注意：考試開始鈴響前，不得翻閱試題，
並不得書寫、畫記、作答。

國立清華大學 113 學年度碩士班考試入學試題

系所班組別：化學工程學系

科 目 代 碼 ：0901

考 試 科 目 ：輸送現象及單元操作

一作答注意事項一

1. 請核對答案卷（卡）上之准考證號、科目名稱是否正確。
2. 考試開始後，請於作答前先翻閱整份試題，是否有污損或試題印刷不清，得舉手請監試人員處理，但不得要求解釋題意。
3. 考生限在答案卷上標記「由此開始作答」區內作答，且不可書寫姓名、准考證號或與作答無關之其他文字或符號。
4. 答案卷用盡不得要求加頁。
5. 答案卷可用任何書寫工具作答，惟為方便閱卷辨識，請儘量使用藍色或黑色書寫；答案卡限用 2B 鉛筆畫記；如畫記不清（含未依範例畫記）致光學閱讀機無法辨識答案者，其後果一律由考生自行負責。
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。

Problem 1 (20%)

Multiple choice: (Pick only one answer for each problem. Each sub-question is 2%)

1. What is the SI unit of Stefan-Boltzmann constant?
   (A) Dimensionless (B) W/m^2 (C) J/m^2K^2 (D) W/m^2K^4

2. For the following materials at room temperature and under 1 atm, (a) mercury, (b) hydrogen, (c) carbon dioxide, and (d) copper, place them in the order of increasing thermal conductivity.
   (A) (c)(b)(a)(d) (B) (b)(c)(a)(d) (C) (b)(c)(d)(a) (D) (c)(b)(d)(a)

3. What is the order of magnitude of the Prandtl number of lithium at 700 K?
   (A) << 1 (B) >> 1 (C) ~ 1 (D) ~ -1

4. 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. At steady state, what is the heat flow rate normal to the interface of the wire and insulating material?
   (A) $\pi(R+d)^2 LSe$ (B) $k\left(\frac{T_0}{d}\right)(2\pi RL)$ (C) $\pi R^2 LSe$ (D) $k\left(\frac{T_0}{R}\right)(2\pi RL)$

5. A viscous fluid with temperature-independent physical properties is in fully developed laminar flow between two flat surfaces placed a distance $2B$ apart. For $z < 0$ the fluid temperature is uniform at $T = T_1$. For $z > 0$ heat is ***added*** at a constant, uniform flux q_0 at both walls. The asymptotic solution for large z can be derived to be as follows:
   $\Theta(\sigma,\varsigma) = a\varsigma + \frac{3}{4}\sigma^n - \frac{1}{8}\sigma^m - \frac{39}{280}$
   Here, $\Theta = \dfrac{T-T_1}{q_0 B/k}$, $\sigma = \dfrac{x}{B}$, $\varsigma = \dfrac{kz}{\rho\hat{C}_p v_{z,\max} B^2}$, a is a constant, and n and m are integers. Which of the following statements is **correct**?
   (A) a is positive (B) a is negative (C) a is zero (D) a is a complex number.

6. Continued from Problem 1-5. Which of the following statements is **correct**?
   (A) n is odd and m is even. (B) n and m are both even. (C). n and m are both odd. (D) n is even and m is odd.

7. Consider a Newtonian fluid of constant density and viscosity, flowing between two large plates separated by a distance b. The fluid flow is driven by the motion of the upper plate at a constant velocity V. 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 $x = b$). Let Br be the Brinkman number of the fluid flow. The temperature distribution can be derived to be the following. $\frac{T-T_0}{T_b-T_0} = \frac{1}{2}Br\frac{y}{b}\left(1-\frac{y}{b}\right) + \frac{y}{b}$.
   Which of the following statements is **correct**?
   (A) The temperature distribution is linear when viscous heating is negligible.

(B) The temperature distribution is linear when heat conduction is negligible.
(C) The temperature distribution may have a maximum when *Br* is small enough.
(D) The temperature distribution may have a maximum when heat conduction is dominant.

8. Continued from Problem 1-7. If a maximum temperature exists, which of the following statements is **correct**?
   (A) The maximum temperature is located near the lower plate.
   (B) The maximum temperature is located near the upper plate.
   (C) The maximum temperature is located at $y/b = 1/2$.
   (D) None of the above.

9. 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 $t > 0$. Which of the following statements is **correct**?
   (A) The temperature profile reaches a steady state after a long time.
   (B) The normal heat flux at $y = 0$ increases with increasing thermal conductivities.
   (C) The thermal boundary layer grows faster for materials with lower thermal diffusivities.
   (D) The temperature increases linearly with increasing y.

10. Which of the following equations most accurately describes the transient decay of the temperature of a fluid-filled tank? The tank (mass m, surface area A, overall heat transfer coefficient U, specific heat capacity including contents, C_p) is initially at T_0, and the ambient air temperature is T_∞ ($< T_0$).
    (A) $\frac{T(t)-T_\infty}{T_0-T_\infty} = exp\left(-\frac{mC_p}{UA}t\right)$　(B) $\frac{T(t)-T_0}{T_0-T_\infty} = exp\left(-\frac{UA}{mC_p}t\right)$
    (C) $\frac{T(t)-T_0}{T_0-T_\infty} = exp\left(-\frac{mC_p}{UA}t\right)$　(D) $\frac{T(t)-T_\infty}{T_0-T_\infty} = exp\left(-\frac{UA}{mC_p}t\right)$

Problem 2 (20%)

Multiple choice: (Pick only one answer for each problem. Each sub-question is 2%)

Drug delivery in cancer treatment encounters hurdles due to various complexities within tumors. These complexities involve factors like heightened pressure within tumors impeding drug entry, irregular blood vessel structures causing uneven drug distribution, and hypoxic regions with inadequate drug access. The extracellular matrix surrounding cells acts as a barrier, while altered cellular conditions make it challenging for drugs to reach their targets. Tumors' diverse cell composition contributes to varying treatment responses, and the immune system within the tumor may not function optimally. Researchers are actively developing advanced strategies to navigate these challenges and enhance the efficacy of cancer treatments, aiming for more precise and effective therapeutic approaches.

11. What is the primary mechanism of mass transport that relies on the random movement of molecules from areas of high concentration to areas of low concentration within solid tumors?
(A) Convection (B) Osmosis (C) Diffusion (D) Active transport
(E) Facilitated diffusion
12. In the context of mass transport in tumors, what role does convection play?
(A) Convection is the result of random molecular movement.
(B) Convection involves the movement of molecules against a concentration gradient.
(C) Convection is the bulk flow of fluid carrying solutes through the tumor microenvironment.
(D) Convection relies on energy provided by cells for substance transport.
(E) Convection is independent of fluid flow.
13. Which of the following factors can impact the rate of diffusion of drugs within tumor tissues?
(A) Elevated interstitial fluid pressure (B) Regular blood vessel structure
(C) Homogeneous tumor composition (D) Low tumor cell density
(E) High blood viscosity
14. The diffusion coefficient (D) of a drug in a tumor is 0.5×10^{-3} cm^2/s. If the concentration gradient across the tumor is 20 μM/cm and the distance for diffusion is 50 μm, what is the drug diffusion flux?
(A) 0.005 μmol/cm$^2\cdot$s (B) 0.01 μmol/cm$^2\cdot$s (C) 0.05 μmol/cm$^2\cdot$s
(D) 0.1 μmol/cm$^2\cdot$s (E) 0.5 μmol/cm$^2\cdot$s
15. Continued from Problem 2-14, if the drug needs to diffuse through a tumor tissue with a thickness of 100 μm, how much time (in seconds) will it take for the drug to traverse the tissue?
(A) 1×10^5 s (B) 5×10^5 s (C) 1×10^6 s (D) 5×10^6 s (E) 1×10^7 s
16. Continued from Problem 2-14, if the characteristic flow velocity (u) of blood in the tumor vasculature is 0.5 cm/s, and the characteristic length (L) representing the typical distance between blood vessels in the tumor is 50 μm, calculate the Peclet number (Pe) for drug transport in the tumor using the given values.
(A) 0.5 (B) 5 (C) 50 (D) 500 (E) 5000

17. Drug X has a smaller molecular size than Drug Y. Both drugs have the same diffusion coefficient of 3×10^{-6} cm^2/s. Which drug is likely to have a more effective diffusion distance within a tumor?
 (A) Drug X (smaller size).
 (B) Drug Y (larger size).
 (C) Both drugs have similar diffusion distances.
 (D) Diffusion distance is not influenced by molecular size.
 (E) It depends on other factors such as tissue structure.

18. Imagine you're studying how drugs move in a tumor. Fick's second law of diffusion helps us understand this, especially when the tumor has varying features. If we use $D_{eff} = D\cdot e^{-\gamma z}$ to represent the effective diffusion coefficient influenced by these features, what is the **correct** format of Fick's second law for drug transport in solid tumors? Assume z is the depth of tumor and γ is a constant associated with drug diffusion.
 (A) $\frac{\partial c}{\partial t} = D\frac{\partial}{\partial z}\left(D_{eff}\gamma\frac{\partial c}{\partial z}\right)$
 (B) $\frac{\partial c}{\partial t} = D\frac{\partial}{\partial z}\left(De^{\gamma z}\frac{\partial c}{\partial z}\right)$
 (C) $\frac{\partial c}{\partial t} = D_{eff}\frac{\partial}{\partial z}\left(D_{eff}e^{\gamma z}\frac{\partial c}{\partial z}\right)$
 (D) $\frac{\partial c}{\partial t} = D_{eff}\frac{\partial}{\partial z}\left(De^{\gamma z}\frac{\partial c}{\partial z}\right)$
 (E) $\frac{\partial c}{\partial t} = D\frac{\partial}{\partial z}\left(D_{eff}e^{\gamma z}\frac{\partial c}{\partial z}\right)$

19. Which one does represent the **correct** partial differential equation?
 (A) $\frac{\partial c}{\partial t} = D\gamma^2 ze^{-\gamma z} + D\gamma\frac{\partial c}{\partial z} + D\frac{\partial^2 c}{\partial z^2}$
 (B) $\frac{\partial c}{\partial t} = D\gamma^2 ze^{\gamma z} + D\gamma\frac{\partial c}{\partial z} + D_{eff}\frac{\partial^2 c}{\partial z^2}$
 (C) $\frac{\partial c}{\partial t} = D\gamma^2 ze^{-\gamma z} + D\gamma\frac{\partial c}{\partial z} + D_{eff}\frac{\partial^2 c}{\partial z^2}$
 (D) $\frac{\partial c}{\partial t} = D\gamma^2 ze^{\gamma z} + D_{eff}\frac{\partial c}{\partial z} + D_{eff}\frac{\partial^2 c}{\partial z^2}$
 (E) $\frac{\partial c}{\partial t} = D\gamma^2 ze^{\gamma z} + D\gamma\frac{\partial c}{\partial z} + De^{\gamma z}\frac{\partial^2 c}{\partial z^2}$

20. Given the equation for drug concentration in solid tumor as $C(z,t) = C_0 \cdot e^{-\frac{D_{eff}}{D} \cdot \int_0^z e^{-\gamma z} dz \cdot t}$, calculate the drug concentration $C(z, t)$ at a depth of $z = 0.1$ cm after 60 s, assuming a constant drug supply $C_0 = 10$ μM, $D = 0.5$ μM/s, and $\gamma = 0.2$/cm.

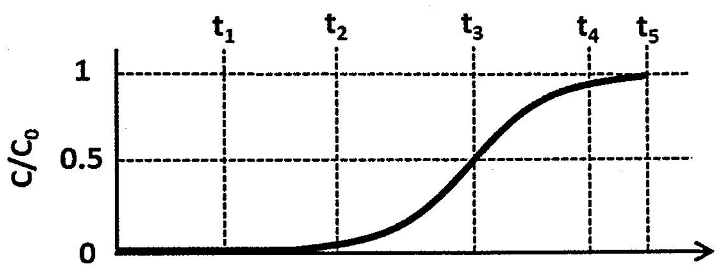
(A) 0.03 μM　(B) 0.15 μM　(C) 2.23 μM　(D) 4.17 μM　(E) 8.32 μM

Problem 3 (9%)

Please answer the following questions concerning an adsorption bed using porous adsorbent. Each sub-question is 3%

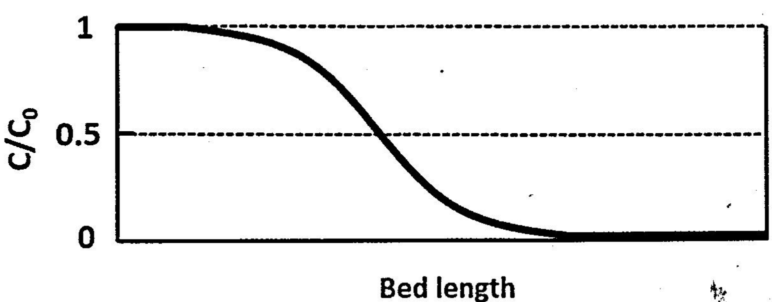
21. The adsorption breakthrough curve is shown below (C is the outlet concentration of adsorbate; C_0 is the inlet concentration of adsorbate). What is the breakthrough time?

(A) t_1　(B) t_2　(C) t_3　(D) t_4　(E) t_5



22. At time t during the adsorption, the concentration profile in the bed is shown below (C is outlet concentration of adsorbate; C_0 is the inlet concentration of adsorbate). What is the approximate ratio of mass transfer zone to the total bed length?

(A) 0　(B) 0.1　(C) 0.3　(D) 0.6　(E) 1



23. The adsorption kinetic is typically controlled by micropore diffusion. If you are asked to enhance the mass transfer coefficient, which one of the following is least likely to help?
    (A) Select an adsorbent with larger micropore size.
    (B) Select an adsorbent with smaller particle size.
    (C) Increase bulk velocity.
    (D) Elevate operating temperature.
    (E) Reduce operating pressure.

Problem 4 (10%)

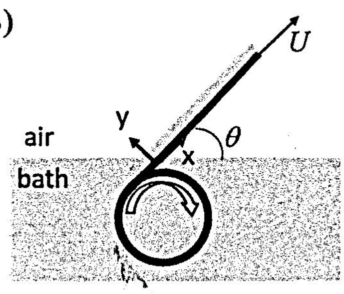
Please indicate whether each of the following statements is **true** or **false**. Provide the correction if a statement is false.

(a) Newtonian fluid only undergoes laminar flow. **(2%)**
(b) Laminar flow occurs when the Reynolds number (*Re*) is smaller than 2100. **(2%)**
(c) Navier-Stokes equation can be used to obtain the velocity profile of a pseudoplastic fluid flowing in a circular tube under steady state. **(2%)**
(d) At the liquid-air interface, "zero fluid velocity" is the common boundary condition used. **(2%)**
(e) The Fanning friction factor (f) for a Newtonian fluid flowing in a circular tube is given by $f = 24/Re$ when the flow is laminar. **(2%)**

Problem 5 (10%)

The following figure shows a coating system. A film is being pulled from a liquid bath by rollers with a steady velocity U and an angle θ to the horizontal. As the film leaves from the bath, it brings a liquid film with constant thickness δ. The flow in the liquid film is in steady-state and Newtonian, with constant density and viscosity.

(a) Find velocity profile $v_x(y)$ and sketch the velocity profile. **(4%)**
(b) Find shear stress profile τ_{yx} and sketch the shear stress profile. **(2%)**
(c) Express net liquid flow rate Q (per unit width). **(2%)**
(d) If $Q = 0$, express the liquid film thickness δ. **(2%)**



Problem 6 (10%)

Fluid transport is of importance to the plant. Here, we aim to transport benzene from a reservoir to a fixed-bed reactor packed with solid catalysts. The pipe used is made of 316 stainless steel with the outer diameter of 50 cm and the wall thickness is 5 cm.

The system is operated at a constant temperature of 26.0 °C, and the corresponding vapor pressure of benzene at this temperature is 0.13 bar. At 26.0 °C, the measured mass of the one-liter benzene is 900 grams, and we will use the data to determine the density of benzene.

The operating flow rate of the benzene to the reactor should be set at 120 m^3/hour. The pressure at the reservoir is constant at 1.0 bar, and gauge pressure at the end of discharge line (i.e., at the reactor) is also 1.0 bar. The discharge point is 15.0 m above the level of the reservoir. The pump is 2.0 m above the level of reservoir, and the pump efficiency is about 50%.

On the basis of the same flow rate of benzene (120 m^3/hour) in the same pipe, the friction in the suction (i.e., before the pump) is assumed to be 0.05 bar, and the friction in the discharge line (i.e., after the pump) is 0.5 bar.

(a) Please draw a scheme of the layout based on the descriptions. **(2%)**
(b) Calculate the developed head of the pump and the net positive suction head available (i.e., use the unit of meter). **(4%)**
(c) Calculate the total power "input". **(3%)**
(d) What is the definition of the required net positive suction (in brief; using the question of (b) as the example)? **(1%)**

Problem 7 (10%)

Due to the recent malfunction, the department staff is considering of buying a new heat exchanger from the vendor: a simple-design double-pipe heat exchanger. For the operation of this new heat exchanger, a heavy hydrocarbon oil having a heat capacity of 2.0 kJ/kg·K is used as the heat flow in this new heat exchanger. At the same time, the water flowing through the heat exchanger can be heated up from 283 K to the target temperature of 313 K, which can be used for the downstream, continuous water flow reaction, with a water flow rate of 2.0 m^3/hour. The density of water is assumed to be constant at 1.0 g/cm^3, and the heat capacity of the water is 4.18 kJ/kg·K.

For the convenience in the future cleaning, we aim to use the oil in the center/inner pipe and the water in the outer pipe. The flow rate of oil is adjustable, and we choose to use the minimum flow rate, 5.0 m^3/hour. The temperature of oil should be in the range of 303 K to 373 K, in which the density of oil can be assumed to be constant at 0.8 g/cm^3. Therefore, we aim to use the maximum temperature, 373 K, for the oil flow entering the heat exchanger. The overall heat transfer coefficient of this heat exchanger is assumed to be constant as 1000 W/m^2·K.

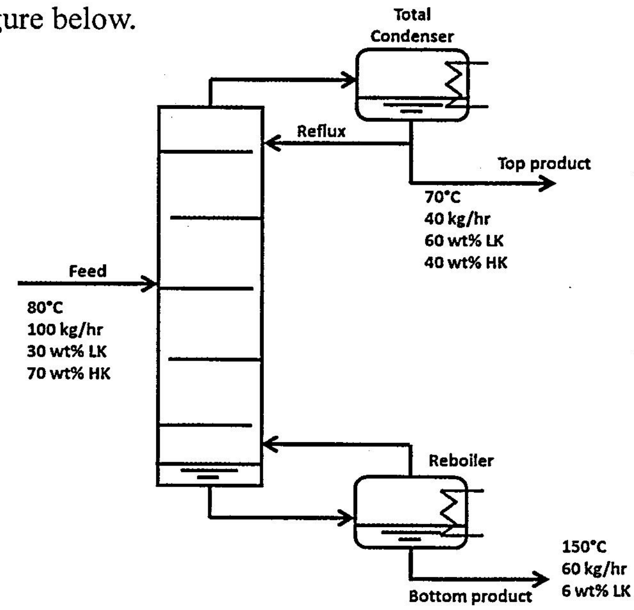
(a) Calculate the oil outlet temperature and the rate of heat flow. **(2%)**

(b) Calculate required heat transfer areas, if the streams of oil and water are countercurrent and co-current. **(4%)**

(c) Due to the incorrect measurement, the temperature measured at the outlet of the water flow is 2.5% lower than the correct value (i.e., the actual temperature should be 2.5% higher than the target value). In this regard, calculate the correct required heat transfer areas, if the streams of oil and water are countercurrent and co-current. **(4%)**

Problem 8 (11%)

A distillation column is employed to concentrate the light key component (LK) at the top and heavy key component (HK) at the bottom. The light key component tends to degrade into degradation products (DP) in the column. The operating conditions are shown in the figure below.



Please answer the questions using the following information:

- Assume the degradation is negligible above the feed and the degradation products only appear at the bottom.
- The saturated temperature at top is 120°C; the condenser temperature is subcooled by 50°C.
- The reflux ratio is 2 (kg reflux to kg top product).
- The heat of condensation in the total condenser (ΔH_{cond}) is 2000 kJ/kg.
- The liquid heat capacity of top products $(C_{p,top})$ and bottom product $(C_{p,bot})$ are 4 $\frac{kJ}{kg-°C}$
- The heat of reaction of degradation is endothermic and is 3000 kJ/kg light key component.

(a) What are the concentrations of heavy key component and degradation product at the bottom? **(3%)**

(b) What is the condenser cooling duty? The sensible heat of vapor can be assumed negligible. **(3%)**

(c) What is the reboiler duty and how much (in percentage) is spent on degradation? **(5%)**