla^2 T$, (C) $\rho \hat{C}_p \frac{\partial T}{\partial t} = k\nabla^2 T + \frac{Dp}{Dt}$,

(D) $\rho \hat{C}_p \frac{\partial T}{\partial t} = k\nabla^2 T$.

19. A solid material occupying the space from $y=0$ to $y=\infty$ is initially at temperature T_0. At time $t=0$, the surface at $y=0$ is suddenly raised to temperature T_1 and maintained at that temperature for $t>0$. (α and k are the thermal diffusivity and thermal conductivity of the material, respectively.) What is the normal heat flux at the solid surface?

(A) $\frac{\alpha}{\sqrt{\pi k t}}(T_0 - T_1)$, (B) $\frac{\alpha}{\sqrt{\pi k t}}(T_1 - T_0)$, (C) $\frac{k}{\sqrt{\pi \alpha t}}(T_0 - T_1)$, (D) $\frac{k}{\sqrt{\pi \alpha t}}(T_1 - T_0)$.

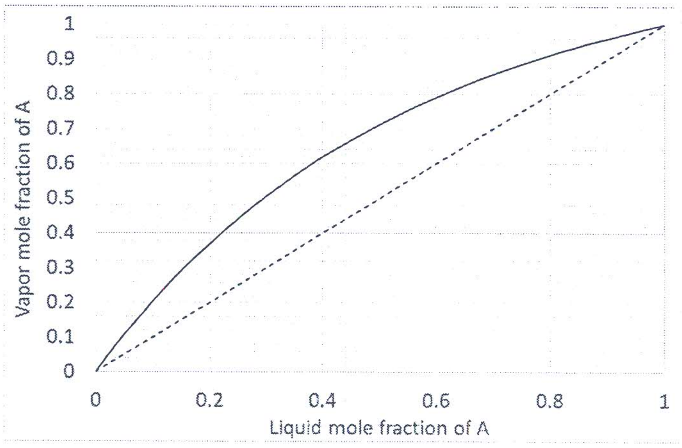
20. Consider a Newtonian fluid of velocity v_∞ and temperature T_∞ flowing over a flat plate fixed in space with its temperature maintained at T_S. There will be generated momentum and thermal boundary layers along the plate. What is the relationship between the thicknesses of the momentum boundary layer δ and thermal boundary layer δ_T if Pr is greater than 1?

(A) $\delta = \delta_T$; (B) $\delta > \delta_T$; (C) $\delta < \delta_T$; (D) none of the above.

Problem 3 (20%)

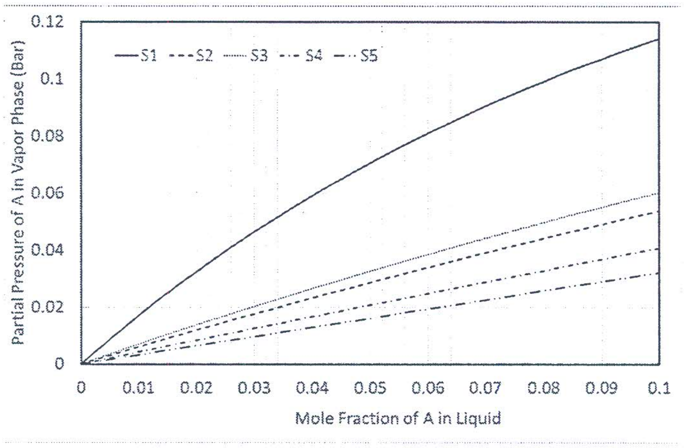
(Pick only one answer for each problem.)

Consider the following y-x diagram of a mixture A and B.



21. Calculate the minimum number of stage N_{min} required to separate a mixture containing 50 mol% of A into a distillate containing 90 mol% of A and a bottom containing 10 mol% of A. (5%)
    (A) $N_{min} < 3$
    (B) $3 \leq N_{min} < 4$
    (C) $4 \leq N_{min} < 5$
    (D) $5 \leq N_{min} < 6$
    (E) $6 \leq N_{min}$

22. Calculate the minimum reflux R required to separate a liquid mixture containing 50 mol% of A into a distillate containing 90 mol% of A and a bottom containing 10 mol% of A. (5%)
    (A) $R_{min} < 1$
    (B) $1 \leq R_{min} < 2$
    (C) $2 \leq R_{min} < 3$
    (D) $3 \leq R_{min} < 4$
    (E) $4 \leq R_{min}$



23. Partial pressures of a volatile organic compound A over 5 different solvents S1, S2, S3, S4 and S5 are given. Select the best solvent for A. (5%)
    (A) S1
    (B) S2
    (C) S3
    (D) S4
    (E) S5

24. Calculate the minimum solvent rate per mol of total gas inlet required at 1 Bar if the inlet gas contain 2 mol% of A, and is required to get rid of 99% of all the A if solvent S2 is used. (5%)
    (A) 0.3
    (B) 0.39
    (C) 0.56
    (D) 0.63
    (E) 1.53

Problem 4

(A) Answer the following questions regarding mass transport:

(a) Which of the following dimensionless group(s) is (are) significant for the process of slow sublimation of a naphthalene ball in a stagnant air? (4%)

(i) Schmidt number　　(ii) Reynolds number　　(iii) Stanton number

(b) Write down the SI units of the following terms (3%)

i. Mass diffusivity
ii. Mass flux
iii. Mass transfer coefficient

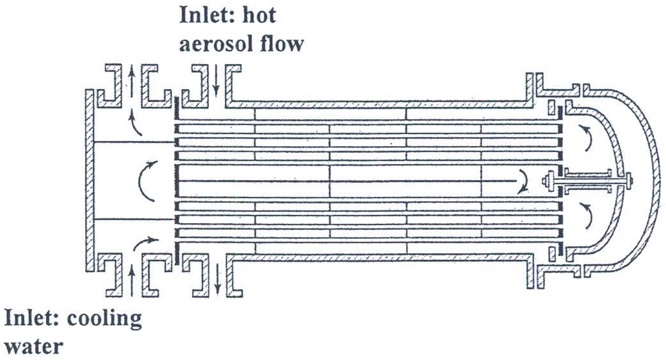
(c) Is the homogeneous reaction in the system described by boundary conditions or in the differential equations of change for mass transport? (3%)

(B) A chemical species A diffuses from a gas phase into a porous catalyst sphere of radius R in which it is converted into species B. The concentration of A at the surface of the sphere is C_{AS}. The rate at which A is consumed per unit volume of the sphere is $R_A = -k_1 a C_A$, where k_1 is the first-order reaction rate constant and a is the available catalytic surface area per unit volume of the sphere. Find the steady-state concentration distribution of A in the sphere. The effective diffusion coefficient of A in the sphere is D_{AB}. Assume constant properties. (10%)

Problem 5

(A) A gas-phase, spray pyrolysis process is used to generate aerosol particles (i.e., particles in an air flow) at a pyrolysis temperature of 500 °C (i.e., 773K) and a flow rate of 100 m^3/min. After pyrolysis, the hot aerosol flow is delivered to a heat exchanger. The design of the heat exchange is shown in the figure below. The maximum operating temperature is at least 600 °C.

(a) Based on the design shown in the figure below: (1) please provide the name of this heat exchanger. (2) According to the design, please provide a plot to show the temperature-length curve (i.e., temperature versus length) in this heat exchanger. (4%)



(b) A cooling water circulator is used as the first-stage cooling source for the heat exchanger. The temperature of cooling water leaving the cooling water circulator (i.e., to the entrance of this heat exchanger) is 290K, and the temperature of cooling water returning to the circulator (i.e., leaving the heating exchanger) is 305K. The temperature of hot aerosol flow (i.e., to carry the aerosol particles) delivered to the heat exchanger is assumed to be identical to the pyrolysis temperature. The flow rate of cooling water in circulation was set at 500 kg/min.

After cooling by this heat exchanger, the aerosol flow enters a double pipe heat exchanger (i.e., the second heat exchanger), where a co-current heavy hydrocarbon oil circulator is employed with a flow rate of 7200 kg/hr. The temperature of heavy hydrocarbon oil leaving the oil circulator (i.e., to the entrance of 2nd heat exchanger) is 300K, and the temperature of heavy oil returning to the circulator (i.e., leaving the 2nd heat exchanger) is 320K.

The heat capacity of the heavy hydrocarbon oil is constant at 2.500 kJ/kg*K. The heat capacity of the water is constant at 4.187 kJ/kg*K. The heat capacity of the hot aerosol flow is constant at 1.000 kJ/kg*K. Please calculate the corrected log-mean temperature differences in the two heat exchangers, respectively.

Assumptions: (1) The density of aerosol flow is 1 kg/m^3. (2) The properties of the fluids are independent of the temperature over the temperature range we studied. (3) The efficiency factor, F_G, is equal to 1 for the both heat exchanger. (4) The effect of fouling is assumed to be negligible, even in the presence of aerosol deposition. (5) No phase transition occurred in both heat exchangers. (6 %)

(B) A continuous flow reactor is developed, which has been shown to be useful for removing the organic solvent from a polymer solution. Here the flow reactor is employed to concentrate a feed solution of Polymer C, which is composed of 10 wt% of Polymer C, 50 wt% of Solvent A, and 40 wt% of Solvent B. The flow rate of the feed solution is constant at 1000 kg/min, and the pressure of the flow reactor is constant at 1 atm.

Our first objective is to increase the concentration of Polymer C by 2 times (i.e., in terms of molar concentration). Since the boiling point of Solvent A is 150 °C and the boiling point of Solvent B is 60 °C (i.e., under 1 atm), we assume the removal of Solvent A is negligible based on the operating temperature, 60 °C. Through the removal of Solvent B via the heat, the concentration of Polymer C in the final product (i.e., the concentrated solution) increases.

The molecular weight (M_w) of the organic solvent A is 73 g/mol, and the M_w of the organic solvent B is 34 g/mol. Polymer C is a linear polymer with 500 repeating units of monomer C. The M_w of the monomer C is 44 g/mol. Since the contribution of the molecular weight from the end group of the polymer is assumed to be negligible, the M_w of Polymer C is approximately equal to the total mass of the repeat units (i.e., the M_w of monomer × the number of repeating units).

The latent heat of Solvent B is 34 kJ mol^{-1}, and the latent heat of Solvent A is 7.9 kJ mol^{-1}. The heat capacity of Solvent B is 146 J/(mol*K). The heat capacity of Solvent A is 79.5 J/(mol*K). The properties of the fluids are assumed to be independent of the temperature over the temperature range we studied.

(a) What is the rate of heat flow required in the flow reactor? (3%)

(b) Presumably the required area of heat exchanger shown in (a) is 1 m^2. In order to reduce the amount of Solvent B in the concentrated solution to be 50 % of the amount shown in (a), please calculate the required area of heat exchanger. (2%)

(C) Our goal is to remove 95 wt% of the Solvent A from a partially-dried colloid composed of 60 wt% of dry solid silica particles, 38 wt% of Solvent A and 2 wt% of Solvent B. Due to the fast evaporation under the drying condition, 100 % of Solvent B is removed immediately when the partially dried colloid enters the flow reactor. Therefore, the free moiture content, X, is defined as kg of Solvernt A per kg of dry solid silica particles. The dry solid weight is 500 kg. Based on the surface area measurment, the surface area of the dry solid silica particles available for drying is 10 m^2.

The drying involved two steps: a constant rate zone and a falling rate zone. The critical free moisture content is 0.25 kg of Solvernt A per kg of dry solid silica particles. Via an in-situ measurment, the drying rate in the constant-rate period is found to be 0.1 kg of Solvent A/(min*m^2). In the falling-rate period, the drying rate is assumed to be linearly proportional to the free moisture content (i.e., when $X>0$).

What is the total time of drying required? The molecular weight (M_w) of the organic solvent A is 73 g/mol, and the M_w of the organic solvent B is 34 g/mol. The latent heat of Solvent B is 34 kJ mol^{-1}, and the latent heat of Solvent A is 7.9 kJ mol^{-1}. The heat capacity of Solvent B is 146 J/(mol*K). The heat capacity of Solvent A is 79.5 J/(mol*K). (5%)