

Answers to Selected Problems

- 3.1 (a) 268.8 K and 4.625×10^5 Pa; (b) at 90° (horizontal) 282.6 K and 4.863×10^5 Pa; (c) at 180° (vertical downward) 296.4 K and 5.1×10^5 Pa.
- 3.2 (a) $\delta Q / \delta t = 3.51 \times 10^8$ J/hr [contractor pays]
 (b) $\delta Q / \delta t = 3.23 \times 10^8$ 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 $W = 9.807y$ 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) $\Delta \underline{S} = 13.3$ J/K
 (e) Same as (d).
 (f) $W_{\max} = -4000$ 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) $\Delta \underline{S}_{\text{gas}} = 4.93 \times 10^3$ J/K = $\Delta \underline{S}_{\text{universe}}$
 (d) $\Delta \underline{S}(\text{gas in tank}) = -813.6$ J/K
 $\Delta \underline{S}(\text{gas vented}) = +2020$ J/K
 $\Delta \underline{S}(\text{surroundings}) = +1203$ J/K
 (e) $W_{\min} = +2.83 \times 10^5$ 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 $W_{net} = -3.17 \times 10^6 \text{ J}$
- 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) $W_{max} = 1.38 \times 10^5 \text{ J/kg}$
- 4.15 (a) $\Delta \underline{S} = -1.38 \times 10^3 \text{ J/K hr}$; (b) $\Delta \underline{S} = 2 \text{ J/K hr}$
- 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 $T \rightarrow \infty$
 (e) Power (minimum) = 20.9 W
- 4.24 (a) $W_{max} = -198.76 \text{ kJ/kg}$ (Carnot + expansion work)
 W_p = ideal pump work (estimated to include PE for lifting water and for the compression of gas space in storage tanks)
- 4.30 (a) $\dot{W}_{max} = 6.38 \times 10^6 \text{ J/s}$
 (b) $\eta_u = 0.90 = (\text{actual power})/(\text{maximum power})$
 (c) no, the maximum power outputs are the same

- 5.2 (a) $y^{(n+1)} = y^{(0)} - T \underline{S} - \sum \mu_j N_j \quad dy^{(n+1)} = -\underline{S} dT - \sum_{j=1}^n N_j d\mu_j - P d\underline{V}$
 (b) $y^{(1)} = \underline{S} - (1/T) \underline{U} \quad dy^{(1)} = -\underline{U} d(1/T) + (P/T) d\underline{V} - \sum_{j=1}^n (\mu_j/T) dN_j$
- 5.4 (a) $(\partial P / \partial T)_{\underline{V}, N_i}$
 (b) $(\partial P / \partial T)_{T, N} = G_P + T(-G_{PT}) = \underline{V} - T(\partial \underline{V} / \partial T)_{P, N}$
 (c) \underline{U}
 (d) $(\partial H / \partial \underline{V})_{T, N} = \underline{V} / G_{PP} - T G_{PT} / G_{PP}$

- 5.7 (a) $(\partial S / \partial T)_{G,N} = -S(\partial V / \partial T)_P / V + C_p / T$
 (b) $(\partial A / \partial G)_{T,N} = -P(\partial V / \partial T)_T / V = -(\partial \ln V / \partial \ln P)_T$
- 5.10 $T_f = 1087 \text{ K}$
- 5.12 $y_{22}^{(1)} = -NC_v / T = -NC_p / T + V\alpha_p^2 / \kappa_T$
- 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 \underline{U} .
- 5.24 (a) $dy^{(0)} = -\underline{S}dT - P\underline{dV} + \mu_1 dN_1 + \mu_2 dN_2 + F_1 d\underline{Z}$
 (b) $y^{(0)} = -P\underline{V} + \mu_1 N_1 + \mu_2 N_2 + F_1 \underline{Z}_1$
 (c) $dy^{(5)} = +T\underline{dS} + \underline{V}dP - N_1 d\mu_1 - N_2 d\mu_2 + \underline{Z}_1 dF_1 \neq 0$
 (d) $(\partial F_1 / \partial \mu_1)_{T,\underline{V},N_2,Z} = -(\partial N_1 / \partial \underline{Z}_1)_{\mu_1,T,\underline{V},N_2}$
 (e) $y_{SSS}^{(1)} = [T^2(\partial \underline{C}_V^{**} / \partial T) - T] / (C_V^{**})^3$
- 5.25 (a) $y^{(5)} = 0 \quad dy^{(5)} = -\underline{S}dT + \underline{V}dP - N_1 d\mu_1 - N_2 d\mu_2 - \underline{V}\mathbf{B}d\mathbf{H}$
 (b) $(\partial \mu_1 / \partial \mathbf{B})_{T,\underline{V},H,N_2} = \underline{V}(\partial \mathbf{H} / \partial N_1)_{T,\underline{V},\mu_2,N_2}$
 (c) Yes, using the Gibbs-Duhem relationship

$$\mu_2 - \mu_2^\circ = \int d\mu_2 = -\int \frac{x_1}{(1-x_1)} d\mu_1 = f(\mu_1)$$

6.2 $d\underline{A} = -(P^V - P^L)d\underline{V}^V + (\mu^V - \mu^L)dN^V \geq 0$

thus, $P^V = P^L$ and $\mu^V = \mu^L$ 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) $\underline{V}_1 = \underline{V}_2 = RT/10^5$

$$\mu_{A,1} = \mu_{A,2}$$

(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) $P_1 = 2 \text{ bar}$, $N_1 = 5 \text{ moles}$; $\underline{V}_1 = 2.5 RT/10^5 = 0.0752 \text{ m}^3$ 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	x_B
0.1	0.286, 0.614
0.2	0.4 (critical pt.)
0.3	no solution
0.4	0.2, 0.4 (critical pt.)
0.5	0.175, 0.325
0.6	0.085, 0.28

7.11 $\Delta G = 221.3 \text{ J/mol at } 10^\circ\text{C}$ or $= -217.8 \text{ J/mol at } -10^\circ\text{C}$

8.4 At 365.8 K, 16.5 bar

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

8.5 At $T = 319.4 \text{ K}$

P_r	κ_H / κ_S	$Z = PV/RT$
0.1	0.100	0.967
0.2	0.194	0.932
0.4	0.369	0.862
1.0	0.798	0.598
4.0	0.426	0.547
10.0	-0.296	1.108

8.9 Using an isenthalpic expansion across an insulated valve to 1 bar, 0.236 kg of dry ice could be produced per kg of CO_2 drawn from the cylinder. For an isentropic expansion, 0.41 kg dry ice/kg of CO_2 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 $T_{B,f} \approx 256 \text{ to } 257 \text{ K}$, $P_{B,f} \approx 21.5 \text{ bar}$, $x_g = 0.63$ (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 $Q = \sim 28 \text{ kJ/mol acid} = -11.2 \text{ kJ/mol}$ of solution same for both cases

9.2 (b) $Q = -3.86 \times 10^5 \text{ J}$

(c) $\delta N / \delta t = -6.43 \times 10^3 / [(\bar{H}_A - H_A)x_{A,in} + (\bar{H}_A - H_w)x_{w,in} - \Delta H_{mix,in}]$

$$\delta Q / \delta t = -3.96 \times 10^5 / (60) \text{ J / min}$$

(d) $\delta N / \delta t$ at 64.9wt% = 41.8 kg / min

9.3 mole % $\text{NH}_3 = 51.37 \%$

9.6 $W = 326 \text{ J}$

9.7 $(dS/dt)_{universe} = [(\mu_{w,in} - \mu_w)\dot{n}_w + (\mu_{s,in} - \mu_s)\dot{n}_s]/T$
 w = water and s = salt (NaCl)

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

9.9 $\dot{W} = 3$ MW

9.11	x salt (wt fraction)	Π (bar)	Π^{ID} (bar), (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

9.13 $\Delta H_{mix} = Q = 1624$ J
 $\Delta S_{mix} = 12.34$ J/K

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

9.20 $\delta Q / \delta t = 675$ W
 $\delta W_{min} / \delta t = 108$ W

9.21 (a) $\dot{W} = 1.32 \times 10^5$ 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 $\partial W_{max} / \partial t = 676$ kW while Gyro claims -400 kW which gives $\eta_u = 0.623$ not 0.95

10.2 $H - H^0 = PV - RT - a/V$

10.3 $r = 2 \text{ \AA}$ $\Phi_{ij,max} / kT = 20.43$
 $r = 3$ $\Phi_{ij,max} / kT = 6.05$
 $r = 5$ $\Phi_{ij,max} / kT = 1.31$
 $r = 10$ $\Phi_{ij,max} / kT = 0.16$

10.4 $\langle \Phi_{i,j} \rangle = 0$

10.6	$r, \text{\AA}$	$\Phi_{(\text{H}_2\text{O}-\text{H}_2\text{O})}$	$\Phi_{(\text{CO}-\text{CO})}$
		(10^{-21} J)	(10^{-21} J)
	2	-288.42	-2.52
	10	-0.0185	-0.000164

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

10.9 (a) $[\langle (\delta\rho)^2 \rangle] / \rho = (1 - b\rho) / V_c^{1/2} [\rho(1 - 2\beta a\rho(1 - b\rho)^2)]^{1/2}$
 (b) $\rho_c = 1/(3b)$ and $\beta_c = 27b/(8a)$
 (c) for $T/T_c = 1.00001$ $\Delta\mathbf{I}/\mathbf{I}_0 \approx 9.29 \times 10^{-5}$

10.10 $\hat{\phi}_{\text{CO}_2} = 0.245$

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 Λ_{ij} , a large number of values $[\Lambda_{ij}, \Lambda_{ji}]$ exist as a function of x_i that yield extrema, e.g.

for $x_1 = 0.2$	Λ_{12}	Λ_{21}
	0	3.236
	0.500	1.699
	1.000	1.000
	1.500	0.586
	2.000	0.209
	2.118	0

11.5 for $x_1 = x_2 = 0.5$ $\alpha_{\max} = 0.4276$
 for $x_1 = 0.1, x_2 = -0.9$ $\alpha_{\max} = 0.6177$

11.7 (c) fraction of solution precipitated = 0.0067

11.8 for 2-suffix Margules $T_c = w/2 \text{ k}$

11.9 for quasi-chemical model $T_c = w/2.23 \text{ k}$

12.3 (a) selected values of γ_{\pm} are given below for LiCl

molality	γ_{\pm} (Meissner)	γ_{\pm} (Pitzer)
0.1	0.9651	0.9653
0.01	0.9032	0.9044
0.1	0.7850	0.7927
1.0	0.7636	0.7758
5.0	1.9586	2.0222
10.0	7.9948	11.0827

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

given that $s = 9$ mol/kg for pure LiCl in H₂O. Using the Meissner model for γ_{\pm} predictions for both pure and mixed electrolyte.

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

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

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 Na₂SO₄ influences γ_{\pm} for LiCl.

For example is the effect on γ_{\pm} large enough to compensate for the Cl⁻ common ion effect?

12.8 Some representative values for κ follow for $T = 25^{\circ}\text{C}$, $D_s = 78.5$

molality	κ^{-1} , nm (NaCl or LiCl)	κ^{-1} , nm (CuCl ₂)
0.1	0.96	0.55
1.0	0.30	0.18
10.0	0.096	0.055

At $T = 300^{\circ}\text{C}$ $D_s \approx 22.3$ 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 $T_b = 225.5\text{K}$ (exp. value)

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

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

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

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

$$\ln P_{vp} = 7.3106 \left(1 - \frac{663.5}{T}\right) - 3.4723$$

- 13.4 For pure caffeine, $T_b \approx 640$ K, $T_c = 872$ K, $V_c = 488.5$ cm³/mol, and $P_c = 41.46$ bar
Using the PR EOS for density estimate for 5 mol % caffeine CO₂ mixture at 80 bar, 310 K
 $\rho_{mix} \approx 1151$ kg/m³. The vapor pressure of liquid caffeine is approximated by Eq. (13-18)

$$\ln\left(\frac{P_{vp}}{P_c}\right) = \left(\frac{\ln(P_c/1.013)}{1 - T_b/T_c}\right) \frac{T_b}{T_c} \left(1 - \frac{1}{T/T_c}\right) \quad T \text{ in K and } P_c \text{ in bar.}$$

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

- 14.2 Using the PR EOS,

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

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

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

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

- 14.6 (a) $W_{max} = C_p(T_2 - T_1) + T_o C_p \ln(T_2/T_1) = \Delta B$
(b) η_{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 $PVTN$ 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,

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

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

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

- 14.12 (a) and (b) $W_{max} = -1.26 \times 10^6 \text{ J} = 0.35 \text{ kWhr}$ 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) $\dot{W}_{max} = -9471 \text{ kW}$
(b) no fundamental laws or concepts are violated
(c) $\underline{a} = \dot{Q}_{total} / \langle U \rangle \Delta T$

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 $x(\text{Naphthalene}) = 0.196$

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

(e) $\text{O}_2: q = 0.54$ and $\text{H}_2: q = 0.36$

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

15.13 $\bar{H}_{EtOH}^V - \bar{H}_{EtOH}^L = \Delta \bar{H}_{vap} = 4.0 \times 10^4 \text{ J/mol}$

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

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

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

(c) $\bar{\Delta S}_A^{EX} = R \ln \gamma_A ((1 - \eta)/\eta)$

(i) if $\bar{\Delta S}_A^{EX} = 0$, solution is regular

(ii) if $\bar{\Delta S}_A^{EX} > 0$, less structural ordering in mixture versus pure state

(iii) if $\bar{\Delta S}_A^{EX} < 0$, more structural ordering in mixture versus pure state,

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

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) $\Delta S_{universe} = 2.96 \times 10^4$ J/K

16.22	T , K	C_p (effective), J/gK
	293	4.69
	313	7.20
	333	8.29
	353	6.36
	373	3.64

- 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 \underline{A}_{ijk} and \underline{A}_{ij} derivatives
 (c) $d \ln P / d(1/T) = \Delta H_{rx}^0 / R = (H^{(H)} - 17H^{(L_1)} - H^{(G)}) / R$
 (d) for x_{hexane} small, $T_0 - T \approx (RT_0^2 / \Delta H_{rx}^0) x_{hexane} = 5.6 x_{hexane}$
 $\Delta H_{rx}^0 = H^{(H)} - 17H^{(L_2)} - H^{(L_2)}$ in this case

17.6 $d \ln P / d(1/T) = -\Delta H_{vap} / R$ where $\Delta H_{vap} \approx H^{(V)} - y_1^{(V)} H^{(L_1)} - y_2 H^{(L_2)}$

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

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

18.5 $T_i = 269$ K = -4°C (winter!)

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

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

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

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

19.5 $\ln P_{vp}(\text{drop}) = -3.93 \times 10^4 / T + \text{constant}$

19.7 $x_{\text{butanol}} = 0.436$

19.8 (a) 0.046 J/m^2
(b) 296 K