Homework 9 Solutions

1. ideal pump is isentropic (adiabatic & reversible)

   Since for liquid $s_2 - s_1 = c_p \ln\left(\frac{T_2}{T_1}\right)$ it is also isothermal

2. boiling water at constant pressure is isothermal and internally, BUT NOT externally, reversible

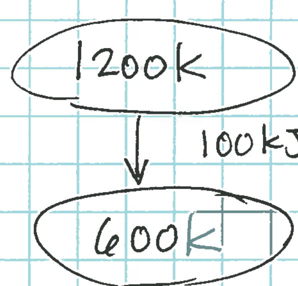
3. turbine is isentropic only if it is adiabatic and reversible

4. for $s_2 - s_1 = 0$ and $S_{gen} > 0$

   $S_{gen} = -\frac{q}{T}$ and $-\frac{q}{T} > 0$

   so system must lose heat

5. $s_2 - s_1 = S_{gen}$ AND $s_2 > s_1$

6. 

   for reservoir

   $\Delta s = q/T$ OR $\frac{Q}{T} = \Delta S$

   $\Delta S_{HTR} = \frac{-100\text{ kJ}}{1200\text{ K}} = -0.0833 \frac{\text{kJ}}{\text{K}}$

   $\Delta S_{LTR} = \frac{+100}{600\text{ K}} = 0.167 \frac{\text{kJ}}{\text{K}}$

   $\Delta S_{sys} = -0.0833 + 0.167 = \boxed{0.0833 \frac{\text{kJ}}{\text{K}}}$

7. CARNOT Heat pump

$\dot{Q}_H = 100\,kW \quad T_H = 21°C = 294K$

$T_L = 10°C = 283K$

a) $COP = \dfrac{1}{1 - \frac{T_L}{T_H}} = \dfrac{1}{1 - \frac{283}{294}} = 26.7$

$26.7 = \dfrac{100\,kW}{\dot{W}} \qquad \dot{W} = 3.74\,kW$

$\dot{Q}_L = -3.74\,kW - (-100\,kW)$
$= 96.3\,kW$

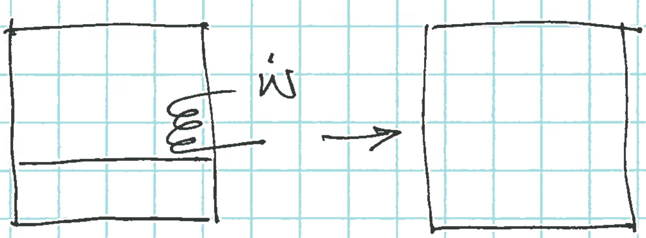
$\Delta S_{HTR} = -\dfrac{100\,kW}{294K} = -0.34\,\dfrac{kW}{K}$

$\Delta S_{LTR} = \dfrac{96.3}{283} = +0.34\,\dfrac{kW}{K}$

$\dot{S}_{gen} = -\sum_k \left(\dfrac{\dot{Q}}{T}\right)_k = -0.34 - (-0.34$
$= 0$

Satisfies CLAUSIUS $-\sum_k \left.\dfrac{\dot{Q}}{T}\right)_k \leq 0$
(= 0 for reversible cycle)

8.



$v_2 = v_1$

$v_1 = 0.25(v_{fg}) + v_f$ @ 100kPa
$= 0.25(1.6941) + 0.001043$

$m = 2kg$
$X_1 = 0.25$
$P_1 = 100kPa$

$X = 1$
[redacted]

$v_2 = 0.4246\ m^3/kg$
$= v_g \Rightarrow$ interpolate for P_2 to get S_2

$S_2 = S_g$ @ T_2

$400 < P_2 < 450$

$P_2 = 439\,kPa \Leftarrow \dfrac{P_2 - 400}{50} = \dfrac{0.4246 - 0.46242}{0.41392 - 0.46242}$

8.

$$\frac{439-400}{450-400} = \frac{s_2 - 6.8955}{6.8561-6.8955}$$

$$s_2 = 6.8648 \ \frac{kJ}{kg\,K}$$

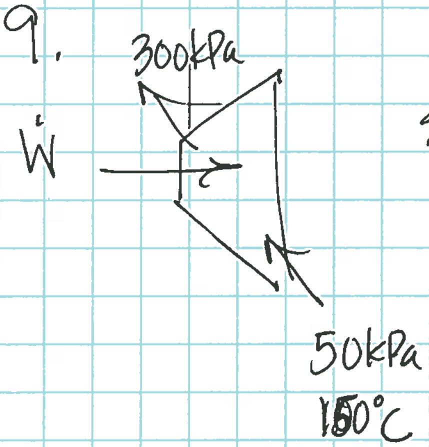
$$s_1 = 0.25(s_{fg}) + s_f \ @ \ 100kPa$$

$$= 0.25\,(6.0562) + 1.3028 = 2.8169 \ \frac{kJ}{kg\,K}$$

$$m\Delta s = (s_2 - s_1)m = 2kg\,(6.8648 - 2.8169)\frac{kJ}{kg\,K}$$

$$\boxed{\Delta S = 8.1 \ \frac{kJ}{K}}$$

9.



steam in adiabatic + reversible compressor

$$s_2 = s_1$$

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

$$-w = h_2 - h_1$$

a)

$$s_1 = 7.9413 \ \frac{kJ}{kg\,K} = s_2 \ @ \ 300kPa \quad s_2 > s_g \ \text{(still superheated)}$$

$$\frac{T_2 - 300}{400-300} = \frac{7.9413 - 7.7037}{8.0347 - 7.7037}$$

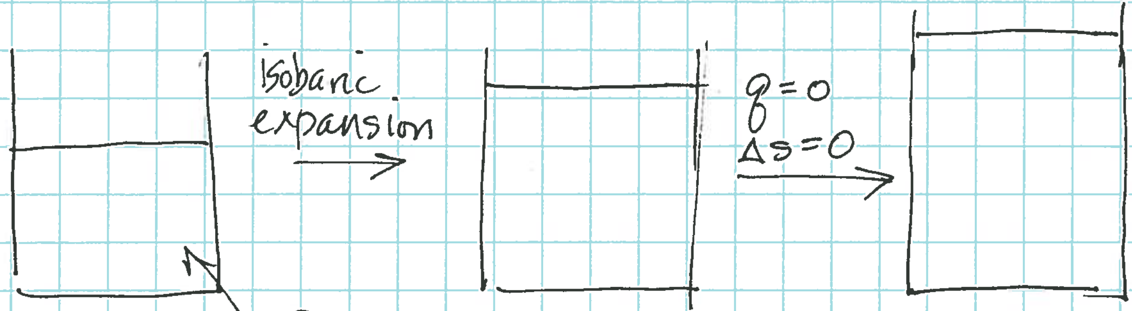
$$\boxed{T_2 = 371.8\,°C}$$

b)

$$\frac{h_2 - 3069.6}{3275.5 - 3069.6} = \frac{371.8 - 300}{100}, \quad h_2 = 3217.4 \ \frac{kJ}{kg}$$

$$-w = 3217.4 - 2780.2 = \boxed{437.2 \ \frac{kJ}{kg} \ \text{input}}$$

10.



$m = 5\,kg$ Q_{12} $X_2 = 1$ $P_3 = 15\,kPa$

$X_1 = 0.5$ (200°C)

$T_1 = 100°C$ $T_2 = 100°C$ $S_3 = S_2$

$S_1 = 0.5(S_{fg}) + S_f$ @100°C $= 0.5(6.047) + 1.3072 = 4.33\ \frac{kJ}{kg\,k}$ $S_2 = S_g$ @100°C

i) diagram: $S_2 = 7.3542 = S_g$ @100°C $= S_3$ @15kPa

	T	s
1	100	4.33
2	100	7.35
3	54	7.35

$S_f < S_3 < S_g$ @ 15kPa ⇒ sat. mixture

$\therefore T_3 = T_s = 54°C$

$X_3 = (7.3542 - 0.7549)/7.2522 = 0.91$

$Q_{12} = m(h_2 - h_1)$ $h_1 = 0.5(2256.4) + 419.17 = 1547.9\ kJ/kg$

b. $Q_{12} = 5kg(2675.6 - 1547.9)$
$= \boxed{5{,}638.5\ kJ}$

$h_2 = h_g$ @100°C $= 2675.6\ kJ/kg$

$h_3 = 0.91(2372.3) + 225.94 = 2384.7\ kJ/kg$

c. $-W = m(h_3 - h_2) = 5kg(2384.7 - 2675.6)$

$\boxed{W = 1{,}454.7\ kJ}$

11. a) $\sum_k \left(\frac{\dot{Q}}{T}\right)_k \leq 0$ (clausius)

$\dot{Q}_H = -25kW$ $-5\ kW = -25\ kW + \dot{Q}_L$
$\dot{W} = -5kW$ $\dot{Q}_L = 20kW$

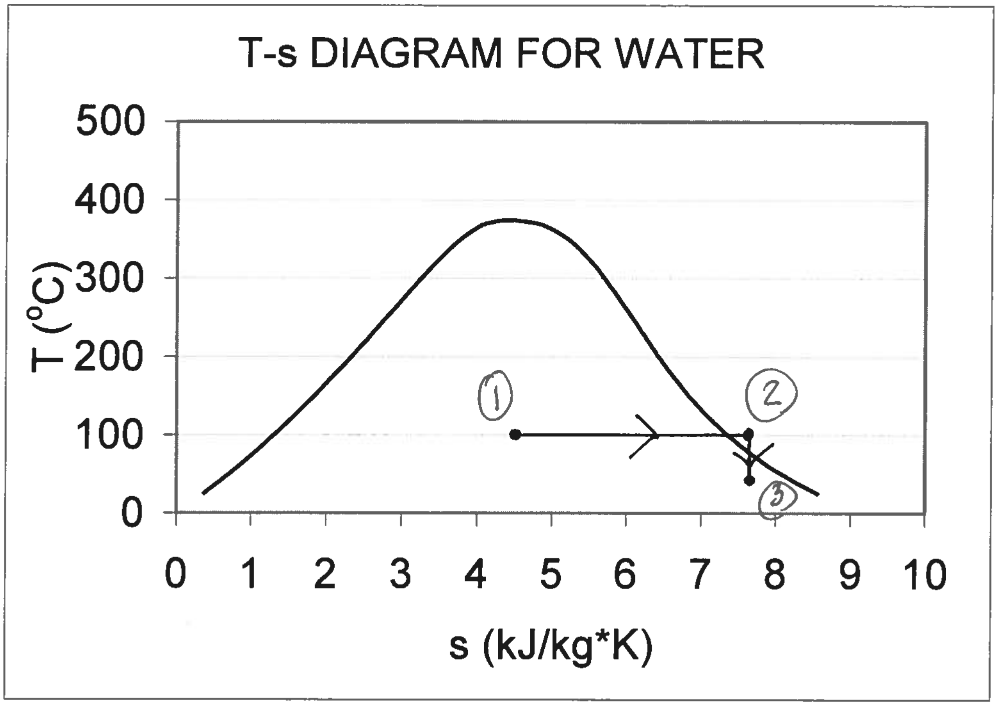
$\frac{-25kW}{300k} + \frac{20kW}{260k} = -0.0064 \leq 0$ ✓

b) $COP_{CHP} = \frac{1}{1 - T_L/T_H} = 7.5$, $COP = \frac{25}{5} = 5 < COP_{CHP}$ ✓

c) $\dot{S}_{gen} = -\sum_k \left(\frac{\dot{Q}}{T}\right)_k = -(-0.0064) = \boxed{0.0064\ \frac{kW}{K}}$

(4)

a. Draw the process on the T-s diagram below



b. Determine the heat transfer in process 1→ 2 in kJ.

c. Determine the work done in process 2→3 in kJ.

d. What is the change in entropy in the surroundings for the two-step process in kJ/K?

11. (7 points, 3 for a and 2 each for b and c) A heat pump design is proposed that provides 25 kw heat while consuming 5 kw electrical power. The high- and low-temperature reservoirs are 300K and 260K, respectively.

   a. Show that the cycle satisfies Clausius' principle.
   b. Show that the cycle satisfies Carnot's principle.
   c. What is the entropy produced in the surroundings (kw/K)?