Homework 5 Solutions

1. **No**

1st Law: $Q - W = \Delta U$

isothermal process, IG, $\Delta U = 0$

adiabatic $Q = 0$

so $-W = 0$ BUT $-W_b = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right) \neq 0$

since $V_2 < V_1$

2. 1st Law $Q - \dot{W}(t) = \Delta U$

$Q = 0$

$$-\dot{W}\left(15\,min\left(\frac{60\,s}{min}\right)\right) = \frac{P_1 V_1}{R T_1} C_v (T_2 - T_1)$$

$$-\dot{W}(900\,s) = \frac{100\,kPa\,(4 \cdot 5 \cdot 6)\,m^3}{0.287\,\frac{kJ}{kgK}\,(280\,K)}\,0.718\,\frac{kJ}{kgK}\,(23-7)\,K$$

$$-\dot{W} = \boxed{1.91\,\frac{kJ}{s} \text{ or } kW}$$

(input)

3.

$$Q - \dot{W}(t) = m C_v (T_2 - T_1)$$

$Q = 0$

$\dot{W} = -0.15\,kW$

$t = 10\,hr\,\frac{3600\,s}{hr}$

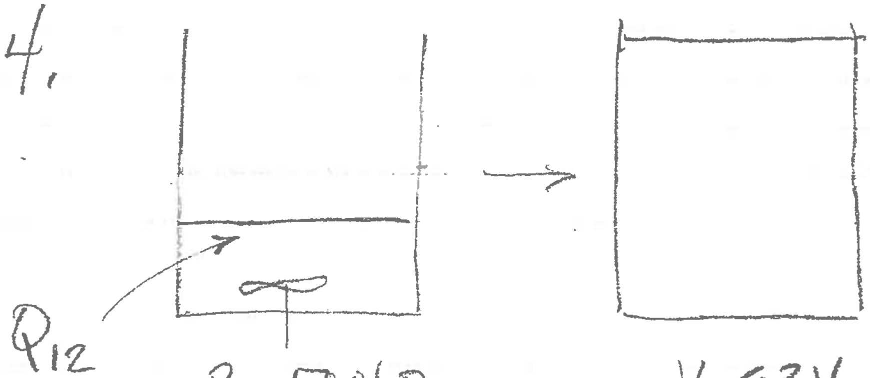
$$m = \frac{P_1 V_1}{R T_1} = \frac{100\,kPa\,(144\,m^3)}{0.287\,\frac{kJ}{kgK}\,(288\,K)} = 174.2\,kg$$

3. $$T_2 = \frac{-(-0.15\,kW)(36{,}000\,s)}{174.2\,kg\,(0.718\,\frac{kJ}{kg\,K})} + 288\,K$$

$$= 331.2\,K$$

$$\boxed{T_2 = 58^\circ C}$$

4.



$P_1 = 500\,kPa$ $\quad V_2 = 3V_1$

$T_1 = 27^\circ C = 300\,K$ $\quad T_2 = 300\,K$

$w = -50\,kJ/kg$

find q_{12}

1st Law $\quad q_{12} - w_{0,12} - w_{b12} = u_2 - u_1 = 0$ since $\Delta T = 0$

$$w_{0,12} = -50\,kJ/kg$$

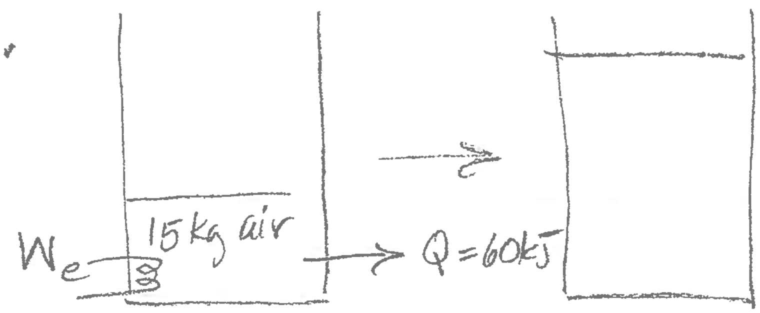
$$w_{b,12} = RT\ln\left(\frac{V_2}{V_1}\right) = 0.287(300)\ln(3)\ \frac{kJ}{kg}$$

$$w_{b,12} = 94.6\,kJ/kg$$

$$q_{12} - \left(-50\,\frac{kJ}{kg}\right) - 94.6\,\frac{kJ}{kg} = 0$$

$$\boxed{q_{12} = 44.6\,\frac{kJ}{kg}\ \text{INPUT}}$$

5.



$T_1 = 298K$ $\qquad T_2 = 350K$

$P_1 = P_2 = 300kPa$ find W_e in kwh

1st Law

$kwh = \frac{kJ}{s} \cdot 1hr \cdot \frac{3600s}{hr}$ $\quad (3600 \; kJ/kwh)$

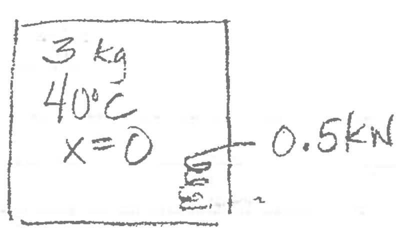
$$Q - W_e = \Delta H = mC_p(T_2 - T_1)$$

$C_p @ 325K = 1.0065 \frac{kJ}{kgK}$

$$-60 - (W_e) = 15kg\left(1.0065\frac{kJ}{kgK}\right)(350-298)K$$

$$-W_e = 845 kJ \left(\frac{1 kwh}{3600 kJ}\right) = \boxed{0.235 \; kwh}$$

6.



find T_2 after 30 min

$$Q - W = \Delta U = m(u_2 - u_1)$$

$Q = 0$, $\quad \dot{W} = -0.5kW$

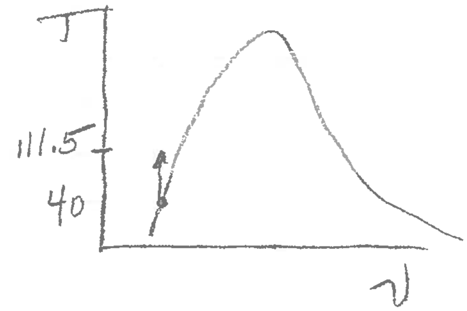
$\qquad\qquad t = 30 min$

$$-\left(-0.5\frac{kJ}{s}\right)(0.5hr)\left(\frac{3600s}{hr}\right) = 3kg(u_2 - u_1)$$

$u_1 \cong u_f @ 40°C = 167.53 \, kJ/kg$

6 a) $u_2 = \frac{900\,kJ}{3\,kg} + 167.53\,kJ/kg$

$= 467.53\,kJ/kg$



u_2 is compressed liquid

$u_2 \simeq u_f$ @ T_2 (A-4)

$110 < T_2 < 115$

$$\frac{T_2 - 110}{115-110} = \frac{467.53 - 461.27}{482.42 - 461.27}$$

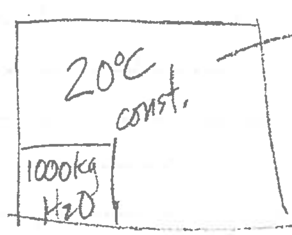
$\boxed{T_2 = 111.5°C}$ from tables

b) $-W = m C_p (T_2 - T_1)$

$900\,kJ = 3(4.184\,\frac{kJ}{kg\,k})(T_2 - 40°c)$

$\boxed{T_2 = 111.7°C}$ $< 0.2\%$ difference

7.



$8000\,kJ/hr = \dot{Q}$

$W = 0$

$Q = -8000\,\frac{kJ}{hr}(24\,hr)$ $T_2 = 20°C$

find T_1

$Q = \Delta U_w + \Delta U_{air}^{\nearrow 0}$

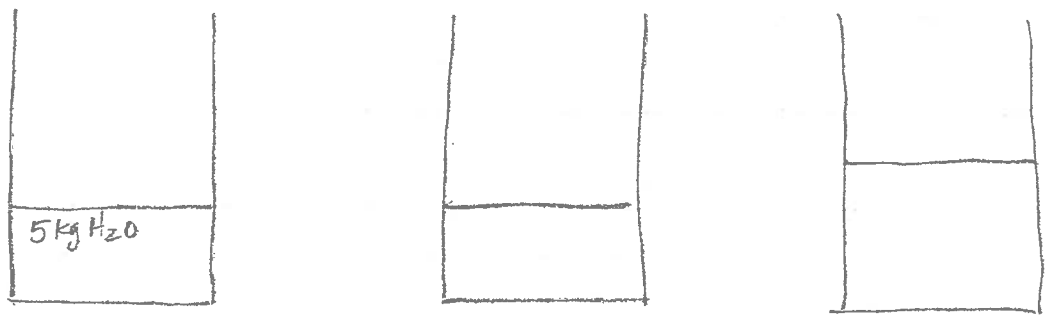
$-8000(24)\,kJ = m_w C_{pw}(T_2 - T_1)$

$= 1000\,kg(4.184\,kJ/kg\,k)(20 - T_1)$

7. $$T_1 = \frac{8000(24)\,kJ}{1000\,kg\,(4.184\,kJ/kgK)} + 20°C$$

$$\boxed{T_1 = 65.9°C}$$

8.



$P_1 = 125\,kPa$, sat mix

$P_2 = 300\,kPa$, $V_2 = V_1$, piston starts to move

$P_3 = 300\,kPa$, $V_3 = 1.2\,V_1$, end

a) $T_{sat} = \boxed{T_1 = 105.97°C}$

$$X = \frac{5-2\,kg}{5\,kg} = 0.6$$

need $v_1 = 0.6(1.375 - 0.001048) + 0.001048$

$v_1 = 0.8254\ m^3/kg = v_2$

$v_3 = 1.2\,v_1 = 0.9905\ m^3/kg$

@ 300kPa $v_3 > v_g$ (superheated)

$300 < T_3 < 400$

$$\frac{T_3 - 300}{400-300} = \frac{0.9905 - 0.87538}{1.03155 - 0.87535}$$

$$\boxed{T_3 = 373.7°C}$$

8. b) @ state 2, $v_2 = 0.8254 > v_g$ @ 300 kPa (0.60582 m^3/kg)
superheated also
so mass liquid when piston starts to move $\boxed{=0}$

c) work = $W_b = m(h_3 - h_2)$
easier
$W_b = m P_2 (v_3 - v_2)$
$= 5kg(300kPa)(0.9905 - 0.8254)\frac{m^3}{kg}$
$\boxed{W_b = 247.7 \, kJ \quad (+)}$

d $Q_{13} - W_{b_{23}} = \Delta U_{13} = m(u_3 - u_1)$

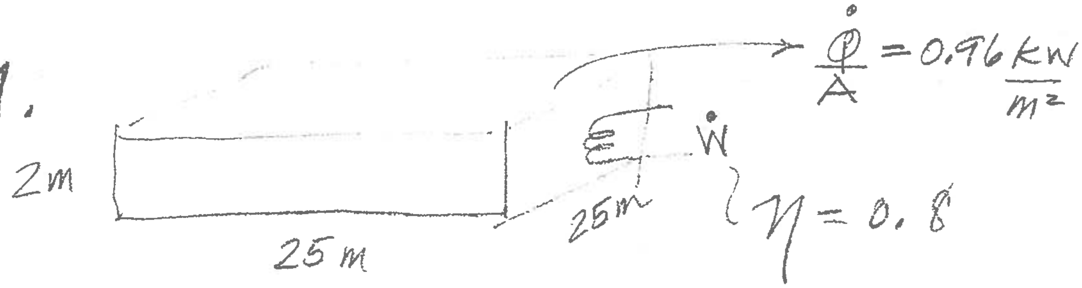
$u_3: \dfrac{373.7-300}{400-300} = \dfrac{u_3 - 2807.0}{2966.0-2807.0}$

$u_3 = 2,924.2 \, kJ/kg$

$u_1 = 0.6(u_{fg}) + u_f$ @ 125 kPa
$u_1 = 0.6(2068.8) + 444.23 = 1,685.5 \, \frac{kJ}{kg}$

$Q_{13} = 5kg(2924.2 - 1685.5)\frac{kJ}{kg} + 247.7 kJ$
$\boxed{= 6,441 \, kJ}$

9.



A. 1st Law for heating pool $T_1 = 20°C$, $T_2 = 30°C$

$t = 2\,hr$

$$\frac{\dot{Q}}{A}(A)t - \dot{W}_A(t) = mC_p(T_2 - T_1)$$

$$A = 25 \times 25 = 625\,m^2$$

$$-0.96\frac{kW}{m^2}(625\,m^2)\left(3600\frac{s}{hr}\right)(2\,hr) - \dot{W}(7200s) =$$

$$= 625(2)m^3 \cdot 1000\frac{kg}{m^3}\left(4.184\frac{kJ}{kgK}\right)(10)K$$

$$-\dot{W}_A = \frac{1}{7200}\left[5.23 \times 10^7\,kJ + 4.32 \times 10^6\,kJ\right]$$

$$-\dot{W}_A = 7.86 \times 10^3\,kW \times \frac{1}{0.8} = 9.83 \times 10^3\,kW$$

B. maintaining pool @ 30°C

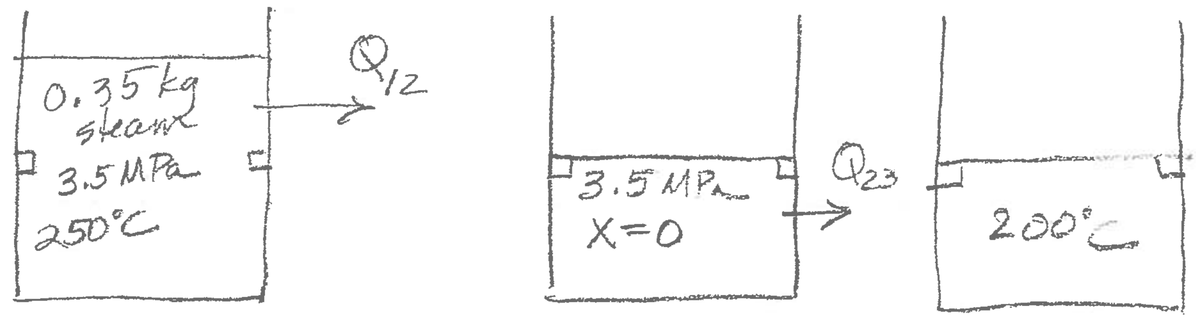
$$\dot{Q} = \dot{W}_B = -0.96\frac{kW}{m^2}(625\,m^2) = -600\,kW$$

for 80% η $\dot{W}_B = -750\,kW$

must design for A if client insists on heating pool in 2 hr $\sim 10^4\,kW$!

if pool heated in 24 hr: $-\dot{W}_e \sim 1{,}500\,kW$ (closer to B)

10.



superheated

$v_1 = 0.05876 \ \frac{m^3}{kg}$

$T_2 = 242.56°C$

$v_2 = v_f @ 3.5 MPa$
$= 0.001235 \ m^3/kg = v_3$

$P_3 = P_s = 1555 \ kPa$

$v_f < v_3 < v_g @ 200°C$

a) $P_3 = P_s @ 200°C = \boxed{1555 \ kPa}$

$$X_3 = \frac{v_3 - v_f}{v_{fg}} = \frac{0.001235 - 0.001157}{0.12721 - 0.001157} = \boxed{6.2 \times 10^{-4}}$$

b) $W_{b12} = mP(v_2 - v_1) = 0.35kg(3500 \ kPa)(0.001235 - 0.05876)$

$W_{b12} = \boxed{-70.5 \ kJ}$

c) $Q_{12} - W_{b12} = m(u_2 - u_1)$

$u_2 = u_f @ 3.5 MPa = 1{,}045.4 \ \frac{kJ}{kg}$

$u_1 = 2624.0 \ kJ/kg$

$Q_{12} = -70.5 + 0.35(1045.4 - 2624.0)$

$Q_{12} = \boxed{-623.0 \ kJ}$

10d) $Q_{13} - W_{b12} = m(u_3 - u_1)$

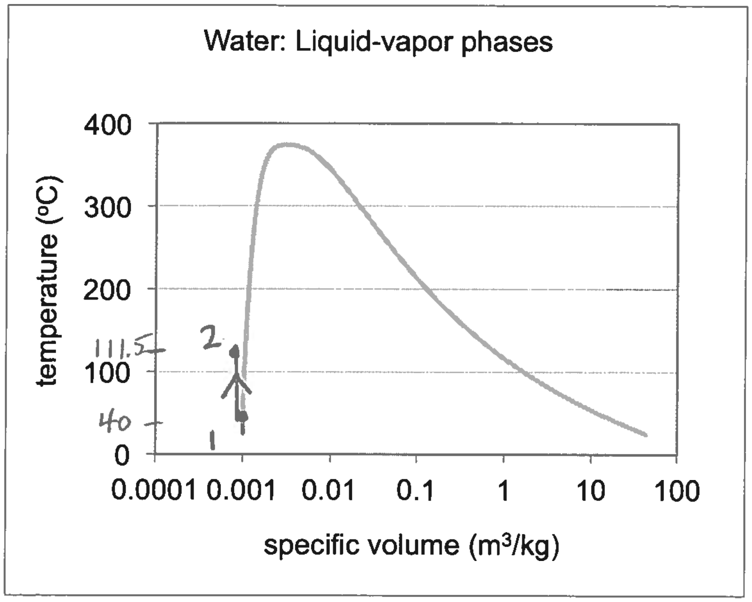
$u_3 = 6.2 \times 10^{-4}(u_{fg}) + u_f$ @ 200°C

$= 6.2 \times 10^{-4}(1743.7) + 850.46 =$

$= 851.5 \text{ kJ/kg}$

$Q_{13} = -705 \text{ kJ} + 0.35 \text{ kg}(851.5 - 2624.0)$

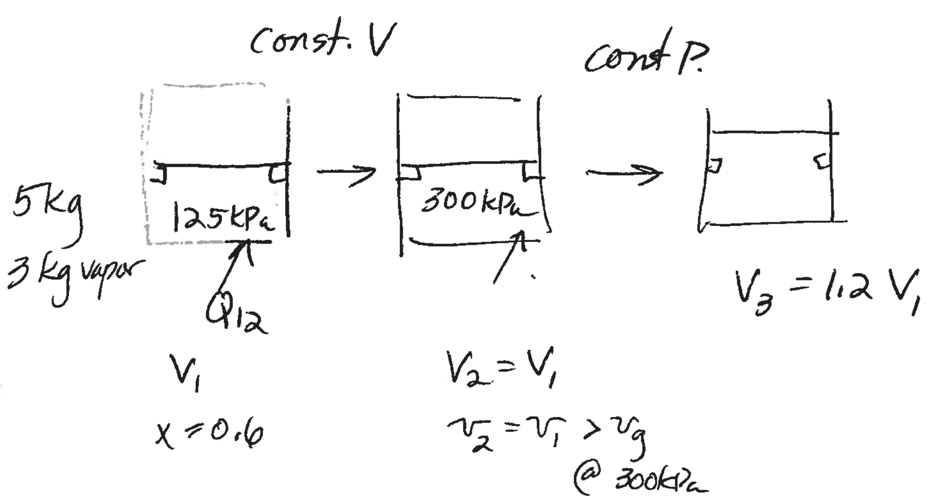
$= -690.9 \text{ kJ}$



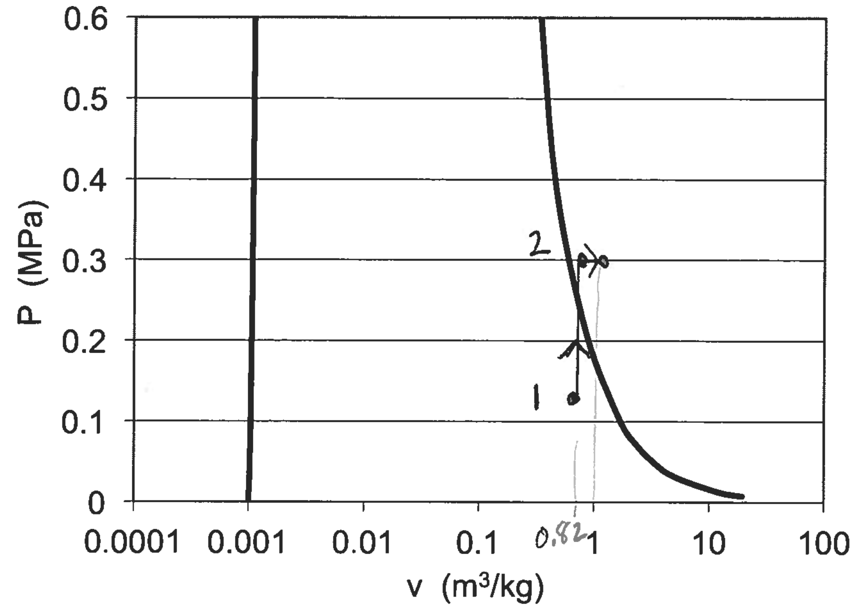
7. (2 points) A room containing 120 m^3 air at 100 kPa is to be maintained at 20 °C by heat transfer from a one metric ton (1000 kg) tank of water in the room. The room loses heat to the outside at an average rate of 8000 kJ/hr, averaged over 24 hours. What must the initial temperature of the water be at the beginning of a 24-hour cycle?

8. (5 points) A mass of 5 kg of saturated liquid-vapor water mixture is contained in a piston cylinder device where a pressure of 300 kPa is required to lift the piston. The initial pressure of the water is 125 kPa, and at the initial state, 2 kg of the water is saturated liquid. Heat is now transferred to the water until the volume increases by 20%.

   a. Find the initial and final temperatures of the water.
   b. What is the mass of liquid water when the piston starts to move?
   c. What is the work done in the process?
   d. What is the amount of heat that must be added?
   e. Draw the process on the P-v diagram (next page).



P-v diagram for water 7e.



9. (5 points) You have been hired to design a heating system for a swimming pool that is 2-m deep, 25-m long and 25-m wide. The heater must satisfy two criteria. First, it must supply enough heat to raise the temperature of the water in the outdoor pool from 20 to 30 °C in 2 hours. Second it must be able to maintain the pool at 30 °C. The average rate of net heat loss to the air is 960 w/m^2. Losses to the ground through the pool walls can be neglected. The efficiency of the heater is 80%. What is the heater size you would design for your client (kw).

10. (5 points) A piston cylinder contains 0.35-kg steam initially at 3.5 MPa and 250 °C. The steam loses heat to the surroundings and the piston moves down until it hits a set of stops. At this point, the steam has been condensed to saturated liquid. The cooling continues while the piston is resting on the stops until the water temperature is 200 °C. Determine:

   a. The final pressure and quality (if a mixture)
   b. The boundary work over the entire process sequence (kJ)
   c. The heat transferred when the piston first hits the stops (kJ)
   d. The total heat transfer over the entire process sequence (kJ)

12. (5 points) THERMODYNAMICS IN THE NEWS. Iceland gets about one-third of its electricity and almost all of its heating from geothermal sources. Using the article in the link, http://www.sciencecentric.com/news/11021810-magma-power-geothermal-energy.html, or other sources, comment on the advantages and disadvantages of geothermal sources for power generation and heating/cooling.