HOMEWORK 7 SOLUTIONS

1. Problem is overspecified and does not have single answer – DELETED

2. heat added to R-134a in rigid tank with one region evacuated and one with $0.02\,m^3$ R-134a, $X_1 = 0$, $P_1 = 0.7\,MPa$

$P_2 = 200\,kPa$, $T_2 = 30°C$

a) $m = \frac{V_1}{v_1}$ and $v_1 = v_f @ 700\,kPa = 0.0008331\,\frac{m^3}{kg}$

$m = 0.02\,m^3 / 0.0008331\,m^3/kg = \boxed{24\,kg}$

b) $V_2 = m v_2$ superheated @ state 2

$v_2 = 0.11874\,m^3/kg$

$V_2 = 24\,kg\,(0.11874\,m^3/kg) = \boxed{2.85\,m^3}$

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

$u_1 = u_f @ 700\,kPa = 88.24\,kJ/kg$

$u_2 = 255.14\,kJ/kg$ (A-13)

$Q = 24\,kg\,(255.14 - 88.24\,kJ/kg) = \boxed{4006\,kJ}$

3. Adiabatic expansion for R-134a in problem 2
state 1 same, P_2 same, $m = 24\,kg$

1st Law: $u_2 = u_1 = 88.24\,kJ/kg$

3. a) @ state 2 (200 kPa)

$u_f < u_2 < u_g$, so $T_2 = T_{sat} = \boxed{-10.09°C}$
mixture

b) $V_2 = m v_2$

$v_2 = x_2 (v_{fg}) + v_f \quad x_2 = \frac{88.24 - 38.28}{186.21} = 0.268$

$v_2 = 0.268(0.099867 - 0.0007533) + 0.0007533 = 0.02735 \, m^3/kg$

$V_2 = 24 \, kg \,(0.02735 \, m^3/kg) = 0.66 \, m^3$

c) $m_g = x_2 m = 0.268(24 \, kg) = \boxed{6.4 \text{ kg sat vapor}}$

4. Ideal gas @ 1000 kPa, 127°C
expands from 2 m³ to 4 m³, closed system
adiabatic process

1st Law $\quad 0 = \Delta U = m c_v (T_2 - T_1)$

$T_2 = T_1$

IGL $\quad P_1 V_1 = P_2 V_2$

$P_2 = P_1 \left(\frac{V_1}{V_2}\right) = 1000 \, kPa \left(\frac{2}{4}\right) = \boxed{500 \, kPa}$

5. Steam in adiabatic throttling process

1st Law $\quad h_2 = h_1$

state 1: 9 MPa, 600°C, superheated, $h_1 = 3634.1$ kJ/kg
state 2: 400 kPa

a) $h_2 > h_g$ superheated T_2 between 500 & 600°C

interpolate from A-13: $\frac{T_2 - 500}{600 - 500} = \frac{3634.1 - 3485.3}{3703.3 - 3485.3}$

$T_2 = \boxed{568.3°C}$

5 b) steady flow $\frac{\mathcal{V}_1 A_1}{v_1} = \frac{\mathcal{V}_2 A_2}{v_2}$ for $\Delta ke = 0$

$\mathcal{V}_1 = \mathcal{V}_2$

$\frac{A_2}{A_1} = \frac{v_2}{v_1}$

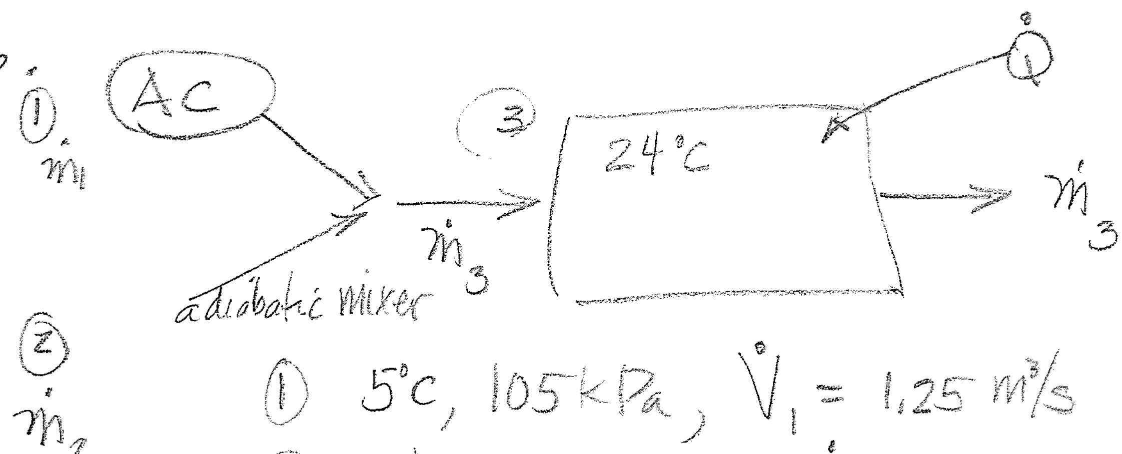
$v_1 = 0.042861 \ m^3/kg$ (A-13)

$\frac{v_2 - 0.88936}{1.00558 - 0.88936} = \frac{568.3 - 500}{100}$

$v_2 = 0.683 \ m^3/kg$

$\frac{A_2}{A_1} = \frac{0.683}{0.042861} = \boxed{22.6}$

6.



① 5°C, 105 kPa, $\dot{V}_1 = 1.25 \ m^3/s$

② 34°C, 105 kPa, $\frac{\dot{m}_2}{\dot{m}_1} = 1.6$

find T_3, $\dot{Q}$

a) 1st Law adiabatic mixer, air

$$0 - 0 = \dot{m}_3 h_3 - \dot{m}_2 h_2 - \dot{m}_1 h_1$$

Continuity $\dot{m}_3 = \dot{m}_2 + \dot{m}_1$

$$0 = (\dot{m}_2 + \dot{m}_1) h_3 - \dot{m}_2 h_2 - \dot{m}_1 h_1$$

$$= \dot{m}_1 (h_3 - h_1) + \dot{m}_2 (h_3 - h_2)$$

$$0 = \dot{m}_1 \cancel{C_p} (T_3 - T_1) + \dot{m}_2 \cancel{C_p} (T_3 - T_2)$$

(assume Cp constant)

$$\dot{m}_1 = \dot{V}_1 \rho_1 = \frac{P_1}{RT_1} \dot{V} = \frac{105 \ kPa}{0.287 \frac{kJ}{kg \cdot K} (278 K)} 1.25 \ m^3/s = 1.65 \ \frac{kg}{s}$$

6 a) $\dot{m}_2 = 1.6\,\dot{m}_1 = 1.6(1.65) = 2.63\ \mathrm{kg/s}$

$$0 = 1.65\ \tfrac{\mathrm{kg}}{\mathrm{s}}(T_3 - 5^\circ C) + 2.63\ \tfrac{\mathrm{kg}}{\mathrm{s}}(T_3 - 34^\circ C)$$

$4.28\,T_3 = 97.75$, $\boxed{T_3 = 22.8^\circ C}$

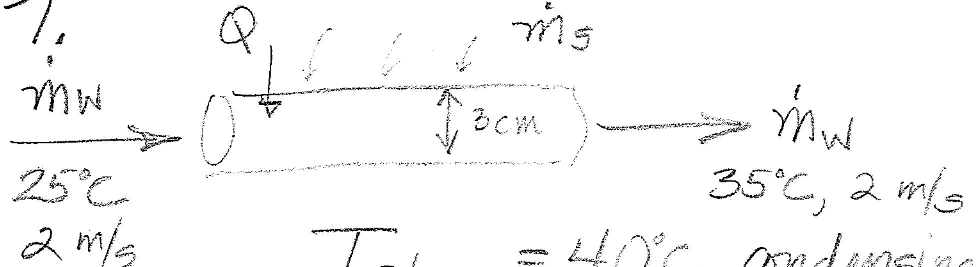
b) 1st Law, house, $T_H = 24^\circ C$

$$\dot{Q} = \dot{m}\left(c_p\left(T_H - T_3\right)\right)$$

$$= 4.28\ \tfrac{\mathrm{kg}}{\mathrm{s}}\left(1.005\ \tfrac{\mathrm{kJ}}{\mathrm{kg\,K}}\right)(24 - 22.8)\,\mathrm{K}$$

$$\dot{Q} = \boxed{5.2\ \mathrm{kW}}$$

7.



Find: $\dot{m}_s$

$T_{steam} = 40^\circ C$ condensing steam from sat vapor to sat liquid

1st Law water only

$$\dot{Q} = \dot{m}_W c_p (T_2 - T_1) \quad \text{where } \dot{m} = \rho V A$$

$$\dot{Q} = 1000\ \tfrac{\mathrm{kg}}{\mathrm{m}^3}\left(2\ \tfrac{\mathrm{m}}{\mathrm{s}}\right)\frac{(0.03\,\mathrm{m})^2}{4}\pi\left(4.184\ \tfrac{\mathrm{kJ}}{\mathrm{kg\,K}}\right)(35-25)\,\mathrm{K}$$

$$\dot{Q} = 59.1\ \mathrm{kW}\ (+)$$

1st Law steam only

$$-59.1\ \mathrm{kW} = \dot{m}_s(-h_{fg})$$

h_{fg} @ $40^\circ C = 2406.1\ \mathrm{kJ/kg}$

$$\dot{m}_s = \frac{59.1\ \mathrm{kJ/s}}{2406.1\ \mathrm{kJ/kg}} = \boxed{0.0245\ \mathrm{kg/s}}$$

8. Adiabatic pump

1^{st} Law $-\dot{W} = \dot{m}(h_2 - h_1)$,

also for pump $du \simeq 0$

$$dh = 0 + d(Pv) = P\,dv + v\,dP$$

incompressible $P\,dv = 0$

$$w = v(P_2 - P_1) \quad P_1 = 25\text{kPa},\ P_2 = 10\text{MPa}$$

a) $-\dot{W} = \dot{m}v(P_2 - P_1)$ $\quad v = v_f @ 25\text{kPa} = 0.00102\ m^3/kg$

$$= 15\frac{kg}{s}\ 0.00102\frac{m^3}{kg}(10000 - 25)\text{kPa}$$

$$-\dot{W} = \boxed{152.6\text{ kW}} = \dot{m}(h_2 - h_1)$$

b) $h_1 = h_f @ 25\text{kPa} = 271.96\ \frac{kJ}{kg}$

$$h_2 = \frac{152.6\ kJ/s}{15\ kg/s} + 271.96\ \frac{kJ}{kg}$$

$$\boxed{h_2 = 282.1\ kJ/kg}$$

9. adiabatic nozzle with steam

① inlet 3 MPa, 400°C, 40 m/s

② outlet 2.5 MPa, 300 m/s

a) find T_2

1^{st} Law $$0 - 0 = h_2 - h_1 + \frac{V_2^2 - V_1^2}{2000}$$

h_1 (superheated) $= 3231.7$ kJ/kg

$$h_2 = 3231.7 - \frac{(V_2^2 - V_1^2)}{2000} = 3231.7 - \frac{(300^2 - 40^2)}{2000}$$

$h_2 = 3,187.5$ kJ/kg

$h_2 > h_g @ 2.5\text{MPa}$ so superheated $350 < T_2 < 400°C$

9. a) interpolate $\frac{T_2 - 350}{400-350} = \frac{3187.5-3127}{3240.1-3127}$ & $T_2 = \boxed{376.7°C}$

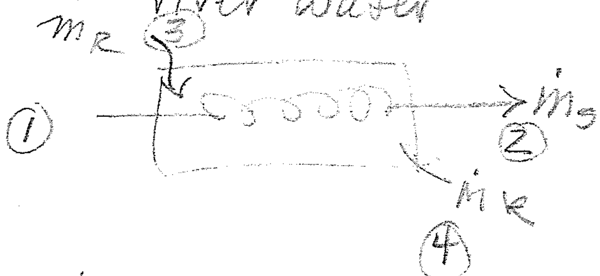
b) find $\frac{A_1}{A_2} = \left(\frac{V_2}{V_1}\right)\left(\frac{v_1}{v_2}\right)$

$v_1 = 0.09938\ m^3/kg$ (A-13 @ 3MPa)

$\frac{v_2 - 0.10979}{0.12012-0.10979} = \frac{376.7-350}{50}$, $v_2 = 0.11531\ m^3/kg$

$\frac{A_1}{A_2} = \left(\frac{300}{40}\right)\left(\frac{0.09938}{0.11531}\right) = \boxed{6.46}$

10. steam in heat exchanger (adiabatic) cooled by river water



$\Delta T_R \leq 10°C$

$\dot{m}_s = 20{,}000\ kg/hr$

① 20 kPa, $x=0.95$

② 20 kPa, $x=0$

1st Law for entire CV: $0 = \dot{m}_R(C_p(10°)) + \dot{m}_s(h_2 - h_1)$

$\dot{m}_R = \frac{\dot{m}_s(h_2-h_1)}{-C_p(10)}$

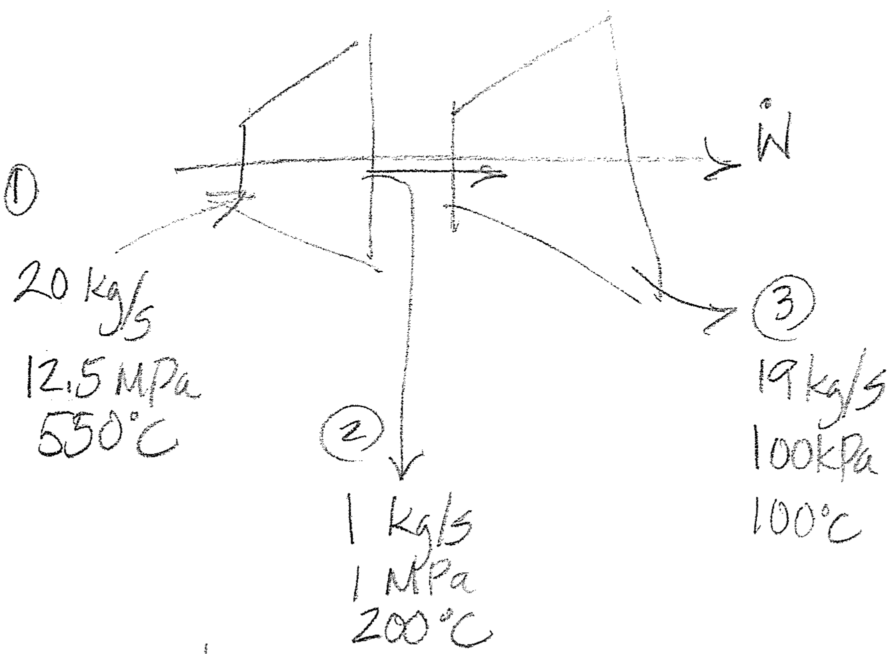
$h_1 = 0.95 h_{fg} + h_f$ @ 20kPa
$= 0.95(2357.6) + 251.42 = 2491.14\ kJ/kg$

$h_2 = h_f$ @ 20kPa $= 251.42\ kJ/kg$

$\dot{m}_R = \frac{20{,}000\ \frac{kg}{hr}(251.42 - 2491.14)\ kJ/kg}{-4.184\ \frac{kJ}{kgK}(10)K} = \boxed{1.07\times10^6\ \frac{kg}{hr}}$

$\dot{m}_R = \frac{1.07\times10^6\ kg/hr}{3600\ s/hr} = \boxed{297.4\ kg/s}$

11. 2-stage turbine adiabatic, 5% steam removed after stage 1



find $\dot{W}$

$h_1 = 3476.5$ kJ/kg (A-6)

$h_2 = 2828.3$ kJ/kg (A-6)

$h_3 = 2675.8$ kJ/kg (A-6)

1st Law: $0 - \dot{W} = \dot{m}_1 (h_2 - h_1) + \dot{m}_3 (h_3 - h_2)$

$$-\dot{W} = 20 \frac{kg}{s} (2828.3 - 3476.5) + 19 \frac{kg}{s} (2675.8 - 2828.3)$$

$$\dot{W} = 15,862 \text{ kW} \times 10^{-3} \frac{\text{MW}}{\text{kW}} = \boxed{15.9 \text{ MW}}$$

AREN 2110: Thermodynamics
Spring 2011

HOMEWORK 7: Due Monday, March 14, 6 PM (11 problems, 35 points possible)

1. (5 points, 1 point per part) 997 kJ heat is added to a rigid tank containing 3 kg water of which 0.6 kg is vapor, at 150 kPa. The final pressure in the tank is 325 kPa.

a) What is the final temperature?

b) What is the mass of water in the vapor phase after heat addition to the rigid tank?

c) If one boundary were movable to obtain an isobaric process, what would the final temperature be with the same heat addition?

d) What is the work done in the isobaric process?

e) Draw both processes on the T-v diagram below.