

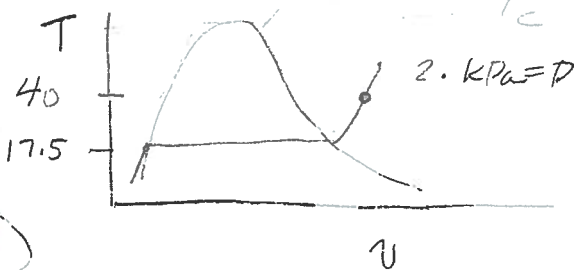
MATERIAL PROPERTIES

P_c Ideal

①

1.a) $P = 2 \text{ kPa}$
 $T_s = 17.5^\circ\text{C}$
 $T = 40^\circ\text{C} > T_s$

$T > T_s$ superheated



2.b) $P \ll P_c, T \gg T_s \Rightarrow$ ideal

3. $\begin{matrix} 0.5 \text{ m}^3 \\ \hline \end{matrix}$

① $V_f = V_g$ $T = 312 \text{ K}$
 $V_f + V_g = 0.5 \text{ m}^3$

$v_f = 0.01872 \text{ m}^3/\text{kg}$
 $v_g = 0.000795$

$X_1 = 0.5$
 $= \frac{m_g}{m_f}$

$m_f v_f = m_g v_g = 0.25 \text{ m}^3, m_g = \frac{0.25}{0.01872} = 13.355 \text{ kg}$

$\frac{v_f}{v_g} = \frac{m_g}{m_f} = \frac{0.000795}{0.01872} = 0.0425$
 $m_f = 314.23 \text{ kg}$

$m = 314.23 + 13.355$
 $= 327.6 \text{ kg}$

$\begin{matrix} 400 \text{ kg} \\ \hline 0.5 \text{ m}^3 \end{matrix}$

② $m_2 = 400 \text{ kg}$
 $T_2 = 312 \text{ K}$
 $P_2 = 0.9334 \text{ MPa}$

$v_2 = \frac{0.5 \text{ m}^3}{400 \text{ kg}} = 0.00125 \text{ m}^3/\text{kg}$

$X_2 = \frac{0.00125 - v_f}{v_{fg}} = \frac{0.00125 - 0.000795}{0.01872 - 0.000795} = 0.0254$

3a

$\frac{m_g}{m_f} = X, m_g = 0.0254(400 \text{ kg}) = 10.15 \text{ kg}$

4c

$V_f = m_f v_f = (400 - 10)(0.000795)$

$V_f = 0.31 \text{ m}^3$

5d

$400 - 327.6 = \Delta m$
 $= 72.4 \text{ kg}$

6.a $\Delta u = C_v \Delta T$

$C_v = 0.718 \frac{\text{kJ}}{\text{kgK}}$

$\Delta u = 0.718(550-100)$

$= 323 \frac{\text{kJ}}{\text{kg}}$

(recall $C_v = \frac{2u}{2T}$)

$2u = C_v 2T$

also $C_p = \frac{2h}{2T}$, $2h = C_p 2T$

2)

7.c assume closed ($\Delta m = 0$)

$Pv = RT$

$P_1 = \frac{RT_1}{v_1}$

$P_2 = \frac{RT_2}{v_2}$

$\frac{P_1}{P_2} = \frac{v_2 RT_1}{v_1 RT_2}$

$\frac{P_1}{P_2} = 4$

$\frac{v_2}{v_1} = 2$

$\frac{T_1}{T_2} = 2$

$P_2 = \frac{P_1}{4}$

8b $P = \rho RT$

$\rho = \frac{P}{RT}$

$= \frac{101.325 \text{ kPa}}{0.287 \frac{\text{kJ}}{\text{kgK}} (873) \text{ K}}$

$R = \frac{\bar{R}}{\text{MW}} = \frac{8.314 \text{ kJ}}{28.97 \text{ kg} \cdot \text{kmol}^{-1} \cdot \text{K}} = 0.287 \frac{\text{kJ}}{\text{kgK}}$

$= 0.405 \frac{\text{kg}}{\text{m}^3}$

$\frac{\text{kJ}}{\text{m}^3} \rightarrow \frac{\text{kJ}}{\text{m}^3}$

$N = \frac{I}{m}$

9b U measures internal energy $\propto T$

$(H = U + PV)$

$dS = \frac{\delta Q}{T_{\text{sur}}}$

10. d)

- a) if $T < 100^\circ\text{C}$ won't boil @ 1 atm
 b) X c) X d) ✓



boiling

bubbles form
 for $P_{\text{sat}} = P_{\text{sur}} = P_u$
 @ T

11. c)

pure $\Rightarrow$ homogeneous molecular composition throughout volume

12. d)



$$\begin{aligned} h_g &= h_f @ T_c, P_c \\ v_g &= v_f \\ s_g &= s_f \\ u_g &= u_f \end{aligned}$$

critical T

13. c)

① steam @ 1 MPa, 200°C

② 40°C, $x_2 = 0.83$ (superheated $P_1 < P_s = 1.55 \text{ MPa}$)

$$s_1 = 6.6940 \frac{\text{kJ}}{\text{kgK}}$$

$$s_2 = x_2(s_{fg}) + s_f$$

$$\Delta s = 6.951 - 6.694 = 0.257 \frac{\text{kJ}}{\text{kgK}} = 0.83(7.6845) + 0.5725 = 6.951 \frac{\text{kJ}}{\text{kgK}}$$

14. b)



isobaric process, water

$$m_T = 3 \text{ kg}, T_1 = 70^\circ\text{C}$$

$$P_1 = P_s @ 70 = 31.2 \text{ kPa}$$

$$P_1 = P_2$$

$$h_2 - h_1 = 50 \frac{\text{kJ}}{\text{kg}}$$

$$q - w = \Delta h$$

$$q = \Delta s = \frac{50 \text{ kJ/kg}}{(273+70) \text{ K}}$$

$$= 0.146 \frac{\text{kJ}}{\text{kgK}}$$

(4)

(15d) $\frac{C_p}{C_v} = 1.4$, $C_p = 1100 \frac{\text{kJ}}{\text{kgK}}$



$h_2 = h_1$ for adiabatic throttle
for ideal gas
($Q=0, W=0$)

$h = h(T)$ only so $T_2 = T_1 = 100^\circ\text{C}$

(16b) v of R 134a @ $h = 570 \frac{\text{kJ}}{\text{kg}}$ $P = 0.6 \text{ MPa}$ (superheated)

$v \approx 0.06 \text{ m}^3/\text{kg}$ from R-134a $P-h$
diagram in formula book

(17d) $h_1 = 480 \frac{\text{kJ}}{\text{kg}} = h_2$ $q - w = h_2 - h_1$

(18a) $P_{\text{const}} = 0.8 \text{ MPa}$

$h_2 = 300 \frac{\text{kJ}}{\text{kg}}$ from chart, $x \approx 0.32$

(19a) intensive property does not depend on
mass (amount) Temp.

1st LAW

5

1.d

Isentropic process from $\Delta S = 0 = C_v \ln\left(\frac{T_2}{T_1}\right) + R \ln\left(\frac{V_2}{V_1}\right)$

$$T_1 V_1^{(k-1)} = T_2 V_2^{(k-1)} \quad \text{where } k = \frac{C_p}{C_v} \approx 1.4 \text{ for air}$$

$$(273+35) \left(\frac{V_1}{V_2}\right)^{(k-1)} = T_2$$

$$T_2 = (273+35) (10)^{(0.4)} = 774K$$

(2nd law)

$$\ln\left(\frac{T_2}{T_1}\right) = -\frac{R}{C_v} \ln\left(\frac{V_2}{V_1}\right)$$

(cheating - not really 1st law)

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{R/C_v} = \left(\frac{V_1}{V_2}\right)^{(k-1)}$$

$$k = \frac{C_p}{C_v}$$

$$R = C_p - C_v$$

$$\frac{R}{C_v} = \frac{C_p}{C_v} - \frac{C_v}{C_v} = (k-1)$$

2.b

$$W = -7.2 \text{ MJ}$$

$$Q = -1.5 \text{ kW} \times 3600 \text{ s} = -5400 \text{ kJ} = -5.4 \text{ MJ}$$

$$Q - W = \Delta U$$

$$-5.4 \text{ MJ} - (-7.2 \text{ MJ}) = 1.8 \text{ MJ} = \Delta U$$

3d

polytropic

$$P V^n = C$$

$$W_p = P_2 V_2 - P_1 V_1$$

$$W_p = \frac{P_2 V_2 - P_1 V_1}{1-n} = \frac{1000(0.147) - 100}{1-1.2} = -235 \text{ kJ}$$

$$V_1 = 1 \text{ m}^3 \quad V_2 = 0.147 \text{ m}^3$$

$$P_1 = 100 \text{ kPa} \quad P_2 = 1000 \text{ kPa}$$

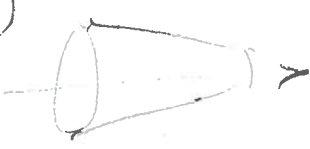
$$\textcircled{1} \text{ find } n: P_1 V_1^n = P_2 V_2^n$$

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^n$$

$$n = 1.2$$

6

4.d



1 MPa 30 $\frac{m}{s}$
250C

$Q=0$, nozzle

$$q - w = h_2 - h_1 + \frac{(v_2^2 - v_1^2)}{2000}$$

$$h_2 - h_1 = -40 \text{ kJ/kg}$$

$$40 \text{ kJ/kg} = \frac{v_2^2 - 30^2}{2000}$$

$$v_2 = 284 \text{ m/s}$$

5.b

$$q - \dot{w} = \dot{m}(h_2 - h_1) = \dot{m}v(P_2 - P_1)$$

pump

$$h_1 = h_f @ 50C = 209.33 \frac{\text{kJ}}{\text{kg}}$$

$$v_1 = v_f @ 50C = 0.001012 \frac{\text{m}^3}{\text{kg}}$$

$$\dot{m} = 10^5 \text{ kg/hr}$$

$$\text{KPa} = \frac{\text{kJ}}{\text{m}^3}$$

$$-\dot{w} = \frac{10^5 \text{ kg}}{3600 \text{ s}} (1000 - 12.35) \text{ KPa} \cdot 0.001012 \frac{\text{m}^3}{\text{kg}}$$

$$\dot{w} = -27.8 \text{ kW}$$

6.d

assume
adiabatic

$$q - \dot{w} = (h_2 - h_1) \dot{m} = (1023 - 290.4) 10 \frac{\text{kg}}{\text{s}}$$

$$-\dot{w} = 7326 \text{ kW}$$

7.a

Isentropic $P_1 v_1^k = C$

$$k = \frac{C_p}{C_v}$$

derived from $\Delta s = 0 = C_p \ln \frac{T_2}{T_1} - R \ln \left(\frac{P_2}{P_1} \right)$

assume ideal gas

7. proof

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$$0 = C_p \ln \left(\frac{P_2 V_2}{P_1 V_1} \right) - R \ln \left(\frac{P_2}{P_1} \right)$$

$$0 = C_p \ln \left(\frac{P_2}{P_1} \right) + C_p \ln \left(\frac{V_2}{V_1} \right) - R \ln \left(\frac{P_2}{P_1} \right)$$

$$0 = C_p \ln \left(\frac{V_2}{V_1} \right) + (C_p - R) \ln \left(\frac{P_2}{P_1} \right)$$

$$C_p - R = C_v$$

$$0 = C_p \ln \left(\frac{V_2}{V_1} \right) + C_v \ln \left(\frac{P_2}{P_1} \right)$$

$$-\ln \left(\frac{V_2}{V_1} \right) = \frac{C_v}{C_p} \ln \left(\frac{P_2}{P_1} \right) = + \ln \left(\frac{V_1}{V_2} \right)$$

$$\frac{V_1}{V_2} = \left(\frac{P_2}{P_1} \right)^{C_v/C_p}$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2} \right)^{C_p/C_v}$$

$$\frac{C_p}{C_v} = k$$

$$P_2 V_2^k = P_1 V_1^k$$

8d)

$$\dot{m}(\dot{q} - \dot{w}) = \dot{m}(h_2 - h_1)$$

$$-\dot{m}w = \dot{m}(h_2 - h_1 - \dot{q})$$

$$= \dot{m}(C_p(T_2 - T_1) - \dot{q})$$

$$= 2.16 \frac{\text{kg}}{\text{s}} (1 \frac{\text{kg}}{\text{kg}} (130 - 40) - (-90))$$

$$-\dot{m}w = 389 \text{ kW}$$

$$\dot{q} = -90 \frac{\text{kJ}}{\text{kg}}$$

$$\dot{m} = \dot{V} \rho = \dot{V} P / RT$$

$$= \frac{10 \text{ m}^3}{60 \text{ s}} \frac{1500 \text{ kPa}}{0.287(130 + 273)}$$

$$= 2.16 \text{ kg/s}$$

9b

$$(\dot{Q} - \dot{W}) = \Delta \dot{E}$$

net energy
crossing
boundary

change in
system energy

8

2ND LAW

1.a

$$\frac{\dot{Q}_H}{T_H} = \frac{\dot{Q}_L}{T_L} \text{ for CARNOT } \frac{100}{(273+370)} = \frac{37}{T_L}$$

$$T_L = 238K$$

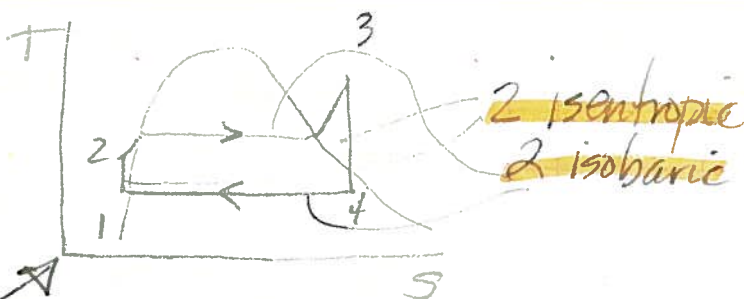
2b

max η @ Carnot

$$= 35C$$

$$\eta = 1 - \frac{T_L}{T_H} = 1 - \frac{110+273}{600+273} = 0.56$$

3b



4.a

5b

$$\eta = 1 - \frac{\dot{Q}_L}{\dot{Q}_H}$$

$$\eta = 1 - \frac{(2333 - 190)}{(3061.6 - 190.6)}$$

$$= 0.25$$

$$\dot{q}_L = h_4 - h_1$$

$$\dot{q}_H = h_3 - h_2$$

$$h_1 = h_f @ 10 \text{ kPa} = 190 \text{ kJ/kg}$$

$$h_2 = h_1 + v(P_2 - P_1) = 190 + 0.001(600 - 10) = 190.6$$

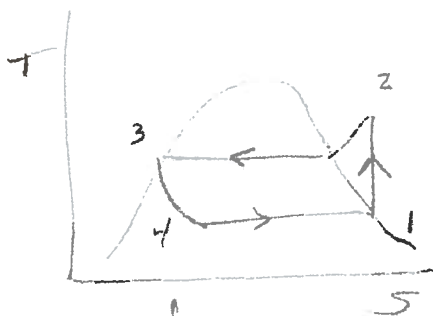
$$h_3 = 3061.6$$

$$s_3 - s_4 = 7.3724$$

$$x_4 = 7.3724 - 0.6387 = 0.895$$

$$h_4 = 0.895(2395) + 190 = 2333$$

6.c)



$$\dot{W} = \frac{\dot{Q}_L}{\text{COP}_R} = \frac{3 \text{ kW}}{3.9}$$

$$= 0.77 \text{ kW}$$

$$\text{COP}_R = \frac{\dot{Q}_L}{\dot{W}} = 0.8 \text{COP}_{RC}$$

$$\text{COP}_{RC} = \frac{1}{\left(\frac{T_H}{T_L} - 1\right)} \quad T_H = 50^\circ\text{C} \quad T_L = -5^\circ\text{C}$$

$$= \frac{1}{\left(\frac{273+50}{273-5} - 1\right)} = 4.9$$

$$\text{COP}_R = 0.8(4.9) = 3.9$$

$$\dot{Q}_L = 3 \text{ kW}$$

$$\text{max COP}_{HP} = \text{COP}_{CHP}$$

$$\text{COP}_{CHP} = 21$$

$$= \frac{1}{\left(1 - \frac{T_L}{T_H}\right)} = \frac{1}{\left(1 - \frac{280}{294}\right)}$$

8.b)

$$\dot{W} = 130 \text{ kW}$$

$$\dot{Q}_{in} = \frac{20 \text{ kg}}{3600 \text{ s}} \frac{40000 \text{ kJ}}{\text{kg}} = 222.2 \text{ kW}$$

$$\text{claimed } \eta = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{130}{222.2} = 0.585$$

$$\text{Carnot } \eta = 1 - \frac{T_L}{T_H} = 1 - \frac{273+50}{273+500} = 0.582$$

claim violates 2nd law

$$\text{check 1st Law: } \dot{Q}_{net} - \dot{W}_{net} = 0 \quad \text{for cycle}$$

$$130 \text{ kW} = \dot{Q}_{in} - \dot{Q}_{out} = 222.2 - \dot{Q}_{out}$$

$$\text{OK if } \dot{Q}_{out} = 92.2 \text{ kW (possible)}$$

1st Law is OK ✓

9.d Carnot cycle $T_H = 800\text{K}$

10)

$$T_L = 300\text{K} \quad \Delta S_L = 2.34 \text{ kJ/kg}$$

2nd Law $\Delta S = \frac{Q_H}{T_H} + \frac{Q_L}{T_L} = 0$

$$Q_H = T_L \Delta S_L = 300(2.34) = 702 \text{ kJ}$$

$$-\frac{702}{300} + \frac{Q_H}{800} = 0$$

$$Q_H = 800 \left(\frac{702}{300} \right) = 1872$$

1st Law $\dot{W}_{\text{net}} = \dot{Q}_H - \dot{Q}_L = 1872 - 702$
 $= 1170 \text{ kJ}$

10.b completely reversible
adiabatic (no friction)

$\Rightarrow$ isentropic $\Delta S = 0$

11.c $\left[\begin{array}{l} \text{N}_2 \text{ 2 MPa} \\ \text{250C} \\ 10 \text{ m}^3 \end{array} \right] 35\text{C}$

entropy change in surr = S_{gen}

$$\textcircled{3} \Delta S = \sum \frac{Q}{T} + S_{\text{gen}}$$

$$\textcircled{2} Q = m C_v (T_2 - T_1)$$

$$\textcircled{1} m = \frac{PV}{RT} = \frac{2000(10)}{0.297(250+273)} = 129 \text{ kg}$$

$$R_{\text{N}_2} = \frac{8.314}{28} = 0.297 \frac{\text{kJ}}{\text{kgK}}$$

$$Q = 129(0.743(35-250)) = -20573 \text{ kJ}$$

for surroundings $S_{\text{gen}} = -\frac{Q}{T} = -\frac{(-20573)}{308}$

$$S_{\text{gen}} = 66.8 \text{ kJ}$$

(12b) Rankine cycle, g_L

$$\eta = 1 - \frac{q_L}{q_H} = 1 - \frac{2144.17}{2868.77} = 0.25$$

(11)

(13b) 1 MPa $T_3 = 500^\circ\text{C}$ $\dot{W}_{\text{net}} = 300 \text{ MW}$
 35C

$$h_3 = 3478.5 \quad s_3 = s_4 = 7.7622$$

$$x_4 = \frac{7.7622 - 0.5053}{7.8478} = 0.924 (\sim 92\%)$$

(14a) $h_4 = 0.92(2418.6) + 146.7$
 $= 2372 \text{ kJ/kg}$

(15d) $\eta = 1 - \frac{q_L}{q_H}$

$$= 1 - \frac{2372 - 146.7}{3478.5 - 147.7} = 0.33$$

$$h_1 = 146.7$$

$$h_2 = 146.7 + 0.001(1000 - 5.6) = 147.7$$

$$\eta = \frac{\dot{W}_n}{\dot{m}(h_3 - h_2)} = 0.33 = \frac{300,000 \text{ kW}}{\dot{m}(3478.5 - 147.7)}$$

$$\dot{m} = 273 \text{ kg/s}$$

(16d) 1 kg steam 400C 800kPa
 $h_1 = 3267.1$ adiabatic

1st law check

(2) 200C 400kPa
 $h_2 = 2860.5$

$$W = 450 \text{ kJ}$$

$$\Phi - W = \Delta U$$

$$0 - 450 = (2646.8 - 2959)(1)$$

$$-450 \neq -312.2$$

2nd Law check

$$\Delta S = \frac{\Phi}{T} + S_{\text{gen}} = (1)(7.1766 - 7.5716) = -0.40 \text{ kJ/K}$$

Violates both 1st & 2nd Laws

17d

$$Q_{in} = 350 \text{ MJ}$$

$$Q_{out} = 297.5 \text{ MJ}$$

$$\eta = 1 - \frac{297.5}{350}$$

$$= 0.15$$

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