

ANSWERS TO TEST YOURSELVES

p. 9

1. A ratio of equivalent values of a quantity expressed in different units.
2. $(60 \text{ s})/(1 \text{ min})$
3. $(1 \text{ min}^2)/(3600 \text{ s}^2)$
4. $(1 \text{ m}^3)/(10^6 \text{ cm}^3)$

p. 11

1. **(a)** $(1000 \text{ mm})/(1 \text{ m})$; **(b)** $(10^{-9} \text{ s})/(1 \text{ ns})$;
(c) $(1 \text{ m}^2)/(10^4 \text{ cm}^2)$; **(d)** $(1 \text{ m}^3)/(35.3145 \text{ ft}^3)$;
(e) $(9.486 \times 10^{-4} \text{ Btu/s})/(1.341 \times 10^{-3} \text{ hp})$

2. m/s; cm/s; ft/s

p. 13

1. $2 \text{ N}; (2/32.174) \text{ lb}_f$
2. No
3. 1 kg; same; less
4. 2 lb_m ; same; less

p. 15

1. **(a)** 1.22×10^4 (3 s.f.); **(b)** 1.22000×10^4 (6 s.f.);
(c) 3.040×10^{-3} (4 s.f.)
2. **(a)** 134,000 (3 s.f.); **(b)** 0.01340 (4 s.f.); **(c)** 4200 (3 s.f.)
3. **(a)** 3 s.f.; **(b)** 2 s.f.; **(c)** 3 s.f., 11.2; **(d)** 2 s.f., 12
4. **(a)** 1460; **(b)** 13.4; **(c)** 1.76×10^{-7}
5. **(a)** 4.25–4.35; **(b)** 4.295–4.305;
(c) 2.7775×10^{-3} – 2.7785×10^{-3} ;
(d) 2450–2550; **(e)** 2499.5–2500.5

p. 18

1. Breakdowns, routine or unplanned shutdowns, or installing new equipment in the second week. (Many other possibilities exist.)
2. 35.5 or 35 batches/week.
3. 40 batches/week. The second week was clearly abnormal and shouldn't influence the prediction.

p. 19

1. $\bar{V} = 237.4 \text{ cm}^3/\text{s}$, range = $21 \text{ cm}^3/\text{s}$, $s_V^2 = 66.3 \text{ cm}^6/\text{s}^2$,
 $s_V = 8.1 \text{ cm}^3/\text{s}$
2. $\dot{V} = 237.4 \text{ cm}^3/\text{s} \pm 16.2 \text{ cm}^3/\text{s}$

p. 22

1. All additive terms have the same dimensions. No. Yes.
2. $\text{m}^{-2} \cdot \text{s}^{-2}$

3. A multiplicative combination of factors with no net units; st^2/r or r/st^2 .

4. $a(\text{lb}_f)$; Q is dimensionless.

p. 23

1. Substitute in Equation 2.7-1.
2. Correct; too high; too low; too low.

p. 27

1. $y = a(x^2 - 2)$
2. **(b)** Plot $1/y$ versus $(x - 3)^2$: a = slope, b = intercept.
(c) Plot y^3 versus x^2 : a = slope, b = –intercept.
(d) Plot $\sqrt{x}/\sin y$ versus x : a = slope, b = intercept.
(e) Plot $\ln y$ versus x : $b = \ln(y_2/y_1)/(x_2 - x_1)$,
 $\ln a = \ln y_1 - bx_1$, $a = e^{\ln a}$.
(f) Plot $\ln y$ versus $\ln x$: $b = \ln(y_2/y_1)/\ln(x_2/x_1)$, $\ln a = \ln y_1 - b \ln x_1$, $a = e^{\ln a}$.

p. 29

1. **(a)** $P = at + b$; **(b)** $P = ae^{bt}$;
(c) $P = at^b$; **(d)** $y^2 = 3 + a \exp(b/x^2)$;
(e) $1/F = a(t^2 - 4)^b$.
2. **(a)** P versus t on a semilog paper;
(b) P versus t on log paper;
(c) P^2 versus t^3 on semilog paper;
(d) $1/P$ (or P) versus $(t - 4)$ on log paper.

p. 44

1. Dimensionless.
2. 0.50 g/cm^3 ; $2.0 \text{ cm}^3/\text{g}$; $31 \text{ lb}_m/\text{ft}^3$; 1.5 g ; 36 cm^3
3. Yes.
4. No—possibly different reference densities used for each.
5. $\rho_{\text{H}_2\text{O(s)}} < \rho_{\text{H}_2\text{O(l)}}$; $\rho_{\text{NBA(s)}} > \rho_{\text{NBA(l)}}$
6. When T rises, the mercury in the thermometer expands. At higher temperatures the same mass thus occupies a greater volume, meaning that the density of mercury ($= m/V$) decreases.

p. 46

1. $10.0 \text{ cm}^3/\text{s}$
2. 159.5 g/min
3. Same; same; greater at outlet.

p. 47

1. 100 mL/min ; 100 g/min
2. Flowmeters—see Figure 3.2-1.

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3. Too low (the gas is much less dense, so it must flow at a much higher rate than the liquid to raise the float to the same position).

p. 49

1. (a) 6.02×10^{23} molecules; (b) M grams
2. The molecular weight of the species expressed in tons.
3. (a) 1 lb-mole, 2 lb_m; (b) 2 lb-moles, 2 lb_m
4. 2000
5. 50 kmol/h

p. 52-a

1. (a) 80/81; (b) 0.5
2. 0.25 lb_m A/lb_m; 0.75 lb_m B/lb_m; 0.333 mole A/mole; 0.667 mole B/mole; 100 lb_m A/min; 100 lb-moles B/min; 400 lb_m/min; 150 lb-moles/min

p. 52-b

1. n/V (mol/L)
2. nM/V (g/L)
3. $(20/C_A)$ (L)
4. $(120 c_A)$ g/h

p. 54

1. $x = 125 \times 10^{-9}$ kg C₆H₅OH/kg liquid (or g/g or lb_m/lb_m)
2. 0.125 mg C₆H₅OH
3. 125×10^{-6} g C₆H₅OH/L. (Solution density \approx 1 kg/L.)

p. 56-a

1. See Figures 3.4-1 and 3.4-2 and Equation 3.4-2.
2. The fluid pressure is higher at the bottom than at the top (hydrostatic head effect). No. Maybe. Yes. (The answers depend on how large the tank is.)
3. No. Convert 1300 mm Hg to (say) dynes/cm², then multiply by 4 cm² to calculate F (dynes).
4. 79 mm Hg

p. 56-b

1. No
2. Pressure relative to a vacuum; pressure relative to atmospheric pressure.
3. 735 mm Hg (absolute); 20 mm Hg of vacuum.
4. 4 in. Hg; 33.9 in. Hg

p. 59

1. See Figure 3.4-3; 0–7000 atm; gauge.
2. See Figure 3.4-4.

3. (a) True; (b) true; (c) false
4. –14 mm Hg

p. 62

1. Immerse in ice–water mixture, mark mercury level as 0°. Immerse in boiling water, mark level as 100°. Divide 0 to 100 interval into 100 equal subintervals, label appropriately.
2. 1°C
3. 1°C

p. 84

1. Semibatch, transient
2. Batch, transient
3. Semibatch, transient
4. (a) Continuous, transient; (b) continuous, steady state

p. 89

3. Steady-state, either no reactions or no net mole change on reaction (e.g., A → B but not A → 2B or A + B → C).
4. Steady-state, A is nonreactive.
5. Steady-state, no density change from inlet to outlet. (Good approximation for liquids and solids, effectively requires no reactions and constant temperature and pressure for gases.)

p. 93

2. $\dot{m}_T = 250(1 - x)/60$
3. $n = (75)(1.595)/(154)$
4. $\dot{m} = 50 + \dot{m}_{dg}; \dot{m}_{co} = 0.25\dot{m}_{dg}; y = 0.75\dot{m}_{dg}/(50 + \dot{m}_{dg})$

p. 95

1. $(\text{atoms})_{in} = (\text{atoms})_{out}$ for each atomic species; multiply all stream amounts by a constant factor; an assumed amount of an input or output stream.
2. (a) Flow rates are 1000, 20,000, and 21,000 (all kmol/h), mole fractions are unchanged.
(b) Flow rates are 200, 100, and 100 (all lb_m/min), mass fractions are unchanged.

p. 98

1. H₂: $(5 \text{ lb}_m)_{in} = (1 \text{ lb}_m + 4 \text{ lb}_m)_{out}$; O₂: $(5 \text{ lb}_m)_{in} = (4 \text{ lb}_m + 1 \text{ lb}_m)_{out}$; total mass: $(10 \text{ lb}_m)_{in} = (10 \text{ lb}_m)_{out}$.
2. Balance on B, solve for \dot{m}_1 ; balance on C, solve for x ; total mass balance, solve for \dot{m}_2 .

p. 117

1. Yes
2. 4

3. $(4 \text{ moles H}_2\text{O produced}) / (6 \text{ moles O}_2 \text{ consumed})$
4. $(400)(6) / (4) = 600$
5. 200 mol/min

p. 119

1. C_2H_4
2. 100%
3. 50 kmol O_2 ; 100 kmol $\text{C}_2\text{H}_4\text{O}$; 50 kmol
4. 50 kmol C_2H_4 ; 75 kmol O_2 ; 50 kmol $\text{C}_2\text{H}_4\text{O}$; 25 kmol
5. 0.80; 0.40; 40 kmol

p. 125

1. 0.90
2. 80%
3. 16 mol B/mol C
4. 80 mol, 10 mol

p. 128

1. Three independent molecular species (C_2H_4 , C_4H_8 , N_2). Two independent atomic species (N and either C or H).
 2. (a) $\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$
(b) $\text{CH}_4 + \frac{3}{2}\text{O}_2 \rightarrow \text{CO} + 2\text{H}_2\text{O}$
(c) $\text{C}_2\text{H}_6 + \frac{7}{2}\text{O}_2 \rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O}$
(d) $\text{C}_2\text{H}_6 + \frac{5}{2}\text{O}_2 \rightarrow 2\text{CO} + 3\text{H}_2\text{O}$
- Since (b) can be obtained as (a) $- \frac{1}{2}[(\text{c}) - (\text{d})]$ (verify), the four equations are not independent.

p. 134

1. 60 mol; 0.60
2. 120 mol; 0.48
3. $40 \text{ mol CH}_4 = 100 \text{ mol CH}_4 - \xi \Rightarrow \xi = 60 \text{ mol}$
 $130 \text{ mol O}_2 = 250 \text{ mol O}_2 - 2\xi \Rightarrow \xi = 60 \text{ mol}$
 $60 \text{ mol CO}_2 = 0 \text{ mol O}_2 + \xi \Rightarrow \xi = 60 \text{ mol}$
4. Four molecular species balances (CH_4 , O_2 , CO_2 , H_2O). Three atomic species balances (C, H, O).
5. (b) I = O. $(250)(2) \text{ mol O in} = [(130)(2) + (60)(2) + (120)(1)] \text{ mol O out}$
(c) I = O + C. $250 \text{ mol O}_2 \text{ in} = 130 \text{ mol O}_2 \text{ out} + 120 \text{ mol O}_2 \text{ consumed}$
(d) G = O. $120 \text{ mol H}_2\text{O generated} = 120 \text{ mol H}_2\text{O out}$
(e) I = O. $(100)(4) \text{ mol H in} = [(40)(4) + (120)(2)] \text{ mol H out}$

p. 135

1. Overall $= 100/110 = 0.909 \text{ mol A consumed/mol A fed}$; single pass $= 100/200 = 0.500 \text{ mol A consumed/mol A fed}$.

p. 138

1. Overall conversion $= 0.833$ (83.3%), single-pass conversion $= 0.25$ (25%).

2. Customers want B, not a mixture that contains mostly A. Makes no sense to pay for 200 mol of A (fresh feed) and then discard 140 mol of it.
3. C would keep building up in the system. Take off a purge stream from the recycle.
4. The cost of the reactor that would be required to achieve an 83.3% conversion in a single pass could be much greater than the cost of the separation and recycle equipment.

p. 145

1. 21% O_2 , 79% N_2 ; $79/21 = 3.76 \text{ moles N}_2/\text{mole O}_2$
2. 25% H_2 , 25% O_2 , 50% H_2O ; 50% H_2 , 50% O_2
3. 20; 0.95; $5/95 = 0.0526$

p. 146

1. 200 mol O_2/h
2. 200 mol O_2/h
3. $(4.76 \times 200) \text{ mol air/h}$
4. $(2 \times 4.76 \times 200) \text{ mol air/h}$
5. 50%

p. 190

1. $255 \text{ cm}^3/\text{s}$. If T is raised, mass flow rate remains constant but volumetric flow rate increases slightly. Look up the density of liquid water at 75°C and divide it into 200 g/s.
2. $P_h = \rho gh$, and ρ_{H_2} varies with temperature. The difference would be extremely slight.

$$3. V_{\text{tot}} = \frac{m_1}{\rho_1} + \frac{m_2}{\rho_2} + \dots + \frac{m_n}{\rho_n}; \\ \frac{1}{\rho} = \frac{V_{\text{tot}}}{m_{\text{tot}}} = \frac{m_1}{m_{\text{tot}}\rho_1} + \frac{m_2}{m_{\text{tot}}\rho_2} + \dots = \frac{x_1}{\rho_1} + \frac{x_2}{\rho_2} + \dots$$

p. 193

1. A relation between absolute pressure, specific volume, and absolute temperature of a substance. $P\hat{V} = RT$. High T , low P .
2. (c), (e). The mass and mass density of CO_2 are each greater by a factor $(\text{MW}_{\text{CO}_2}/\text{MW}_{\text{H}_2}) = 22$.
3. (a) and (c).

$$\dot{V} = \frac{\dot{n}RT}{P} = \frac{\dot{m}}{MW} \frac{RT}{P}$$

Let E denote ethylene and B denote butene. $MW_B = 2MW_E \Rightarrow \dot{V}_E = 2\dot{V}_B$.
 $\hat{V} = RT/P$, which is the same for B and E.
Mass density: $\rho = \dot{m}/\dot{V} = (MW)P/RT \Rightarrow \rho_B = 2\rho_E$
4. $RT/P = [0.08206 \text{ L}\cdot\text{atm}/(\text{mol}\cdot\text{K})](200 \text{ K})/(20 \text{ atm}) = 0.8206 \text{ L/mol} < 5 \text{ L/mol}$. From Equation 5.2-3, the error is likely to be greater than 1%.

p. 196

1. See Table 5.2-1.
2. $V_{\text{new}} = V_{\text{old}}/2$; $V_{\text{new}} = 2V_{\text{old}}$

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3. Decreases (n is unchanged, V increases); nothing

4. (a)

p. 197

1. (b), (d)

2. 5 bar; 50 m³; p_{H_2} increases, v_{H_2} is unchanged.

3. Greater than

p. 200

1. Vapor

2. (a) $P_a < P_b$; (b) $\rho_{va} ? \rho_{vb}$; (c) $\rho_{la} > \rho_{lb}$

3. Gas. Supercritical fluid.

p. 206

1. The equation to determine \hat{V} for given values of T and P is a cubic equation.

2. Critical temperature and pressure (Table B.1), Pitzer acentric factor (Table 5.3-1).

3. (b), (a), (c)

p. 210

1. No; $T_r = (-190)/(T_c + 8)$, $P_r = 300/(P_c + 8)$, look up z on charts, calculate $V = znRT/P$.

2. Need a different chart for each species.

3. See p. 207.

p. 212

See Example 5.3-4. Nonpolar compounds with similar critical properties.

p. 238

1. Distillation. The naphthas come off from the top of the column, the lubricating oils from the bottom, and the heating oils from the middle.

2. Evaporation, filtration, centrifugation

3. Evaporation, reverse osmosis (membrane filtration at high pressure)

4. Condensation, absorption; 5. Adsorption.

p. 243

1. -5°C, 3 mm Hg

2. -56.6°C, 5.112 atm

3. All CO₂ solidifies at 1 atm, solid melts at 9.9 atm, and -56°C, liquid boils at 9.9 atm and -40°C.

4. 1 atm; 9.9 atm

5. -78.5°C; -56°C, -40°C; 6. No

p. 246

1. Cox chart (Figure 6.1-4); Antoine equation (Equation 6.1-4)

2. Plot p^* versus $1/T_{\text{absolute}}$ on semilog paper, draw line through points, and extrapolate to $1/T_4$.

3. The plot is more likely to be linear on the Cox chart.

p. 249

1. Eq. 6.2-1

2. (a) 2; (b) 2; (c) 4; (d) 3

p. 253

1. Yes; yes.

2. 200 mm Hg; 760 mm Hg; 200/960; look up or calculate the temperature at which $p_{\text{acetone}}^* = 960$ mm Hg.

3. (a) The temperature to which a gas must be cooled before any constituent condenses; superheated, saturated.

(b) $y_{\text{H}_2\text{O}} = p_{\text{H}_2\text{O}}^*(T_0)/P_0$ (i) nothing; (ii) condense; (iii) condense; (iv) nothing

(c) $p_{\text{H}_2\text{O}}^*(T_{\text{dp}}) = y_{\text{H}_2\text{O}}P_0$. Look up the temperature at which the vapor pressure is $p_{\text{H}_2\text{O}}^*$.

(d) $T_{\text{dp}} = T_0 - T_{\text{sh}}$; $y_{\text{H}_2\text{O}} = p_{\text{H}_2\text{O}}^*(T_{\text{dp}})/P_0$.

p. 254

1. 82°C

2. 50%

3. $s_m = 0.111$, $s_p = 44.4\%$

p. 258

1. Raoult's law: $p_A = x_A p_A^*$, where x_A is the mole fraction of A in the liquid phase; most likely to be valid as $x_A \rightarrow 1.0$.

2. Henry's law: $p_A = x_A H_A$; most likely to be valid when $x_A \rightarrow 0$.

3. A solution for which either Raoult's law or Henry's law is obeyed for all species at all solution compositions.

4. Henry's law for x_{CO_2} and p_{CO_2} , Raoult's law for $x_{\text{H}_2\text{O}}$ and $p_{\text{H}_2\text{O}}$. Look up Henry's law constant for CO₂ (*Perry's Chemical Engineers' Handbook*, 7th Edition, p. 2-125) and vapor pressure of H₂O (Table B.3 of this book).

p. 264

1. The temperature at which the first bubble of vapor forms if the liquid is heated at the given pressure. The temperature at which the first drop of liquid forms if the vapor mixture is cooled at the given pressure.

2. 92°C; 0.70 mol benzene/mol (from Figure 6.4-1a)

3. 99°C; 0.30 mol benzene/mol (from Figure 6.4-1a); decreases

4. Increase (see Equation 6.4-4); increase (see Equation 6.4-6)

5. The hydrostatic head of the liquid must be added to the pressure at the liquid surface. Convert 5 ft of water to atm,

add it to 1 atm, and look up the boiling point of water at the corrected pressure.

6. The nonlinear equations cannot be solved explicitly for I .

p. 268

1. 380 g. The added salt will not remain undissolved.
2. 55°C. Increasing quantities of KNO_3 crystals precipitate (come out of solution).
3. See p. 267. Magnesium sulfate tetrahydrate.
4. $120.4/138.4 = 0.870$
5. Above 40°C the crystals that precipitate are hydrated salts.

p. 270

1. A solution property that depends only on concentration, and not what the solute and solvent are. Vapor pressure, boiling point, and freezing point.
2. 850 mm Hg. Solute is nonvolatile, nondissociative, and nonreactive with the solvent; Raoult's law holds.
3. Greater. $p^* = (1000 \text{ mm Hg})/0.85 = 1176 \text{ mm Hg}$.
4. It lowers the freezing point of water, so it keeps ice from forming at temperatures where it would otherwise form.
5. Antifreeze lowers the freezing point and raises the boiling point of water, so the radiator is less likely to freeze in winter and to boil in summer.

p. 273

1. See definition at bottom of p. 271. Extraction is transferrence of a solute from one liquid solvent to another.
2. Less soluble; $m_{\text{VA}} \gg m_{\text{W}}$

p. 274

1. A tie line connects compositions of two phases in equilibrium.
2. H_2O -rich phase—95.0% H_2O , 2.5% acetone, 2.5% MIBK; MIBK-rich phase—92.5% MIBK, 2.5% H_2O , 5.0% acetone. Mass ratio of MIBK phase to H_2O phase = $\frac{0.950 - 0.450}{0.450 - 0.025} = 1.18$.

p. 278

1. In absorption a gas species dissolves in a liquid; in adsorption a gas or liquid species adheres to the surface of a solid.
2. An adsorbate is a species adhering to the surface of a solid adsorbent.
3. Concentration equals partial pressure times a constant (and vice versa).
4. Toxic species in the air are adsorbed on the surface of the carbon. Nonactivated carbon has much less surface area so the mask would become saturated in much less time.

p. 316

1. Kinetic, potential, internal; heat, work
2. Heat is only defined in terms of energy being transferred.
3. $E_i + Q - W = E_f$

p. 318

1. The mass flow rates are the same; $\rho_{\text{outlet}} < \rho_{\text{inlet}}$; $V_{\text{outlet}} > V_{\text{inlet}}$.
2. $\Delta E_p > 0, \Delta E_k > 0$

p. 319

1. Closed system: no mass crosses system boundaries.
Open system: mass crosses system boundaries.
Adiabatic system: no heat transferred to or from system.
2. $Q = 250 \text{ J}$
 $W = -250 \text{ J}$
3. $\Delta U = -50 \text{ kcal}$
4. If the substance is a liquid or a solid, or a gas under nearly ideal conditions, it is reasonable to neglect the dependence of U on pressure.

p. 321

1. $\dot{V}_{\text{in}} = \dot{V}_{\text{out}}$
2. $P_{\text{in}} > P_{\text{out}}$

p. 322

1. 6000 cal
2. 1000 cal/min
3. The specific volume and pressure: $\hat{H} = \hat{U} + P\hat{V}$

p. 324

1. $\dot{W}_s = 0$
2. $\dot{Q} = 0$
3. $\Delta \dot{E}_k = 0$
4. $\Delta \dot{E}_p = 0$

p. 327

1. A property whose change of value in any process depends only on its initial and final states and not on the path between them.
2. (a) 0;
(b) 5000 J/kg;
(c) $\Delta \hat{H} = \hat{H}_A(v, 0^\circ\text{C}, 1 \text{ atm}) - \hat{H}_A(v, 30^\circ\text{C}, 1 \text{ atm})$
 $= (5000 \text{ J/kg} - 7500 \text{ J/kg}) = -2500 \text{ J/kg}$
(e) No— \hat{H} is a state property.

p. 337

1. Incompressible fluid, negligible heat transfer, and no internal energy changes due to anything but friction.
2. Above, plus no friction or shaft work.

p. 359

$$\hat{H} = -2751 \text{ kJ/kg}, \hat{U} = -2489 \text{ kJ/kg}.$$

p. 361

2. Lower P isothermally to 1 atm, cool at 1 atm to 80.7°C, condense at 80.7°C and 1 atm, cool liquid at 1 atm to 25°C, raise pressure to 5 atm.
3. Keeping pressure constant at 1 atm, cool water to 25°C, dissolve NaOH in water at 25°C, raise solution to 50°C.
4. Keeping pressure constant at 1 atm, cool O₂ to 25°C, mix O₂ and CH₄ at 25°C, carry out reaction at 25°C, raise product gas to 300°C.

p. 366

1. **(a)** ii; **(b)** i; **(c)** iii
2. Determine z for C₂H₆ at each of the system conditions. If z is close to 1 for both states, it may be reasonable to neglect $\Delta\hat{H}$.

p. 368

1. $C_v = (\partial\hat{U}/\partial T)_v, C_p = (\partial\hat{H}/\partial T)_p$
2. **(a)** exact;
(b) inaccurate;
(c) good approximation
3. $\Delta H = (5 \text{ g})[0.5 \text{ cal/(g}\cdot\text{C)}](20^\circ\text{C}) = 50 \text{ cal}$

p. 371

1. 28.5 J/(mol·°C)
2. 5 cal/(mol·°C); 7 cal/(mol·°C)
3. **(a)** 22.44 kJ/mol;
(b) -25.78 kJ/mol;
(c) $-2.22 \times 10^5 \text{ Btu/h}$ (Neglect pressure effects.)

p. 373

1. CaCO₃(s): $C_p = 26 + 7.5 + 3(17) = 84.5 \text{ J/(mol}\cdot\text{C)}$
2. $\Delta H = \{(2 \text{ kg})[2.5 \text{ kJ/(kg}\cdot\text{C)}] + (1 \text{ kg})(1.8 \text{ kJ/(kg}\cdot\text{C)})\}(10^\circ\text{C}) = 68 \text{ kJ}$
 $\Delta\hat{H} = 68 \text{ kJ}/3 \text{ kg} = 23 \text{ kJ/kg}$
3. $\Delta\hat{H} = 25 \text{ cal/g}$
4. $(C_p)_{\text{mixture}} = [(0.50)(1.00) + (0.50)(0.54)] \text{ cal/g} = 0.77 \text{ cal/g}$

p. 381

1. Yes; no
2. **(a)** 0; **(b)** 900 J/mol
(c) Cool the vapor to 75°C; condense at 75°C; cool the liquid to 25°C.
3. $\Delta\hat{U}_f \approx 5500 \text{ cal/mol}$
 $\Delta U_v = \Delta\hat{H}_v - RT = 26,710 \text{ cal/mol}$

p. 382

1. Equation 8.4-3
2. Equation 8.4-4
3. From Equation 8.4-6, slope of line is $-\Delta\hat{H}_v/R$.
4. From Equation 8.4-7, slope of tangent to curve at $p^* = 1 \text{ atm}$ is $-\Delta\hat{H}_v/R$.
5. Equation 8.4-8
6. $\Delta\hat{H}_v(T_2) = \int_{T_2}^{T_1} C_{pl} dT + \Delta\hat{H}_v(T_1) + \int_{T_1}^{T_2} C_{pv} dT$

p. 392

Air at 25°C, $h_r = 20\% \implies h_a = 0.0040 \text{ kg H}_2\text{O/kg dry air}; T_{wb} = 12.5^\circ\text{C}; T_{dp} = 0.5^\circ\text{C}; \hat{V}_H = 0.85 \text{ m}^3/\text{kg dry air}, \hat{H} = (35.00 - 0.27) \text{ kJ/kg dry air} = 34.73 \text{ kJ/kg dry air}$

p. 395

1. **(a)** $(C_p)_{\text{gas}}, (C_p)_{\text{liquid}}$, and $(\Delta\hat{H}_v)_{\text{liquid}}$ are independent of temperature, and the enthalpy change of unevaporated liquid is small compared to the heat of vaporization and the enthalpy of the gas.

(b) Yes; **(c)** no

2. $T_{as} = 11^\circ\text{C}; h_a = 0.0069 \text{ kg H}_2\text{O/kg dry air}; h_r = 70\%; \hat{H} = (31.60 - 0.06) \text{ kJ/kg dry air} = 31.54 \text{ kJ/kg dry air}$

p. 397

1. **(a)** $\hat{H} = -40 \text{ kJ/mol A}; \mathbf{(b)} \hat{H} = 20 \text{ kJ/mol A}$
2. $Q = \Delta H = (5)(-40) \text{ kJ} = -200 \text{ kJ}$ (evolved)
3. $Q = 5(-60 + 40) \text{ kJ} = -100 \text{ kJ}$ (evolved)

p. 402

1. -97 Btu/lb_m solution
2. 77°F (the reference temperature for H₂SO₄)
3. 190°F. 65 wt% H₂SO₄. (Highest temperature on a line between the feed points.)
4. **(a)** -60 Btu/lb_m solution. **(b)** 30 Btu/lb_m solution. The heat of solution at 77°F (or the energy required to heat the solution from 77°F to its adiabatic mixing temperature of about 195°F).

p. 406

1. 130°F, 0.15
2. 600 Btu/lb_m
3. Vapor fraction $\approx (0.50 - 0.18)/(0.88 - 0.18) = 0.46$

p. 441

2. The second sentence is wrong and the first sentence is correct, but only if the reactants and products are at the same temperature. The energy released by the breaking of reactant bonds and forming of product bonds must be transferred from the reactor to keep the products at the

same temperature; otherwise it remains in the reactor and raises the product temperature. If the reactor is adiabatic, the products at the higher temperature would be at the *same* energy level as the reactants at the lower temperature.

p. 445

- $H_{\text{products}} - H_{\text{reactants}}$ when stoichiometric quantities of reactants are fed, the reaction proceeds to completion, and reactants and products are at the same temperature and pressure. As above, with reactants and products at 25°C and 1 atm.
- (a) -20 kJ/mol A reacted; (b) exothermic; (c) withdrawn; (d) higher
- The latent heat of vaporization of C₆H₁₄ at 25°C and 1 atm
- $\Delta\hat{U}_r(T) = \Delta\hat{H}_r(T) + 2RT$

$$\Delta\hat{H}_r = \sum_{\text{products}} |v_i|\hat{H}_i - \sum_{\text{reactants}} |v_i|\hat{H}_i$$

In general, $\hat{H}_i = \hat{U}_i + PV_i$; for liquids and solids, $\hat{H}_i \approx \hat{U}_i$; and for ideal gases, $PV_i = RT$, so that $\hat{H}_i = \hat{U}_i + RT$. To obtain the desired result, substitute for \hat{H}_i in the expression for $\Delta\hat{H}_r$, and recognize that

$$\Delta\hat{U}_r = \sum_{\text{products}} |v_i|\hat{U}_i - \sum_{\text{reactants}} |v_i|\hat{U}_i$$

p. 447

- See last paragraph of Section 9.2.
- Multiply Equation 2 by -2 and add the result to Equation 1



p. 448

- The formation reaction of CO is C + $\frac{1}{2}\text{O}_2 \rightarrow \text{CO}$, so the heat of formation is $-\frac{1}{2}$ times the heat of the given reaction, or -110.5 kJ/mol. (This checks with the value in Table B.1.)
- The heat of vaporization of propane at 25°C.

$$3. \Delta\hat{H}_r^\circ = (\Delta\hat{H}_f^\circ)_{\text{CO}_2} + 2(\Delta\hat{H}_f^\circ)_{\text{H}_2\text{O}(v)} - (\Delta\hat{H}_f^\circ)_{\text{CH}_4}$$

p. 464

- (a) $\Delta\hat{H}_f^\circ(\text{soln}, n = 50) = (\Delta H_f)_A - 100 - 10 = -110 \text{ kJ/mol A}$
(b) $\Delta\hat{H}_f^\circ(\text{soln}, n = \infty) = -115 \text{ kJ/mol A}$
- (a) $\hat{H}(25^\circ\text{C}) = -110 \text{ kJ/mol A}$
(b) $H(25^\circ\text{C}) = -550 \text{ kJ}$

p. 466

- $LHV = 2658 \text{ kJ/mol}$
 $HHV = 2658 \text{ kJ/mol} + 5(44.013 \text{ kJ/mol}) = 2878 \text{ kJ/mol}$

$$2. HHV = (0.40)(143 \text{ kJ/g}) + (0.60)(55 \text{ kJ/g}) = 90.2 \text{ kJ/g}$$

- For coal:

$$(\$150/\text{ton})(1 \text{ lb}_m/15,000 \text{ Btu})(1 \text{ ton}/2000 \text{ lb}_m) = 5.0 \times 10^{-6} \text{ \$/Btu}$$

For natural gas:

$$x(\$/\text{ton})(1 \text{ ton}/2000 \text{ lb}_m)(1 \text{ lb}_m/23,000 \text{ Btu}) = 5.0 \times 10^{-6} \text{ \$/Btu}$$



$$x = \$230/\text{ton}$$

p. 469

- The product temperature when the fuel is burned completely in an adiabatic reactor.
- Heat loss through reactor walls, incomplete reaction.
- With an air feed, the heat released from combustion of a fixed amount (say, 1 mol) of fuel goes into heating the nitrogen in the air as well as the reaction products and excess oxygen, whereas only the latter must be heated for a pure O₂ feed. If a fixed quantity of heat is added to a greater amount of material, the resulting temperature rise must be less.

p. 471

- (a) Ignition—abrupt increase in the rate of an oxidation reaction.
(b) Ignition temperature—the temperature at which ignition occurs when a combustible mixture is heated slowly.
(c) Ignition lag—time between a mixture reaching its ignition temperature and the occurrence of ignition.
(d) Flammability limits—composition limits outside of which ignition or explosion cannot occur.
(e) Flash point of a liquid—temperature at which a liquid gives off enough vapor to form an ignitable mixture with the air above the liquid surface.
- (a) An explosion or ignition; no reaction would occur.
(b) Yes; the reaction would cease.
(c) There is a region between the emerging jet (pure methane) and the bulk of the room air (almost no methane) within which the methane fraction falls between the flammability limits. The flame persists in this region.

p. 473

- A flame is a combustion zone in which various species undergo transitions from states of high energy to states of lower energy. The energy lost in the transitions is given off as visible light.
- In low-temperature flames, which occur when the fuel and oxygen are not well mixed, carbon particles are formed

and remain unburned, but the heat in the reaction zone raises them to a temperature at which they glow incandescently. The result is a yellow flame. At higher combustion temperatures, various intermediate species are formed and excited to high-energy states, and emit blue light as they return to lower states. The result is a blue flame.

3. In a detonation, a pressure front (shock wave) forms and propagates at supersonic speed, rapidly compressing and igniting the flammable mixture and giving the appearance of an instantaneous combustion. In the vicinity of the detonation, the force of the shock wave can demolish a building or propel a bullet. The noise is the vibration of the eardrums caused by the shock wave.
4. The rate of the reaction depends strongly on temperature; at room temperature it is immeasurably low.

p. 507

1. **(a)** 1; **(b)** x_1
2. Ten variables (flows of A, B, C, and D at inlet, A, B, and C in vapor product, and B, C, and D in liquid product) – 4 balances (A, B, C, and D) – 2 relations (given split of B, equilibrium relation for C) = 4 degrees of freedom.

p. 510

1. Mixer—3, separator—4
2. 5 degrees of freedom (7 local degrees of freedom – 2 ties)

p. 548

1. **(a)** Accumulation, input, output (although the mass balance will yield the result that accumulation = 0);
(b) all but generation;
(c) accumulation, output, consumption
2. $dm/dt = 10 \text{ kg/h} - 10 \text{ kg/h} = 0 \text{ kg/h}$

p. 551

1. $dy = (2-t)dt \implies \int_1^y dy = \int_0^t (2-t)dt$
 $\implies y = 1 + 2t - \frac{t^2}{2}$

2. $\frac{dy}{2-y} = dt \implies \int_1^y \frac{dy}{2-y} = \int_0^t dt$
 $\implies -\ln(2-y)]_1^y = t$

$$\begin{aligned}\implies \ln\left(\frac{1}{2-y}\right) &= t \\ \implies \left(\frac{1}{2-y}\right) &= e^t \\ \implies y &= 2 - e^{-t}\end{aligned}$$

3. $\frac{dy}{2-y} = (2-t)dt \implies \int_1^y \frac{dy}{2-y} = \int_0^t (2-t)dt$
 $\implies -\ln(2-y)]_1^y = 2t - \frac{t^2}{2}$
 $\implies \ln\left(\frac{1}{2-y}\right) = 2t - \frac{t^2}{2}$
 $\implies \left(\frac{1}{2-y}\right) = \exp\left(2t - \frac{t^2}{2}\right)$
 $\implies y = 2 - \exp\left(-2t + \frac{t^2}{2}\right)$

p. 560

1. Neglect changes in \dot{E}_k and \dot{E}_p ; no mass accumulation; \hat{U} and \hat{H} independent of P ; no phase changes or chemical reactions; no spatial variations in T ; constant C_v and C_p .
2. When the expression for U_{sys} is differentiated to yield Equation 11.3-9, if C_v varies with temperature (and hence with time) another term of the form $M(T_{\text{sys}} - T_r)(dC_v/dt)$ would have to be added.

p. 609

1. –1, +2
2. The line for which the sum of the squares of the residuals is a minimum.
3. Yes. (Corollary—no.)
4. Positive and negative deviations from the line would cancel out, possibly making a terrible fit look good.

p. 611

1. Linear
2. Nonlinear
3. Nonlinear
4. **(a)** Linear; **(b)** nonlinear
5. **(a)** Linear (multiply equation by z); **(b)** nonlinear;
(c) linear

p. 612

1. A straight line on a plot of f versus x can only intersect the x axis at one point.
2. One root. (The intersection of a 45° line through the origin with a curve that begins at 1 when $x = 0$ and decreases, approaching 0 as x approaches infinity.)

p. 613

1. **(a)** $x = 4$ and $x = 0$; **(b)** $x_p = 15/4$; $x_n = 5$. Converge to $x = 4$.
2. The equation for a line on an f versus x plot through (x_n, f_n) and (x_p, f_p) is $f = f_n + [(f_p - f_n)/(x_p - x_n)](x - x_n)$. The intercept of this line on the x axis, which we will call x_{new} , is obtained by setting $f = 0$

and solving the resulting equation for x . The result is Equation A.2-1.

p. 615

1. Yes. No. You can solve for the roots directly.
2. The value of $f'(x_0)$ would be 0, and the correction term f/f' would blow up.

p. 617

1. **(a)** Modified successive substitution; **(b)** successive substitution; **(c)** acceleration
2. 13.6

p. 618

1. 2.60
2. A line on an f versus x plot through $(2, 2.3)$ and $(2.3, 2.45)$ intersects the 45° line at $x = 2.60$.

p. 626

1. 80
2. 84
3. 80. The function is cubic, so Simpson's rule is exact.

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ANSWERS TO SELECTED PROBLEMS

CHAPTER TWO

2. (c) 120 hp
6. 4.3×10^5 miles
8. (b) 2.6 kg
10. 25 m³
14. (b) 0.135 m/s²
18. (a) $s_T = 2.3^\circ\text{C}$
20. (a) $s_X = 2.2$
24. (a) 88.8 cm/s (or 0.888 m/s)
26. (b) 1.13 g/cm³
28. (b) $t(C = 0.1 \text{ mol/L}) = 1.12 \text{ min (extrapolated)}, 1.70 \text{ min (exact)}$
30. (d) $xy = 2e^{3y/x}$
32. (b) 109 kg/h
34. (a) $k = 9.3 \times 10^{-3} \text{ min}^{-1}$
36. $k = 1.573$ (dimensionless). Answer may vary slightly.
38. (b) Runs 1, 2, 3, 4 $\Rightarrow b = 0.52$. Answer may vary slightly.
40. (c) $t = 209.5 \text{ h}$
42. (b) For Lab 1, $k = 0.0062 \text{ s}^{-1}$
44. $a = 6.536$

CHAPTER THREE

2. (b) 360 lb_m/ft³
4. \$68.42 in France
6. (a) 445 L
8. (SG)_{solution} = 1.5
10. (b) $1.00 \times 10^3 \text{ N}$
12. (b) 4.6 kg Ile/h
14. (f) $1.08 \times 10^6 \text{ g C}$
16. (b) 8715 lb_m/h
18. 0.300 g CaCO₃/g suspension
20. (c) $3.84 \times 10^{-5} \text{ kg CaSO}_4$
22. (a) SG = 0.903
24. 0.917 g/cm³
26. (a) Sample 1: 15.6 mole% CH₄, 6.2 wt% CH₄
28. (c) 87.7 s
30. 0.155 g
32. (e) 0.737 atm
36. $P = 32.9 \text{ psi}$
38. (b) $F_{\min} = 2.0 \times 10^5 \text{ N}$
40. $P_{\text{atm}} = 775 \text{ mm Hg}$

42. (a) $h = 400 \text{ cm} \Rightarrow R_{\text{water}} = 646 \text{ cm}$
44. (b) 6.54 psig
46. (a) 393 mm Hg
48. (c) 153°F
50. (b) 3.26°C/s
52. (b) 2.6 lb_m CO
54. At 94°C, $k = 0.707 \text{ L/(mol} \cdot \text{min)}$

CHAPTER FOUR

4. (d) $x_{O_2} = 0.21 n_2/(n_1 + n_2)$
6. (b) Two unknowns must be specified
8. (c) .22 (22%) of the large eggs are broken
10. 207 gal.
12. (b) $5.80 \times 10^3 \text{ mol CH}_3\text{OH/h}$
14. (a) 6480 lb-moles/h
16. (b) 2.96 L 20% solution/L 60% solution
18. (b) $\$8.8 \times 10^7/\text{year}$
20. (a) $1.2 \times 10^{-3} \text{ mol H}_2\text{O(v)/mol}$
22. (c) $x_P = 0.20, m_P = 100.0 \Rightarrow n_A = 3.29, n_B = 1.10$
24. (b) velocity = 8.33 m/s
26. (c) 423 kg SO₂/min removed from feed gas
28. 3 balances on overall system, 2 on Unit 1
30. (c) 39.8% salt in the effluent from the 4th evaporator
32. (b) 28.6 kg of 42% concentrate
34. (b) Recycle ratio = 1.60
36. (b) 9.71 kg C₆H₁₄ recycled/kg C₆H₁₄ fed
38. (c) 3796 kg steam fed to stripper
40. (c) 17.6% excess NH₃
42. $\dot{\xi} = 56.2 \text{ mol/s}$
44. 7380 kg 80% H₂SO₄
46. (b) $X_A = X_B = 0.688$
48. (c) $X_{CO} = 0.156$
50. (c) Fractional yield of C₂H₅Cl = 0.875
52. 1533 kg ore
54. For the 1st feed mixture, $y_A = 0.2027, y_E = 0.0393$
56. (b) CH₃OH enters the reactor at the rate of 50.0 kmol/h
58. (c) 85.9 kmol/h recycle
60. (a) S.P. Conversion = 14%
62. (b) $2.535 \times 10^4 \text{ kmol/h } n\text{-C}_4\text{H}_{10}$ in emulsion recycle, 2220 kmol H₂SO₄/h and 1200 kmol H₂O/h in acid recycle, 1040 kmol i-C₄H₁₀/h recycled from distillation column

666 Answers to Selected Problems

64. (b) 66.5 kmol/h
66. 250 kmol/h
68. (b-iii) 9.1 mole% CO₂
70. (c) 18.6% excess air
72. (a) Desired percent excess air = 11%
74. 10.7% CO₂, 9.8% H₂O
76. (b) 3.72×10^5 mol air/tonne coal
78. 30% bypass
80. (b) Minimum percent excess air = 117%.

CHAPTER FIVE

2. Bulk density = 3.26 g/cm³
4. (c) 35.4 kg CuSO₄ (anhydrous)
6. (b) 9.3% error
8. (b) 555
10. 165 m/s
12. Unknown MW = 3.9
14. (a) 880 cm³/s
16. 71.2%
18. 1.52
20. (c) 58.5 g/L
22. (a) y_B (9 am) = 0.62×10^{-6}
24. (b) \$1,747,000/month
26. (b) 3595 mol diluting air/s
28. (b) 3.3 cm H₂O
30. 4.0×10^4 m³(STP) air/h
32. (a) 346 kPa
34. (c) 1.2×10^5 Å
36. (b) $x = 0.5 \Rightarrow V = 2.16 \times 10^4$ L
38. (b) 71% conversion of propylene
40. (b) 196 kg acetone vaporized/h
42. 0.150 mol Cl₂/mol
44. 1.8% Fe₂O₃
46. (a) 4.08×10^5 L gas/min leaves the condenser
48. (b) $f_{SO_2} = 0.367$ at 600°C
50. 846 SCMH recycled
52. 25.7 mole% CO₂, 6.5% CO, ...
54. (a) Reactor effluent (C): 49.4 kmol/h, 26% H₂, 53% CH₃OH, 0.03% H₂O
56. 135 m³/h
58. $P_{SRK} = 7.3$ atm
60. 1.57×10^4 L/h
62. (b) 37.4 lb_m
64. (b) $z = 1.6$
66. 320°F

68. 74.3 mol
70. (b) $P > 2.1 \times 10^4$ atm (c) 5 cycles
72. (b) 34,900 gallons
74. 0.041 m³
76. 126 ft³/min
78. (b) 29.9 m³/h
80. 1.63 kmol/min
82. (b) C₁₁H₂₀O₁₀

CHAPTER SIX

2. (b) 0.235 g vapor/g total
4. 58.8 kJ/mol
6. $T_b = 116^\circ\text{C}$
8. 8.0×10^{-4} mol
10. (b) 6.85°C
12. (b) 99.7% condensation
14. At 70°F and 50% r.h., $\rho_{air} = 1.196$ g/L
16. 5.04×10^4 ft³/min
18. 0.310 m³ outlet air/m³ feed air
20. (c) 0.479 lb-mole octane lost
22. (c) 2.52°C
24. (b) 29°C
26. (b) 96% recovery if the refrigerant is used
28. 1.81 gal. condensed/min
30. (b) Cool to 7.8°C
32. (a) 0.0148 kmol CH₃OH/min
34. $\dot{V}_{in} = 2.09 \times 10^5$ ft³/h
36. (b) $\dot{V}_{inlet} = 2590$ ft³/h
38. $T_{dp} = 58.8^\circ\text{C}$
40. (b) $x = 0.00536$ mol C₃H₈/mol
42. (a) 1097 mol leave converter, 15.5% H₂O
44. (b) 8.33×10^{-2} m³ gas feed/kg liquid feed
46. 0.0711 mol benzene/mol
48. $x_{CH_4} = 1.46 \times 10^{-4}$ mol CH₄/mol
50. (c) 127 cm³
52. 85.85°C
54. (a) $P = 76$ psig
56. (a) 0.096 mol C₆H₆/min
58. (b) 22.6% benzene $\Rightarrow T_{bp} = 108.1^\circ\text{C}$
60. (d) 0.39 m
62. (d) $x_B = 0.400 \Rightarrow y_B = 0.795$, $P = 444$ mm Hg
66. (c) 0.46 mol vapor/mol liquid
68. (d) 64.5°C
70. 79.9°C

72. (c) 0.19 lb-mole H₂O/lb-mole
 74. 32.3%
 76. (c) 23.0 kg A
 78. 0.428 lb_m crystals/lb_m liquid
 80. 2044 kg/h recycled
 82. (c) 64 lb_m recycle/lb_m fresh feed
 84. $T_m = 1.9^\circ\text{C}$
 86. 83.5 g/mol, 6.38 kJ/mol
 88. 4.4 g styrene in ethylene glycol phase
 90. (a) The extraction requires 13,000 kg of hexane
 92. (b) 0.2965 kg alkaline solution/kg acidified broth
 94. Water-rich phase: 21% acetone, 3% MIBK, 76% water (answers may vary)
 96. (c) For System 2, $\beta_{aw} = 41.8$ (answers may vary)
 98. (a) 33.1 grams of silica gel
 100. (b) 1.13 hours (68 minutes)

CHAPTER SEVEN

2. (b) 3000 MW
 4. (a) $\dot{E}_k = 1.40 \times 10^{-5}$ hp
 6. (b) $u = 25.4$ ft/s
 8. $\dot{E}_{\max} = 3.43 \times 10^6$ kW · h/wk
 10. (b) $Q = -765$ J
 12. 2338 J/mol
 14. 9.0×10^3 cal
 16. (a) (i) 941 cm³, (ii) 19.5 J, (iii) 64.3 J
 18. (c) $\Delta\dot{E}_p = -\dot{W}_s, \dot{W}_s > 0$
 20. (a) 246 L/s
 22. 477 m/s
 24. (a) 6.02×10^7 J/s
 26. 5.80×10^4 kW
 28. (b) 1.27 m³ steam/s
 30. (a) 300 kJ/h
 32. (b) 1.8 kW
 34. (a) Every 13 seconds
 36. (a) 0.296 evaporates
 38. (b) 2920 kJ/s
 40. 587 kJ/h
 42. (a) 1.82×10^4 cal
 44. (c) 5.70×10^4 kJ
 46. 38 g
 48. (a) 0.53 g evaporated
 50. 2.6 g evaporated
 52. (a) 0.894 m/s
 54. (a) 122 L/min

56. 76.2 m³/min
 58. 0.62 kW

CHAPTER EIGHT

2. (c) $\Delta\hat{U} = 2160$ J/mol
 4. (d) 31.71 kJ/mol
 6. (c) -110.7 kJ/mol
 8. 7193 kW
 10. (b) $C_p \approx 0.223$ kJ/(mol · K)
 12. (c) Total daily cost = \$4.72
 14. (a) -2156 kW
 16. 1833 Btu/h
 18. -0.07643 kJ/g
 20. 1810 m²
 22. (c) 3.41 m³/s
 24. (c) 0.400 m³ steam/m³ propane
 26. (b) Relative humidity = 79.7%
 28. 1.39×10^6 J/day
 30. (b) 290 kW
 32. (a) 792°C
 34. $\Delta\hat{H}_{\text{analytical}} = -1730$ cal/g
 36. (c) 60.12 kJ/mol
 38. -1.90×10^4 kW
 40. (a) 1.95×10^5 kJ/h
 42. $\Delta\hat{H}_v(100^\circ\text{C}) \approx 38.2$ kJ/mol
 44. (c) 33.4 kJ/mol
 46. (d) -181 kJ/m³ air fed
 48. 733 kW
 50. (b) 257 kW
 52. (a) 2.42×10^4 kW
 54. (d) $T_{f2} = 34^\circ\text{C} \implies T_{a1} = 504.6^\circ\text{C}$
 56. (b) 163 kg/h additional steam
 58. (c) 3733 kg/h fresh water
 60. (c) 0.51 g evaporate
 62. (a) 1760 kW
 64. (d) 1.16×10^5 kJ/h
 66. (b) $x_F = 0.5, T_f = 110^\circ\text{C}, P = 760$ mm Hg $\implies T_{\text{evap}} = 52.2^\circ\text{C}$
 68. (a) 0.840 kg steam generated, 973 kJ transferred from condenser
 70. $T_{dp} = 77.3^\circ\text{F}, \hat{H} = 43.9$ Btu/lb_mDA
 72. (d) $Q = -31$ J
 74. (b) 2.9 tons of cooling
 76. (b) 0.0119 kg H₂O added/min
 78. (b) 67 m³

80. (b) -15.5 kW
 82. (b) 11.09 kJ/mol HCl
 84. $6.09 \times 10^4 \text{ J/mol H}_2\text{SO}_4$
 86. (b) $-471 \text{ kJ/L product}$
 88. (b) $291.4 \text{ g H}_2\text{O(l)}, 547.3 \text{ g H}_2\text{O(s)}$
 90. (c) 60 kJ/h transferred from the crystallizer
 92. (b) $T_{\max} = 125^\circ\text{C}$
 96. (b) 140°F
 98. Liquid: $10.5 \text{ g NH}_3, 64.5 \text{ g H}_2\text{O}$

CHAPTER NINE

2. (c) $-1.53 \times 10^5 \text{ kW}$
 4. (c) $+122 \text{ kJ}$
 6. (a) 122.7 kJ/mol
 8. (c) $-1.26 \times 10^5 \text{ kJ/h}$ (evolved)
 10. (b) $\Delta\hat{H}_c^\circ = -5068 \text{ kJ/mol}$
 12. (c) $\dot{Q} = -0.0536 \text{ kW}$
 14. (c) $Q = 251 \text{ kJ}$
 16. (b) 1350 kW
 18. (c) $Q = 11,863 \text{ kJ}$
 20. (b) -81.5 kW
 22. (b) $-6.44 \times 10^4 \text{ Btu/h}$
 26. (c) -279 kW (process), -265 kW (reactor)
 28. (b) A: $3.67 \times 10^5 \text{ kJ/h}$, F: $1.34 \times 10^6 \text{ kJ/h}$, C: $5.65 \times 10^4 \text{ kJ/h}$
 30. (c) $55.9 \text{ kmol recycled/h}$
 32. (a) 80.1% conversion
 34. (b) 59.2 kJ/mol feed
 36. (a) $0.417 \text{ mol C}_2\text{H}_4/\text{mol CH}_4$ consumed
 38. (c) $n_0 = 9.0 \text{ mol O}_2$
 40. $-55.0 \text{ kJ/mol}, -177.9 \text{ kJ/mol}$
 42. (a) $\Delta\hat{H}_r^\circ = 222.4 \text{ kJ/mol}$
 44. (a) $177 \text{ kJ/mol (NH}_4)_2\text{SO}_4$
 46. (a) 94°C
 48. (a) LHV = 843 kJ/mol

50. $72.5\% \text{ CH}_4, 18.8\% \text{ C}_2\text{H}_6, 8.7\% \text{ CO}$
 52. (a) 2.5 gal/h
 54. (b) $40.3 \text{ kJ}, 534 \text{ kJ}$
 56. (b) $2.13 \times 10^4 \text{ kJ/m}^3$ fuel
 58. (c) -655 kW
 60. (b) $1.16 \times 10^5 \text{ kg steam/h}$
 62. (a) 99% excess air
 64. (b) 2780°C
 66. (a) 1832°C
 68. (d) For Run 2, $T_{\text{ad}} = 1738^\circ\text{C}$
 70. (a) $\dot{m}_B = 30.3 \text{ tonnes/d}, \dot{m}_F = 11.2 \text{ tonnes/d}, \dot{Q}_1 = 8.04 \times 10^7 \text{ kJ/d}, \dot{Q}_4 = 1.38 \times 10^7 \text{ kJ/d}$

CHAPTER TEN

2. (b) $n_1, n_2, n_3, x_1, x_2, x_3$
 4. (a) 7 degrees of freedom
 6. (b) 1.80 mol recycle/mol fresh feed
 10. (c) For the given conditions, $\dot{Q} = -23.7 \text{ kW}$
 12. (b) $T = 1560^\circ\text{C}$

CHAPTER ELEVEN

2. (a) $n'_p = 0.3743, n_p(0) = 7.5$
 4. (d) $t = 120 \text{ s}, n_{\text{O}_2} = 0.30 \text{ lb-mole}$
 6. (d) 26.5 min.
 8. (d) C_{SO_2} (2 min.) = 3.82×10^{-7}
 10. (e) 90% conversion at $t = 4.6 \text{ min.}$
 12. (c) 20.6 seconds
 14. (b) $3.5 \times 10^{-3} \text{ min}^{-1}$
 16. (b) $k_2 = 0.115 \text{ L/mol}$
 18. (b) 2.7 hours
 20. (b) 4.29 kW
 22. (c) $T_b = 30^\circ\text{C} \Rightarrow t = 100 \text{ min}$
 24. (b) 200 g
 26. (b) 54.8°C
 28. (a) $dC_{\text{S}2}/dt = 0.080(C_{\text{S}1} - C_{\text{S}2})$
 30. (c) $dx/dt = -(\dot{n}_V/N_L)[-x + ax/(x + b)]$