Answers to Selected Problems

3.1 (a) 268.8 K and 4.625 x 10^5 Pa; (b) at 90° (horizontal) 282.6 K and 4.863 x 10^5 Pa; (c) at 180° (vertical downward) 296.4 K and 5.1 x 10^5 Pa.

3.2 (a) δQ/δt = 3.51 x 10^8 J/hr [contractor pays]  
(b) δQ/δt = 3.23 x 10^8 J/hr [contractor collects fee]

3.5 (a) \( L_A = 0.4352 \) m, \( L_B = 0.0218 \) m, \( T_A = T_B = 311 \) K, \( P_A = P_B = 7 \) bar  
(b) Same as (a)  
(c) There is no real solution given the constraints, we must specify more about the expansion (or compression) of A or B. For example, if A expands adiabatically, \( P_A = P_B = 6.68 \) bar, \( T_A = 263.6 \) K, \( T_B = 881.3 \) K, \( L_A = 0.3917 \) m, and \( L_B = 0.0655 \) m.

3.7 Many variations are possible. If we assume gas in the cylinder is ideal and that it expands adiabatically, then (a) total time \( t = 0.9 \) s, (b) height \( h(max) = 4.78 \) m, by reducing tube length to 1.64 m.

3.12 (a) After 6 s, \( T = 349.5 \) K, \( P = 1.139 \times 10^5 \) Pa in the bulge.  
(b) After 3 s, \( T = 454.6 \) K, \( P = 6.26 \times 10^3 \) Pa in the large tank.

4.1 For the minimum condition \( T_A(\text{final}) = 132 \) K and for the maximum condition \( T_A(\text{final}) = 617 \) K, these extrema require using the object with the lowest mass x heat capacity product.

4.2 \( W = 9.807 y \) in J/kg evaporated, for typical values of ambient dry bulb and wet bulb temperatures of 300 K and 280 K respectively, \( y = 16.8 \) km!

4.3 (a) \( \dot{n}_B = 0.166 \) mol/s, \( \dot{n}_C = 0.833 \) mol/s  
(b) \( T_D = 299.1 \) K  
(c) \( W = -26.4 \) J/s  
(d) \( \Delta S = 13.3 \) J/K  
(e) Same as (d).  
(f) \( W_{\text{max}} = -4000 \) J/s

4.4 \( W = -1.11 \times 10^4 \) J, \( T_f = 288.7 \) K, \( P_f = 0.54 \) bar

4.6 (a) 21.6 s  
(b) 391.8 K and 2.2 bar at 10 s  
(c) \( \Delta S_{\text{gas}} = 4.93 \times 10^3 \) J/K = \( \Delta S_{\text{universe}} \)  
(d) \( \Delta S(\text{gas in tank}) = -813.6 \) J/K  
\( \Delta S(\text{gas vented}) = +2020 \) J/K  
\( \Delta S(\text{surroundings}) = +1203 \) J/K  
(e) \( W_{\text{min}} = +2.83 \times 10^5 \) J
4.7 (a) $\dot{Q} = 2400 \text{ W}$, $T = 327.7 \text{ K}$, and $Q = 22,200 \text{ J after 10 s}$
(b) $T = 1750 \text{ K}$ at $t = 57.7 \text{ s with all stored work consumed.}$

4.9 $W_{\text{net}} = -3.17 \times 10^6 \text{ J}$

4.12 (a) $T_2 = 227.9 \text{ K}, T_1 = 392.9 \text{ K (2) after venting (1) before venting}$
(b) $T_2 = 211.1 \text{ K}, T_1 = 363.9 \text{ K}$
(c) $W = 2547 \text{ J/mol}$
(d) $W_{\text{max}} = 1.38 \times 10^5 \text{ J/kg}$

4.15 (a) $\Delta S = -1.38 \times 10^3 \text{ J/K hr}$; (b) $\Delta S = 2 \text{ J/K hr}$

4.16 (a) Case (1) $1.98 \times 10^{-2} \text{ kWhr}$; (2) $2.78 \times 10^{-2} \text{ kWhr}$; (3) $2.16 \times 10^{-2} \text{ kWhr}$; (4) $2.78 \times 10^{-2} \text{ kWhr}$
(b) Case (1) 420 K, 42 J/K; (2) 300 K, 0 J/K; (3) 300 K, 73.9 J/K; (4) 300 K, 0 J/K

4.18 $W = 5.23 \times 10^3 \text{ J} = -Q$

4.22 (a) $P = 6.35 \times 10^4 \text{ Pa}$
(b) $T = 272.8 \text{ K}$
(c) $P = 3.68 \times 10^4 \text{ Pa with 2 pumps}$
(d) $P = 1.91 \times 10^4 \text{ Pa and } T \to \infty$
(e) Power (minimum) = 20.9 W

4.24 (a) $W_{\text{max}} = -198.76 \text{ kJ/kg (Carnot + expansion work)}$
$b) W_{\text{p}} = \text{ideal pump work (estimated to include PE for lifting water and for the compression of gas space in storage tanks)}$

4.30 (a) $\dot{W}_{\text{max}} = 6.38 \times 10^6 \text{ J/s}$
(b) $\eta_a = 0.90 = (\text{actual power})/(\text{maximum power})$
(c) no, the maximum power outputs are the same

5.2 (a) $y^{(n+1)} = y^{(0)} - T S - \sum \mu_j N_j$ \quad $dy^{(n+1)} = -SdT - \sum_{j=1}^{n} N_j d\mu_j - PdV$
(b) $y^{(1)} = S - (1/T)U$ \quad $dy^{(1)} = -Ud(1/T) + (P/T)dV - \sum_{j=1}^{n} (\mu_j / T)dN_j$

5.4 (a) $\left(\frac{\partial P}{\partial T}\right)_{\nu,N, i}$
(b) $\left(\frac{\partial P}{\partial T}\right)_{\tau,N} = G_P + T(-G_{PT}) = V - T(\frac{\partial V}{\partial T})_{P,N}$
(c) $U$
(d) $\left(\frac{\partial H}{\partial V}\right)_{T,N} = V / G_{pp} - TG_{PT} / G_{pp}$
5.7  (a) \[
\left( \frac{\partial S}{\partial T} \right)_{G,N} = -S \left( \frac{\partial V}{\partial T} \right)_p / V + C_p / T
\]
(b) \[
\left( \frac{\partial A}{\partial G} \right)_{T,N} = -P \left( \frac{\partial V}{\partial T} \right)_T / V = \left( -\frac{\partial \ln V}{\partial \ln P} \right)_T
\]

5.10  \( T_f = 1087 \text{ K} \)

5.12  \[
y^{(1)}_{22} = -NC_v / T = -NC_p / T + V \alpha_p^2 / \kappa_T
\]

5.21  \( V_c = \kappa RT = (C_p/C_v) RT \approx 330 \text{ m/s} \) (use mass units for \( R \) with molecular weight)
distance at 2 s \( \approx 660 \text{ m} \)

5.22  (a) \( C_p - C_v = V \alpha_p^2 / \kappa_T \)

5.23  (b) No, the ratio as shown in Problem 5.17 is expressed in terms of \( PVT \) properties and an isentropic derivative which in turn requires non-\( PVT \) property information specifically related to the temperature dependence of energy stored in \( U \).

5.24  (a) \[
dy^{(0)} = -SdT - PdV + \mu_1 dN_1 + \mu_2 dN_2 + F_1 dZ
\]
(b) \[
y^{(0)} = -PV + \mu_1 N_1 + \mu_2 N_2 + F_1 Z_1
\]
(c) \[
dy^{(5)} = +TdS + VdP - N_1 d\mu_1 - N_2 d\mu_2 + Z_1 dF_1 \neq 0
\]
(d) \[
\left( \frac{\partial F_1}{\partial \mu_1} \right)_{T,V,N_2,Z} = -\left( \frac{\partial N_1}{\partial Z_1} \right)_{\mu_1,T,V,N_2}
\]
(e) \[
y^{(1)}_{SXS} = \left[ T^2 \left( \frac{\partial C_v^{**}}{\partial T} \right) - T \right] / \left( C_v^{**} \right)^3
\]

5.25  (a) \( y^{(5)} = 0 \)
(b) \[
y^{(5)} = -SdT + VdP - N_1 d\mu_1 - N_2 d\mu_2 - VBdH
\]
(c) Yes, using the Gibbs-Duhem relationship
\[
\mu_2 - \mu_2^0 = \int d\mu_2 = -\int \frac{x_1}{(1-x_1)} d\mu_1 = f(\mu_1)
\]

6.2  \[
d\mathcal{A} = -P^r dV^r + (\mu^r - \mu^L) dN^r \geq 0
\]
thus, \( P^r = P^L \) and \( \mu^r = \mu^L \) at equilibrium

6.3  \( T = T_i / (1 + \alpha) \) and \( \alpha = f(T) \) from chemical equilibrium criteria, intersections define equilibrium states.
6.4  (a) \( T^{(i)} = T^{(ii)} = T^{(iii)} \)
\( P^{(ii)} = P^{(iii)} \)
\( \mu_{H_2}^{(i)} = \mu_{H_2}^{(ii)} \)
\[ \sum v_j \mu_j = 0 \]

6.5  (a) \( V_1 = V_2 = RT / 10^5 \)
\( \mu_{A_1} = \mu_{A_2} \)

(b) \( T = 366.5 \text{ K}, P_{A_1} = P_{A_2} = 2 \text{ bar}, P_{B_2} = 1 \text{ bar} \)
\( N_{B_1} = 0 \quad N_{B_2} = 1 \text{ mole} \quad N_{A_1} + N_{A_2} = 4 \text{ moles} \)

(c) \( P_1 = 2 \text{ bar}, N_1 = 5 \text{ moles}; V_1 = 2.5 RT/10^5 = 0.0752 \text{ m}^3 \) with \( T = 367 \text{ K} \) and no gas on side 2.

6.7  Fraction evaporated \( \varepsilon = 0.227 \)
\( Q = \Delta U = 136 \varepsilon \text{ (in J)} \)
\( \Delta S = \varepsilon [0.581 - 0.462 (6 \times 10^{-2}) \ln (4.40 \varepsilon)] \)
\( \Delta A = -5.63 \varepsilon [1 - \ln (4.40 \varepsilon)] \)

7.1  if \( A_{NN} = 0 \) then \( A_{VV} = 0 = A_{NN}/V^2 \)

7.3  \( T = 55.1 \text{ K} \)

7.6  for \( \alpha = 2.5 \)
\[ x_A \quad x_B \]
\[ 0.1 \quad 0.286, 0.614 \]
\[ 0.2 \quad 0.4 \text{ (critical pt.)} \]
\[ 0.3 \quad \text{no solution} \]
\[ 0.4 \quad 0.2, 0.4 \text{ (critical pt.)} \]
\[ 0.5 \quad 0.175, 0.325 \]
\[ 0.6 \quad 0.085, 0.28 \]

7.11 \( \Delta G = 221.3 \text{ J/mol at } 10^0 \text{C} \) or \( = -217.8 \text{ J/mol at } -10^0 \text{C} \)
8.4 At 365.8 K, 16.5 bar

\[
(\partial S / \partial P)_V = [C_p / T + (\partial P / \partial T)_V (\partial V / \partial P)_T ](\partial P / \partial T)_V = 3.33 \times 10^{-5} \text{ J/mol K}(N/m^2)^{-1}
\]

8.5 At \( T = 319.4 \text{ K} \)

<table>
<thead>
<tr>
<th>( P_r )</th>
<th>( \kappa_{tv}/\kappa_s )</th>
<th>( Z = PV/RT )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.100</td>
<td>0.967</td>
</tr>
<tr>
<td>0.2</td>
<td>0.194</td>
<td>0.932</td>
</tr>
<tr>
<td>0.4</td>
<td>0.369</td>
<td>0.862</td>
</tr>
<tr>
<td>1.0</td>
<td>0.798</td>
<td>0.598</td>
</tr>
<tr>
<td>4.0</td>
<td>0.426</td>
<td>0.547</td>
</tr>
<tr>
<td>10.0</td>
<td>−0.296</td>
<td>1.108</td>
</tr>
</tbody>
</table>

8.9 Using an isenthalpic expansion across an insulated value to 1 bar, 0.236 kg of dry ice could be produced per kg of CO₂ drawn from the cylinder. For an isentropic expansion, 0.41 kg dry ice/kg of CO₂ is possible.

8.10 (a) \( T_f = 379.3 \text{ K at 48.3 bar} \)
(b) \( W = -9.1 \times 10^7 \text{ J} \)

8.14 \( T_{B,f} \approx 256 \) to 257 K, \( P_{B,f} \approx 21.5 \text{ bar, } x_g = 0.63 \) (fraction vapor)

8.15 (a) Power = 508 kW
(b) Power = 516 kW

8.30 \( \dot{W} = 90.9 \text{ kW and } \dot{Q} = 68.3 \text{ kW} \)

8.31 Yes, the vdW EOS gives at the Zeno condition (\( Z = 1 \)) a straight line:
\( T_r = T/T_c = 27/8 - (9/8) \rho_r \)

9.1 (a) −31.36 kJ/mole water added to acid at the start; −61.1 kJ/mole and added to water at the start
(b) maximum heat load occurs at the start
(c) total \( Q = -28 \text{ kJ/mol acid} = -11.2 \text{ kJ/mol of solution same for both cases} \)

9.2 (b) \( Q = -3.86 \times 10^5 \text{ J} \)
(c) \( \delta N / \delta t = -6.43 \times 10^3 \text{ } /\{([H_A - H_A]x_{A,in} + [H_A - H_w]x_{w,in} - \Delta H_{mix,in}] \}
\( \delta Q / \delta t = -3.96 \times 10^5 \text{ J/min} \)
(d) \( \delta N / \delta t \text{ at } 64.9 \text{ wt%} = 41.8 \text{ kg/min} \)

9.3 mole % NH₃ = 51.37 %

9.6 \( W = 326 \text{ J} \)
9.7 \( \frac{dS}{dt}_{\text{universe}} = \left[ (\mu_{w,in} - \mu_w) \dot{n}_w + (\mu_{s,in} - \mu_s) \dot{n}_s \right] / T \)

w = water and s = salt (NaCl)

9.8 (a) \( W_{\text{min}} = -1069 \text{ J (PR EOS)} \)
(b) \( W_{\text{min}} = -1812 \text{ J (ideal gas mixture)} \)

9.9 \( \dot{W} = 3 \text{ MW} \)

9.11 \begin{array}{ccc}
\text{x salt (wt fraction)} & \Pi(\text{bar}) & \Pi^{ID}(\text{bar}),\text{(completely dissociated)} \\
0.01 & 7.2 & 8.5 \\
0.05 & 42.2 & 43.9 \\
0.10 & 90.5 & 91.1 \\
0.15 & 156.6 & 142.0 \\
0.20 & 242.0 & 197.0 \\
0.25 & 355.0 & 257.0 \\
\end{array}

9.13 \( \Delta H_{\text{mix}} = Q = 1624 \text{ J} \)
\( \Delta S_{\text{mix}} = 12.34 \text{ J/K} \)

9.14 (a) \( \gamma_{\text{EtOH}} = 1.18 \quad \gamma_{\text{MeOH}} = 4.17 \) at \( 0.8 = x_{\text{EtOH}} \)
(b) At \( -85^\circ \text{C} (188 \text{ K}) \), there are two phases in equilibrium at \( x_{\text{EtOH}} = 0.07 \) and 0.35.

9.20 \( \delta Q / \delta t = 675 \text{ W} \)
\( \delta W_{\text{min}} / \delta t = 108 \text{ W} \)

9.21 (a) \( \dot{W} = 1.32 \times 10^5 \text{ W} \)
(b) See Section 14.4 for details, information provided in part (a) is not sufficient, ideal gas state heat capacities and a mixture \( PVTN \) EOS are needed.

9.27 \( \partial W_{\text{max}} / \partial t = 676 \text{ kW} \) while Gyro claims \( -400 \text{ kW} \) which gives \( \eta_u = 0.623 \) not 0.95

10.2 \( H - H^0 = PV - RT - a/V \)

10.3 \begin{align*}
r = 2 & \quad \Phi_{ij,\text{max}} / kT = 20.43 \\
r = 3 & \quad \Phi_{ij,\text{max}} / kT = 6.05 \\
r = 5 & \quad \Phi_{ij,\text{max}} / kT = 1.31 \\
r = 10 & \quad \Phi_{ij,\text{max}} / kT = 0.16 \\
\end{align*}

10.4 \(< \Phi_{ij} > = 0 \)
10.6 \( r, \text{Å} \) \( \Phi_{(\text{H}_2\text{O}+\text{H}_2\text{O})} \) \( \Phi_{(\text{CO}+\text{CO})} \)
\[
\begin{array}{cccc}
10^{-21} \text{ J} & 10^{-21} \text{ J} \\
2 & -288.42 & -2.52 \\
10 & -0.0185 & -0.000164 \\
\end{array}
\]

10.7 \( b = 4RT_c / (\sqrt{30}P_c) = 4V_c / \sqrt{30} \)
\( a = 1 + 4RT_c V_c \sqrt{30} \)

10.9 (a) \( [<\langle \delta \rho \rangle^2 >] / \rho = (1 - b \rho) / V_1^{1/2} [\rho (1 - 2\beta a \rho (1 - b \rho)^2)]^{1/2} \)
(b) \( \rho_c = 1/(3b) \) and \( \beta_c = 27b/(8a) \)
(c) for \( T/T_c = 1.0001 \) \( \Delta I / I_0 \approx 9.29 \times 10^{-5} \)

10.10 \( \tilde{\Phi}_{\text{CO}_2} = 0.245 \)

11.4 (a) \( \Lambda_{12} = 0.0961, \Lambda_{21} = 1.0273, \beta = -0.8381 \)
(b) \( \gamma_1^\infty = -10.13, \gamma_2^\infty = 2.41 \)
(c) for only positive values of \( \Lambda_{ij} \), a large number of values \( [\Lambda_{ij}, \Lambda_{ji}] \) exist as a function of \( x_i \) that yield extrema, e.g.

for \( x_1 = 0.2 \)
\[
\begin{array}{ccc}
\Lambda_{12} & \Lambda_{21} \\
0 & 3.236 \\
0.500 & 1.699 \\
1.000 & 1.000 \\
1.500 & 0.586 \\
2.000 & 0.209 \\
2.118 & 0 \\
\end{array}
\]

for \( x_1 = x_2 = 0.5 \) \( \alpha_{\text{max}} = 0.4276 \)
for \( x_1 = 0.1, x_2 = -0.9 \) \( \alpha_{\text{max}} = 0.6177 \)

11.5 (c) fraction of solution precipitated = 0.0067

11.7 for 2-suffix Margules \( T_c = w/2 \) k

11.8 for quasi-chemical model \( T_c = w/2.23 \) k
12.3 (a) selected values of $\gamma_\pm$ are given below for LiCl

<table>
<thead>
<tr>
<th>molality</th>
<th>$\gamma_\pm$ (Meissner)</th>
<th>$\gamma_\pm$ (Pitzer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.9651</td>
<td>0.9653</td>
</tr>
<tr>
<td>0.01</td>
<td>0.9032</td>
<td>0.9044</td>
</tr>
<tr>
<td>0.1</td>
<td>0.7850</td>
<td>0.7927</td>
</tr>
<tr>
<td>1.0</td>
<td>0.7636</td>
<td>0.7758</td>
</tr>
<tr>
<td>5.0</td>
<td>1.9586</td>
<td>2.0222</td>
</tr>
<tr>
<td>10.0</td>
<td>7.9948</td>
<td>11.0827</td>
</tr>
</tbody>
</table>

(b) $s^* (s^* + 10)\gamma_\pm = \exp[-\Delta G^\circ_{rx} / RT] = f(T)$ only

given that $s = 9$ mol/kg for pure LiCl in H$_2$O. Using the Meissner model for $\gamma_\pm$ predictions for both pure and mixed electrolyte.

\[
K_{sp} \approx (9)^2 (\sim 6)^2 = 2916 \text{ for pure LiCl at } 25^\circ C
\]

\[
\gamma_\pm^2 (\text{HCl}(10m) + \text{LiCl}(s^*) (s^* + 10) = 2916
\]

Iterating $s^* = 2.4$ and $\gamma_\pm = 10$ 3H for mixed LiCl and HCl at 25°C

(c) Difficult to say without more information on how much Na$_2$SO$_4$ influences $\gamma_\pm$ for LiCl.

For example is the effect on $\gamma_\pm$ large enough to compensate for the Cl$^-$ common ion effect?

12.8 Some representative values for $\kappa$ follow for $T = 25^\circ C, D_s = 78.5$

<table>
<thead>
<tr>
<th>molality</th>
<th>$\kappa^{-1}$, nm (NaCl or LiCl)</th>
<th>$\kappa^{-1}$, nm (CuCl$_2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.96</td>
<td>0.55</td>
</tr>
<tr>
<td>1.0</td>
<td>0.30</td>
<td>0.18</td>
</tr>
<tr>
<td>10.0</td>
<td>0.096</td>
<td>0.055</td>
</tr>
</tbody>
</table>

At $T = 300^\circ C$ $D_s \approx 22.3$ so multiply above values by $(22.3 \times 573)/(78.5)(298) = 0.74$

12.10 $I = 0.546$ or $m = I/3 = 0.182$ molal

13.2 Using Joback’s method with $T_b = 225.5$K (exp. value)

$T_c = 364$ K, $P_c = 46.7$ bar, and $\omega = 0.1606$

\[
C_p^\circ = -2.83 + 0.269T + 3.15 \times 10^{-4}T^2 + 4.2 \times 10^{-8}T^3
\]

13.3 $T_c = 663.5$ K, $P_c = 32.21$ bar, $V_c = 429.5$ cm$^3$/mol, and $T_b = 450.38$ K

Using Eq. (13-18) for vapor pressure:

\[
\ln P_{vp} = 7.3106(1-\frac{663.5}{T}) - 3.4723
\]

Updated: 1/14/04
13.4 For pure caffeine, $T_b \approx 640$ K, $T_c = 872$ K, $V_c = 488.5$ cm$^3$/mol, and $P_c = 41.46$ bar
Using the PR EOS for density estimate for 5 mol % caffeine CO$_2$ mixture at 80 bar, 310 K $\rho_{mix} \approx 1151$ kg/m$^3$. The vapor pressure of liquid caffeine is approximated by Eq. (13-18)

$$\ln \left( \frac{P_{vp}}{P_c} \right) = \left( \frac{\ln(P_c / 1.013)}{1 - T_b / T_c} \right) \left( \frac{1}{T_c} \right) \left( \frac{T}{T_c} \right)$$

$$\ln P_{vp} = 9.571 \left( \frac{1 - \frac{872}{T}}{872} \right) - 3.482 \text{ (in bar)}$$

14.2 Using the PR EOS,

$\Delta \dot{H}$ for geofluid = $(H_{in} - H_{out}) \dot{m}_{gf} = 7.97 \times 10^8$ J/s

$\Delta \dot{H}$ for R $-115 = 2.30 \times 10^4$ J/mol

$\dot{m}_{R-115} = 5370$ kg/s

$\dot{m}_{R-115} / \dot{m}_{gf} = 2.87$

14.6 (a) $W_{max} = C_p(T_2 - T_1) + T_oC_p \ln(T_2 / T_1) = \Delta B$

(b) $\eta_{net}$ (at $T_2 = 600$ K) = 0.52

(c) Using the RKEOS and a suitable mixing rule, $a_{mix}$ and $b_{mix}$ parameters can be calculated and used to calculate all $PLTN$ properties. With an ideal-gas state $C_p$ all derived properties needed for the cycle calculation can be obtained using a departure function approach. Then,

$$\dot{W}_{net} \approx \eta_i \dot{m}_{wf} (H_B - H_C) - \frac{\dot{m}_{wt}}{\eta_p} V_{i}^{sat} (P_A - P_{vp}^{sat} (T_o))$$

14.8 (a) $\alpha^* = \frac{\pi \dot{W}}{0.428 \left( \frac{1 - \eta_{cycle}}{\eta_{cycle}} \right) \left( \frac{V_{g}^{sat}}{\Delta H_{vap}} \right) \left( \frac{m}{\sqrt{RT_0}} \right)}$

(b) $\alpha^*(\text{NH}_3) / \alpha^*(\text{H}_2\text{O}) = 6.4 \times 10^{-3}$ (about 150 times smaller!)

14.12 (a) and (b) $W_{max} = -1.26 \times 10^6$ J = 0.35 kWh so CTI’s claim of 1 kWhr production violates the 2nd Law limit

(c) All heat transfer and work production and utilization steps have some irreversibility in practical systems.

14.14 (a) $\dot{W}_{max} = -9471$ kW

(b) no fundamental laws or concepts are violated

(c) $\alpha = \dot{Q}_{total} / <U> \Delta T$
about 17% more area for heat exchange is required for the GH process

(d) $\dot{W}_{net}(GH)/\dot{W}_{net}(Rankine) = 1.15$ which is less than 22%

NB: If an electric motor drive is used for the feed pump in the conventional Rankine system, then the net output would be reduced possibly accounting for the discrepancy.

15.1 $(\partial P/\partial T)_{(S-L)} = 1.35 \times 10^7 \text{ Pa/K}$

15.3 $x$ (Naphthalene) = 0.196

15.6 (c) $q$ (critical quality) = $\kappa T_{in} C_v \Delta H_v$

(e) $O_2$: $q = 0.54$ and $H_2$: $q = 0.36$

15.12 $x_{KCl} = 0.413$ and $T = 624 \text{ K}$

15.13 $\overline{H^V_{EtOH}} - \overline{H^L_{EtOH}} = \Delta H_{vap} = 4.0 \times 10^4 \text{ J/mol}$

15.15 Anesthetic pressure of CCl$_4$ $\approx 4.9 \times 10^3 \text{ bar}$.

15.19 (a) $\ln \gamma_A = f(P, x_i) / (T)^{1/\eta}$

(b) $\gamma_A(400 \text{ K}) = 1.17$

(c) $\Delta S^A = R \ln \gamma_A ((1 - \eta) / \eta)$

(i) if $\Delta S^A = 0$, solution is regular

(ii) if $\Delta S^A > 0$, less structural ordering in mixture versus pure state

(iii) if $\Delta S^A < 0$, more structural ordering in mixture versus pure state,

implies $|\Phi_{ij}| > |\Phi_{ii} or \Phi_{jj}|$

16.9 (a) $y_A = 0.764, y_B = 0.236$

(b) not in equilibrium, estimate $y_B$ assuming equilibrium

16.12 $\dot{W}_{max} = 4.868 \times 10^5 \text{ J/s}$

16.14 $W_{max} = 9.15 \times 10^5 \text{ J}$

16.16 $\Delta T = 7.95 \text{ K}$ using expansion valve

$\Delta T = 2.39 \text{ K}$ using expansion turbine

Consider net energy, entropy, and work flows using 1st and 2nd Law concepts to show
process is not feasible as described.

16.20  
(a) $P = 21.9$ bar  
(b) $T = 51.5$ K  
(c) $\Delta S_{\text{universe}} = 2.96 \times 10^4 \text{ J/K}$

16.22  
<table>
<thead>
<tr>
<th>$T$, K</th>
<th>$C_p$ (effective), J/gK</th>
</tr>
</thead>
<tbody>
<tr>
<td>293</td>
<td>4.69</td>
</tr>
<tr>
<td>313</td>
<td>7.20</td>
</tr>
<tr>
<td>333</td>
<td>8.29</td>
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<tr>
<td>353</td>
<td>6.36</td>
</tr>
<tr>
<td>373</td>
<td>3.64</td>
</tr>
</tbody>
</table>

17.3  
(a) $F = 4 - \pi$ with $n = 3$ and $r = 1$; at $A$: $L_1$-$L_2$-$H$-$G$ and at $B$: $L_1$-$H$-$I$-$G$  
(b) $L_1 = 0$ and $M_1 = 0$ use $P$-explicit EOS to determine required $A_{ijk}$ and $A_{ij}$ derivatives  
(c) $d \ln P / d(1/T) = \Delta H^0_{rx} / R = (H^0 - 17H^{(L_3)} - H^{(G)}) / R$  
(d) for $x_{\text{hexane}}$ small, $T_0 - T \approx (RT_0^2 / \Delta H^0_{rx})x_{\text{hexane}} = 5.6x_{\text{hexane}}$

$\Delta H^0_{rx} = H^0 - 17H^{(L_2)} - H^{(L_2)}$ in this case

17.6  
$d \ln P / d(1/T) = -\Delta H_{\text{vap}} / R$ where $\Delta H_{\text{vap}} \approx H^{(V)} - y_1^{(V)}H^{(L_1)} - y_2H^{(L_2)}$  

18.1  
$P^\alpha - P^\beta \approx \varepsilon_o (D_s - 1) E^2 / 2$, $T^\alpha = T^\beta$, and $\mu^\alpha = \mu^\beta$

18.4  
$W = 9 \times 10^6 \text{ J/kg mol}$

18.5  
$T_i = 269$ K = $-4^\circ$C (winter!)

18.6  
$T_{\text{bath}} = 317$ K, efficiency $= 0.065$

18.8  
$z = \text{depth} = 764$ m

18.9  
$y_{\text{He}}^{4}$ (tube bottom) $= 0.501$, if $L \to \infty$ $y_{\text{He}}^{4} \to 4/7$

18.11  
$\alpha = 1.075$, $P(\text{rim}) = 4600$ bar

18.14  
$y_{\text{tritium}} = 0.065$ and $y_{\text{deuterium}} = 0.538$ at rim

18.16  
h $= 252$ m, for an equilibrium ocean, fresh water cannot rise above a level $252$ m below sea surface. For the well-mixed case, process becomes feasible if $Z = \text{depth} > 9850$ m (32,000 ft.).
19.1 \[ \alpha_{\text{EtOH to H}_2\text{O}} = 2.17 \]

19.2 \[ y_{\text{ethane}} = 0.995, \quad P(\text{bubble}) = 1.97 \times 10^6 \text{ Pa}, \quad r = 4.2 \times 10^{-9} \text{ m} \]

19.5 \[ \ln P_v(drop) = -3.93 \times 10^4 / T + \text{constant} \]

19.7 \[ x_{\text{butanol}} = 0.436 \]

19.8 (a) 0.046 J/m²
(b) 296 K