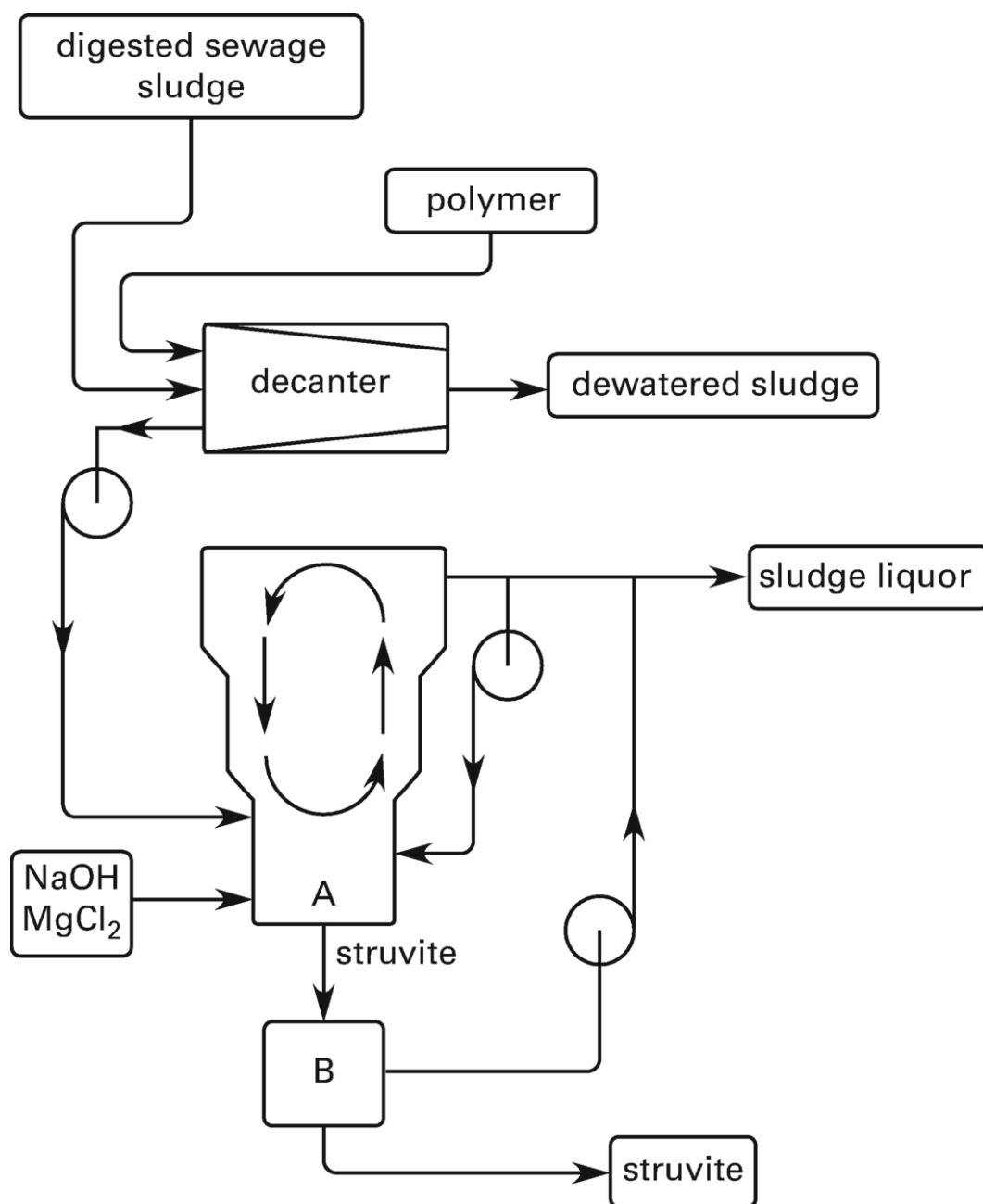


[Chapter 26. Solid-Liquid Processes](#)

Practice Problems

1.

One method of recovering phosphorus from wastewater streams is to precipitate magnesium ammonium phosphate ( $\text{NH}_4\text{MgPO}_4 \cdot 6\text{H}_2\text{O}$ ), commonly known as struvite, which is a potentially troublesome precipitate in pipelines. Struvite can be recovered in a controlled manner through various processes and can then be collected and applied as a phosphorus-based fertilizer in farmlands. One process for recovering struvite is shown.



In this process, struvite is precipitated by dosing  $\text{MgCl}_2$  and increasing the pH by adding caustic soda ( $\text{NaOH}$ ). Process equipment A and B are, respectively,

(A)

a dryer and a crystallizer

(B)

a crystallizer and a dryer

(C)

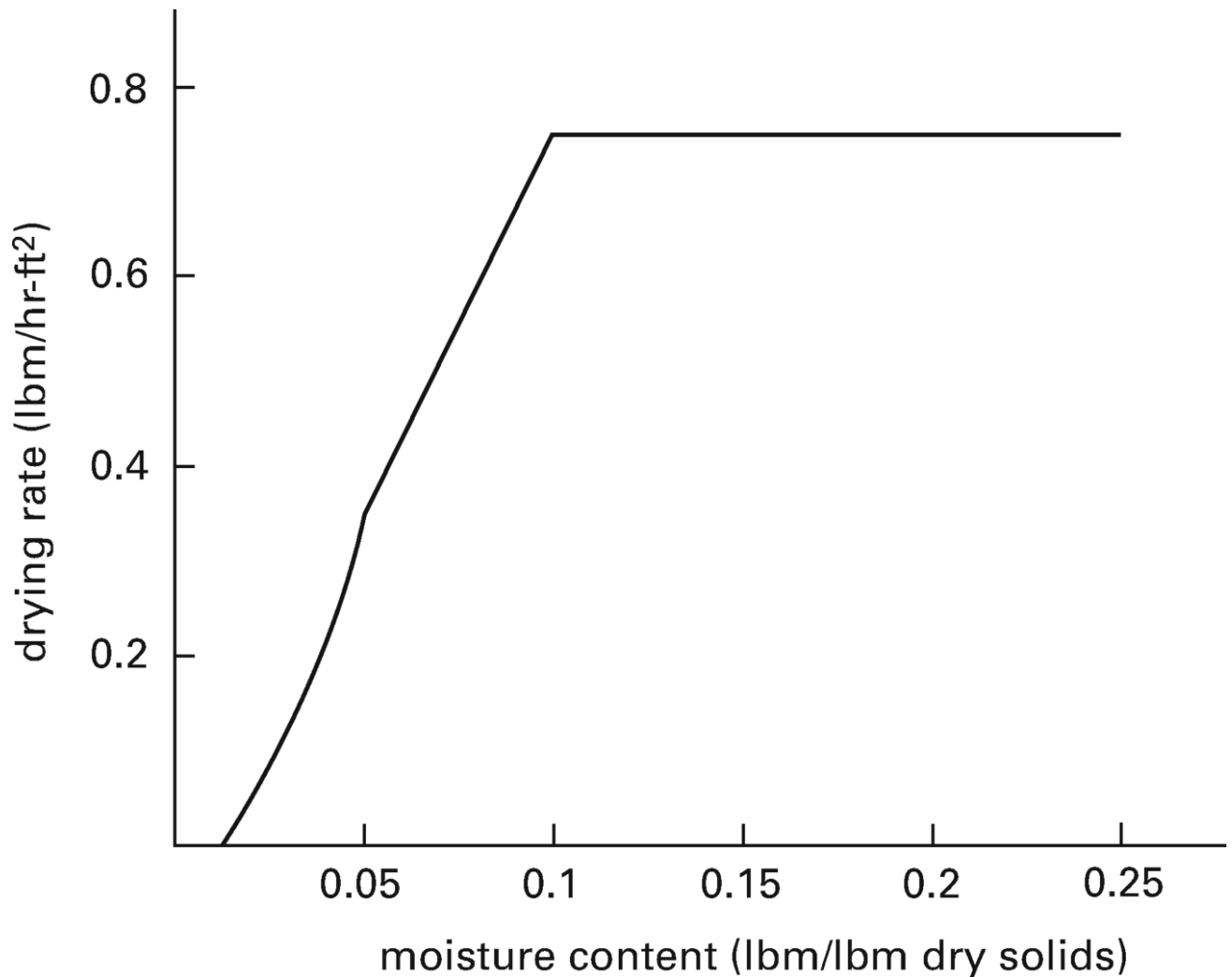
a flotation column and a microfiltration/reverse osmosis package

(D)

a microfiltration/reverse osmosis package and a flotation column

[2.](#)

A batch of material with a 20% moisture content must be dried to a 2.5% moisture content. The drying curve is shown. The initial damp solids weight is 700 lbm, and the drying surface is  $0.2 \text{ ft}^2/\text{lbm}$  dry weight. Estimate the total drying time given that the drying rate in falling rate period II is  $e^X$ .



(A)

1 hr

(B)

1.6 hr

(C)

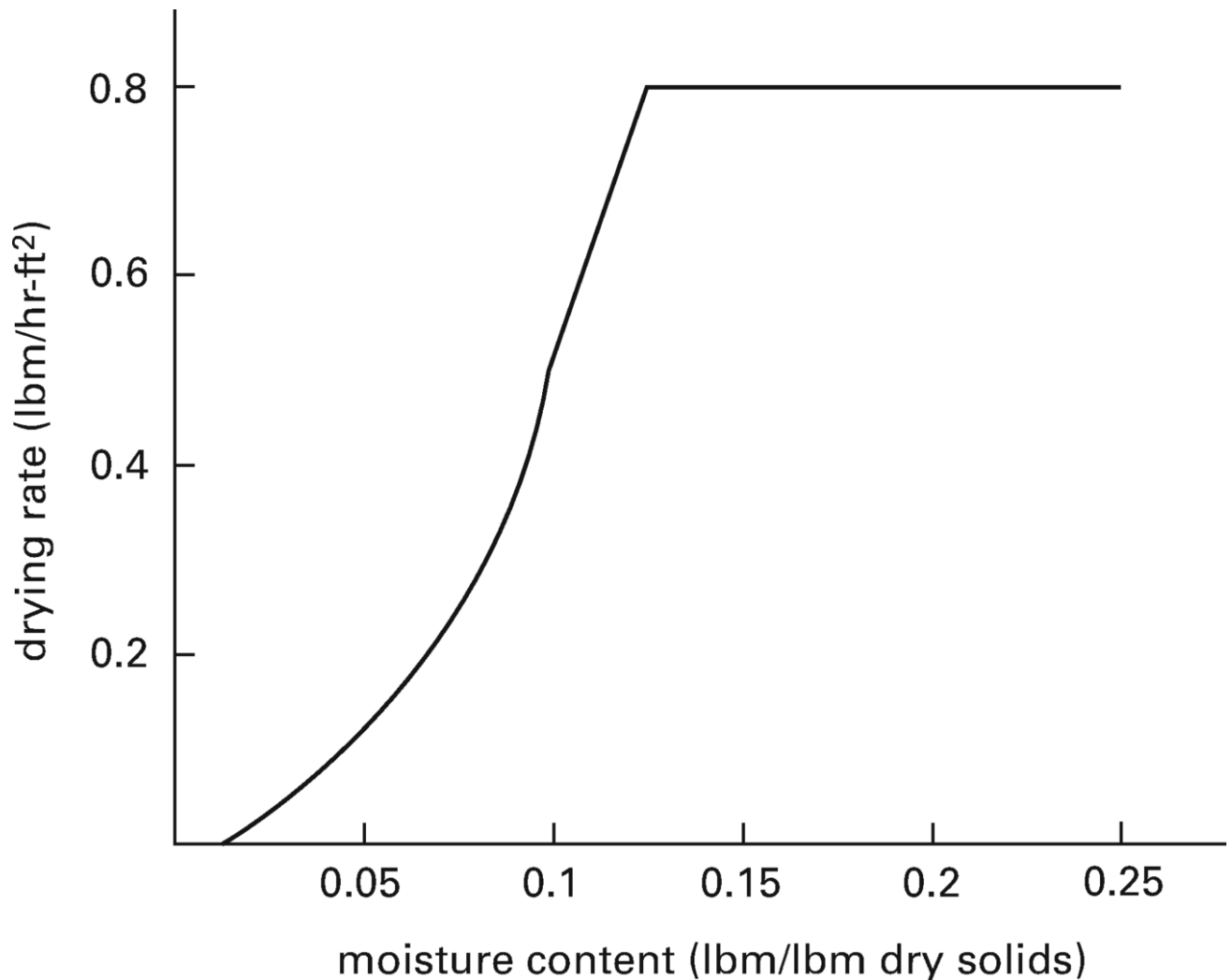
2 hr

(D)

2.4 hr

3.

A batch of material that has a 22.5% moisture content must be dried to a 2.5% moisture content. The drying curve is shown. The initial, total moist solids mass is 1000 lbm, and the drying surface is 0.4 ft<sup>2</sup>/lbm (dry mass basis). Estimate the total drying time given that the drying rate in falling rate period II is  $e^{5X}$ .



(A)

0.36 hr

(B)

0.52 hr

(C)

0.76 hr

(D)

0.91 hr

4.

Stormwater washes over a farm field and into an adjacent watershed. Which of the following phenomena is most likely to occur?

(A)

leaching

(B)

distillation

(C)

sublimation

(D)

chemosynthesis

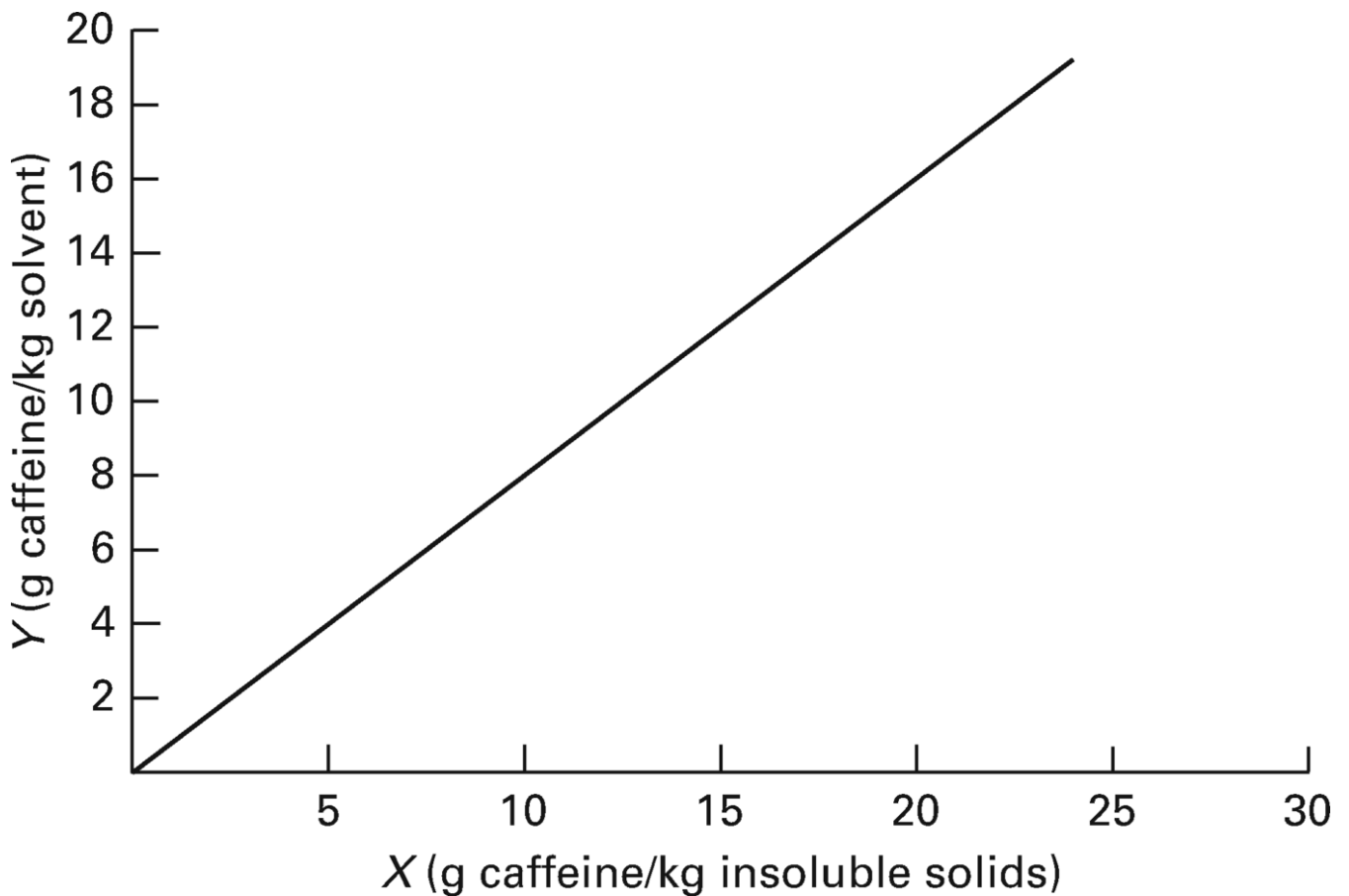
[5.](#)

A proprietary solvent leaches caffeine from coffee beans. Analyses indicate that nothing else dissolves in this solvent except caffeine. The equilibrium relationship is known to be  $Y = 0.8X$  for caffeine in the solvent, where

$$Y = \frac{\text{g caffeine}}{\text{kg solvent}}$$

$$X = \frac{\text{g caffeine}}{\text{kg insoluble solids}}$$

Starting with pure solvent and coffee beans that have 20 g caffeine/kg beans, the goal is to reduce the caffeine content in the beans to 5% of the original content (i.e., 1 g caffeine/kg beans).



Determine the minimum amount of solvent required to achieve this separation using a countercurrent, equilibrium-staged system.

(A)

0.8 kg solvent/kg insoluble solids

(B)

0.84 kg solvent/kg insoluble solids

(C)

1.2 kg solvent/kg insoluble solids

(D)

1.25 kg solvent/kg insoluble solids

[6.](#)

Which of the following statements about the leaching process is NOT correct?

(A)

Solution mining is a leaching process used to recover minerals through boreholes drilled into a deposit that occurs *in situ*.

(B)

If the density and viscosity of liquid is constant from stage to stage, the overflow and underflow rates are both constant and the operating line is straight.

(C)

In leaching, equilibrium occurs when the concentration of the underflow at a given stage equals the concentration of the overflow at the same stage.

(D)

A Pachuca tank is an air-lift reactor used in oxidative leaching processes where the solids settling velocity is small.

[7.](#)

A saturated solution contains 3300 lbm of potassium chloride (KCl) at 212°F. The solution is slowly cooled in a crystallizer to 176°F. The solubility of potassium chloride is 56.37 g per 100 g of solution at 212°F and 48.5 g per 100 g of solution at 176°F. The loss of water by evaporation is negligible. The mass of KCl that crystallizes is most nearly

(A)

0.14 lbm

(B)

460 lbm

(C)

3200 lbm

(D)

3300 lbm

[8.](#)

Which pair of membrane filtration processes can remove both dissolved solids and salts (ions) from a water or wastewater stream?

(A)

microfiltration and ultrafiltration

(B)

ultrafiltration and nanofiltration

(C)

nanofiltration and reverse osmosis

(D)

reverse osmosis and electrodialysis reversal

Solutions

1.

Equipment A is a crystallizer and equipment B is a dryer. Option A puts the equipment in the wrong order. Options C and D are not appropriate for this purpose.

The answer is (B).

2.

*Constant Rate Period:*

*NCEES Handbook:* Specific Drying Applications contains equations for each step in this problem. The moisture content of the material is reduced from the initial moisture content of 20% to the critical moisture content,  $X_c$ , in the constant rate period. The initial material has 20% moisture, so the initial moisture content,  $X_1$ , is

$$\begin{aligned} X_1 &= \frac{X_T}{L_s} \\ &= \frac{\left(0.2 \frac{\text{lbm moisture}}{\text{lbm total}}\right) (700 \text{ lbm total})}{\left((1 - 0.2) \frac{\text{lbm dry solids}}{\text{lbm total}}\right) (700 \text{ lbm total})} \\ &= 0.25 \text{ lbm moisture/lbm dry solids} \end{aligned}$$

From the given drying curve, the critical moisture content,  $X_c$ , is

$$X_c = 0.1 \text{ lbm moisture/lbm dry solids}$$

Reading from the drying curve, in the constant rate period, the drying rate,  $N_c$ , is

$$N_c = 0.75 \text{ lbm moisture/hr-ft}^2$$

In the constant rate drying period, the drying time,  $t_c$ , is

$$\begin{aligned} t_c &= \left(\frac{L_s}{A}\right) \left(\frac{X_1 - X_c}{N_c}\right) \\ &= \left(\frac{\text{lbm dry solids}}{0.2 \text{ ft}^2}\right) \\ &\quad \times \left(\frac{0.25 \frac{\text{lbm moisture}}{\text{lbm dry solids}} - 0.1 \frac{\text{lbm moisture}}{\text{lbm dry solids}}}{0.75 \frac{\text{lbm moisture}}{\text{hr-ft}^2}}\right) \\ &= 1 \text{ hr} \end{aligned}$$

*Falling Rate Period I:*

In falling rate period I, the initial drying rate,  $N_1$ , is  $N_c$ .

$$N_1 = N_c = 0.75 \text{ lbm moisture/hr-ft}^2$$

From the drying curve, the final drying rate,  $N_2$ , is

$$N_2 = 0.35 \text{ lbm moisture/hr-ft}^2$$

The initial moisture content,  $X_1$ , is the critical moisture content,  $X_c$ .

$$X_1 = X_c = 0.1 \text{ lbm moisture/lbm dry solids}$$

From the drying curve, the final moisture content,  $X_2$ , is

$$X_2 = 0.05 \text{ lbm moisture/lbm dry solids}$$

Since the drying curve in falling rate period I is linear, the total drying time,  $t_I$ , is

$$\begin{aligned} t_I &= \left( \frac{L_s}{A} \right) \left( \frac{X_1 - X_2}{N_1 - N_2} \right) \ln \frac{N_1}{N_2} \\ &= \left( \frac{\text{lbm dry solids}}{0.2 \text{ ft}^2} \right) \\ &\quad \times \left( \frac{0.1 \frac{\text{lbm moisture}}{\text{lbm dry solids}} - 0.05 \frac{\text{lbm moisture}}{\text{lbm dry solids}}}{0.75 \frac{\text{lbm moisture}}{\text{hr-ft}^2} - 0.35 \frac{\text{lbm moisture}}{\text{hr-ft}^2}} \right) \\ &\quad \times \left( \ln \frac{0.75 \frac{\text{lbm moisture}}{\text{hr-ft}^2}}{0.35 \frac{\text{lbm moisture}}{\text{hr-ft}^2}} \right) \\ &= 0.48 \text{ hr} \end{aligned}$$

*Falling Rate Period II:*

In falling rate period II, the drying rate,  $N_{II}$ , is given as

$$N_{II} = e^X$$

From the drying curve, the initial moisture content,  $X_1$ , is

$$X_1 = 0.05 \text{ lbm moisture/lbm dry solids}$$

From the problem statement, the final material has 2.5% moisture. The final moisture content,  $X_2$ , is

$$\begin{aligned} X_2 &= \frac{X_T}{L_s} = \frac{0.025}{1 - 0.025} = \frac{0.025 \text{ lbm moisture}}{0.975 \text{ lbm dry solids}} \\ &= 0.026 \text{ lbm moisture/lbm dry solids} \end{aligned}$$

In falling rate period II, the drying time,  $t_{II}$ , is

$$\begin{aligned} t_{II} &= \left( \frac{L_s}{A} \right) \int_{X_2}^{X_1} \frac{dX}{N} \\ &= \left( \frac{1}{0.2} \right) \int_{0.026}^{0.05} e^{-X} dX \\ &= (5) \left( -e^{-X} \Big|_{0.026}^{0.05} \right) \\ &= (5) \left( -e^{-0.05} - (-e^{-0.026}) \right) \\ &= 0.12 \text{ hr} \end{aligned}$$

The total drying time,  $t_D$ , is the sum of the drying times for each period.

$$t_D = t_c + t_I + t_{II} = 1 \text{ hr} + 0.48 \text{ hr} + 0.12 \text{ hr} = 1.6 \text{ hr}$$

The answer is (B).

[3.](#)

### Constant Rate Period:

*NCEES Handbook*: Specific Drying Applications contains equations for each step in this problem. The moisture content of the material is reduced from the initial moisture content of 22.5% to the critical moisture content,  $X_c$ , in the constant rate period. The initial material has 22.5% moisture, so by definition the initial moisture content,  $X_1$ , is

$$\begin{aligned} X_1 &= \% \text{ moisture in solids} = \frac{m_w}{m_s} \\ &= \frac{\left(0.225 \frac{\text{lbm moisture}}{\text{lbm total}}\right) (1000 \text{ lbm total})}{\left((1 - 0.225) \frac{\text{lbm dry solids}}{\text{lbm total}}\right) (1000 \text{ lbm total})} \\ &= 0.29 \text{ lbm moisture/lbm dry solids} \end{aligned}$$

From the given drying curve, the critical moisture content,  $X_c$ , is

$$X_c = 0.125 \text{ lbm moisture/lbm dry solids}$$

Reading from the drying curve, in the constant rate period, the drying rate,  $N_c$ , is

$$N_c = 0.8 \text{ lbm moisture/hr-ft}^2$$

In the constant rate drying period, the drying time,  $t_c$ , is

$$t_c = \left(\frac{m_s}{A}\right) \left(\frac{X_1 - X_2}{N_c}\right) = \left(\frac{m_s}{A}\right) \left(\frac{X_1 - X_c}{N_c}\right)$$

The ratio,  $m_s/A$ , which is the drying surface per 1 lb<sub>m</sub> (dry weight basis), is equal to (1 lb<sub>m</sub> dry solids)/0.4 ft<sup>2</sup>.

$$\begin{aligned} t_c &= \left(\frac{1 \text{ lbm dry solids}}{0.4 \text{ ft}^2}\right) \left(\frac{0.29 \frac{\text{lbm moisture}}{\text{lbm dry solids}} - 0.125 \frac{\text{lbm moisture}}{\text{lbm dry solids}}}{0.8 \frac{\text{lbm moisture}}{\text{hr-ft}^2}}\right) \\ &= 0.52 \text{ hr} \end{aligned}$$

### Linear Falling Rate Period I:

In falling rate period I, the initial drying rate,  $N_1$ , is  $N_c$ .

$$N_1 = N_c = 0.8 \text{ lbm moisture/hr-ft}^2$$

From the drying curve, the final drying rate,  $N_2$ , is

$$N_2 = 0.5 \text{ lbm moisture/hr-ft}^2$$

The initial moisture content,  $X_1$ , is the critical moisture content,  $X_c$ .

$$X_1 = X_c = 0.125 \text{ lbm moisture/lbm dry solids}$$

From the drying curve, the final moisture content,  $X_2$ , is

$$X_2 = 0.10 \text{ lbm moisture/lbm dry solids}$$

Since the drying curve in falling rate period I is linear, the total drying time,  $t_I$ , is

$$\begin{aligned} t_I &= \left(\frac{m_s}{A}\right) \left(\frac{X_1 - X_2}{N_1 - N_2}\right) \ln \frac{N_1}{N_2} \\ &= \left(\frac{1 \text{ lbm dry solids}}{0.4 \text{ ft}^2}\right) \left(\frac{0.125 \frac{\text{lbm moisture}}{\text{lbm dry solids}} - 0.10 \frac{\text{lbm moisture}}{\text{lbm dry solids}}}{0.8 \frac{\text{lbm moisture}}{\text{hr-ft}^2} - 0.5 \frac{\text{lbm moisture}}{\text{hr-ft}^2}}\right) \left(\ln \frac{0.8 \frac{\text{lbm moisture}}{\text{hr-ft}^2}}{0.5 \frac{\text{lbm moisture}}{\text{hr-ft}^2}}\right) \\ &= 0.098 \text{ hr} \quad (0.10 \text{ hr}) \end{aligned}$$

### Falling Rate Period II:



In falling rate period II, the drying rate  $N_{II}$ , is given as

$$N_{II} = e^{5X}$$

From the drying curve, the initial moisture content,  $X_1$ , is

$$X_1 = 0.10 \text{ lbm moisture/lbm dry solids}$$

From the problem statement, the final material has 2.5% moisture. The final moisture content,  $X_2$ , is

$$\begin{aligned} X_1 &= \% \text{ moisture in solids} = \frac{m_w}{m_s} = \frac{0.025 \text{ lb}_m \text{ moisture}}{(1-0.025) \text{ lb}_m \text{ dry solids}} \\ &= 0.026 \text{ lb}_m \text{ moisture/lb}_m \text{ dry solids} \end{aligned}$$

In falling rate period II, the drying time,  $t_{II}$ , is

$$\begin{aligned} t_{II} &= \left( \frac{m_s}{A} \right) \int_{X_2}^{X_1} \frac{dX}{N} = \left( \frac{m_s}{A} \right) \int_{X_2}^{X_1} N^{-1} dX \\ &= \left( \frac{1 \text{ lb}_m \text{ dry solids}}{0.4 \text{ ft}^2} \right) \left( \int_{0.26}^{0.10} e^{-5X} dX \frac{\text{hr-ft}^2}{\text{lb}_m \text{ moisture}} \right) \\ &= \left( \frac{1}{0.4} \right) \left( \left( -\frac{1}{5} \right) e^{-5X} \Big|_{0.26}^{0.10} \right) \\ &= \left( \frac{1}{0.4} \right) \left( \left( -\frac{1}{5} \right) e^{-(5)(0.10)} - \left( \left( -\frac{1}{5} \right) e^{-(5)(0.26)} \right) \right) \\ &= \left( \frac{1}{0.4} \right) (-0.1213 - (-0.1756)) \\ &= 0.1358 \text{ hr} \quad (0.14 \text{ hr}) \end{aligned}$$

The total drying time,  $t_D$ , is the sum of the drying times for each period.

$$\begin{aligned} t_D &= t_c + t_I + t_{II} = 0.52 \text{ hr} + 0.10 \text{ hr} + 0.14 \text{ hr} \\ &= 0.76 \text{ hr} \end{aligned}$$

The answer is (C).

[4.](#)

The stormwater is a solvent. The nutrients in the farmland's soil are soluble solutes. The water washes away some or all of the solutes into the watershed. This process is called leaching. Nutrients like nitrogen-rich fertilizers are leached into the watershed. Option A is correct.

Distillation occurs when a liquid is converted to a vapor by vaporization. Sublimation occurs when a solid directly converts to a vapor. Chemosynthesis is the biological conversion of one or more carbon-containing molecules (usually carbon dioxide or methane) and nutrients into organic matter using the oxidation of inorganic compounds.

The answer is (A).

[5.](#)

To find the minimum solvent required, use the McCabe-Thiele method to draw the operating curve.

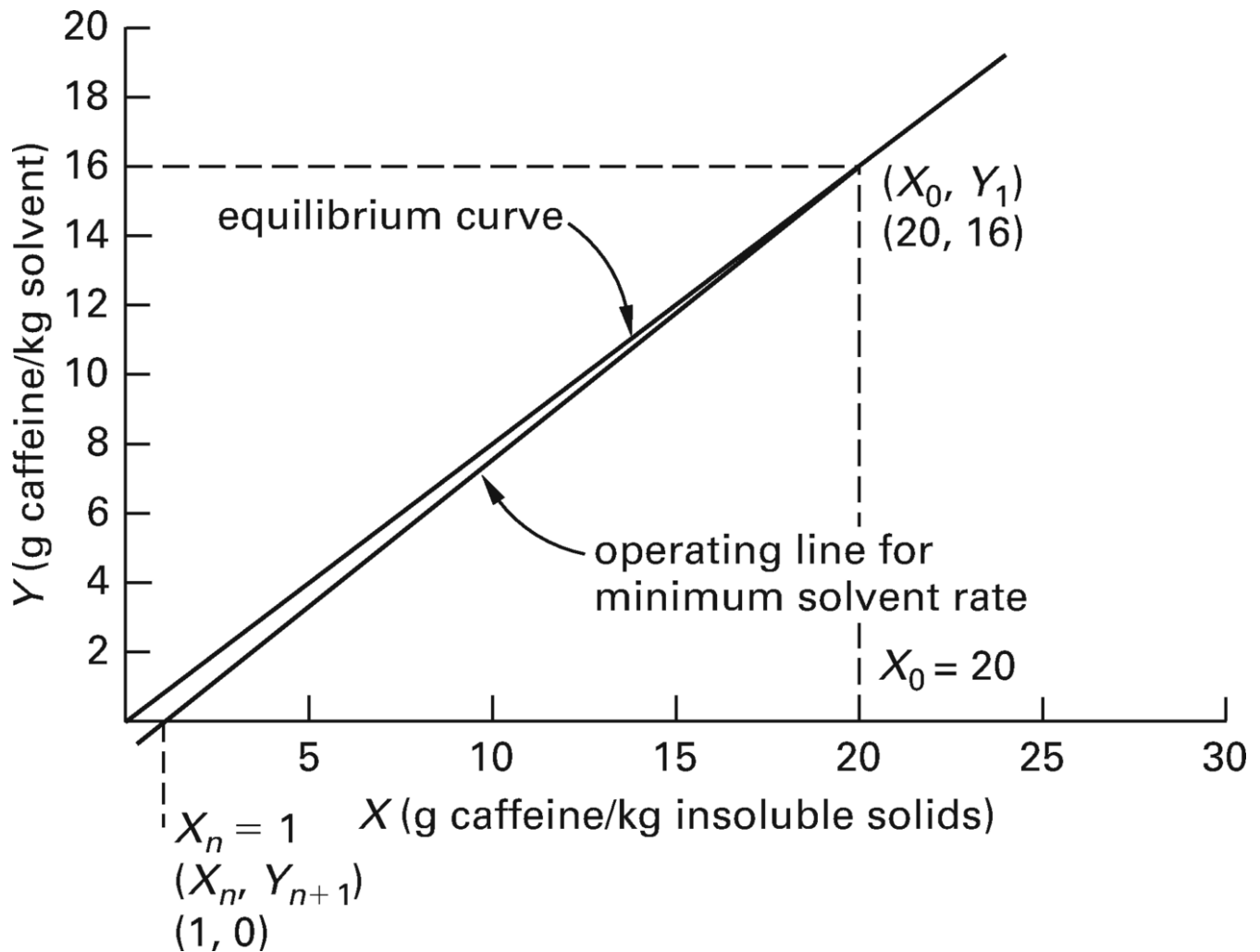
The data given in the problem are shown in the following illustration.



The operating equation for leaching is

$$Y_{n+1} = \left( \frac{L_n}{V_{n+1}} \right) X_n + \frac{V_a Y_a - L_a X_a}{V_{n+1}}$$

The slope of the operating line represents the ratio of insoluble solids to solvent flow rates. For the operating line, only enough information is available to plot one point at  $(X_1, Y_{n+1}) = (1, 0)$ . However, the minimum solvent flow rate is related to the slope of the operating line that intersects the equilibrium curve (to create a pinch point) at the point where  $X_0 = 20$  g caffeine/kg insoluble solids. Using these points and drawing this operating line on the equilibrium diagram reveals the corresponding value of  $Y_1 = 16$  g caffeine/kg solvent.



The slope is

$$\begin{aligned} \text{slope} &= \frac{L_n}{V_{n+1}} = \frac{\Delta Y}{\Delta X} = \frac{Y_1 - Y_{n+1}}{X_0 - X_n} \\ &= \frac{16 \frac{\text{g caffeine}}{\text{kg solvent}} - 0 \frac{\text{g caffeine}}{\text{kg solvent}}}{\left( 20 \frac{\text{g caffeine}}{\text{kg insoluble solids}} - 1 \frac{\text{g caffeine}}{\text{kg insoluble solids}} \right)} \\ &= 0.84 \text{ kg insoluble solids/kg solvent} \end{aligned}$$

The minimum amount of solvent needed is the reciprocal of the minimum slope.

$$\begin{aligned} \frac{L_n}{V_{n+1}} &= \frac{1}{\text{slope}} = \frac{1}{0.84 \frac{\text{kg insoluble solids}}{\text{kg solvent}}} \\ &= 1.2 \text{ kg solvent/kg insoluble solids} \end{aligned}$$

Therefore, the separation requires a minimum of 1.2 kg of solvent per kg of coffee beans.

The answer is (C).

[6.](#)

Equilibrium in a leaching process is irrelevant to the underflow or overflow concentration at any stage; equilibrium is reached when all the solute is solved within the solvent in the liquid phase.

The answer is (C).

[7.](#)

The mass of potassium chloride in the saturated solution at the original temperature of 212°F,  $m_{\text{KCl},212}$ , is known to be 3300 lbm. The solubility of potassium chloride at 212°F,  $K_{\text{KCl},212}$ , is 56.37 g per 100 g of solution. The mass of water needed to dissolve the potassium chloride in the original solution is

$$m_{\text{water}} = \frac{m_{\text{KCl},212}}{K_{\text{KCl},212}} = \frac{3300 \text{ lbm}}{\frac{56.37 \text{ g}}{100 \text{ g}}} = 5854 \text{ lbm}$$

The mass of potassium chloride dissolved in the same amount of water at 176°F is

$$\begin{aligned} m_{\text{KCl},176} &= m_{\text{water}} K_{\text{KCl},176} = (5854 \text{ lbm}) \left( \frac{48.5 \text{ g}}{100 \text{ g}} \right) \\ &= 2839 \text{ lbm} \end{aligned}$$

The loss in the dissolved mass from 212°F to 176°F is the mass of potassium chloride that crystallizes.

$$\begin{aligned} m_{\text{KCl},\text{crystal}} &= m_{\text{KCl},212} - m_{\text{KCl},176} \\ &= 3300 \text{ lbm} - 2839 \text{ lbm} \\ &= 461 \text{ lbm} \quad (460 \text{ lbm}) \end{aligned}$$

The answer is (B).

[8.](#)

Dissolved solids and salts contain very fine particles. Of the filtration processes listed, only reverse osmosis and electro dialysis reversal can remove particles as small as these from a liquid.

The answer is (D).

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[Topic VI: Kinetics](#)

Practice Problems

[1.](#)

The rate constant for a reaction doubles when the temperature is raised from 37°C to 57°C. The temperature at which the rate constant again doubles is most nearly

(A)

77°C

(B)

80°C

(C)

97°C

(D)

124°C

[2.](#)

Compound A reacts to form compound P in a constant-volume, isothermal batch reactor.

time(h)	concentration of reactant A(mol/L)
0	5.00
0.5	0.69
1.0	0.37
1.5	0.25
2.0	0.19
2.5	0.16

The rate that best fits the data is

(A)

$k$

(B)

$kC_A$

(C)

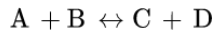
$kC_A^2$

(D)

$kC_A/(1+C_A)$

3.

Consider the reversible reaction



The feed stream contains 3 mol of A, 2 mol of B, and one mol of both C and D. The equilibrium constant,  $K_{eq}$ , is 1.45. At equilibrium, the amount of A is most nearly

(A)

1.81 mol

(B)

2.02 mol

(C)

2.13 mol

(D)

2.36 mol

4.

An endothermic first-order reaction,  $A \rightarrow P$ , is carried out in a batch reactor.

heat of reaction	97 000 kJ/kmol
reactor volume	1 m <sup>3</sup>
heat capacity of mixture	2.5 kJ/kg · K
total mass	975 kg
initial number of moles	10.5 kmol
rate constant	$4750e^{-8500/T} \text{ s}^{-1}$

After the reaction mixture is heated to 300°C, it is allowed to proceed adiabatically. 15 mol% of A is converted during the heat-up. What is the temperature in the reactor at 75% conversion?

(A)

155K

(B)

260K

(C)

322K

(D)

510K

5.

The reaction  $A \xrightarrow{k_1} P \xrightarrow{k_2} S$  is carried out in a tubular plug-flow reactor. Both reactions are first order.

reactor diameter	10 cm
feed rate	0.15 m <sup>3</sup> /h pure A
feed concentration	0.10 kmol A/m <sup>3</sup>
rate constants	$k_1 = 175 \text{ h}^{-1}$ $k_2 = 12.5 \text{ h}^{-1}$

Determine the reactor length that will maximize the yield of P.

(A)

0.08 m

(B)

0.31 m

(C)

0.97 m

(D)

1.5 m

[6.](#)

In a liquid-phase batch reactor, the elementary reaction  $2A \rightarrow B$  occurs. The initial concentration of A is 3 mol/L, and 90% conversion is achieved in 2 hr. Assume density and temperature are constant during the reaction. Most nearly, the reaction rate constant is

(A)

0.67 L/mol·h

(B)

1.0 L/mol·h

(C)

1.5 L/mol·h

(D)

2.3 L/mol·h

[7.](#)

A CSTR is used to produce B at a rate of 55 kmol/h by the first-order reaction,  $A \rightarrow B$ , with a rate constant of  $7.0 \text{ h}^{-1}$ . The feed concentration of reactant A is  $1 \text{ kmol/m}^3$ . What total reactor volume is required to achieve 70% conversion in a series of two CSTRs?

(A)

9.27 m<sup>3</sup>

(B)

13.10 m<sup>3</sup>

(C)

18.55 m<sup>3</sup>

(D)

26.20 m<sup>3</sup>

[8.](#)

The activation energy of a first-order reaction is 60.3 kJ/mol at 35°C. The temperature at which the rate constant will triple is most nearly

(A)

35°C

(B)

38°C

(C)

41°C

(D)

50°C

[9.](#)

The hydrolysis of propene (C<sub>3</sub>H<sub>6</sub>) produces a mixture of the two isomers of propanol (C<sub>3</sub>H<sub>7</sub>OH). The by-product of the reaction is propyl ether ((C<sub>3</sub>H<sub>7</sub>)<sub>2</sub>O). The feed into a reactor contains 58 mol% propene, 35 mol% water, and 7 mol% inert substances. The product from the reactor contains 4.89 mol% isomers of propanol, 48.26 mol% propene, 0.21 mol% propyl ether, 35.87 mol% water, and 10.77 mol% inert substances. Most nearly, the yield of propanol based on propene is

(A)

0.12%

(B)

3.8%

(C)

12%

(D)

300%

[10.](#)

The parallel competing reactions  $M \rightarrow N$  and  $M \rightarrow P$  are to be carried out in an ideal continuous stirred tank reactor (CSTR) operating at steady state. The conversion of species M is 92%. The initial concentration of species M is 4.8 mol/L. The reaction to produce species N is a zero-order reaction, having a reaction constant

of  $2.8 \text{ mol/L} \cdot \text{min}$ . The reaction to produce species P is a first-order reaction, having a rate constant of  $1.2 \text{ 1/min}$ . The overall yield of formation of species N is most nearly

(A)

0.31

(B)

0.63

(C)

0.73

(D)

0.86

[11.](#)

The dehydration of ethanol ( $\text{C}_2\text{H}_5\text{OH}$ ) produces mainly diethyl ether ( $\text{C}_4\text{H}_{10}\text{O}$ ). The by-product of the reaction is ethene ( $\text{C}_2\text{H}_4$ ). The main reaction, having a reaction rate constant of  $20 \text{ 1/min}$ , is first order in the concentration of  $\text{C}_2\text{H}_5\text{OH}$ . The reaction rate of the independent parallel reaction, having a reaction rate constant of  $10 \text{ 1/min}$  is first order in the concentration of  $\text{C}_2\text{H}_5\text{OH}$ . The selectivity is defined as the ratio of the moles of diethyl ether produced to the moles of ethene produced. Most nearly, the selectivity is

(A)

0.5

(B)

1.0

(C)

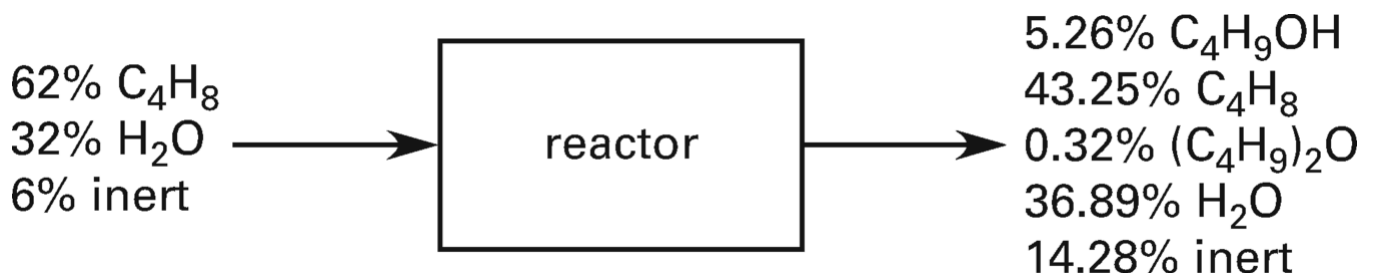
2.0

(D)

5.0

[12.](#)

The hydrolysis of 1-butene ( $\text{C}_4\text{H}_8$ ) produces mainly an undistinguishable mixture of the two isomers of butanol with the molecular formula  $\text{C}_4\text{H}_9\text{OH}$ . The by-product of the reaction is butyl ether ( $(\text{C}_4\text{H}_9)_2\text{O}$ ). The reactor is fed with a stream containing 62 mol% 1-butene, 32 mol% water, and 6 mol% inert. The product from the reactor contains 5.26 mol% of the isomers mixture, 43.25 mol% 1-butene, 0.32 mol% butyl ether, 36.89 mol% water, and 14.28 mol% inert.



The selectivity of butanol is most nearly



(A)

0.06

(B)

2.2

(C)

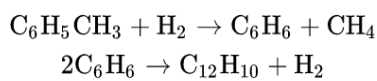
7.4

(D)

16

[13.](#)

A reactor is fed with a stream containing toluene ( $\text{C}_6\text{H}_5\text{CH}_3$ ), hydrogen ( $\text{H}_2$ ), methane ( $\text{CH}_4$ ), and benzene ( $\text{C}_6\text{H}_6$ ). In addition to the desirable product of this reaction,  $\text{C}_6\text{H}_6$ , the subproduct, diphenyl ( $\text{C}_{12}\text{H}_{10}$ ) is also obtained according to the following balanced parallel reactions.



The following table shows the molar flow rate of the reactor feed and the effluent streams.

species	feed flow rate, $n_f(\text{kmol/h})$	effluent flow rate, $n_o(\text{kmol/h})$
$\text{H}_2$	1875	1548
$\text{CH}_4$	798	1012
$\text{C}_6\text{H}_6$	16	375
$\text{C}_6\text{H}_5\text{CH}_3$	365	112
$\text{C}_{12}\text{H}_{10}$	0	5

The  $\text{C}_6\text{H}_6$  yield from  $\text{C}_6\text{H}_5\text{CH}_3$  is most nearly

(A)

0.75

(B)

0.98

(C)

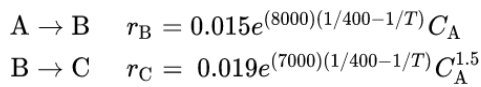
1.4

(D)

1.5

[14.](#)

Two simultaneous reactions take place in a CSTR at a temperature of  $200^\circ\text{C}$ . B is the desired product of the first reaction, and C is the undesired product of the second reaction. The two gas phase reactions, and the rate expressions for the formation of B and C are



Temperature is in kelvins. The initial concentration of A is 3.4 mol/L. The desired fractional conversion of A is 0.90. Most nearly, the selectivity for the formation of B and C is

(A)

0.65

(B)

1.3

(C)

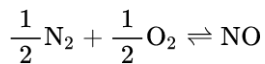
0.1

(D)

2.0

[15.](#)

The following reversible reaction takes place in air at 1 atm and 1500°C.



The correct expression for the equilibrium constant,  $K_{\text{eq}}$ , for this reaction is

(A)

$$K_{\text{eq}} = \frac{[\text{NO}]}{[\text{N}_2][\text{O}_2]}$$

(B)

$$K_{\text{eq}} = \frac{[\text{N}_2]^{1/2}[\text{O}_2]^{1/2}}{[\text{NO}]}$$

(C)

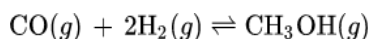
$$K_{\text{eq}} = \frac{[\text{NO}]}{[\text{N}_2]^{1/2}[\text{O}_2]^{1/2}}$$

(D)

$$K_{\text{eq}} = \frac{[\text{N}_2][\text{O}_2]}{[\text{NO}]}$$

[16.](#)

The following system is at equilibrium.



Pressure is increased by compressing the system. As a consequence, the concentration of methanol ( $\text{CH}_3\text{OH}$ )

(A)

remains the same

(B)

decreases

(C)

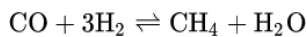
increases

(D)

decreases for a while and then increases

[17.](#)

The gas-phase reaction shown takes place at 500°C with a Gibbs free energy of  $-13\,000$  cal/mol.



Most nearly, the equilibrium constant for the reaction is

(A)

4700

(B)

5900

(C)

7300

(D)

9100

Solutions

[1.](#)

From the problem statement,  $k_2 = 2k_1$ . The activation energy,  $E$ , can be found by taking a ratio of rate constants as defined by the Arrhenius law equation. First, all temperatures must be absolute. As in *NCEES Handbook* table “Conversion Table for Temperature Units,”

$$T_1 = 37^\circ\text{C} + 273^\circ = 310\text{K}$$

$$T_2 = 57^\circ\text{C} + 273^\circ = 330\text{K}$$

From *NCEES Handbook*: Temperature Dependence,

$$\ln \frac{k_1}{k_2} = - \left( \frac{E}{R^*} \right) \left( \frac{1}{T_1} - \frac{1}{T_2} \right)$$
$$\ln \frac{1}{2} = - \left( \frac{E}{8.314 \frac{\text{J}}{\text{mol}\cdot\text{K}}} \right) \left( \frac{1}{310\text{K}} - \frac{1}{330\text{K}} \right)$$
$$E = 29\,477 \text{ J/mol} \quad (29\,500 \text{ J/mol})$$

Doubling the rate constant again implies that

$$k_2' = 2k_1 = (2)(2k_1) = 4k_1$$

$$\ln \frac{k_1}{k_2'} = - \left( \frac{E}{R^*} \right) \left( \frac{1}{T_1} - \frac{1}{T_2'} \right)$$

$$\ln \frac{1}{4} = - \left( \frac{29500 \frac{\text{J}}{\text{mol}}}{8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}}} \right) \left( \frac{1}{310\text{K}} - \frac{1}{T_2'} \right)$$

$$T_2' = 353\text{K} \quad (80^\circ\text{C})$$

The answer is (B).

[2.](#)

Find  $k$  by substituting data points into the integrated form of the material balance for each rate. The rate that best fits the data is the rate that gives the least divergent values of  $k$ . For this problem, it suffices to find the value of  $k$  for the first two data points—(0, 5) and (0.5, 0.69)—and compare to the value of  $k$  for the first and last data points—(0, 5) and (2.5, 0.16).

Use *NCEES Handbook: Zero-Order Reactions* to find the integrated form for each rate. Solving for both values of  $k$  in option A,

$$k = \frac{C_{A0} - C_A}{t} = \frac{5 - 0.69}{0.5} = 8.62$$

$$k = \frac{C_{A0} - C_A}{t} = \frac{5 - 0.16}{2.5} = 1.94$$

These two values of  $k$  are not close. For option B, the integrated form can be found in *NCEES Handbook: First-Order Reactions*.

$$k = \frac{\ln \frac{C_{A0}}{C_A}}{t} = \frac{\ln \frac{5}{0.69}}{0.5} = 3.96$$

$$k = \frac{\ln \frac{C_{A0}}{C_A}}{t} = \frac{\ln \frac{5}{0.16}}{2.5} = 1.38$$

These two values are closer, but not close enough. For option C, the integrated form can be found in *NCEES Handbook: Second-Order Reactions*.

$$k = \left( \frac{1}{t} \right) \left( \frac{1}{C_A} - \frac{1}{C_{A0}} \right)$$

$$= \left( \frac{1}{0.5} \right) \left( \frac{1}{0.69} - \frac{1}{5} \right)$$

$$= 2.5$$

$$k = \left( \frac{1}{t} \right) \left( \frac{1}{C_A} - \frac{1}{C_{A0}} \right)$$

$$= \left( \frac{1}{2.5} \right) \left( \frac{1}{0.16} - \frac{1}{5} \right)$$

$$= 2.42$$

Option C values of  $k$  diverge less than option A or option B values. For option D, the integrated form looks like a combination of the integrated forms of option A and option B.

$$k = \frac{C_{A0} - C_A}{t} + \frac{\ln \frac{C_{A0}}{C_A}}{t} = \frac{5 - 0.69}{0.5} + \frac{\ln \frac{5}{0.69}}{0.5} = 12.58$$

$$k = \frac{C_{A0} - C_A}{t} + \frac{\ln \frac{C_{A0}}{C_A}}{t} = \frac{5 - 0.16}{2.5} + \frac{\ln \frac{5}{0.16}}{2.5} = 3.32$$

Option D values of  $k$  diverge the most. The rate that best fits the data is option C.

The answer is (C).

3.

As in *NCEES Handbook: Chemical Equilibrium Constants from Rate Constants for Reversible Reactions*, the equilibrium constant is

$$K_{\text{eq}} = \frac{C_{\text{C}}^1 C_{\text{D}}^1}{C_{\text{A}}^1 C_{\text{B}}^1} = \frac{(1 + \epsilon)^2}{(2 - \epsilon)(3 - \epsilon)} = 1.45$$

Rearranging into a quadratic equation,

$$-0.45\epsilon^2 + 9.25\epsilon - 7.7 = 0$$

Using the properties of quadratic equations found in *NCEES Handbook: Polynomials*, the extent of reaction is

$$\begin{aligned}\epsilon &= \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \\ &= \frac{-9.25 \pm \sqrt{(9.25)^2 - (4)(-0.45)(-7.7)}}{2(-0.45)} \\ &= 0.87\end{aligned}$$

Assume a base volume of 1 L for ease of calculation. The amount of A at equilibrium is

$$\begin{aligned}C_{\text{A}} &= C_{\text{A}0} - \epsilon = 3 \text{ mol} - \epsilon \\ &= 3 \text{ mol} - 0.87 \text{ mol} \\ &= 2.13 \text{ mol}\end{aligned}$$

The answer is (C).

4.

The mass balance and the energy balance around the batch reactor are solved simultaneously to determine the final temperature in the reactor. See *NCEES Handbook* section titled “Heat Effects in Reactors.” For a batch reactor,

$$\begin{aligned}\frac{dX_{\text{A}}}{d\theta} &= \left( \frac{V}{N_{\text{A}0}} \right) (-r_{\text{A}}) \\ m_t c_p \frac{dT}{d\theta} &= V (-\Delta H_r) (-r_{\text{A}}) + q A_k\end{aligned}$$

In an adiabatic reactor, the heat flux,  $q$ , is 0. Since the reaction is endothermic,  $\Delta H_r$  is positive. The negative term,  $-\Delta H_r$ , indicates that the temperature will decrease during the reaction. Combining the two equations results in the following expression.

$$\frac{dT}{dX} = \frac{(-\Delta H_r) N_{\text{A}0}}{m_t c_p}$$

Upon integration,

$$\begin{aligned}T &= T_0 + \left( \frac{-\Delta H_r N_{\text{A}0}}{m_t c_p} \right) (X_{\text{A}} - X_{\text{A}0}) \\ &= 300^\circ\text{C} + 273^\circ \\ &\quad + \left( \frac{\left( -97\,000 \frac{\text{kJ}}{\text{mol}} \right) (10.5 \text{ kmol})}{(975 \text{ kg}) \left( 2.5 \frac{\text{kJ}}{\text{kg}\cdot\text{K}} \right)} \right) (0.75 - 0.15) \\ &= 322\text{K}\end{aligned}$$

The answer is (C).

5.

From *NCEES Handbook*: Two First-Order Irreversible Reactions in Series, the residence time for maximum yield of an intermediate is

$$\tau_{\max} = \frac{\ln \frac{k_2}{k_1}}{k_2 - k_1} = \frac{\ln \frac{12.5 \text{ h}^{-1}}{175 \text{ h}^{-1}}}{12.5 \text{ h}^{-1} - 175 \text{ h}^{-1}} = 0.0162 \text{ h}$$

From *NCEES Handbook*: Plug-Flow Reactor, the residence time is

$$\tau = \frac{C_{A0} V_{\text{PFR}}}{F_{A0}}$$

Substituting  $V = \pi(D^2/4)L$  into the previous equation and rearranging to solve for reactor length,

$$\begin{aligned} L &= \tau_{\max} \left( \frac{F_{A0}}{C_{A0}} \right) \left( \frac{4}{\pi D^2} \right) = \tau_{\max} \dot{V}_{A0} \left( \frac{4}{\pi D^2} \right) \\ &= (0.0162 \text{ h}) \left( 0.15 \frac{\text{m}^3}{\text{h}} \right) \\ &\quad \times \left( \frac{4}{\pi \left( (10 \text{ cm}) \left( \frac{1 \text{ m}}{100 \text{ cm}} \right) \right)^2} \right) \\ &= 0.31 \text{ m} \end{aligned}$$

The answer is (B).

6.

The final reactant A concentration is found from the conversion in *NCEES Handbook* Reaction Parameters Nomenclature.

$$\begin{aligned} C_A &= C_{A0} (1 - X_A) = \left( 3 \frac{\text{mol}}{\text{L}} \right) (1 - 0.90) \\ &= 0.3 \text{ mol/L} \end{aligned}$$

The rate constant is found in *NCEES Handbook* Second-Order Reactions: Constant Volume—Batch Reactor.

$$\begin{aligned} k &= \frac{\frac{1}{C_A} - \frac{1}{C_{A0}}}{t} = \frac{\frac{1}{0.3 \frac{\text{mol}}{\text{L}}} - \frac{1}{3 \frac{\text{mol}}{\text{L}}}}{2 \text{ h}} \\ &= 1.5 \text{ L/mol} \cdot \text{h} \end{aligned}$$

The answer is (C).

7.

From the problem statement, B is produced at 55 kmol/h with a 70% conversion ( $X_A = 0.7$ ) of A to B. Therefore, the feed concentration of A is

$$\begin{aligned} F_{A0} X_A &= F_B \\ F_{A0} &= \frac{F_B}{X_A} \\ &= \frac{55 \frac{\text{kmol}}{\text{h}}}{0.7} \\ &= 78.6 \text{ kmol/h} \end{aligned}$$

As in *NCEES Handbook*: Continuous Stirred Tank Reactors in Series, the total residence time of  $N$  is

$$\begin{aligned}\tau &= \left(\frac{N}{k}\right) \left( \left( \frac{C_{Ao}}{C_A} \right)^{1/N} - 1 \right) \\ &= \left( \frac{2}{7 \text{ h}^{-1}} \right) \left( \left( \frac{1 \frac{\text{kmol}}{\text{m}^3}}{0.3 \frac{\text{kmol}}{\text{m}^3}} \right)^{1/2} - 1 \right) \\ &= 0.236 \text{ h}\end{aligned}$$

As in *NCEES Handbook*: Continuous Stirred Tank Reactor (CSTR), the total reactor volume required to achieve 70% conversion in a series of two CSTRs is

$$\begin{aligned}\tau &= \frac{C_{Ao} V}{F_{Ao}} \\ V &= \frac{\tau F_{Ao}}{C_{Ao}} \\ &= \frac{(0.236 \text{ h}) \left( 78.6 \frac{\text{kmol}}{\text{h}} \right)}{1 \frac{\text{kmol}}{\text{m}^3}} \\ &= 18.55 \text{ m}^3\end{aligned}$$

The answer is (C).

[8.](#)

The equation for a first-order reaction at two temperatures is

$$\ln \frac{k_2}{k_1} = \frac{E}{R} \left( \frac{1}{T_1} - \frac{1}{T_2} \right)$$

To find the temperature at which the rate constant will triple, set  $k_2$  to three times  $k_1$  and solve for  $T_2$ .

$$\begin{aligned}\ln \frac{3k_1}{k_1} &= \frac{E}{R} \left( \frac{1}{T_1} - \frac{1}{T_2} \right) \\ T_2 &= \frac{1}{\frac{1}{T_1} - \frac{R \ln 3}{E}} \\ &= \frac{1}{\frac{1}{35^\circ \text{C} + 273^\circ} - \frac{\left( 8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}} \right) (1.0986)}{60\,300 \frac{\text{J}}{\text{mol}}}} \\ &= 323 \text{ K}\end{aligned}$$

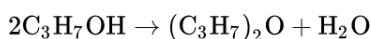
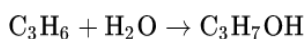
Converting to degrees Celsius gives

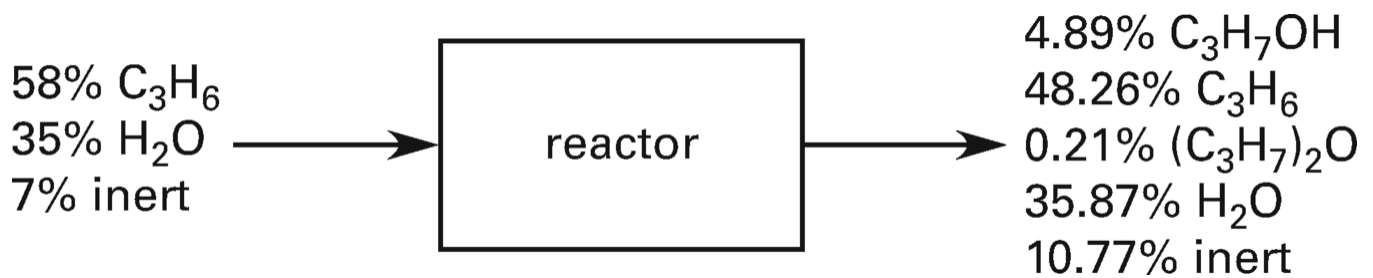
$$323 \text{ K} - 273^\circ = 50^\circ \text{C}$$

The answer is (D).

[9.](#)

The balanced reactions are





Each 100 mol in the feed stream contains 58 mol of propene and 7 mol of inert substances. From the hydrolysis reaction, the stoichiometric coefficient is 1. As the inert substances remain constant, the ratio of moles of inert substances in the feed stream to moles of inert substances in the product remains constant. This ratio is applicable to the other components in the product stream. The number of moles of propanol in the product stream, assuming 100 mol of feed, is

$$\begin{aligned}(n_{\text{C}_3\text{H}_7\text{OH}})_p &= (4.89) \left( \frac{n_{\text{inert,feed}}}{10.77} \right) \\ &= (4.89) \left( \frac{7 \text{ mol}}{10.77} \right) \\ &= 3.18 \text{ mol}\end{aligned}$$

The number of moles of propene in the product stream, assuming 100 mol of feed, is

$$\begin{aligned}(n_{\text{C}_3\text{H}_6})_p &= (48.26) \left( \frac{n_{\text{inert,feed}}}{10.77} \right) \\ &= (48.26) \left( \frac{7 \text{ mol}}{10.77} \right) \\ &= 31.37 \text{ mol}\end{aligned}$$

A mole balance around the reactor gives the number of moles of  $\text{C}_3\text{H}_6$  that react.

$$\begin{aligned}n_{\text{C}_3\text{H}_6,\text{reacted}} &= n_{\text{C}_3\text{H}_6,\text{feed}} - n_{\text{C}_3\text{H}_6,\text{product}} \\ &= 58 \text{ mol} - 31.37 \text{ mol} \\ &= 26.63 \text{ mol}\end{aligned}$$

The yield of the hydrolysis reaction is the ratio of the number of moles of desired product (propanol) to the number of moles of propanol that reacted. The percent yield of propanol based on propene is

$$\begin{aligned}y &= \frac{n_{\text{C}_3\text{H}_7\text{OH,product}}}{n_{\text{C}_3\text{H}_6,\text{reacted}}} \times 100\% \\ &= \frac{(3.18 \text{ mol})(1)}{26.63 \text{ mol}} \times 100\% \\ &= 11.93\% \quad (12\%)\end{aligned}$$

The answer is (C).

[10.](#)

The final concentration of species M is

$$\begin{aligned}C_M &= (1 - x_M)C_{M,o} \\ &= (1 - 0.92) \left( 4.8 \frac{\text{mol}}{\text{L}} \right) \\ &= 0.384 \text{ mol/L}\end{aligned}$$

Because the formation of species N is given as a zero-order reaction, the rate of formation of species N is  $r_N = k_N = 2.8 \text{ mol/L} \cdot \text{min}$ . A mole balance of species M gives the rate of reaction of disappearance of species M.

$$\begin{aligned}-r_M &= k_N + k_P C_M \\ &= 2.8 \frac{\text{mol}}{\text{L} \cdot \text{min}} + \left( 1.2 \frac{1}{\text{min}} \right) \left( 0.384 \frac{\text{mol}}{\text{L}} \right) \\ &= 3.261 \text{ mol/L} \cdot \text{min}\end{aligned}$$



For a CSTR, the residence time is

$$\begin{aligned}\theta &= \frac{C_{M,o} - C_M}{-r_M} \\ &= \frac{4.8 \frac{\text{mol}}{\text{L}} - 0.384 \frac{\text{mol}}{\text{L}}}{3.261 \frac{\text{mol}}{\text{L} \cdot \text{min}}} \\ &= 1.354 \text{ min}\end{aligned}$$

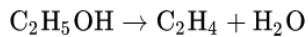
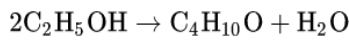
The overall yield is

$$\begin{aligned}y_N &= \frac{r_N \theta}{C_{M,o} - C_M} \\ &= \frac{\left(2.8 \frac{\text{mol}}{\text{L} \cdot \text{min}}\right) (1.354 \text{ min})}{4.8 \frac{\text{mol}}{\text{L}} - 0.384 \frac{\text{mol}}{\text{L}}} \\ &= 0.8585 \quad (0.86)\end{aligned}$$

The answer is (D).

[11.](#)

The balanced reactions are



In the first reaction, the reaction rate constant for the disappearance of ethanol,  $k_1$ , is given as 20 1/min. In the second reaction,  $k_2$  is given as 10 1/min. Let  $C_A$  be the instantaneous concentration of ethanol at a given time. Because the first reaction is first order, by definition the rate of disappearance of ethanol in the first reaction is

$$r_1 = -k_1 C_A$$

Because diethyl ether is produced in the first reaction, the rate of formation of diethyl ether equals the rate of disappearance of ethanol in the first reaction. The rate of formation of the desired product, diethyl ether, is

$$r_D = -r_1 = k_1 C_A$$

Ethanol is also consumed in the second reaction. Because the second reaction is a first-order reaction, by definition the rate of disappearance of ethanol in the second reaction is

$$r_2 = -k_2 C_A$$

The rate of formation of ethene in the second reaction equals the rate of disappearance of ethanol in the second reaction. The rate of formation of ethene in the second reaction is

$$r_U = -r_2 = k_2 C_A$$

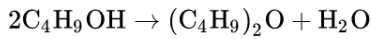
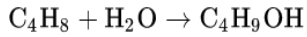
By definition the selectivity of ethanol toward the formation of diethyl ether is

$$\begin{aligned}S_{D/U} &= \frac{r_D}{r_U} = \frac{k_1 C_A}{k_2 C_A} = \frac{k_1}{k_2} \\ &= \frac{20 \frac{1}{\text{min}}}{10 \frac{1}{\text{min}}} \\ &= 2.0\end{aligned}$$

The answer is (C).

[12.](#)

The balanced reactions are



Let the basis of calculation be 100 mol of feed. The number of moles of 1-butene in the feed stream,  $n_{\text{C}_4\text{H}_8,f}$ , is 62 mol. From the hydrolysis reaction, the stoichiometric coefficient,  $s$ , is 1. The number of moles of inert in the feed stream,  $n_{\text{inert},f}$ , is 6 mol. As the inert material remains constant, the ratio of moles inert in the feed stream to moles inert in the product remains constant. This ratio is also applicable to the other components in the product stream. The number of moles of butanol in the product stream is

$$\begin{aligned} n_{\text{C}_4\text{H}_8,p} &= (5.26) \left( \frac{n_{\text{inert},f}}{14.28} \right) \\ &= (5.26) \left( \frac{6 \text{ mol}}{14.28} \right) \\ &= 2.21 \text{ mol} \end{aligned}$$

The number of moles of butyl ether in the product stream is

$$\begin{aligned} n_{(\text{C}_4\text{H}_8)_2\text{O},p} &= (0.32) \left( \frac{n_{\text{inert},f}}{14.28} \right) \\ &= (0.32) \left( \frac{6 \text{ mol}}{14.28} \right) \\ &= 0.1345 \text{ mol} \end{aligned}$$

The selectivity of a reaction is the ratio of the desired product (butanol) to the undesired product (butyl ether). The selectivity of butanol is

$$\begin{aligned} y &= \frac{n_{\text{C}_4\text{H}_8,p} s}{n_{(\text{C}_4\text{H}_8)_2\text{O},p}} \\ &= \frac{(2.21 \text{ mol})(1)}{0.1345 \text{ mol}} \\ &= 16.438 \quad (16) \end{aligned}$$

The answer is (D).

[13.](#)

Perform a molar flow rate balance to find the molar flow rate of  $\text{C}_6\text{H}_5\text{CH}_3$  consumed in the reactor.

$$\begin{aligned} n_{\text{C}_6\text{H}_5\text{CH}_3,c} &= n_{\text{C}_6\text{H}_5\text{CH}_3,f} - n_{\text{C}_6\text{H}_5\text{CH}_3,o} \\ &= 365 \frac{\text{kmol}}{\text{h}} - 112 \frac{\text{kmol}}{\text{h}} \\ &= 253 \text{ kmol/hr} \end{aligned}$$

Perform a molar flow rate balance to find the molar flow rate of  $\text{C}_6\text{H}_6$  produced in the reactor.

$$\begin{aligned} n_{\text{C}_6\text{H}_6,p} &= n_{\text{C}_6\text{H}_6,o} - n_{\text{C}_6\text{H}_6,f} \\ &= 375 \frac{\text{kmol}}{\text{h}} - 16 \frac{\text{kmol}}{\text{h}} \\ &= 359 \text{ kmol/hr} \end{aligned}$$

The yield of  $\text{C}_6\text{H}_6$  from  $\text{C}_6\text{H}_5\text{CH}_3$  is

$$\begin{aligned} Y &= \frac{n_{\text{C}_6\text{H}_6,p}}{n_{\text{C}_6\text{H}_5\text{CH}_3,c}} \\ &= \frac{359 \frac{\text{kmol}}{\text{h}}}{253 \frac{\text{kmol}}{\text{h}}} \\ &= 1.4189 \quad (1.4) \end{aligned}$$

The answer is (C).

[14.](#)

Find the amount of A converted in the reaction by multiplying the initial concentration of A by the desired fractional conversion of A.

$$\left(3.4 \frac{\text{mol}}{\text{L}}\right)(0.90) = 3.06 \frac{\text{mol}}{\text{L}}$$

Find the final concentration of A by subtracting the converted amount of A from the initial amount of A.

$$3.4 \frac{\text{mol}}{\text{L}} - 3.06 \frac{\text{mol}}{\text{L}} = 0.34 \frac{\text{mol}}{\text{L}}$$

The selectivity for the formation of B and C is the molar ratio of desired product B to undesired product C formed by the parallel reactions.

$$S = \frac{r_B}{r_C}$$

Use the final concentration of A to find the selectivity for the formation of B and C.

$$\begin{aligned} S = \frac{r_B}{r_C} &= \frac{0.015e^{(8000)(1/400-1/T)} C_A}{0.019e^{(7000)(1/400-1/T)} C_A^{1.5}} \\ &= \frac{0.789e^{(1000)(1/400-1/T)}}{C_A^{0.5}} \\ &= \frac{0.789e^{(1000)(1/400-1/(200^\circ\text{C}+273^\circ))}}{(0.34)^{0.5}} \\ &= 1.99 \quad (2.0) \end{aligned}$$

The answer is (D).

[15.](#)

For the reaction  $aA + bB \rightleftharpoons cC + dD$ , the equilibrium constant is

$$K_{\text{eq}} = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

For the given reaction, then, the expression for the equilibrium constant is

$$K_{\text{eq}} = \frac{[\text{NO}]}{[\text{N}_2]^{1/2} [\text{O}_2]^{1/2}}$$

The answer is (C).

[16.](#)

According to Le Châtelier's principle, when a stress (such as change in pressure, temperature, or composition) is applied to a system already in equilibrium, the equilibrium shifts in a way that tends to relieve the stress. When pressure is increased from compressing a system in equilibrium, the system moves in the direction of relieving or decreasing the pressure. For a gaseous system, the system pressure is proportional to the number of moles. In the forward reaction of the system specified, 3 mol of reactants result in the formation of 1 mol of product. Therefore, the system pressure decreases as the forward reaction takes place. Since the forward reaction produces methanol, the methanol concentration increases when the system is compressed.

The answer is (C).

[17.](#)

Convert the temperature to kelvins.

$$T = 500^{\circ}\text{C} + 273.15^{\circ} = 773.15\text{K}$$

Calculate the equilibrium constant for the reaction from the Gibbs free energy.

$$\begin{aligned}\Delta\hat{g}_r &= -RT \ln K_{\text{eq}} \\ \ln K_{\text{eq}} &= -\frac{\Delta\hat{g}_r}{RT} \\ K_{\text{eq}} &= e^{-\Delta\hat{g}_r/RT} \\ &= e^{-(-13\,000\text{ cal/mol})/(1.987\text{ cal/mol})(773.15\text{K})} \\ &= 4732.31 \quad (4700)\end{aligned}$$

The answer is (A).