國立清華大學 105 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(0901)

　　*請在【答案卡】作答

請於答案卡作答

Problem 1 (50%)

Multiple choice: (Pick only one answer for each problem.)

1. What is the SI unit of mass diffusivity divided by thermal diffusivity?
   (A) Dimensionless, (B) m^2/s, (C) 1/m, (D) 1/s.
2. Let $\underline{j}_\alpha$ be the mass flux of specie α with respect to the mass average velocity in a mixture containing n species. What is $\sum_{\alpha=1}^{n} \underline{j}_\alpha$?
   (A) 0, (B) mass average velocity, (C) $n\underline{j}_\alpha$, (D) $\underline{0}$.
3. For the following mixtures, (a) He in pyrex at 1 atm and 293 K, (b) Ar-O_2 at 1 atm and 293 K, (c) Sb in Ag at 1 atm and 293 K, and (d) ethanol in H_2O at 1 atm, 293 K, and 0.05 molar ratio of ethanol, place them in the order of increasing mass diffusivity.
   (A) (c)(a)(d)(b), (B) (b)(a)(c)(d), (C) (a)(b)(c)(d), (D) (a)(b)(d)(c).
4. Consider a uniform flow of a dilute solution of A passing over a semi-infinite flat plate. The velocity and concentration of A of the uniform flow are v_{inf} and C_{Ainf}, respectively, whereas the velocity and concentration of A at the plate surface are 0 and C_{As}, respectively. Boundary layers in velocity and concentration of A will develop in the vicinity of the plate. If the Schmidt number of the fluid is less than 1, is the velocity boundary layer thicker than, thinner than, or equal to the concentration boundary layer?
   (A) thicker, (B) thinner, (C) equal, (D) none of the above.
5. Consider an unsteady state evaporation of liquid A into gas B in a tube of infinite length. The liquid level is maintained at z=0 at all times. The temperature and pressure are assumed constant and the vapors of A and gas B form an ideal gas mixture. Hence the molar concentration c is constant throughout the gas phase, and D_{AB} may be considered constant. Gas B is insoluble in liquid A, and that the molar average velocity in the gas phase does not depend on the radial coordinate. What is the molar flux of A at the gas-liquid interface? Here, σ is a dimensionless monotonically increasing function of the interfacial gas-phase concentration x_{A0}.
   (A) $\sigma\sqrt{cD_{AB}/t}$, (B) $\sigma\sqrt{t/cD_{AB}}$, (C) $c\sigma\sqrt{t/D_{AB}}$, (D) $c\sigma\sqrt{D_{AB}/t}$.

6. Continued from the above problem, what is the expression for the volume of A produced by evaporation up to t? Here, S is the surface area of the gas-liquid interface.
   (A) $S\sigma\sqrt{4D_{AB}/t}$, (B) $S\sigma\sqrt{4D_{AB}t}$, (C) $S\sigma\sqrt{4t/D_{AB}}$, (D) $t\sigma\sqrt{4D_{AB}S}$.

7. A droplet of liquid A, of radius r_1, is suspended in a stream of gas B. We postulate that there is a spherical stagnant gas film of radius r_2 surrounding the droplet. The concentration of A in the gas phase is x_{A1} at $r=r_1$ and x_{A2} at the outer edge of the film, $r=r_2$. What is the molar flux of A at $r=r_1$? Here, c is the total molar concentration and D_{AB} is the mass diffusivity.
   (A) $\dfrac{cD_{AB}}{r_2-r_1}\left(\dfrac{r_2}{r_1}\right)\ln\dfrac{x_{A2}}{x_{A1}}$, (B) $\dfrac{cD_{AB}}{r_2-r_1}\left(\dfrac{r_1}{r_2}\right)\ln\dfrac{x_{A2}}{x_{A1}}$, (C) $\dfrac{cD_{AB}}{r_2-r_1}\left(\dfrac{r_2}{r_1}\right)\ln\dfrac{1-x_{A2}}{1-x_{A1}}$, (D) $\dfrac{cD_{AB}}{r_1-r_2}\left(\dfrac{r_2}{r_1}\right)\ln\dfrac{1-x_{A2}}{1-x_{A1}}$.

8. Which of the following statements is true?
   (A) Eddy diffusivity is a physical property of a fluid. (B) Eddy diffusivity is independent of turbulent intensity of the flow. (C) Prandtl's mixing length model implies unity turbulent Schmidt number. (D) none of the above.

9. With Chilton-Colburn analogy, what is the corresponding analog of the expression $\mathrm{Nu}=2+0.6(\mathrm{Re})^{1/2}(\mathrm{Pr})^{1/3}$ in mass transfer problem? Here, Nu is Nusselt number, Re is Reynolds number, Pr is Prandtl number, Sh is Sherwood number, Fr is Froude number, and Sc is Schmidt number.
   (A) $\mathrm{Sh}=2+0.6(\mathrm{Re})^{1/2}(\mathrm{Pr})^{1/3}$, (B) $\mathrm{Sh}=2+0.6(\mathrm{Re})^{1/2}(\mathrm{Sc})^{1/3}$, (C) $\mathrm{Sh}=2+0.6(\mathrm{Fr})^{1/2}(\mathrm{Pr})^{1/3}$, (D) $\mathrm{Sh}=2+0.6(\mathrm{Fr})^{1/2}(\mathrm{Sc})^{1/3}$.

10. The equation of continuity of A in a binary dilute solution can be written as

$$\frac{\partial C_A}{\partial t}+\underline{v}\cdot\underline{\nabla}C_A=D_{AB}\nabla^2C_A+R_A,$$

   Here, $\underline{v}$ is the mass average velocity and R_A is the molar reaction rate of A. For the situation of pure diffusion in stationary liquids, what will the above equation be reduced to?
   (A) $\underline{v}\cdot\underline{\nabla}C_A=D_{AB}\nabla^2C_A+R_A$; (B) $\dfrac{\partial C_A}{\partial t}=D_{AB}\nabla^2C_A+R_A$; (C) $\dfrac{\partial C_A}{\partial t}=D_{AB}\nabla^2C_A$;
   (D) $\dfrac{\partial C_A}{\partial t}+\underline{v}\cdot\underline{\nabla}C_A=D_{AB}\nabla^2C_A$.

11. If we increase the reflux ratio in a distillation operation while maintaining the same distillate output, what will be the change in mole fraction of the light key component in the distillate.

(A) Increase　(B)Decrease　(C)Unchange　(D)Unknown (vary from case to case)

12. If we increase the reflux ratio in a distillation operation while maintaining the same distillate output, what will be the change in mole fraction of the heavy key component in the distillate.
(A) Increase
(B) Decrease
(C) Unchange
(D) Unknown (vary from case to case)

13. If we increase the reflux ratio in a distillation operation while maintaining the same distillate output, what will be the change in mole fraction of a non-key component of which the volatility in between the light and heavy key in the distillate.
(A) Increase
(B) Decrease
(C) Unchange
(D) Unknown (vary from case to case)

14. If we increase the reflux ratio in a distillation operation while maintaining the same distillate output, what will be the change in mole fraction of the light key component in the bottom.
(A) Increase
(B) Decrease
(C) Unchange
(D) Unknown (vary from case to case)

15. If we increase the reflux ratio in a distillation operation while maintaining the same distillate output, what will be the change in mole fraction of the heavy key component in the bottom.

(A) Increase　(B)Decrease　(C)Unchange　(D)Unknown (vary from case to case)

The following is a liquid-liquid equilibrium phase diagram for acetone-MIBK-water system. MIBK is used to extract acetone from a waste water stream containing 20 *mol*% acetone.

16. What is the concentration of the extract if the molar flow rate of MIBK used is equal to the molar flow rate of the waste water stream and only 1 equilibrium stage is used?
(A) 0.075
(B) 0.15
(C) 0.30
(D) 0.50

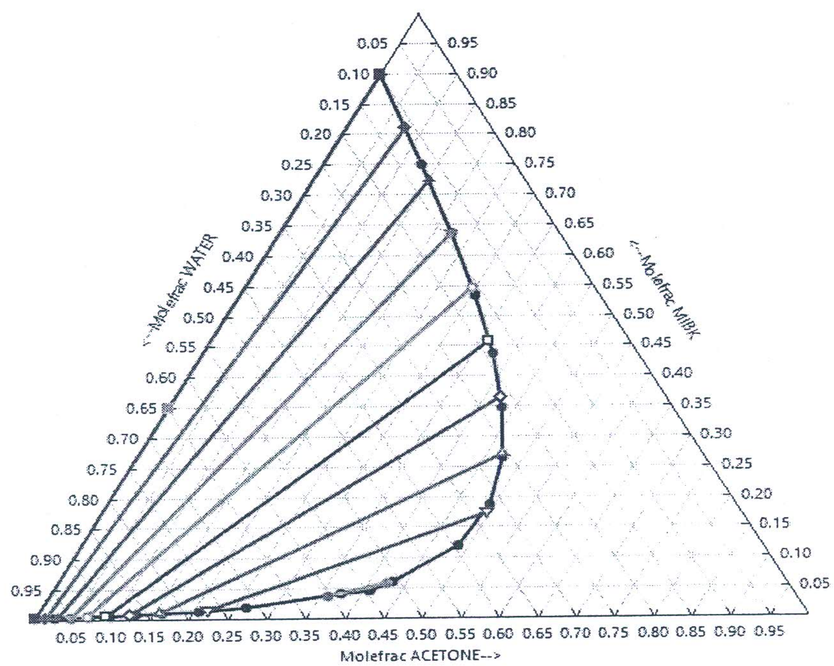
17. What is the concentration of the raffinate if the molar flow rate of MIBK used is equal to the molar flow rate of the waste water stream and only 1 equilibrium stage is used?
(A) 0.02
(B) 0.03
(C) 0.075
(D) 0.175

18. What is the concentration of the extract if the raffinate concentration is 0.02 and only 1 equilibrium stage is used?
(A) 0.075
(B) 0.15
(C) 0.30
(D) 0.50

19. What is the solvent rate required if the raffinate concentration is 0.02 and only 1 equilibrium stage is used?
(A) 0.5
(B) 1
(C) 2
(D) 5

20. What is the concentration of the extract if the raffinate concentration is 0.02 when a minimum solvent rate and many many stages are used?
(A) 0.075
(B) 0.15
(C) 0.30
(D) 0.50

The numbers are only approximate, find the closest value.



21. The unit of thermal conductivity in SI unit is
(A) J/m^{2}sec
(B) J/mKsec
(C) W/mK
(D) (a) and (c)
(E) (b) and (c) above

22. When heat is transferred from hot body to cold body in a straight line without affecting the intervening medium, it is referred as heat transfer by
(A) conduction
(B) convection
(C) radiation
(D) conduction and convection
(E) convection and radiation

23. The concept of overall heat transfer coefficient is used in heat transfer problems of
(A) conduction
(B) convection
(C) radiation
(D) all the three combined
(E) conduction and convection

24. The unit of thermal diffusivity is
(A) m^2/s
(B) m^2/s K
(C) kcal/m^2 s
(D) kcal/m s K
(E) kcal/m^{2}s K

25. In convective heat transfer from hot flue gasses to water tube, even though flow may be turbulent, a laminar flow region (boundary layer of film) exists close to the tube surface. The heat transfer through this film takes place by
(A) convection
(B) radiation
(C) conduction
(D) both convection and conduction
(E) none of the above

以下各題請於答案卷作答

Problem 2 (10%)

Lady Haha is good at making and selling pancakes. Her business is so promising so she decided to hire a chemical engineer to design a system for the mass production of pancakes. This chemical engineer, David, first designed a device to measure the viscosity of the liquid pancake mixture as shown in Fig. 1. He poured the liquid mixture onto top of the device and then measured the time and the weight of the mixture flowing into the receiving pan. Suppose the density of the mixture is q, the weight of the mixture in the receiving pan is W after M seconds.

How does David determine the viscosity μ of this liquid mixture? Assuming the liquid is Newtonian and list your assumptions.

Problem 3 (10%)

David later used the same device as shown in Fig. 1 to deliver a big liquid drop on a flat plate as shown in Fig. 2 and observed how long it took for the drop to flow to the desired geometry. Apparently the drop will expand and becomes flattened. The drop will flow because of gravity and it is balanced by the viscous force. Assuming we can set up a cylindrical coordinate system on this drop, the governing equation can be simplified as

$$\frac{\partial P}{\partial r} = \mu \frac{\partial^2 Ur}{\partial z^2} \qquad (1)$$

Here P is pressure and z is the velocity component in the r-direction.

(a) Can you replace P by $h(r, t)$ in Eq. (1)? (2%) Here $h(r, t)$ is the shape of the drop.

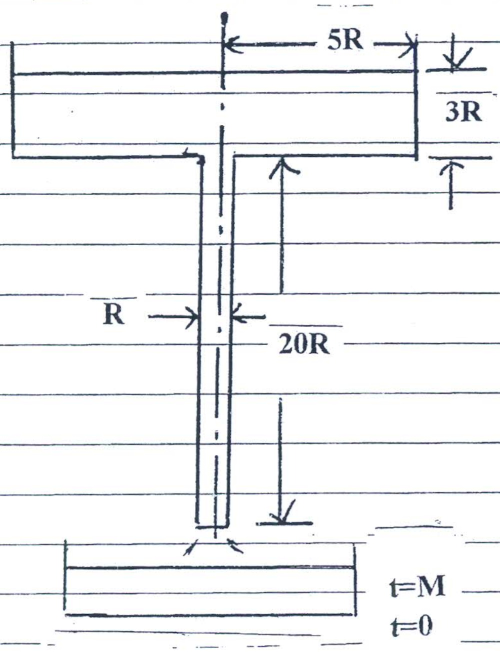
(b) The equation of continuity is as follows:

$$\frac{\partial Uz}{\partial z} + \frac{1}{r}\frac{\partial}{\partial r} rUr = 0 \qquad (2)$$

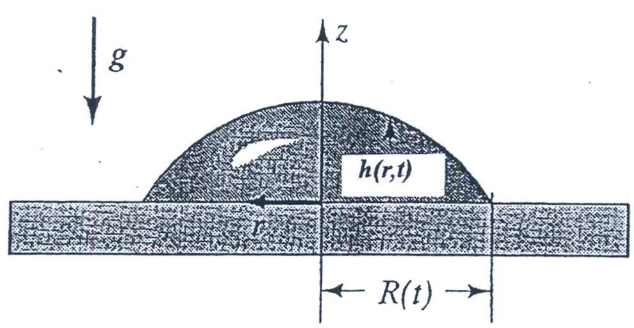
Here Uz is the velocity component in the z-direction. Can you integrate Eq. (2) from $z=0$ to $z=h$? Note that $\begin{cases} z = 0, & Uz = 0 \\ z = h, & Uz = \dfrac{dh}{dt} \end{cases}$ (3%)

(c)Assuming $z=0$, $Ur=0$. $z=h$, $Trz = -\mu \dfrac{\partial Ur}{\partial z} = 0$. Determine Ur from the results of (2). Here Trz is the shear stress at the liquid surface. (3%)

(d)Substitute all the results into Eq. (1) and derive a governing equation with h as the only dependent variable (2%)　You do not need to solve for h.　David can do it, so he can determine what is the right shape to start cooking the pancake.



Receiving Pan
Figure 1



Drop of Volume V

Figure 2 Liquid Mixture on a plate

Problem 4 (8%)

A high performance particle filter was designed to remove the virus particles from the supply of gas flow. The design of the filter is a small fixed-bed with a maximum capacity of 100 grams of packed, specialized adsorbent materials. Due to the restriction of pressure drop in operation, the loading of adsorbent materials is only 50 % of the maximum fill capacity (i.e., partially filled. 50% packed).

The initial concentration of virus particles in the gas flow is 10^6 particles/cm^3, and the gas flow rate is 1.2 liter/min. The whole gas flow, except for the virus particles being filtered, shall completely go through the high performance particle filter described previously.

To identify the performance (i.e., the number of virus particles removed), we use an aerosol particle counter to measure the concentration of virus particles remaining in the gas flow. Since no other species presenting in the gas flow, the only particle counted was virus particle.

The results show that no virus particles went through the filter within 10 hrs of operation. However, when t= 11 hrs (i.e., t is the time of operation), we saw a count of 1000 particles/cm^3 flowing out of the filter. By increasing the operation time to 15 hrs, we observed the particle concentration was 15000 particles/cm^3. When t= 20 hrs, we saw the counting was 60000 particles/cm^3. When t= 25 hrs, we saw the counting was 90000 particles/cm^3. When t=30 hrs, we observed that the counts of virus particles were very close to the initial concentration (i.e., the concentration without being filtrated), and we stop the counting. For an estimate, we assume that the virus particles are uniform with a diameter of 50 nm and a density of 1.5 g/cm^3. Note that the data were collected under the 50 % of the maximum fill capacity of adsorbent materials (i.e., partially filled. 50% packed)..

(a) (5%) Please calculate the maximum amount of virus particles, in term of mass, potentially removed by one filter (i.e., 50% packed filter and when the filter is 100 % saturated).

(b) (3%) If the system is designed to remove at least 98% of the virus particles in the gas flow, please calculate the maximum amount of virus particles adsorbed (in term of mass) during the normal operation of the 50% packed filter .

Problem 5 (6%)

We design an experimental system with a reactor to produce a specialized synthetic oil with a production rate of 1 kg/min. From the catalog, we choose to use a simple condenser with an overall heat transfer coefficient of 300 W/m^2*K that connects to the exit of the reactor.

However, the boiling point of the product was too high, so that all synthetic oil produced were condensed before entering the designed condenser. Instead, this condenser is used to cool the temperature of the oil.

Knowing that the oil having a heat capacity (C_p) of 5 kJ/kg*K is being cooled in the condenser from 380 K to at least 360K. The cooling water used to "condense" the synthetic oil is at a flow rate of 100 kg/hr, with an inlet temperature of 20 ^oC.

Based on the information shown above, please calculate the minimum effective heat transfer area required for the condenser.

Problem 6 (6%)

In a chemical plant, the engineers are planning to design a pumping system that can be used to transport the specialized solvent (denoted as Solvent A).

(a) (4%) The Solvent A with a density of 1500 kg/m^3 flows through a pump at a volumetric flow rate of 6000 liter/min. The pump inlet is a tube of 20 cm in inner diameter. The pump outlet is 10 cm in inner diameter located 10 m above the inlet of the pump. The pressure difference between the inlet and the outlet of the pump is $1*10^5$ Pa. For simplifying the calculation, we assume the temperature constant and no other source of energy involved in the system. Based on the information shown above, please calculate the power of the pump adding to the fluid.

(b) (2%) Please provide a brief description (with an equation) for the requirement of net positive suction head in the system.

Problem 7 (10%)

A long cylindrical rod of radius R and electrical conductivity k is resistance heated by passing an electric current through it. The rate of heat generation per unit volume is S_e. The rod is cooled by directing a fluid of temperature T_f at its surface. The heat transfer coefficient is h. Determine the steady-state radial temperature distribution in the rod and the heat flux across the wire surface. Assume constant thermal properties and neglect radiation and end effects.