# 請在【答案卡】作答

***Problem 1 (20 Points)***

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

1. What is the SI unit of kinematic viscosity?
   (A)Kg/(m s), (B) $m^2/s$, (C) Pa s, (D) $cm^2/s$.
2. What is the SI unit of friction factor?
   (A)1/m, (B) N/m, (C) N/s, (D) dimensionless.
3. For the following fluids, (a) air at 273 K and 1 atm, (b) air at 373 K and 1 atm, (c) water at 300 K, and (d) water at 360 K, place them in the order of increasing viscosity.
   (A)(b)(a)(d)(c), (B) (b)(a)(c)(d), (C) (a)(b)(d)(c), (D) (a)(b)(c)(d).
4. Which one of the following fluids is a Newtonian fluid?
   (A)blood, (B) molten iron, (C) polystyrene melt, (D) tooth paste.
5. Consider a Newtonian fluid of viscosity $\mu$ and density $\rho$ flowing down an inclined flat plate of length $L$ and width $W$. The plate is inclined with an angle $\beta$ to the vertical axis and the film thickness is $\delta$. What is the force exerted by the fluid on the plate?
   (A)$2\rho g\delta LW\cos\beta$, (B) $\rho g\delta LW\sin\beta$, (C) $\rho g\delta LW\cos\beta$, (D) $\rho g\delta LW\sin\beta/2$.
6. When a concentration field, $c$, is in its steady state, then which of the following statement is true?
   (A)The partial time derivative of $c$ is zero. (B) The total time derivative of $c$ is zero. (C) The substantial time derivative of $c$ is zero. (D) None of the above.
7. A semi-infinite body of a Newtonian fluid with constant density and viscosity is bounded below by a horizontal surface (the $xz$-plane). Initially, the fluid and the solid are at rest. Then at time $t$=0, the solid surface is set in motion in the positive $x$ direction with velocity $V$. Here, $\nu$ is the kinematic viscosity. The velocity field is found to be
   $$\frac{v_x}{V}=1-\frac{2}{\sqrt{\pi}}\int_0^{y/\sqrt{4\nu t}}e^{-\eta^2}d\eta.$$
   Derive the shear stress at the wall required to maintain the motion.
   (A)$2V\sqrt{\mu\rho/\pi t}$, (B) $V\sqrt{\mu\rho/\pi t}$, (C) $V\sqrt{\pi t/\mu\rho}$, (D) $V\sqrt{\pi t/\mu\rho}/2$.
8. Consider the following flow fittings: (a) 45° elbow, (b) 90° elbow, (c) 135° elbow, (d) globe valve at open position. Place them in the order of increasing friction loss factor.
   (A)(a)(b)(c)(d), (B) (a)(c)(b)(d), (C) (d)(a)(b)(c), (D) (d)(c)(b)(a).

9. The friction factor, $f$, for flow around a sphere (density $\rho_{sph}$, diameter $D$) is defined by $F_k = (\pi D^2/4)(\rho v_\infty^2/2) f$, where $v_\infty$ is the approach velocity of the fluid (density $\rho$), and $F_k$ is the kinetic force. The friction factor may be obtained experimentally by measuring the terminal velocity of a sphere falling in the fluid using:
(A) $f = \frac{4}{3}\frac{gD}{v_\infty}\frac{\rho_{sph}-\rho}{\rho}$, (B) $f = \frac{3}{4}\frac{gD}{v_\infty^2}\frac{\rho_{sph}-\rho}{\rho}$, (C) $f = \frac{4}{3}\frac{gD}{v_\infty^2}\frac{\rho_{sph}-\rho}{\rho}$, (D) $f = \frac{3}{4}\frac{gD}{v_\infty^2}\frac{\rho}{\rho_{sph}-\rho}$.

10. Which of the following phenomena is caused by the elastic characteristic of a non-Newtonian fluid?
(A)Rod climbing, (B) die swell, (C) non-zero normal stress differences, (D) all of the above.

**以下各題請在【答案卷】作答**

***Problem 2 (12 Points)***

Answer the following questions regarding energy transport.

(a) Both Nusselt number ($Nu$) and Biot number ($Bi$) can be considered as a ratio of the conductive thermal resistance to the convective thermal resistance. What is the fundamental difference between these two dimensionless numbers ? (3%)

(b) Which of the following has a higher Prandtl number: liquid metals flowing in a rectangular channel or molten poly(vinyl chloride) flowing in a circular channel? Why? (3%)

(c) A metal sphere of radius $R$ and thermal conductivity $k$ is initially in equilibrium at T in a furnace. It is suddenly removed from the furnace and cooled in air at room temperature. The convective heat transfer coefficient for this process is $h$. Under what physical condition can the temperature in the sphere be regarded as uniform? Please choose the correct statements from the followings: (3%)
(i) The volume of the sphere is very small.
(ii) The volume of the sphere is very large.
(iii) The value of $Bi$ is very small.
(iv) The value of $Bi$ is very large

(d) Roughly plot the time-smoothed temperature profile in a tube with turbulent flow. Compare it with the case for a laminar flow and point out the major difference between the two cases. (3%)

***Problem 3 (8 Points)***

(a) Write down the equation of change for temperature for a *fully-developed laminar Newtonian flow* in a circular tube of radius R under steady state. The temperature is a function of r and z, i.e. T = T(r,z). Viscous dissipation must be considered and the velocity distribution is given by $v_z = v_{z,max}[1-(r/R)^2]$, where $v_{z,maz}$ is the maximum velocity. (4%)

(b) Show that for the isothermal wall problem ($T=T_0$ at r = R for z > 0 and at z = 0 for all r), the asymptotic expression for T(r) at large z is as follows. Do this by recognizing that $\partial T/\partial z = 0$ at large z. (4%)

$$T - T_0 = \frac{\mu v_{z,\max}^{\;2}}{4k}\left[1-\left(\frac{r}{R}\right)^4\right]$$

**THE EQUATION OF ENERGY FOR PURE NEWTONIAN FLUIDS WITH CONSTANT $\rho$ AND $k$**

$$[\rho\hat{C}_p DT/Dt = k\nabla^2 T + \mu\Phi_v]$$

*Cartesian coordinates (x, y, z):*

$$\rho\hat{C}_p\left(\frac{\partial T}{\partial t} + v_x\frac{\partial T}{\partial x} + v_y\frac{\partial T}{\partial y} + v_z\frac{\partial T}{\partial z}\right) = k\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right] + \mu\Phi_v$$

*Cylindrical coordinates (r, θ, z):*

$$\rho\hat{C}_p\left(\frac{\partial T}{\partial t} + v_r\frac{\partial T}{\partial r} + \frac{v_\theta}{r}\frac{\partial T}{\partial \theta} + v_z\frac{\partial T}{\partial z}\right) = k\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2} + \frac{\partial^2 T}{\partial z^2}\right] + \mu\Phi_v$$

*Spherical coordinates (r, θ, φ):*

$$\rho\hat{C}_p\left(\frac{\partial T}{\partial t} + v_r\frac{\partial T}{\partial r} + \frac{v_\theta}{r}\frac{\partial T}{\partial \theta} + \frac{v_\phi}{r\sin\theta}\frac{\partial T}{\partial \phi}\right) = k\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial T}{\partial r}\right) + \frac{1}{r^2\sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial T}{\partial \theta}\right) + \frac{1}{r^2\sin^2\theta}\frac{\partial^2 T}{\partial \phi^2}\right] + \mu\Phi_v$$

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***Problem 3*** (請接上頁)

**THE DISSIPATION FUNCTION $\Phi_v$ FOR NEWTONIAN FLUIDS**

*Cartesian coordinates (x, y, z):*

$$\Phi_v = 2\left[\left(\frac{\partial v_x}{\partial x}\right)^2 + \left(\frac{\partial v_y}{\partial y}\right)^2 + \left(\frac{\partial v_z}{\partial z}\right)^2\right] + \left[\frac{\partial v_y}{\partial x} + \frac{\partial v_x}{\partial y}\right]^2 + \left[\frac{\partial v_z}{\partial y} + \frac{\partial v_y}{\partial z}\right]^2 + \left[\frac{\partial v_x}{\partial z} + \frac{\partial v_z}{\partial x}\right]^2 - \frac{2}{3}\left[\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z}\right]^2$$

*Cylindrical coordinates (r, θ, z):*

$$\Phi_v = 2\left[\left(\frac{\partial v_r}{\partial r}\right)^2 + \left(\frac{1}{r}\frac{\partial v_\theta}{\partial \theta} + \frac{v_r}{r}\right)^2 + \left(\frac{\partial v_z}{\partial z}\right)^2\right] + \left[r\frac{\partial}{\partial r}\left(\frac{v_\theta}{r}\right) + \frac{1}{r}\frac{\partial v_r}{\partial \theta}\right]^2 + \left[\frac{1}{r}\frac{\partial v_z}{\partial \theta} + \frac{\partial v_\theta}{\partial z}\right]^2 + \left[\frac{\partial v_r}{\partial z} + \frac{\partial v_z}{\partial r}\right]^2$$

$$- \frac{2}{3}\left[\frac{1}{r}\frac{\partial}{\partial r}(r v_r) + \frac{1}{r}\frac{\partial v_\theta}{\partial \theta} + \frac{\partial v_z}{\partial z}\right]^2$$

*Spherical coordinates (r, θ, φ):*

$$\Phi_v = 2\left[\left(\frac{\partial v_r}{\partial r}\right)^2 + \left(\frac{1}{r}\frac{\partial v_\theta}{\partial \theta} + \frac{v_r}{r}\right)^2 + \left(\frac{1}{r\sin\theta}\frac{\partial v_\phi}{\partial \phi} + \frac{v_r + v_\theta\cot\theta}{r}\right)^2\right]$$

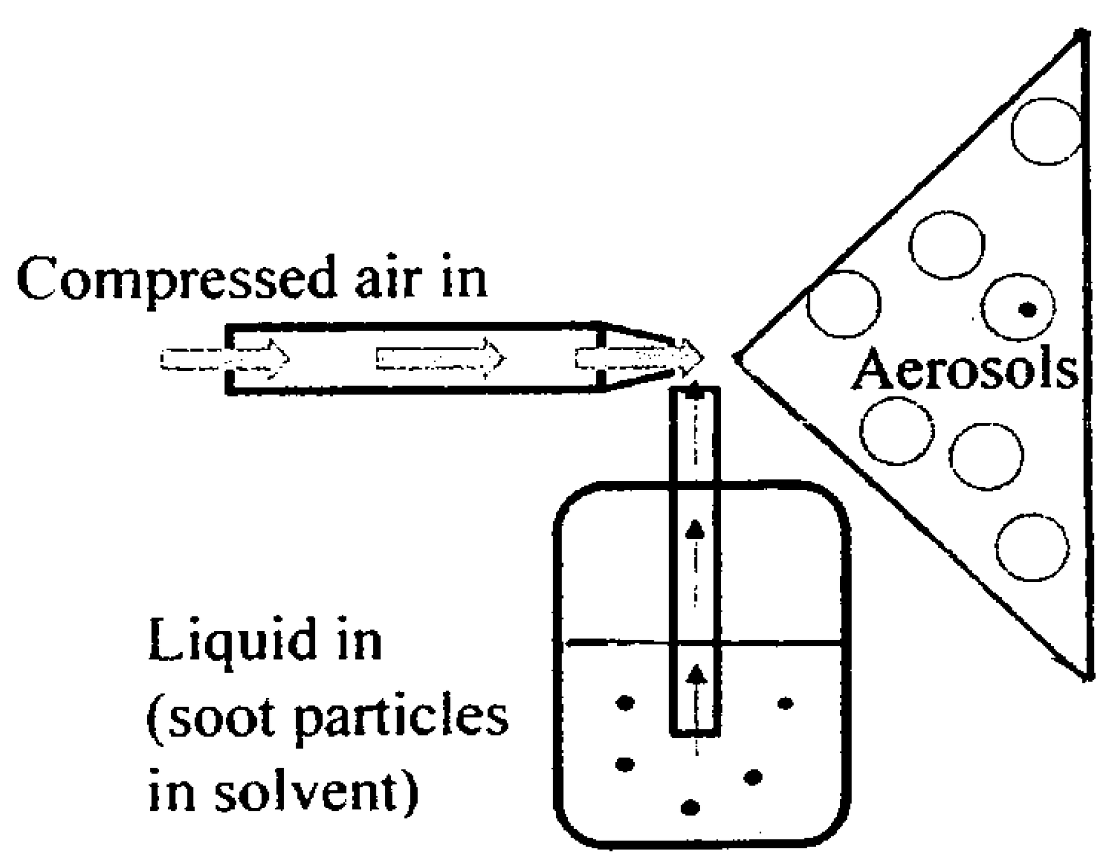
$$+ \left[r\frac{\partial}{\partial r}\left(\frac{v_\theta}{r}\right) + \frac{1}{r}\frac{\partial v_r}{\partial \theta}\right]^2 + \left[\frac{\sin\theta}{r}\frac{\partial}{\partial \theta}\left(\frac{v_\phi}{\sin\theta}\right) + \frac{1}{r\sin\theta}\frac{\partial v_\theta}{\partial \phi}\right]^2 + \left[\frac{1}{r\sin\theta}\frac{\partial v_r}{\partial \phi} + r\frac{\partial}{\partial r}\left(\frac{v_\phi}{r}\right)\right]^2$$

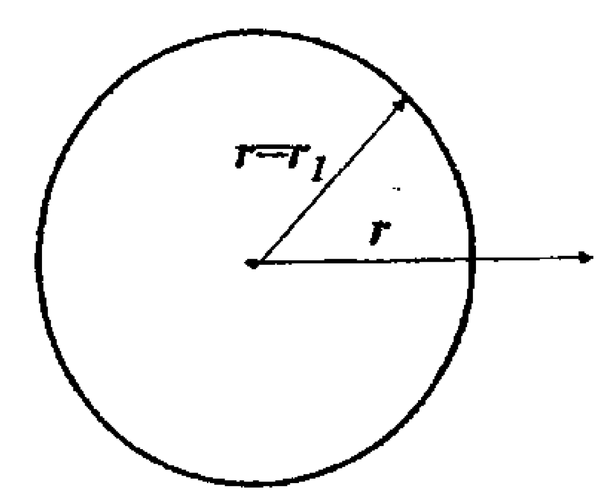
$$- \frac{2}{3}\left[\frac{1}{r^2}\frac{\partial}{\partial r}(r^2 v_r) + \frac{1}{r\sin\theta}\frac{\partial}{\partial \theta}(v_\theta\sin\theta) + \frac{1}{r\sin\theta}\frac{\partial v_\phi}{\partial \phi}\right]^2$$

***Problem 4 (14 Points)***

(a) (8%) A specialized atomizer is used to convert soot colloids (i.e., soot particles as solutes, suspended in a solvent) into aerosols in an air flow.

As shown in the figure on the left, these aerosols are mainly solvent-based droplets. A few droplets may also contain one soot particle with the solvent. Because the diameter of droplets is at least 5 times larger than the diameter of soot particles, we assume only one-size droplets are generated from the atomizer.




Theoretically, the diameter of droplets generated by this atomizer is correlated to its liquid (feed) flow rate: $d_{d,1} = d_{d,0} \times (Q_1 / Q_0)^{1/3}$.

Here $d_{d,1}$ is the droplet diameter corresponding to the liquid flow rate $Q_1$ (2*$10^{-5}$ $cm^3$/min), and $d_{d,0}$ (=500 nm) is the reference value of droplet diameter corresponding to a liquid flow rate of $Q_0$ (=1*$10^{-5}$ $cm^3$).

The operating temperature and pressure in the air flow is 25 °C and 1 atm, respectively. The diffusivity of solvent's vapor (defined as Component A) in the air is 0.282 $cm^2$/s. The vapor pressure of the solvent in this system is 3.1 kPa. The density of solvent is 1.1 g/$cm^3$, and the molecular mass of the solvent is 20 g/mol.

Other assumptions: (1) the size of droplets is uniform; (2) the presence of soot particles has little impact to the vapor pressure of solvent droplets. (3) When $r$>10 μm (r is the distance from the center of the droplet, as shown in the figure on the right), the vapor concentration of solvent in the air flow is negligible. (4) Constant air flow rate and can be assumed as a stagnant flow.

**Based on the information shown above, obtain the molar ratio of Component A in the air flow ($x_A$) as a function of *r*.** (With a detailed derivation).

(b) (6%) (Continue on the Problem 4(a)) After the solvent are fully evaporated, soot particles remained in the air flow are delivered into a tube furnace.

By elevating the temperature of furnace to a constant heating zone (1200K and 1.6 atm), surface atoms of soot particles starts to oxidized and then diffused into the air flow.

Before the heat treatment, the number-average diameter of soot particles is 50 nm, where the flowing gas creates a stagnant gas boundary layer of 50 nm (in thickness) around the external surface of a soot particle.

Assuming the whole process is limited by the molecular diffusion of oxygen to the surface of particles, **determine the final particle diameter, by choosing a 0.1 μ-second residence time (i.e., reaction time) in the constant heating zone of a tube furnace.**

(With a detailed derivation).

Assumptions/experimental parameters:

(1) The diffusivity of oxygen in air is 1.2 $cm^2$/s. (2) Soot particle is assumed to be 100 % pure carbon, and the density of a soot particle is 2.0 g/$cm^3$. (3) The composition of air is 21 mol % of oxygen (defined as component A) and 79 % of nitrogen. (4) The concentration gradient, $dx_A/dr$ (here $r$ is the distance from the center of the droplet) can be simplified as: $dx_A/dr|_{r=r_1} = (x_{A2} - x_{A1})/(r_2 - r_1)$. Here $x_A$ is the molar ratio of A in the air. $x_{A1}$ and $x_{A2}$ are the $x_A$ values at the surface of soot particle ($r$=$r_1$) and at the outer stagnant gas boundary layer ($r$=$r_2$), respectively.

***Problem 5 (6 Points)***

A batch of dried, spherical silica particles (average diameter: $d_{p,0}$) containing a substance A are dispersed into a solvent (B). The initial molar concentration of A in a silica particle is $n_{A,0}$ (unit: mol/m$^3$ of silica). It is known that the substance A will diffuse into the solvent, and the rate-controlling step is the diffusion of A from the particle surface through a stagnant liquid film ($\delta$ in thickness) out into the main stream. The molar solubility of A in the solvent is $C_{A0}$, and the concentration of A in the main stream beyond the liquid film is assumed to be negligible in the whole process. Because $d_{p,0} >> \delta$, the curvature of particle is also negligible. Assuming a steady state diffusion with a diffusivity of $D_{AB}$, **determine the final molar concentration of A in a silica particle ($n_A$), with a reaction time of $t_f$.** (With a detailed derivation).

***Problem 6 (10 Points)***

(drying of solids) Drying of wet solids is by definition a thermal process, while it is sometimes complicated by diffusion in the solid and through a gas. For a simple drying by flowing gases across a static bed: Please write down the equation for the quantity of heat transferred per unit mass of solid (i.e. heat duty for this drying process) (there are a total of five terms, each term representing different function of the heat; remember to define each symbol used in your equation)

***Problem 7 (10 Points)***

(fluid flow through a pipe) Write down the Bernoulli equation for incompressible fluid after considering the friction loss. Fanning friction factor f is defined as: $f = \tau_w/(\rho V^2/2)$ where $\tau_w$ is wall shear stress, $\rho$ fluid density and V is the average velocity of fluid. Derive an expression for f in terms of pressure drop over a length of L.

**_Problem 8 (10 Points)_**

A gas stream containing 2% of component A is passing through a packed column to remove 95 % of A by absorption with pure liquid water.。The molar fluxes of the gas and liquid are 2.0 mol/s-m$^2$ and 10 mol/s-m$^2$, respectively. Mass transfer coefficients and equilibrium constant at the operating conditions are:

Equilibrium: $y = 3x$ (y and x are the molar fractions of A in gas and liquid phases, respectively)

liquid film mass transfer: $k_x a$= 2.4 mol/s-m$^3$ unit mol fraction

gas film mass transfer: $k_y a$= 1.2 mol/s-m$^3$ unit mol fraction

(a) Find the values of $N_{Oy}$, $H_{Oy}$ and $Z_T$. (6%)

where $N_{Oy}$: Overall number of transfer unit

$H_{Oy}$: Overall height of transfer unit

$Z_T$: height of packed zone

(Assuming liquid and gas molar flow rates, L and V, are constant throughout the column)

(b) What percentage of gas film mass transfer resistance is in the total mass transfer resistance? (2%)

(c) Find the minimum liquid molar flux (mol/s-m$^2$) for this separation job. (2%)

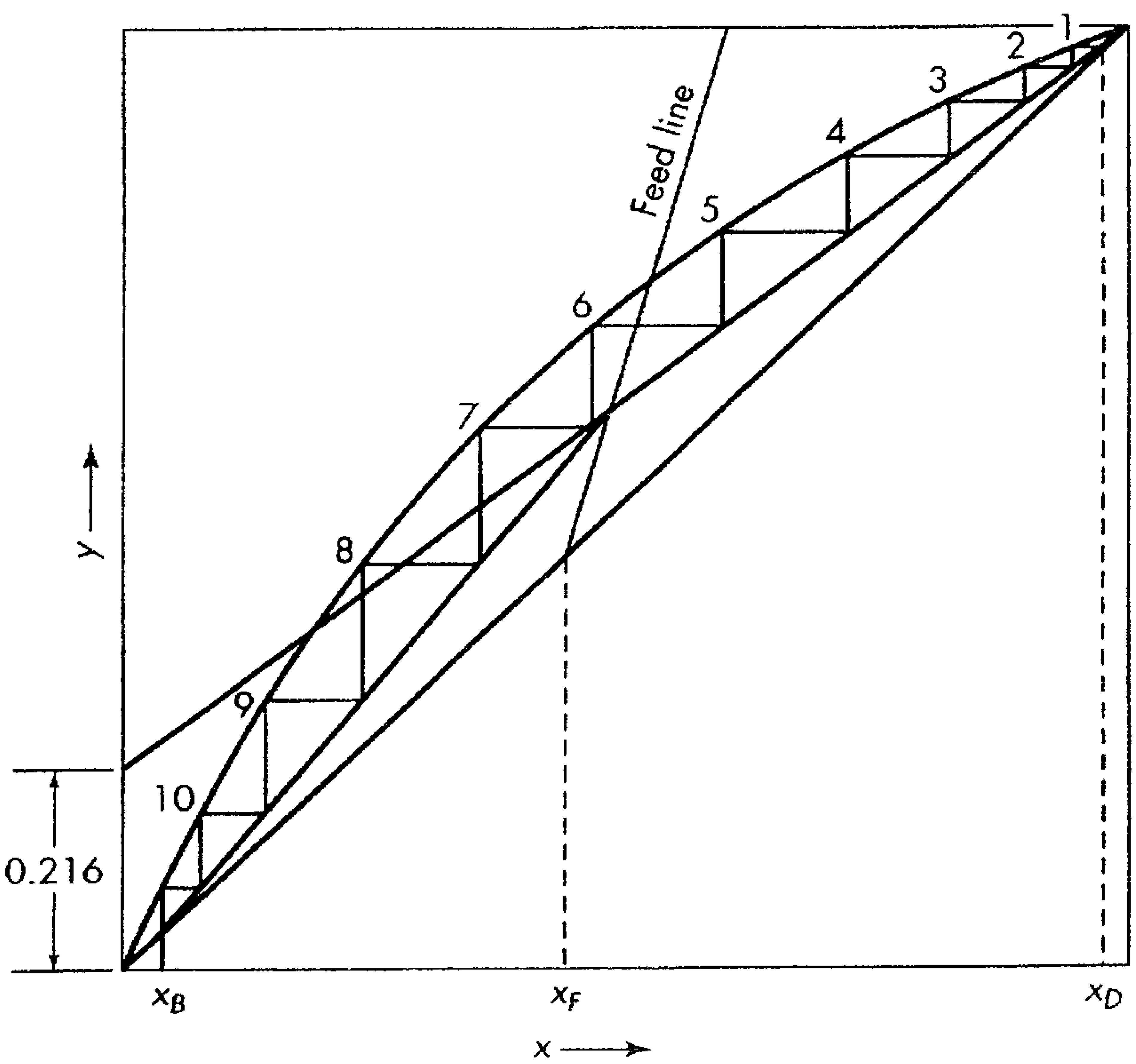
# 國立清華大學 103 學年度碩士班考試入學試題

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)

 *請在【答案卷、卡】作答

***Problem 9 (10 Points)***




A binary distillation process is represented by the McCabe-Thiele diagram shown above. Please answer the following questions based on this diagram. (2% for each question)

(a) What phase(s) is the feed stream on the feed plate?

(b) Is a total or partial condenser used in this case?

(c) Which plate is the feed plate here?

(d) If $x_D = 0.98$, what is the value of reflux ratio R?

(e) If the plate efficiency is 0.75, how many actual plates should be used in the distillation column, in addition to the reboiler?