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國立清華大學 108 學年度碩士班考試入學試題

系所班組別：**化學工程學系**

考試科目(代碼)：**輸送現象及單元操作(0901)**

—作答注意事項—

1. 請核對答案卷（卡）上之准考證號、科目名稱是否正確。
2. 作答中如有發現試題印刷不清，得舉手請監試人員處理，但不得要求解釋題意。
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6. 其他應考規則、違規處理及扣分方式，請自行詳閱准考證明上「**國立清華大學試場規則及違規處理辦法**」，無法因本試題封面作答注意事項中未列明而稱未知悉。

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 *請在【答案卡】作答

Problem 1 (40%)

Multiple choice. Pick only one answer for each question. Each question is 2% in score.

1. Which one of the following physical quantities has an SI unit different from that of all others?
(A) dynamic viscosity, (B) mass diffusivity, (C) thermal diffusivity, (D) kinematic viscosity.

2. Which of the following statements about momentum diffusion is wrong?
(A) Momentum diffuses faster in a more viscous fluid. (B) Fluids with higher kinematic viscosities diffuse momentum faster. (C) Momentum diffuses in a direction opposite to that of the momentum gradient. (D) Momentum diffuses in a direction pointing to the same direction of the momentum gradient.

3. For the following fluids, (a) sulfuric acid, (b) water, (c) silicon oil, and (d) glycerol at the same temperature and pressure, place them in the order of increasing viscosity.
(A) (b)(a)(c)(d), (B) (b)(a)(d)(c), (C) (a)(b)(d)(c), (D) (a)(b)(c)(d).

4. Which one of the following fluids is a Newtonian fluid?
(A) ketchup, (B) shampoo, (C) molten salt, (D) polyethylene melt.

5. Consider a Newtonian fluid flowing down an inclined flat plate. The plate is inclined with an angle β to the vertical axis, no incline when β is zero. Which of the following statements about the average velocity of the fluid is wrong?
(A) It increases with decreasing kinematic viscosity. (B) It increases with increasing inclined angle. (C) It increases with increasing fluid density. (D) Its value is smaller when measured on moon than on Earth.

6. Which of the following statements about friction factor for tubular flow is true?
(A) Friction factor of laminar flow decreases with increasing Reynolds number. (B) Friction factors of flow in rougher tubes are smaller than those in smoother tubes. (C) Friction factor is with an SI unit of m^{-1}. (D) Friction factor decreases with increasing pressure gradient.

7. A semi-infinite body of a Newtonian fluid with constant density and viscosity is bounded below by a horizontal plate (the xz-plane). Initially, the fluid and the plate are at rest. Then at time t=0, the plate is set in motion in the positive x direction with velocity V. Here, y is the measure of distance from the plate. Which of the following statements is true about the fluid velocity?
(A) The fluid velocity increases with increasing y. (B) The fluid velocity increases with increasing kinematic viscosity of the fluid. (C) The fluid velocity decreases with increasing t. (D) The fluid velocity is independent of the kinematic viscosity of the fluid.

8. Consider the following flow fittings: (a) 15° elbow, (b) square 90° elbow, (c) rounded 90° elbow, (d) globe valve at open position. Place them in the order of increasing friction loss factor.
(A) (b)(c)(a)(d), (B) (c)(b)(a)(d), (C) (a)(c)(b)(d), (D) (d)(c)(a)(b).

9. The continuity equation reads as $\frac{D\rho}{Dt} = -\rho(\underline{\nabla} \cdot \underline{v})$, where D/Dt is the substantial time derivative, ρ is the fluid density, and $\underline{\nabla} \cdot \underline{v}$ is the divergence of the velocity field. Which of the following statement is true?
(A) If $\underline{\nabla} \cdot \underline{v}$ is negative, then the fluid is experiencing expansion. (B) If $\underline{\nabla} \cdot \underline{v}$ is zero, then the fluid is flowing in a steady state. (C) If $\underline{\nabla} \cdot \underline{v}$ is zero, then the fluid is incompressible. (D) None of the above.

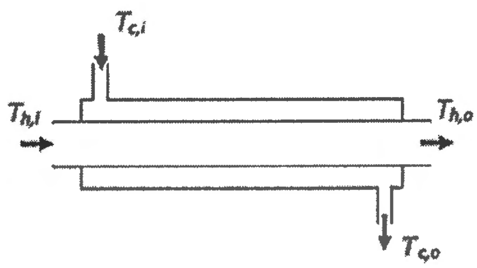
10. Which of the following statements is true for the description of Newtonian and non-Newtonian fluids?
(A) Newtonian fluids exhibit the phenomenon of tubeless siphone. (B) Non-Newtonian fluids swell when flowing out of a tube. (C) The viscosity of a shear-thickening fluid decreases with increasing shear rate. (D) Newtonian fluids exhibit fading memory phenomenon.

11. Fluids containing small quantities of particles with sizes smaller than 100 nm dispersed in a continuous medium, such as water, ethylene glycol, and engine oil, are called nanofluids. By suspending nanophase particles in heating or cooling fluids, the heat transfer performance of the fluid can be significantly improved. Which statements is NOT true.
(A) The suspended nanoparticles increase the surface area and the heat capacity of the fluid.
(B) The suspended nanoparticles increase the effective thermal conductivity of the fluid.
(C) The interaction and collision among particles, fluid and the flow passage surface are intensified.
(D) The mixing fluctuation and turbulence of the fluid are reduced.
(E) The dispersion of nanoparticles flattens the transverse temperature gradient of the fluid.

12. If four types of nanoparticles with the same particle size are uniformly dispersed in water, please place them in the order of increasing thermal conductivity, (1) 1% of SiO_2, (2) 1% of Al_2O_3, (3) 1% of Ag, and (4) 2% of SiO_2.
(A) (1)(4)(2)(3), (B) (1)(4)(3)(2), (C) (3)(2)(1)(4), (D) (3)(2)(4)(1),
(E) (2)(1)(4)(3).

13. Please choose the correct statements for Biot number (Bi) and Nusselt number (Nu). (1) Bi and Nu have the same group of physical parameters: hL/k, where L is a characteristic length, h is a heat transfer coefficient, and k is the thermal conductivity. (2) Bi is used to describe the heat transfer resistance of air from a solid surface. (3) Nu is used to characterize the heat flux from a solid surface to a fluid. (4) When Bi increases, conductive resistance of solid dominates.
(A) (1)(2)(3), (B) (1)(2)(4), (C) (2)(3)(4), (D) (1)(3), (E) (1)(3)(4).

14. Heat transfer in a heat exchanger is usually analyzed using the Logarithmic Mean Temperature Difference (LMTD). If a double pipe heat exchanger has hot water inside and cold water outside to remove the heat, what is the total heat transfer rate (Q_h) of the hot water in the parallel flow heat exchanger? [Note: $T_{h,i}$ is the temperature of hot water in the inlet. $T_{h,o}$ is the temperature of hot water in the outlet. $T_{c,i}$ is the temperature of cold water in the inlet. $T_{c,o}$ is the temperature of cold water in the outlet. U_0 is the overall heat transfer coefficient. D and L are the diameter and the length of the inner tube, respectively.]



(A) $Q_h = U_0(\pi DL)\left[\dfrac{\ln(T_{h,i}-T_{h,o})-\ln(T_{c,i}-T_{c,o})}{(T_{h,i}-T_{h,o})-(T_{c,i}-T_{c,o})}\right]$

(B) $Q_h = U_0(\pi DL)\left[\dfrac{(T_{h,i}-T_{c,o})-(T_{h,o}-T_{c,i})}{\ln(T_{h,i}-T_{c,o})-\ln(T_{h,o}-T_{c,i})}\right]$

(C) $Q_h = U_0(\pi DL)\left[\dfrac{(T_{h,i}-T_{c,i})-(T_{h,o}-T_{c,o})}{\ln(T_{h,i}-T_{c,i})-\ln(T_{h,o}-T_{c,o})}\right]$

(D) $Q_h = U_0(\pi DL)\left[\dfrac{\ln(T_{h,i}-T_{c,o})-\ln(T_{h,o}-T_{c,i})}{(T_{h,i}-T_{c,o})-(T_{h,o}-T_{c,i})}\right]$

(E) $Q_h = U_0(\pi DL)\left[\dfrac{\ln(T_{h,i}-T_{c,i})-\ln(T_{h,o}-T_{c,o})}{(T_{h,i}-T_{c,i})-(T_{h,o}-T_{c,o})}\right]$

15. When hot water flows through the inner pipe of heat exchanger (D = 10 mm, L = 1 m) at 10 kg/h of mass flow rate, what is the overall heat transfer coefficient (U_0)? Assume water has constant specific heat capacity $\hat{C}p$ (4.18 kJ/kg·K) and ρ (1000 kg/m^3) [Note: $T_{h,i}$ = 80°C, $T_{h,o}$ = 50°C, $T_{c,i}$ = 20°C, and $T_{c,o}$ = 30°C]. Choose the closest answer.
(A) 274 W/m^2·K
(B) 305 W/m^2·K
(C) 418 W/m^2·K
(D) 543 W/m^2·K
(E) 621 W/m^2·K

16. If the diameter of the outer tube is set to 20 mm, and the heat capacity remains constant, please determine the mass flow rate of the cold water stream.
(A) 7 kg/h, (B) 10 kg/h, (C) 15 kg/h, (D) 20 kg/h, (E) 30 kg/h.

17. If the thickness of the inner tube is very thin and thermal resistance of the tube is negligible, the Nusselt number (Nu) in the annular space is 5.74. Please calculate the convection heat transfer coefficient inside the tube (h_i). Choose the closest answer.
[Hint]
- Nu = hD_h/k, where h is the convection heat transfer coefficient, D_h is the hydraulic diameter, and k is the thermal conductivity (water is 0.64 W/m·K)
- $1/U_0 = 1/h_i + 1/h_o$, where h_o is the convection heat transfer coefficient outside the tube.

(A) 367 W/m^2·K
(B) 634 W/m^2·K
(C) 1032 W/m^2·K
(D) 1805 W/m^2·K
(E) 5932 W/m^2·K

18. When 1% of nanoparticles are added in the hot water stream to improve the heat transfer performance, the thermal conductive of nanofluid (water + nanoparticles) increases to 0.66 W/m·K and the convection heat transfer coefficient inside the tube (h_i) increases 50%, what percentage of Nusselt number of nanofluid increases?
(A) 35%
(B) 40%
(C) 45%
(D) 50%
(E) 55%

19. Continue the above question, what is the effectiveness of heat exchanger when nanofluid is added? Assume LMTD is the same.
[Hint] Effectiveness= actual heat transfer / maximum heat transfer
(A) 0.80
(B) 0.75
(C) 0.70
(D) 0.65
(E) 0.60

20. Based on the previous concepts of nanofluid, which statement is NOT correct?
(A) After adding the nanoparticles in the fluid, the Prandtl number will become smaller.
(B) After adding the nanoparticles in the fluid, the thermal boundary thickness will become smaller.
(C) When increasing the concentration of nanoparticles, the Nusselt number also increases.
(D) When increasing the size of nanoparticles, the Nusselt number increases.
(E) When the flow in a pip becomes turbulent, the Nusselt number of nanofluid is higher than the Nusselt number of water.

Problem 2 (8%)

A batch of dried, spherical, 100% magnesium particle [Catalyst A; molecular mass: 24.3 g/mol; average diameter ($d_{p,0}$) = 10 μm] is used as a heterogeneous catalyst for transesterification of 0.05 kg of Reactant B to become Product C. The reaction is simplified as follow:

$$B \Rightarrow C$$

The mass ratio of the catalyst to the Reactant B is set at 5 wt%. The amount of Reactant B used per run is 50 grams. After 100 % of conversion of Reactant B to Product C, Catalyst A is separated from Product C and recycled for the next-run use. The density of the particle is 2 g/cm^3, and the molecular masses of Reactant B and Product C are both assumed to be 500 g/mol. Assuming that the conversion ratio of Reactant B to Product C is 50% at the reaction time (t) of 1 hour, 80% at t = 2 h, and ≈100% when t > 5 hours. The operating temperature is 200 °C, under atmospheric condition. It is known that magnesium particle will partially dissolve in Reactant B and Product C with the same solubility of magnesium, 100 mg/L. The rate-determining step of this dissolution is diffusion of dissolved magnesium (i.e., similar to the leaching process from the surface of particle) from the particle surface through a stagnant liquid film (δ in thickness, assuming 100 nm) out into the main stream. In order to merit the quality of the sales, the concentration of magnesium in Product C has to be lower than 5 mg/L. Because $d_{p,0} \gg \delta$, the curvature of magnesia particle is negligible. The change of particle diameter is negligible in this process. Assuming a steady-state diffusion of magnesium with a diffusivity of 10^{-6} m^2/s, please determine:

(a) The dissolution rate of magnesium at t = 10 hour (in term of moles/second), if the concentration of magnesium in Product C is 3 mg/L at t = 10 hour. *(6%)*

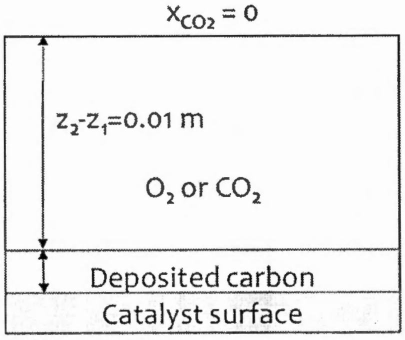
(b) The dissolution rate of magnesium at t = 7 hour, if the reaction time is reduced to 7 hours, and the concentration of magnesium in Product C hikes to 5 mg/L. *(2%)*

Problem 3 (6%)

Through an accidental opening of a valve, water has been spilled on a 2.0 m^2 of laboratory bench of a wet chemistry laboratory. To effectively reduce the moisture and maintain the temperature required for the experiment, air-conditioning machine of the laboratory is powered on. The room temperature of the laboratory is 21 °C, and the pressure in the laboratory is controlled at 1 atm. At this temperature and pressure, the vapor pressure of water in the laboratory is assumed to be $1.0*10^4$ Pa, and the diffusion coefficient of water in the air is assumed to be 10^{-6} m^2/s. Based on the result of a direct measurement, the water vapor concentration is only 10% at the location 10 cm above the liquid level in comparison to the water vapor concentration at the liquid level. Here, the change of liquid level is negligible during the evaporation process. Please determine the volume of water (in SI unit) evaporating from the laboratory bench per minute, assuming that a steady state diffusion occurred in the gas film of 10 cm above the water level.

Problem 4 (6%)

To remove carbon deposits (molecular mass is 12 g/mol; density is 4 g/cm^3) on the surface of a planar nickel catalyst with a surface area of 100 cm^2, oxygen is to diffuse through a gas film (0.01 m in thickness) to the carbon surface where it reacts to form CO_2 ($C+O_2 \Rightarrow CO_2$; see the scheme shown below). To simplify the calculation, we assume that no reaction occurs in the gas film, and the oxygen immediately converts to CO_2 at the surface of carbon deposit (i.e., the rate-determining step is diffusion, and only CO_2 is present at the surface of carbon). The concentration of CO_2 is zero at the top of the gas film. The average concentration ratio of O_2 in the gas film is assumed to be 1 (i.e., dominant species in the binary system). At reaction time (t) of 0 minute, the thickness of carbon deposits is 3 cm. At t = 10 hours, all the carbon is removed from the catalyst surface. The environmental temperature and pressure are 800 K and 1 atm, respectively. Please calculate the diffusion coefficient of CO_2 based on the information given above, assuming that only O_2 and CO_2 are present in the gas phase following a pseudo-steady state diffusion.



Problem 5 (10%)

Consider a slab of unknown material 10 mm thick, with one side held at 100 °C and the other side at 25 °C. The overall heat flux from the hot side to the cold side was determined to be 75 W/m^2.

(a) What is the overall heat transfer coefficient? *(3%)*

(b) What is the thermal conductivity of the material? *(4%)*

(c) Given that the thermal conductivity of the slab is about 1 W/(m^2-K), which one of the following materials: asbestos, brick, or brass, is the slab made of? *(3%)*

Problem 6 (10%)

A condenser containing three parallel shell and tube heat exchange units is supposed to exchange 100 GJ/hr of heat. The inlet temperature of the hot gas stream going into the condenser is about 70 °C and the outlet temperature of the partially condensed fluid is about 55 °C. Temperature of the inlet cooling water is 35 °C and temperature of one of the outlet cooling water is around 55 °C.

(a) What is the log mean temperature difference, LMTD, i.e., the overall driving force of this heat exchanger? *(3%)*

(b) The area of the heat exchanger is about 3300 m^2, what is the overall heat transfer coefficient? *(3%)*

(c) According to literature, overall heat transfer coefficient in the given situation should be around 250 W/(m^2-K), please speculate what is going on? Suggest a plan to confirm your speculation. *(4%)*

Problem 7 (10%)

In two-film theory: derive the following expression:

$$H_{Oy} = H_y + \left(\frac{mV}{L}\right)H_x$$

For straight operating and equilibrium lines, show that

$$N_{Oy} = \frac{y_b - y_a}{\overline{\Delta y_L}}$$

where $\overline{\Delta y_L}$ is the log mean value of $(y_b - y_{b*})$ and $(y_a - y_{a*})$.

(m is the slope of the equilibrium line: $y_e = m\, x_e$; V and L are the molar flow rates of gas and liquid streams; H is the height of a transfer unit, N is the number of transfer units; subscripts x, y, Oy refer to liquid film, gas film, and overall gas, respectively; subscripts a and b refer to the terminal conditions of an absorbing column.)

Problem 8 (10%)

A toxic hydrocarbon is stripped from water with air in a column with eight ideal stages.

(a) What stripping factor is needed for 98 percent removal? *(5%)*

(b) What percentage removal could be achieved with a stripping factor of 2.0? *(5%)*

(Note: stripping factor=$\frac{mV}{L}$)