# QUIZ PE–CE
FE/PE Practice Problems:
Chemical Engineering
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Problem 1. The local velocity of a fluid along a streamline can be measured by

A) A Pitot tube.

B) A Venturi meter.

C) A rotameter.

D) An orifice meter.

Problem 2. The 500-kg load on the hydraulic lift shown below is to be raised by pouring oil of density 780 kg/m³ into a thin tube. The height h (cm) required to begin to raise the weight is most nearly:
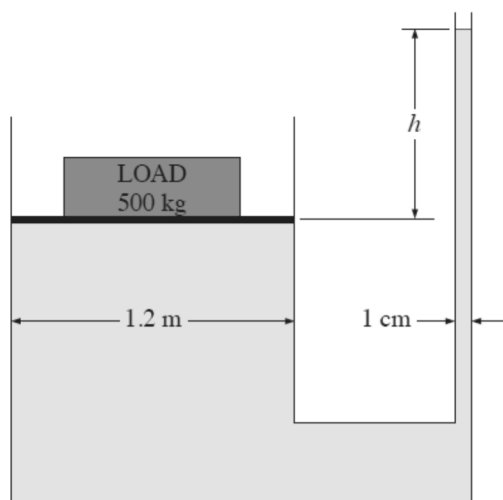
A) 15

B) 32

C) 57

D) 81

Problem 3. A pipeline of 0.08-m² cross-sectional area carries water at an average velocity of 4 m/s. The main pipeline branches into two pipes, one with a 0.02-m² cross-sectional area and another with a 0.04-m² cross-sectional area, as shown. The flow velocity in the 0.02-m² segment is 1.6 times the velocity in the main pipeline. Velocity V_2 (m/s) is most nearly:

$V_1 = 1.6 \times V_0$
$A_1 = 0.02 \text{ m}^2$

Q

$V_2 = ?$
$A_2 = 0.04 \text{ m}^2$

$V_0 = 4.0 \text{ m/s}$
$A_0 = 0.08 \text{ m}^2$
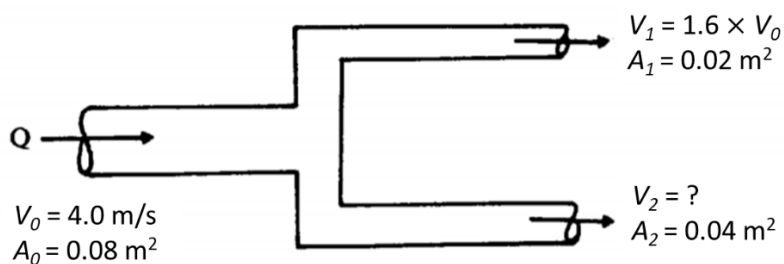
A) 3.8

B) 4.8

C) 6.0

D) 7.2

Problem 4. Water is flowing under laminar conditions in a pipe of length L. If the diameter of the pipe is doubled, for a constant volumetric flow rate, the pressure drop across the pipe

A) Decreases four times.

B) Decreases 16 times.

**C)** Increases four times.

D) Increases 16 times.

Problem 5. A water-in-oil emulsion is being separated in a settling tank. Water droplets slowly settle to the bottom of the tank, which has a height of 4 m. The densities of oil and water are 800 kg/m³ and 1000 kg/m³, respectively, and the viscosities of oil and water are 10^{-3} Pa·s and 5×10^{-3} Pa·s, respectively. Assume Stokes' law can be used to estimate the settling velocity. The time (hours) required for a spherical droplet of 50 μm diameter to settle from the top to the bottom of the tank is most nearly:

A) 5

B) 10

C) 15

D) 20

Problem 6. For a fully-developed turbulent hydrodynamic boundary layer in flow over a flat plate, the thickness of the boundary layer increases with distance x from the leading edge of the plate, along the free-stream flow direction, following the proportion

A) $x^{0.4}$

B) $x^{0.5}$

C) $x^{0.8}$

D) $x^{1.5}$

Problem 7. The following graph illustrates the rheologic behavior of four types of non-Newtonian fluids. Which of the following associations correctly define the four types of fluid?
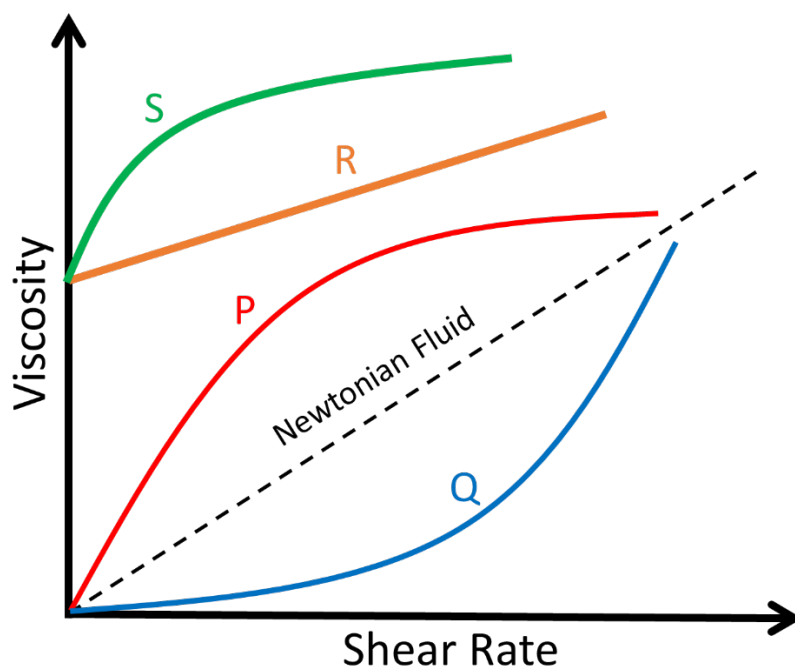
A) P. Shear-thickening fluid; Q. Shear-thinning fluid; R. Casson fluid; S. Bingham plastic;

B) P. Shear-thickening fluid; Q. Shear-thinning fluid; R. Bingham plastic; S. Casson fluid;

C) P. Shear-thinning fluid; Q. Shear-thickening fluid; R. Casson fluid; S. Bingham plastic;

D) P. Shear-thinning fluid; Q. Shear-thickening fluid; R. Bingham plastic; S. Casson fluid;

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Problem 8. In a test of the pump illustrated in the figure below, the data are: pressure at station 1 P_1 = 13.3 kPa, pressure at station 2 P_2 = 66.7 kPa, flow velocity at station 1 V_1 = 1.0 m/s, and flow velocity at station 2 V_2 = 6.0 m/s. The pump is used to drive oil of specific weight equal to 8.8 kN/m³. The discharge is 0.02 m³/s. The pump input power (kW) at 75 percent efficiency is most nearly:
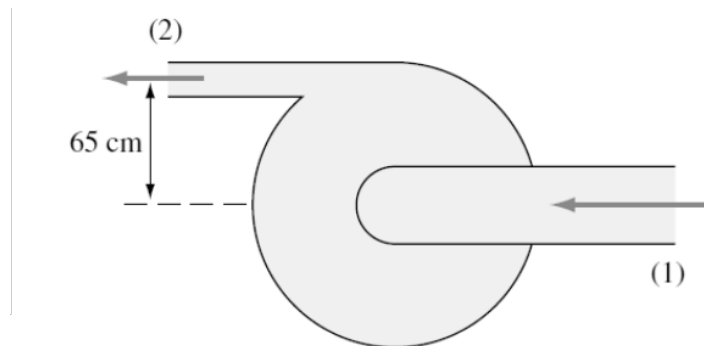
A) 0.5
B) 1
C) 2
D) 3

Problem 9. A three-bladed propeller is used to mix a fluid in the laminar region. The stirrer is 0.3 m in diameter and is rotated at 1.5 Hz. Due to corrosion, the propeller has to be replaced by a flat two-bladed paddle, 0.75 m in diameter. The power requirements in W for a propeller and a flat paddle are given by the expressions listed below, where N is the rotational speed in Hz and D is the diameter in meters. If the same motor is used for the propeller and the paddle, the speed (Hz) at which the paddle should rotate is most nearly:
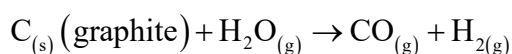
Device	Power requirement P (W)
Propeller	$P = 1964N^2D^3$
Paddle	$P = 1748N^2D^3$

A) 0.1
B) 0.4
C) 0.7
D) 1.0

Problem 10. The internal energy of an ideal gas depends on

A) Pressure only.
B) Temperature only.
C) Pressure and temperature.
D) Pressure, temperature, and volume.

Problem 11. Consider the reaction

$$C_{(s)}\left(\text{graphite}\right) + H_2O_{(g)} \rightarrow CO_{(g)} + H_{2(g)}$$

The standard heats of formation of $H_2O_{(g)}$ and $CO_{(g)}$ are −241.8 kJ/mol and −110.5 kJ/mol, respectively. The standard internal energy change (kJ) for this reaction is most nearly:

A) 102
B) 111
C) 120
D) 129

Problem 12. Which of the following gases has a negative acentric factor?
A) Carbon monoxide.
B) Carbon dioxide.
C) Helium.
D) Propylene.

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Problem 13. In the following table, the left column lists the names of a few equations of state and the right column lists their mathematical statements. In the equations, P is pressure, T is temperature, $\bar{V}$ is molar volume, R is the gas constant, and a and b are parameters that may not be the same from one equation to the other. Which of the following associations is correct?

Equation Name	Definition
1. Van der Waals equation	**P.** $P = \dfrac{RT}{\bar{V}-b} - \dfrac{a}{\bar{V}\left(\bar{V}+b\right)T^{1/2}}$
2. Berthelot equation	**Q.** $P = \dfrac{RT}{\bar{V}-b} - \dfrac{a}{\bar{V}\left(\bar{V}+b\right)+b\left(\bar{V}-b\right)}$
3. Redlich-Kwong equation	**R.** $P = \dfrac{RT}{\bar{V}-b} - \dfrac{a}{\bar{V}^2}$
4. Peng-Robinson equation	**S.** $P = \dfrac{RT}{\bar{V}-b} - \dfrac{a}{T\bar{V}^2}$

A) 1.Q, 2.R, 3.S, 4.P;
B) 1.R, 2.S, 3.Q, 4.P;
C) 1.S, 2.R, 3.P, 4.Q;
D) 1.R, 2.S, 3.P, 4.Q;

Problem 14. A gas expands from a volume of 3.0 dm³ to 5.0 dm³ against a constant pressure of 3.0 atm. The work done during expansion is used to heat 15 g of water at an initial temperature of 290 K. The specific heat of water is 4.18 J/gK. The relation 1 liter-atm = 101.3 J may be useful. The final temperature (K) of the water sample is most nearly:

A) 294
B) 300
C) 306
D) 312

Problem 15. The constant-volume specific heat of silver may be taken as constant and equal to 5.9 cal/(°C·mol). The change in entropy (J/K) involved in heating a mole of silver at constant volume from 0°C to 30°C is most nearly:

A) 0.65
B) 1.3
C) 2.6
D) 5.2

Problem 16. The enthalpy of vaporization of ethanol at its normal boiling point of 352 K is 42.0 kJ/mol. Assume this compound can be modeled with the Clausius-Clapeyron equation. The vapor pressure (bar) of ethanol at 100°C is most nearly:

A) 2.3
B) 3.4
**C)** 4.3
D) 5.5

Problem 17. Consider a vapor-liquid equilibrium of benzene and toluene at 100°C. At this temperature, the vapor pressures of benzene and toluene are 180 kPa and 74 kPa, respectively. The mole fraction of benzene in the vapor phase is 0.33, Assuming the system can be modeled with Raoult's law, the equilibrium mole fraction of benzene in the liquid phase is most nearly:

A) 0.40
B) 0.55
C) 0.70
D) 0.85

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Problem 18. Henry's constant for oxygen in water at 20°C is 1.3×10^{-3} mol/(L·atm) The partial pressure of oxygen in a water sample is 0.5 atm. The solubility of oxygen in water (mmol/L) for this sample, given a temperature of 20°C, is most nearly:

A) 0.65

B) 0.95

C) 1.2

D) 1.5

Problem 19. Consider the following chemical equilibrium reaction.

$$2H_2S_{(g)} + 3O_{2(g)} \rightleftharpoons 2H_2O_{(g)} + 2SO_{2(g)} \ ; \ \Delta H = -1036 \text{ KJ/mol}$$
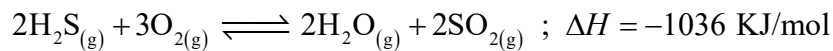
According to Le Chatelier's principle, which of the following modifications would favor the direct reaction – that is, would displace the equilibrium to the right?

A) Increasing the system temperature.

B) Increasing the system pressure.

C) Removing some $O_{2(g)}$ from the system.

D) Adding argon to the system.

Problem 20. An isothermal liquid-phase zero-order reaction A → B (k = 0.5 mol/m³·s) is carried out in a batch reactor. The initial concentration of A is 2 mol/m³. After 2 seconds from the start of the reaction, the concentration of A (mol/m³) is most nearly:

A) 1.0

B) 1.25

C) 1.5

D) 1.75

Problem 21. A mixed flow reactor promotes the conversion of a substrate A to a product R, with the rate equation shown below.

$$A \rightarrow R \ ; \ -r_A = \frac{0.1C_A}{1+0.5C_A} \ \frac{\text{mol}}{\text{liter} \cdot \text{min}}$$
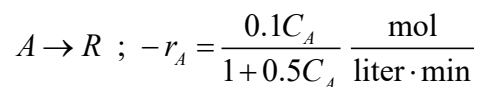
We aim to determine the size of mixed flow reactor needed for 95% conversion of reactant in a feed stream of 25 liter/min of reactant. The initial concentration of A in the feed stream is 2 mol/liter. The minimum reactor volume (m³) that satisfies these requirements is most nearly:

A) 1

B) 3

C) 5

D) 7

Problem 22. A 1 mol/liter gaseous feed of pure A enters a 2-liter mixed flow reactor and reacts as follows.

$$2A \rightarrow R \ ; \ -r_A = 0.05C_A^2 \ \frac{\text{mol}}{\text{liter} \cdot \text{sec}}$$
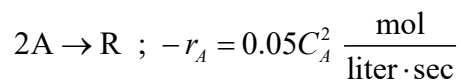
The feed rate (liter/min) that will give an outlet concentration of A equal to 0.5 mol/liter is most nearly:

A) 0.84

B) 1.3

C) 2.3

D) 3.2

Problem 23. The first-order liquid phase reaction A → P is conducted isothermally in a plug flow reactor of 5 liter volume. The inlet volumetric flow rate is 1 liter/min and the inlet concentration of A is 2 mol/liter. If the exit concentration of A is 0.5 mol/liter, then the rate constant (min) is most nearly:

A) 0.04

B) 0.12

C) 0.20

D) 0.28

Problem 24. A gas-phase reaction A → R + S occurs in a PFR reactor. The reactant A is steadily introduced into the PFR at a constant temperature of 300°C. The reaction is first-order and the rate constant at 300°C is 0.42 s^{-1}. The mean residence time is 5 sec. Under these conditions, the conversion of A is most nearly:

A) 0.62

B) 0.70

C) 0.88

D) 0.95

Problem 25. For a first-order reaction in a porous spherical catalyst pellet, diffusional effects are most likely to lower the observed rate of reaction for

A) A slow reaction in a pellet of small diameter.

B) A slow reaction in a pellet of large diameter.

C) A fast reaction in a pellet of small diameter.

D) A fast reaction in a pellet of large diameter.

Problem 26. A steady-state, heterogeneous first-order reaction is carried out on a catalyst that consists of thin platelets of 5 mm thickness. The reaction rate is 1.6×10^{-3} sec^{-1} and the effective mass diffusivity of catalyst particles in the surrounding medium is 10^{-8} m²/s. The effectiveness factor for this system is most nearly:

A) 0.24

B) 0.48

C) 0.60

D) 0.72

Problem 27. A composite wall is made of four different materials of construction in the structure shown below. The resistance, in K/W, of each of the sections of the wall is indicated in the diagram. The equivalent resistance (K/W) of the composite wall, in the direction of heat flow, is most nearly:


A) 3.9

B) 4.2

C) 4.5

D) 4.7

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Problem 28. The bottom face of a horizontal slab of thickness 6 mm is maintained at 300°C. The top face is exposed to a flowing gas at 30°C. The thermal conductivity of the slab is 1.5 W/m·K and the convective heat transfer coefficient is 30 W/m²·K. At steady state, the temperature (°C) of the top face is most nearly:

T_∞ = 30°C

L = 6 mm

300°C

h = 30 W/m²K
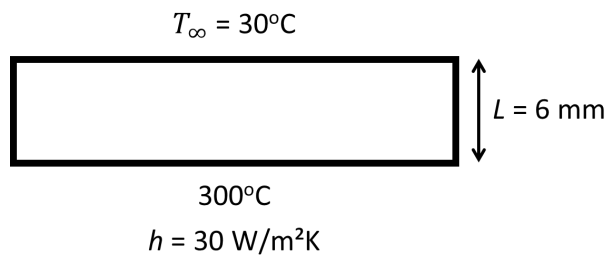
A) 260
B) 271
C) 280
D) 291

Problem 29. An oil with a flow rate of 1000 kg/h is to be cooled using water in a double-pipe counter-flow heat exchanger from a temperature of 70°C to 40°C. Water enters the exchanger at 25°C and leaves at 40°C. The specific heat of oil is 2 kJ/kg·K. The overall heat transfer coefficient is 0.2 kW/m²·K. The minimum heat exchanger area (m²) required for this operation is most nearly;

Oil, 70°C

Water, 25°C   Water, 40°C

Oil, 40°C
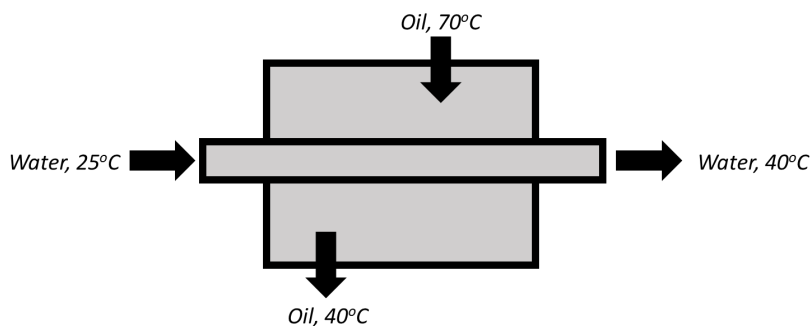
A) 1.7
B) 2.4
C) 3.9
D) 6.0

Problem 30. In a pool boiling experiment, the following phenomena are observed:
P. Natural convection;
Q. Film boiling;
R. Transition boiling;
S. Nucleate boiling;

With increasing excess temperature, the correct sequence in which these phenomena occur is:
A) P → R → Q → S;
B) P → S → R → Q;
C) P → R → S → Q;
D) S → P → R → Q;

Problem 31. A saturated vapor condenses on a vertical, isothermal flat plate in a continuous film. Let T_s denote the plate surface temperature and T_{sat} be the saturation temperature of the fluid. In this case, the rate of heat transfer is proportional to:
A) $(T_s - T_{sat})^{1/4}$
B) $(T_s - T_{sat})^{1/2}$
C) $(T_s - T_{sat})^{2/3}$
**D)** $(T_s - T_{sat})^{3/4}$

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Problem 32. The average heat transfer coefficient for air flow over an odd-shaped body is to be determined using the Chilton-Colburn analogy between heat and mass transfer. The experiment was conducted by blowing dry air over a body covered with a layer of naphthalene, which led to the determination of a convective mass transfer coefficient of 0.08 m/s. Under the conditions in question, the density of air is 1.18 kg/m³, the specific heat of air is 1000 J/kg·K, the thermal diffusivity of air is 2×10^{-5} m²/s, and the mass diffusivity of naphthalene in air is 6×10^{-6} m²/s. The corresponding heat transfer coefficient (W·m²·K⁻¹) is most nearly:

A) 56
B) 112
C) 150
D) 211

Problem 33. Consider steady-state radiation heat transfer between a sphere of radius r_1 = 0.3 m (surface area = 1.13 m²) and a circular disk of radius r_2 = 1.2 m (surface area = 4.52 m²), which are separated by a center-to-center distance of h = 0.6 m. When the normal to the center of disk passes through the center of the sphere, the radiation view factor from surface 1 to surface 2 is given by

$$F_{12} = 0.5\left\{1-\left[1+\left(\frac{r_2}{h}\right)^2\right]^{-0.5}\right\}$$

The view factor F_{21} from surface 2 to surface 1 is most nearly:
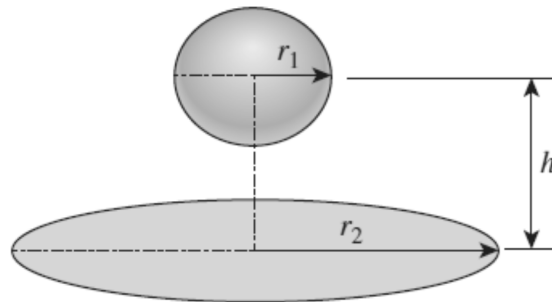
A) 0.035
B) 0.069
C) 0.35
D) 0.69

Problem 34. Below, the column to the left lists mass transfer theories and the column to the right lists possible proportions between the mass transfer coefficient and the mass diffusivity D_{AB}. Which of the following is the correct association?

Model	Proportion
1. Whitman's Film Theory	**P.** $h_m \propto D_{AB}^{1/3}$
2. Higbie's Penetration Theory	**Q.** $h_m \propto D_{AB}^{1/2}$
3. Flat Plate Boundary Layer Theory	**R.** $h_m \propto D_{AB}^{2/3}$
	S. $h_m \propto D_{AB}^{1}$

A) 1.P, 2.R, 3.Q;
B) 1.Q, 2.P, 3.S;
C) 1.S, 2.Q, 3.R;
D) 1.S, 2.R, 3.Q;

Problem 35. In surface renewal theory, the fractional rate of surface renewal has units of (L denotes length and T denotes time):

A) T^{-1}
B) T
C) L/T
D) $\sqrt{L/T}$

Problem 36. Consider the following two cases for a binary mixture of ideal gases A and B under steady-state conditions. In Case 1, the diffusion of A occurs through a non-diffusing B. In Case 2, equimolal counter diffusion of A and B occurs. In both cases, the total pressure is 100 kPa and the partial pressures of A at two points separated by a distance of 10 mm are 10 kPA and 5 kPa. Assume that the system can be modeled with Fick's first law of diffusion. The ratio (absolute value) of the molar flux of A in Case 1 to that in Case 2 is most nearly:

A) 0.38
B) 0.93
C) 1.53
D) 2.18

Problem 37. The ordinary diffusion coefficient of hydrogen in ethane in a porous solid is given by $D_{AB} = 0.86/P$, where P is the total pressure in atm and D_{AB} is given in cm²/s. The porous medium has 50% porosity and tortuosity of 1.6. Flow occurs at 25°C and 2 atm. The effective diffusion coefficient (cm²/s) for this system is most nearly:

A) 0.13
B) 0.28
C) 0.43
D) 0.58

Problem 38. One of the applications of Fick's second law of diffusion is the calculation of the carbon depth obtained during the carburization of steel. Consider the gas carburization of type 1020 steel at 900°C. The steel has a nominal carbon content of 0.2%, and the carbon content at the surface is 1.15%. The diffusion coefficient of carbon in air at the temperature of interest is 1.2×10^{-11} m²/s. Refer to the following table for values of the complementary error function. The time (hours) necessary to increase the carbon content to 0.5% at a distance of 1 mm below the surface is most nearly:

Z	erfc Z
0.68	0.336
0.76	0.283
0.84	0.235
0.92	0.193
1.00	0.157

A) 2.4
B) 4.2
C) 6.0
D) 8.2

Problem 39. Convective mass transfer in flow over a single sphere can be modeled with the Froessling correlation

$$Sh = 2.0 + 0.6 \, Re_d^{1/2} \, Sc^{1/3}$$

where Sh is the Sherwood number, Re_d is the Reynolds number with sphere diameter as the reference dimension, and Sc is the Schmidt number. Consider water flow over a 1-cm-diameter glucose sphere at a uniform temperature of 25°C. The Reynolds number of the flow is 250 and the Schmidt number for flow of water over the glucose sphere is 600. The mass diffusivity of glucose in water at 25°C is 7×10^{-5} cm²/sec. The mass transfer coefficient (cm/sec) in this situation is most nearly:

A) 0.002
B) 0.006
C) 0.02
D) 0.06

Problem 40. A binary distillation column is to be designed using the McCabe-Thiele method. The distillate contains 90 mol% of the more volatile component. The point of intersection of the q-line with the equilibrium curve is (0.5, 0.7). The minimum reflux ratio for this operation is most nearly:

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A) 1.0
B) 1.5
C) 2.0
D) 2.5

▶ SOLUTIONS

P.1 ■ Solution

The local velocity of a fluid along a streamline can be measured with a Pitot tube.

▶ The correct answer is **A**.

P.2 ■ Solution

The gage pressure in the fluid under the load is the ratio of the weight to the area of the lift,

$$P_{gage} = \frac{W}{A} = \frac{500 \times 9.81}{\left(\pi \times 1.2^2 / 4\right)} = 4340 \text{ N/m}^2$$

The oil height that produces this pressure rise is

$$P_{gage} = \rho g h \rightarrow h = \frac{P_{gage}}{\rho g}$$

$$\therefore h = \frac{4340}{780 \times 9.81} = 0.567 \text{ m} = \boxed{56.7 \text{ cm}}$$

▶ The correct answer is **C**.

P.3 ■ Solution

This is a straightforward application of conservation of mass. Applying the continuity equation, we have

$$Q_0 = Q_1 + Q_2 \rightarrow A_0 V_0 = A_1 V_1 + A_2 V_2$$

$$\therefore 0.08 \times 4.0 = 0.02 \times (1.6 \times 4.0) + 0.04 \times V_2$$

$$\therefore 0.32 = 0.128 + 0.04 V_2$$

$$\therefore V_2 = \frac{0.192}{0.04} = \boxed{4.8 \text{ m/s}}$$

▶ The correct answer is **B**.

P.4 ■ Solution

For laminar flow, the pressure drop is given by

$$\Delta p = \frac{32 \mu V L}{D^2} = \frac{32 \mu \times \left(\dfrac{4Q}{\pi D^2}\right) \times L}{D^2} = \frac{128 \mu Q L}{\pi D^4}$$

Accordingly, the pressure drop is inversely proportional to diameter to the fourth power, and hence doubling the diameter of the pipe will decrease the pressure drop 16-fold.

▶ The correct answer is **B**.

P.5 ■ Solution

Stokes' law implies that the settling velocity u is given by

$$u = \frac{\left(\rho_s - \rho_f\right) g d_p^2}{18 \eta}$$

Here, ρ_s = 1000 kg/m³ is the density of the droplet material, ρ_f = 800 kg/m³ is the density of the surrounding medium (namely, oil), d_p = 50×10⁻⁶ m is the

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droplet diameter, and $\eta = 5\times10^{-3}$ Pa·s is the viscosity of the surrounding medium. Substituting in the equation above gives

$$u = \frac{\left(\rho_s - \rho_f\right)gd_p^2}{18\eta} = \frac{(1000-800)\times 9.81\times\left(50\times10^{-6}\right)^2}{18\times\left(5\times10^{-3}\right)} = 5.45\times10^{-5} \text{ m/s}$$

The time required for the droplet to settle to the bottom of the tank follows if we divide the tank height by u; that is,

$$t_S = \frac{h}{u} = \frac{4.0}{5.45\times10^{-5}} = 73,400 \text{ s} = \boxed{20.4 \text{ h}}$$

▶ The correct answer is **D**.

P.6 ■ Solution

For a flow through a flat plate, the local boundary layer thickness varies with $x^{0.5}$ for laminar flow and $x^{0.8}$ for fully-developed turbulent flow.

▶ The correct answer is **C**.

P.7 ■ Solution

Curve P indicates a shear-thinning fluid, that is, a non-Newtonian fluid whose viscosity decreases with increasing shear rate, while curve Q pertains to a shear-thickening fluid, which has the opposite behavior. Curve R is a Bingham plastic, which, like a Newtonian fluid, exhibits linear shear rate-viscosity behavior but differs from Newtonian fluids in that it has a yield stress below which no flow should occur. Lastly, curve S describes the behavior of a shear-thinning fluid with yield stress; one type of fluid that can be classified as such is the Casson fluid, a model first proposed in the 1950s to model the rheologic behavior of printer ink.

▶ The correct answer is **D**.

P.8 ■ Solution

We first compute the head loss H,

$$H = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 - \frac{P_1}{\gamma} - \frac{V_1^2}{2g} - z_1$$

$$\therefore H = \frac{66.7}{8.8} + \frac{6.0^2}{2\times9.81} + 0.65 - \frac{13.3}{8.8} - \frac{1.0^2}{2\times9.81} - 0 = 8.50 \text{ m}$$

The input power follows as

$$P = \frac{\gamma QH}{\eta} = \frac{8800\times0.02\times8.50}{0.75} = \boxed{1.99 \text{ kW}}$$

▶ The correct answer is **C**.

P.9 ■ Solution

For a propeller of 0.3-m diameter rotating at 1.5 Hz, the power required is

$$P_{\text{prop}} = 1964N^2D^3 = 1964\times1.5^2\times0.3^3 = 119 \text{ W}$$

The power required by the paddle should be the same as that of the propeller. Accordingly, the paddle speed is found as

$$P_{\text{pad}} = P_{\text{prop}} = 1748N^2D^3 = 119$$

$$\therefore 1748\times N^2\times0.75^3 = 119$$

$$\therefore 737.4N^2 = 119$$

$$\therefore N = \sqrt{\frac{119}{737.4}} = \boxed{0.402 \text{ Hz}}$$

or, equivalently, 24 rpm.

▶ The correct answer is **B**.

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P.10 ■ Solution

Essentially, an ideal gas may be defined as a gas that can be accurately modeled by the simple equation of state $P\bar{V} = RT$ and whose internal energy is a function of temperature only, that is, $E = E(T)$.

▶ The correct answer is **B**.

P.11 ■ Solution

The reaction ΔH° is determined as

$$\Delta H^{\circ} = \Delta H_f^{\circ}\left(H_{2(g)}\right) + \Delta H_f^{\circ}\left(CO_{(g)}\right) - \Delta H_f^{\circ}\left(H_2O_{(g)}\right) - \Delta H_f^{\circ}\left(C_{(s)}\right)$$

$$\therefore \Delta H^{\circ} = 0 - 110.5 - (-241.8) - 0 = 131.3 \text{ kJ}$$

The variation in the number of moles of gaseous reactants/products is $\Delta n = (1 + 1) - 1 = 1$. The standard change in internal energy follows as

$$\Delta H^{\circ} = \Delta E^{\circ} + \Delta n RT \rightarrow \Delta E^{\circ} = \Delta H^{\circ} - \Delta n RT$$

$$\therefore \Delta E^{\circ} = 131.3 - 1 \times 8.314 \times 298 = \boxed{128.8 \text{ kJ}}$$

▶ The correct answer is **D**.

P.12 ■ Solution

Very few gases have negative acentric factors, and helium ($\omega = -0.390$) and hydrogen ($\omega = -0.216$) are the main examples of gases that do. The acentric factors for other compounds offered as alternatives are $\omega = 0.142$ for propylene, $\omega = 0.066$ for carbon monoxide, and $\omega = 0.239$ for carbon dioxide.

▶ The correct answer is **C**.

P.13 ■ Solution

Equation P is the Redlich-Kwong equation; equation Q is the Peng-Robinson equation, equation R is the Van der Waals equation, and equation S is the Berthelot equation.

▶ The correct answer is **D**.

P.14 ■ Solution

The expansion work is

$$W = P\Delta V = 3.0 \times (5.0 - 3.0) = 6 \text{ liter-atm} = 607.8 \text{ J}$$

Let ΔT be the change in temperature of the water. Accordingly,

$$W = mc\Delta T \rightarrow \Delta T = \frac{W}{mc}$$

$$\therefore \Delta T = \frac{607.8}{15 \times 4.18} = 9.69 \text{ K}$$

The final temperature of the water is then

$$\Delta T = T_f - T_i \rightarrow T_f = T_i + \Delta T$$

$$\therefore T_f = 290 + 9.69 = \boxed{299.7 \text{ K}}$$

▶ The correct answer is **B**.

P.15 ■ Solution

This is a straightforward application of the formula

$$\Delta S = n\int_{T_1}^{T_2} \frac{C_v dT}{T} = nC_v \ln\left(\frac{T_2}{T_1}\right) = 1 \times 5.9 \times \ln\left(\frac{303}{273}\right) = 0.615 \text{ cal/K}$$

$$\therefore \Delta S = 0.615 \frac{\text{cal}}{\text{K}} \times 4.18 \frac{\text{J}}{\text{cal}} = \boxed{2.57 \text{ J/K}}$$

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► The correct answer is **C**.

P.16 ■ Solution

The given data applies to $P = 1$ atm, so let this be state 1. Appealing to the Clausius-Clapeyron equation, we have

$$\ln\left(\frac{P_2^{\text{sat}}}{P_1^{\text{sat}}}\right) = -\frac{\Delta\bar{H}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right) \rightarrow \ln\left(\frac{P_2^{\text{sat}}}{1.0}\right) = -\frac{42,000}{8.314}\times\left(\frac{1}{373} - \frac{1}{352}\right)$$

$$\therefore \ln\left(P_2^{\text{sat}}\right) = 0.808$$

$$\therefore P_2^{\text{sat}} = 2.24 \text{ atm} = \boxed{2.27 \text{ bar}}$$

► The correct answer is **A**.

P.17 ■ Solution

Let 1 denote benzene and 2 denote toluene. The total pressure of the system is

$$P = x_1 P_1^{\text{sat}} + x_2 P_2^{\text{sat}} = 0.33\times180 + 0.67\times74 = 109 \text{ kPa}$$

From Raoult's law, the mole fraction of benzene in the liquid phase is found as

$$y_1 P = x_1 P_1^{\text{sat}} \rightarrow y_1 = \frac{x_1 P_1^{\text{sat}}}{P}$$

$$\therefore y_1 = \frac{0.33\times180}{109} = \boxed{0.545}$$

► The correct answer is **B**.

P.18 ■ Solution

This is a straightforward application of Henry's law:

$$s = k_H P = \left(1.3\times10^{-3}\right)\times0.5 = 0.65\times10^{-3} \text{ mol/L} = \boxed{0.65 \text{ mmol/L}}$$

► The correct answer is **A**.

P.19 ■ Solution

Increasing the system temperature favors the endothermic reaction – in this case, the reverse reaction. Removing some reactant from the system would favor the reverse reaction. Adding an inert gas such as argon would not shift the equilibrium at all. Lastly, increasing the system pressure would favor the side of the reaction with less volume equivalents – which, in this case, happens to be the state to the right.

► The correct answer is **B**.

P.20 ■ Solution

For a zero-order reaction, the variation in the concentration of A is described by the simple expression

$$C_{A,0} - C_A = kt$$

Solving for C_A and substituting, we obtain

$$C_{A,0} - C_A = kt \rightarrow C_A = C_{A,0} - kt$$

$$\therefore C_A = 2.0 - 0.5\times2 = \boxed{1.0 \text{ mol/m}^3}$$

► The correct answer is **A**.

P.21 ■ Solution

The concentration of A at 95% conversion is

$$C_A = C_{A,0}(1 - X_A) = 2 \times (1 - 0.95) = 0.1 \text{ mol}/\ell$$

The reactor volume required follows as

$$V = \frac{v(C_{A,0} - C_A)}{-r_A} = \frac{v(C_{A,0} - C_A)}{\dfrac{0.1 C_A}{1 + 0.5 C_A}} = \frac{25 \times (2 - 0.1)}{\dfrac{0.1 \times 0.1}{1 + 0.5 \times 0.1}} = 4990 \; \ell = \boxed{4.99 \, \text{m}^3}$$

▶ The correct answer is **C**.

P.22 ■ Solution

The expansion parameter is

$$\varepsilon_A = \frac{1 - 2}{2} = -0.5$$

The conversion of A, in turn, is

$$X_A = \frac{C_{A,0} - C_A}{C_{A,0} + \varepsilon_A C_A} = \frac{1 - 0.5}{1 + (-0.5) \times 0.5} = 0.667$$

The corresponding feed rate is

$$v = \frac{V(-r_A)}{C_{A,0} X_A} = \frac{2 \times (0.05 \times 0.5^2)}{1.0 \times 0.667} = 0.0375 \; \ell/\text{s} = \boxed{2.25 \, \ell / \min}$$

▶ The correct answer is **C**.

P.23 ■ Solution

For a plug flow reactor, the following relation holds,

$$\ln\left(\frac{C_{A,0}}{C_A}\right) = k\tau$$

Solving for k and substituting, we get

$$\ln\left(\frac{C_{A,0}}{C_A}\right) = k\tau \rightarrow k = \frac{\ln\left(C_{A,0}/C_A\right)}{\tau}$$

$$\therefore k = \frac{\ln(2/0.5)}{\dfrac{5.0}{1.0}} = \boxed{0.277 \; \text{min}^{-1}}$$

▶ The correct answer is **D**.

P.24 ■ Solution

The mean residence time is given by

$$\tau = -\frac{1}{k}\ln(1 - X_A)$$

Substituting $\tau = 5$ sec, $k = 0.42$ sec^{-1} and solving for X_A, we get

$$5 = -\frac{1}{0.42} \times \ln(1 - X_A)$$

$$\therefore -2.1 = \ln(1 - X_A)$$

$$\therefore 1 - X_A = \exp(-2.1) = 0.122$$

$$\therefore \boxed{X_A = 0.878}$$

▶ The correct answer is **C**.

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P.25 ■ Solution

Diffusional effects become appreciable for fast reactions in pellets of large diameter, as evidenced by the Weisz-Prater criterion

$$N_{WP} = \frac{\Re r_p^2}{C_s D_{\text{eff}}} \leq 0.3$$

where $\Re$ is the reaction rate, r_p is the catalyst particle radius, C_s is reactant concentration at the particle surface, and D_{eff} is the effective diffusivity. If $N_{WP} \geq 0.3$, pore diffusion limitations become appreciable. Since N_{WP} is proportional to reaction rate and particle radius, it is clear that pore diffusion limitations are augmented for fast reactions and large catalyst particles.

▶ The correct answer is **D**.

P.26 ■ Solution

The Thiele modulus is determined as

$$\phi = L \sqrt{\frac{k}{D_{AB,\text{eff}}}} = 5 \times 10^{-3} \sqrt{\frac{1.6 \times 10^{-3}}{10^{-8}}} = 2.0$$
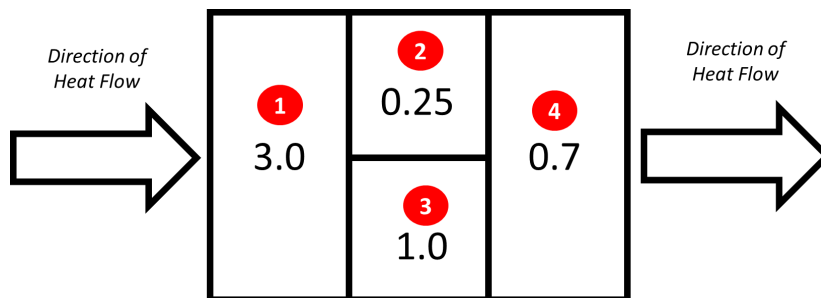
The effectiveness factor follows as

$$\eta = \frac{\tanh \phi}{\phi} = \frac{\tanh(2.0)}{2.0} = \boxed{0.482}$$

▶ The correct answer is **B**.

P.27 ■ Solution

The sections of the wall are numbered as follows.

Resistances 2 and 3 are organized in parallel, so that

$$\frac{1}{R_{23}} = \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{0.25} + \frac{1}{1.0} \rightarrow R_{23} = 0.2 \text{ K/W}$$

Resistances 1, 2-3, and 4 are organized in series, so that

$$R_{eq} = R_1 + R_{23} + R_4 = 3.0 + 0.2 + 0.7 = \boxed{3.9 \text{ K/W}}$$

▶ The correct answer is **A**.

P.28 ■ Solution

From Fourier's law, we have

$$\dot{q}_{\text{cond}} = -kA \frac{\Delta T}{L} = -1.5 \times A \times \frac{(573 - T_s)}{6 \times 10^{-3}} \quad (I)$$

From Newton's law of cooling, we have

$$\dot{q}_{\text{conv}} = hA(T_s - T_{\text{gas}}) = 30 \times A \times (T_s - 303) \quad (II)$$

At steady-state conditions, the conduction heat transfer rate must equal the convection heat transfer rate. Accordingly, we equate relations (I) and (II) to obtain

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$$-1.5 \cancel{A} \frac{(573 - T_s)}{6 \times 10^{-3}} = 30 \cancel{A} (T_s - 303)$$

$$\therefore -\frac{1.5}{6 \times 10^{-3}}(573 - T_s) = 30(T_s - 303)$$

$$\therefore 143,250 - 250T_s = 30T_s - 9090$$

$$\therefore 152,340 = 280T_s$$

$$\therefore T_s = \frac{152,340}{280} = 544.1 \text{ K} = \boxed{271^\circ\text{C}}$$

▶ The correct answer is **B**.

P.29 ■ Solution

For water, $\Delta T_1 = 40 - 25 = 15^\circ$C, and for oil $\Delta T_2 = 70 - 40 = 30^\circ$C. The log-mean temperature difference is then

$$\Delta T_m = \frac{30 - 15}{\ln\left(\dfrac{30}{15}\right)} = 21.6^\circ\text{C}$$

The rate of heat transfer is

$$\dot{Q} = \dot{m}c_{p,\text{oil}}\Delta T_{\text{oil}} = \frac{1000}{3600} \times 2.0 \times (70 - 40) = 16.7 \text{ kJ/s}$$

The exchanger area required to carry out the operation follows from Newton's law of cooling,

$$Q = hA\Delta T_m \rightarrow A = \frac{Q}{h\Delta T_m}$$

$$\therefore A = \frac{16.7}{0.2 \times 21.6} = \boxed{3.87 \text{ m}^2}$$

▶ The correct answer is **C**.

P.30 ■ Solution

The correct sequence is P → S → R → Q.

▶ The correct answer is **B**.

P.31 ■ Solution

In this situation, the rate of heat transfer is proportional to excess temperature to the 3/4 power.

▶ The correct answer is **D**.

P.32 ■ Solution

Per the Chilton-Colburn analogy, the convective heat and mass transfer coefficients are related by

$$h_{\text{heat}} = \rho c_p h_{\text{mass}} \text{Le}^{2/3}$$

where Le is the Lewis number, which is given by

$$\text{Le} = \frac{\alpha}{D_{AB}} = \frac{2 \times 10^{-5}}{6 \times 10^{-6}} = 3.33$$

so that, substituting this and other variables, we obtain

$$h_{\text{heat}} = 1.18 \times 1000 \times 0.08 \times 3.33^{2/3} = \boxed{211 \text{ W/m}^2\text{K}}$$

▶ The correct answer is **D**.

P.33 ■ Solution

To begin, we compute the view factor F_{12},

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$$F_{12} = 0.5 \left\{ 1 - \left[1 + \left(\frac{1.2}{0.6} \right)^2 \right]^{-0.5} \right\} = 0.276$$

Appealing to the reciprocity rule, we have

$$F_{12} A_1 = F_{21} A_2 \rightarrow F_{21} = \frac{A_1}{A_2} F_{12}$$

$$\therefore F_{21} = \frac{1.13}{4.52} \times 0.276 = \boxed{0.0690}$$

▶ The correct answer is **B**.

P.34 ■ Solution

In film theory, the mass transfer coefficient is related to mass diffusivity by an expression of the form

$$h_m = \frac{D_{AB}}{\delta}$$

where δ is film thickness. In penetration theory, in turn, the average mass transfer coefficient is given by

$$h_m = 2\sqrt{\frac{D_{AB}}{\pi t_c}}$$

where t_c is contact time. In boundary layer theory over a flat plate, in turn, the diffusion coefficient appears in the definitions of Sherwood and Schmidt number, and the pertaining correlation is

$$\mathrm{Sh} = \frac{\overline{h_m} \times L}{D_{AB}} = 0.664 \, \mathrm{Re}_L^{1/2} \, \mathrm{Sc}^{1/3}$$

Since the Schmidt number is inversely proportional to D_{AB}, we can manipulate the relation above and verify that $h_m \propto D_{AB}^{2/3}$.

▶ The correct answer is **C**.

P.35 ■ Solution

The surface renewal rate s is related to the convective mass transfer coefficient and mass diffusivity by an expression of the form

$$h_m = \sqrt{s D_{AB}} \rightarrow s = \frac{h_m^2}{D_{AB}}$$

Since h_m has units of L/T and D_{AB} has units of L^2/T, a quick dimensional analysis reveals that s is expressed in reciprocal time.

▶ The correct answer is **A**.

P.36 ■ Solution

In case 1, the molar flux is given by

$$N_{A,1} = \frac{D_{AB} P}{RTZ} \left(y_{A,1} - y_{A,2} \right)$$

In case 2, the molar flux is given by

$$N_{A,2} = \frac{D_{AB} P}{RTZ} \ln \left(\frac{1 - y_{A,1}}{1 - y_{A,2}} \right)$$

where $y_{A,1} = 10/100 = 0.1$ and $y_{A,2} = 5/100 = 0.05$. The ratio of molar fluxes is

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$$\left|\frac{N_{A,1}}{N_{A,2}}\right| = \left|\frac{y_{A,1} - y_{A,2}}{\ln\left(\dfrac{1 - y_{A,1}}{1 - y_{A,2}}\right)}\right| = \left|\frac{0.1 - 0.05}{\ln\left(\dfrac{1 - 0.1}{1 - 0.05}\right)}\right| = \boxed{0.925}$$

▶ The correct answer is **B**.

P.37 ■ Solution

The ordinary diffusion coefficient for a pressure of 2 atm is

$$D_{AB} = \frac{0.86}{P} = \frac{0.86}{2.0} = 0.43 \text{ cm}^2/\text{s}$$

Given a porosity $\varepsilon = 0.4$ and a tortuosity $\tau = 2.5$, the effective diffusivity is calculated with the relation

$$D_{AB,\text{eff}} = \frac{\varepsilon D_{AB}}{\tau} = \frac{0.5 \times 0.43}{1.6} = \boxed{0.134 \text{ cm}^2/\text{s}}$$

▶ The correct answer is **A**.

P.38 ■ Solution

This problem involves transient diffusion in a semi-infinite medium, which is modeled by the equation

$$\frac{C_X - C_0}{C_S - C_0} = \text{erfc}\left(\frac{x}{2\sqrt{D_{AB}t}}\right)$$

Here, $C_X = 0.5\%$ is the desired carbon content at a distance of 1 mm from the surface, $C_0 = 0.3\%$ is the nominal carbon content, $C_S = 1.15\%$ is the carbon content at the surface, $x = 1\times10^{-3}$ m is the distance from the surface, $D_{AB} = 1.2\times10^{-11}$ m²/s is the diffusion coefficient, and t is time. Inserting our data in the left-hand side yields

$$\frac{C_X - C_0}{C_S - C_0} = \frac{0.5 - 0.3}{1.15 - 0.3} = 0.235$$

With reference to the table, if erfc $Z = 0.235$, then $Z = 0.84$. Substituting in the right-hand side of the equation gives

$$\text{erfc}\left(\frac{x}{2\sqrt{D_{AB}t}}\right) = 0.235 \rightarrow \frac{10^{-3}}{2\sqrt{(1.2\times10^{-11})\times t}} = 0.84$$

$$\therefore t = \frac{1}{0.84^2} \times \left(\frac{10^{-3}}{2\sqrt{1.2\times10^{-11}}}\right)^2 = 29,500 \text{ s} = \boxed{8.19\,\text{h}}$$

▶ The correct answer is **D**.

P.39 ■ Solution

The Sherwood number is calculated as

$$\text{Sh} = 2.0 + 0.6 \times 250^{1/2} \times 600^{1/3} = 82.0$$

From the definition of Sh, it follows that

$$\text{Sh} = \frac{h_m \times d}{D_{AB}} \rightarrow h_m = \frac{\text{Sh} \times D_{AB}}{d}$$

$$\therefore h_m = \frac{82.0 \times (7 \times 10^{-5})}{1.0} = \boxed{0.00574\,\text{cm/s}}$$

▶ The correct answer is **B**.

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The minimum reflux ratio is given by

$$R_{\min} = \frac{X_D - Y^1}{Y^1 - X^1} = \frac{0.9 - 0.7}{0.7 - 0.5} = \boxed{1.0}$$

▶ The correct answer is **A**.

▶ ANSWER SUMMARY

1	A	21	C
2	C	22	C
3	B	23	D
4	B	24	C
5	D	25	D
6	C	26	B
7	D	27	A
8	C	28	B
9	B	29	C
10	B	30	B
11	D	31	D
12	C	32	D
13	D	33	B
14	B	34	C
15	C	35	A
16	A	36	B
17	B	37	A
18	A	38	D
19	B	39	B
20	A	40	A

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answer your question as soon as possible.

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