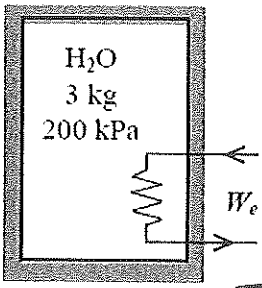
CANKAYA UNIVERSITY
FACULTY OF ENGINEERING AND ARCHITECTURE
MECHANICAL ENGINEERING DEPARTMENT
ME 211 THERMODYNAMICS I

FALL 2016

HW # 6

1) A well-insulated rigid tank contains 3 kg of a saturated liquid–vapor mixture of water at 200 kPa. Initially, three-quarters of the mass is in the liquid phase. An electric resistance heater placed in the tank is now turned on and kept on until all the liquid in the tank is converted to saturated vapor. Determine the entropy change of the steam during this process.



$m = 3\ kg$

$P_1 = 200\ kPa$

$x_1 = (3 - \frac{3}{4}\cdot 3)/3 = 0.25$

$P_1 = 2\ bar$, $x_1 = 0.25$] $v_1 = v_f + x_1 v_{fg} = 0.22224\ m^3/kg$

$s_1 = s_f + x_1 s_{fg} = 1.5301 + 0.25(7.1271 - 1.5301) = 2.9294\ kJ/kgK$

rigid container

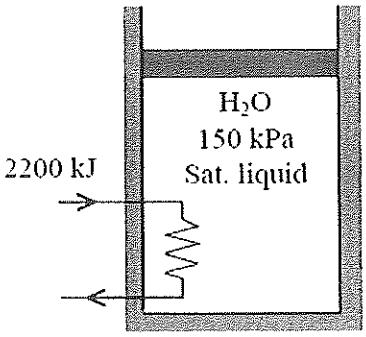
$v_2 = v_1 = 0.22224\ m^3/kg$, $x_2 = 1$] $s_2 = s_g$

v_g	s_g
0.2404	6.6628
0.22224	
0.2150	6.6626

$s_g \approx 6.6335\ kJ/kgK$

$\Delta S = m(s_2 - s_1) = 11.1\ kJ/K$

2) An insulated piston–cylinder device contains 5 L of saturated liquid water at a constant pressure of 150 kPa. An electric resistance heater inside the cylinder is now turned on, and 2200 kJ of energy is transferred to the steam. Determine the entropy change of the water during this process.



$P_1 = 150\,kPa = 1.5\,bar$

$x_1 = 0$

$\rightarrow v_1 = v_f = 0.001053\ m^3/kg$

$h_1 = h_f = 467.13\ kJ/kg$

$s_1 = s_f = 1.4337\ kJ/kg\,K$

$m = \frac{V}{v_1} = \frac{0.005}{0.001053}$

$= 4.75\ kg$

$\cancel{Q}^{0} - W = m(u_2 - u_1) \qquad \Delta KE = \Delta PE = 0 \qquad W = W_b + W_e$

$W_b = \int_1^2 p\,dV = p(V_2 - V_1) = mp(v_2 - v_1)$

$0 - W_e = m(u_2 - u_1) + mp(v_2 - v_1) = m(h_2 - h_1)$

$\therefore h_2 = h_1 + \frac{W_e}{m} = 467.13 + \frac{2200}{4.75} = 930.33\ kJ/kg$

(2) $P_2 = 1.5\ bar \longrightarrow h_f = 467.13\ kJ/kg$

$h_2 = 930.33\ kJ/kg \qquad h_g = 2693.6$ "

$h_f < h_2 < h_g$ sat. liq. vapor mixture.

$h_2 = h_f + x_2(h_g - h_f)$

$930.33 = 467.13 + x_2(2693.6 - 930.33)$

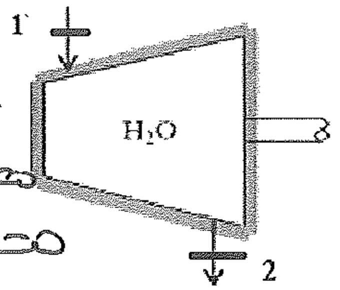
$x_2 = 0.2081$

$s_2 = s_f + x_2(s_g - s_f) = 1.4337 + 0.2081(7.2233 - 1.4337)$

$= 2.6384\ kJ/kg$

$\Delta S = m(s_2 - s_1) = 5.72\ kJ/kg$

3) Steam enters an adiabatic turbine at 6 MPa and 500 ^{0}C and leaves at a pressure of 0.3 MPa. Determine the maximum amount of work that can be delivered by this turbine.



SSSF

$\Delta KE \cong 0$

$\Delta PE \cong 0$

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

$P_1 = 6MPa = 60\,bar \rightarrow T_{SAT} = 275.6°C$

$T_1 = 500°C$

$T_1 > T_{SAT}$ superheated

$h_1 \cong 3423.1$ kJ/kg

$s_1 \cong 6.8826$ kJ/kg K

$P_2 = 0.3MPa = 3\,bar \longrightarrow s_f = 1.6718 \frac{kJ}{kgK}$

$s_g = 6.9919$ ″

$s_2 = s_1 = 6.8826$ kJ/kg

$$6.8826 = 1.6718 + x_2(6.9919 - 1.6718)$$

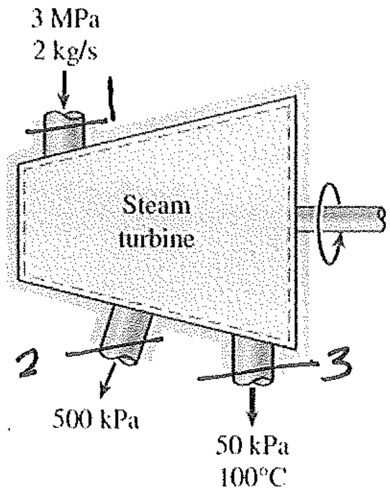
$$x_2 = 0.979$$

$$h_2 = h_f + x_2 h_{fg} = 561.47 + 0.979(2163.8)$$

$$= 2679.83 \text{ kJ/kg}$$

$$\frac{\dot{W}_t}{\dot{m}} = h_1 - h_2 \cong 742.6 \text{ kJ/kg}$$

4) An isentropic steam turbine processes 2 kg/s of steam at 3 MPa, which is exhausted at 50 kPa and 100 ^{0}C. 5 percent of this flow is diverted for feedwater heating at 500 kPa. Determine the power produced by this turbine, in kW.



$\Delta KE = \Delta PE = 0$ SSSF

$$\cancel{\dot{Q}_{cv}}^{0} - \dot{W}_{cv} = \sum \dot{m}_e h_e - \sum \dot{m}_i h_i$$

$$-\dot{W}_t = \dot{m}_2 h_2 + \dot{m}_3 h_3 - \dot{m}_1 h_1$$

$$\dot{W}_t = \dot{m}_1 h_1 - (\dot{m}_2 h_2 + \dot{m}_3 h_3)$$

$\dot{m}_1 = 2$ kg/s $\qquad \dot{m}_1 = \dot{m}_2 + \dot{m}_3$

$\dot{m}_2 = 0.05\,\dot{m}_1 = (0.05)(5) = 0.25$ kg/s

$\dot{m}_3 = 4.75$ kg/s

$P_3 = 50kPa = 0.5$ bar $\rightarrow T_{SAT} = 81.33°C$] $h_3 = 2682.4$ kJ/kg

$T_3 = 100°C$ superheated vapor $\qquad s_3 = 7.6953$ kJ/kg

$T_3 > T_{SAT}$

$P_1 = 3MPa = 30$ bar $\longrightarrow s_f = 2.6457$ kJ/kg K

$s_g = 6.1869$ "

$s_1 = s_3 = 7.6953$ kJ/kg

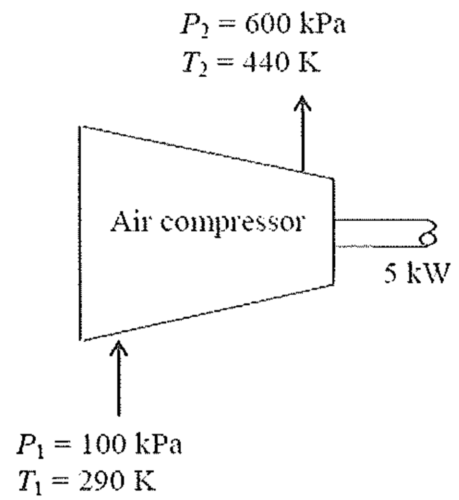
$s_3 > s_g$ superheated vapor

so $h_3 \cong 3206.5$ kJ/kg

$\dot{W}_t = \dot{m}_1 h_1 - [\dot{m}_2 h_2 + \dot{m}_3 h_3] = 2285$ kW

(5)

5) Air is compressed steadily by a 5-kW compressor from 100 kPa and 17 ^{0}C to 600 kPa



SSSF

$\Delta KE \cong 0$

$\Delta PE \cong 0$

$R = 0{,}287 \ \frac{kJ}{kgK}$ ← air

and 167 ^{0}C at a rate of 1.6 kg/min. During this process, some heat transfer takes place between the compressor and the surrounding medium at 17 ^{0}C. Determine the rate of entropy change of air during this process.

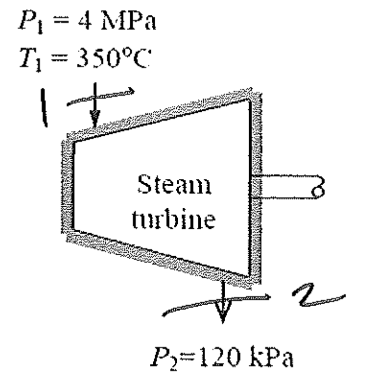
$\left.\begin{array}{l} T_1 = 290K \\ P_1 = 100kPa \end{array}\right] s_1^o = 1.66802 \ \frac{kJ}{kg\,K}$

$\left.\begin{array}{l} T_2 = 440K \\ P_2 = 600 \ kPa \end{array}\right] s_2^o = 2.0887 \ kJ/kg\,K$

$\Delta \dot{S} = \dot{m}[s_2 - s_1] = \dot{m}\left[s_2^o - s_1^o - R \ln \frac{P_2}{P_1}\right]$

$= -0.0025 \ kW/K$

6) Steam at 4 MPa and 350 ^{0}C is expanded in an adiabatic turbine to 120 kPa. What is the isentropic efficiency of this turbine if the steam is exhausted as a saturated vapor?



SSSF

$\Delta KE = 0$

$\Delta PE = 0$

$\cancel{\dot{Q}_{cv}}^{0} - \dot{W}_t = \dot{m}\,(h_2 - h_1)$

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

$P_1 = 4\,MPa = 40$ bar $\rightarrow T_{SAT} = 250.4$ °C

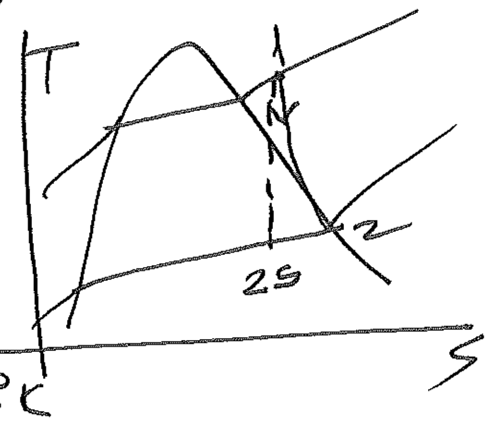
$T_1 = 350$ °C $\quad T_1 > T_{SAT}$ superheated

$\therefore h_1 = 3093.3$ kJ/kg

$s_1 = 6.5843$ kJ/kg

$P_2 = 120$ kPa $= 1.2$ bar $\Big] \; h_2 = h_g = 2683.1$ kJ/kg

$x_2 = 1$



$P_{2s} = 1.2$ bar

$s_{2s} = s_1 = 6.5843$ kJ/kg

$P_{2s} = 1.2$ bar $\rightarrow s_f = 1.3608$ kJ/kg K

$s_g = 7.2981$ "

$6.584 = 1.3608 + x_{2s}\,(7.2981 - 1.3608)$

$x_{2s} = 0.879$

$h_{2s} = h_f + x_{2s} h_{fg} = 439.37 + 0.879(2244.2)$

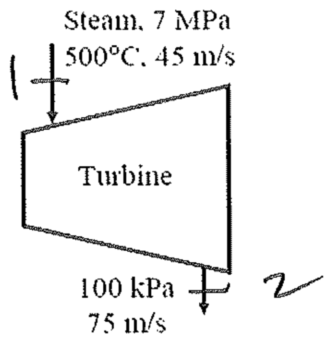
$= 2413$ kJ/kg

$\eta_t = \dfrac{W_a}{W_s} = \dfrac{(h_1 - h_2)\dot{m}}{(h_1 - h_{2s})\dot{m}} = (h_1 - h_2)/(h_1 - h_{2s}) = 0.603$

% 60.3

(7)

7) Steam enters an adiabatic turbine steadily at 7 MPa, 500 °C, and 45 m/s, and leaves at 100 kPa and 75 m/s. If the power output of the turbine is 5 MW and the isentropic efficiency is 77 percent, determine (*a*) the mass flow rate of steam through the turbine, (*b*) the temperature at the turbine exit, and (*c*) the rate of entropy generation during this process.



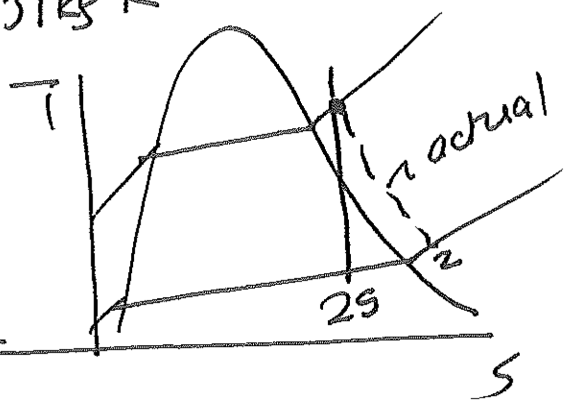
$\cancel{\dot{Q}_{cv}}^{0} - \dot{W}_{cv} = \dot{m}\left[(h_2 - h_1) + \frac{1}{2}(V_2^2 - V_1^2)\right]$

$P_1 = 70$ bar $\rightarrow T_{SAT} = 285.9\,^{\circ}C$

$T_1 = 500\,^{\circ}C$ $\quad T_1 > T_{SAT}$ superheated

$h_1 = 3411.4$ kJ/kg

$s_1 = 6.8$ kJ/kg K



$P_2 = 1$ bar

$s_{2s} = s_1 = 6.8$

$s_f = 1.3026$ kJ/kg

$s_g = 7.3594$ "

$s_f < s_{2s} < s_g$ sat. liq. mixture

$6.8 = 1.3026 + x_{2s}(7.3594 - 1.3026)$

$x_{2s} = 0.907$

$h_{2s} = h_f + x_{2s} h_{fg} = 417.46 + 0.907(2258)$

$= 2465.46$ kJ/kg

$\dot{W}_s = \frac{\dot{W}_a}{\eta_t} = \frac{5000}{0.77} = 6494$ kW

1–2s process:

$-(\dot{W}_t)_s = \dot{m}\left[(h_{2s} - h_1) + \frac{1}{2}(V_2^2 - V_1^2) \div\right]$

$\dot{m} = 6.886$ kg/s

1-2 process (actual process)

$$\dot{m}\left(h_1+\frac{1}{2}V_1^2\right)=\dot{m}\left(h_2+\frac{1}{2}V_2^2\right)+\left(\dot{W}_t\right)_a$$

$h_2 = 2683.5$ kJ/kg

$\therefore$ $P_2 = 1$ bar $\longrightarrow$ $h_f = 417.46$ kJ/kg

$h_2 = 2683.5$ kJ/kg $\qquad h_g = 2675.5$ //

$h_2 > h_g$ superheated

1 bar		
h	s	T
2676.2	7.3614	100
2683.5		
2716.6	7.4668	120

$\therefore$ $T_2 \simeq 103.7°C$

$s_2 = 7.3817 \frac{kJ}{kg K}$

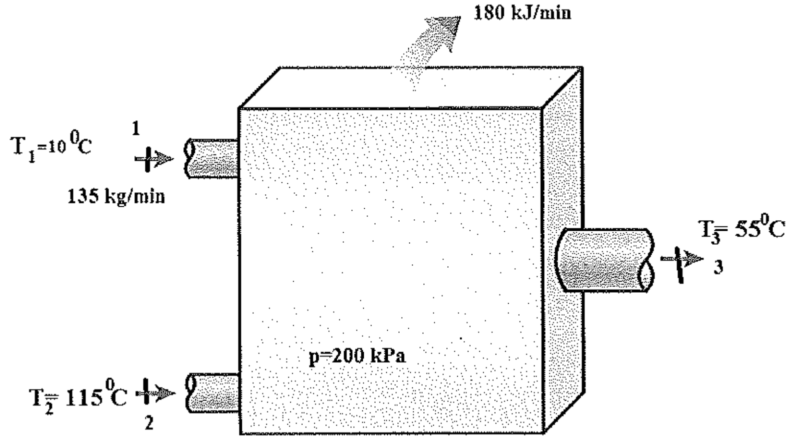
$$\dot{\sigma}_t = \dot{m}(s_2 - s_1) = 4.01 \text{ kJ/kg}$$

i.e. $\cancel{\sum \frac{\dot{Q}_j}{T_j}} + \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \dot{\sigma}_{cv}$

adiabatic $\qquad \dot{m}_1 s_1 - \dot{m}_2 s_2 + \dot{\sigma}_{cv} = 0$

$\dot{m}_1 = \dot{m}_2 = \dot{m} \qquad \dot{\sigma}_{cv} = \dot{m}(s_2 - s_1)$

8) Water at 200 kPa and 10 ^{0}C enters a mixing chamber at a rate of 135 kg/min where it is mixed steadily with steam entering at 200 kPa and 150 ^{0}C. The mixture leaves the chamber at 200 kPa and 55 ^{0}C , and heat is lost to the surrounding air at 20 ^{0}C at a rate of 180 kJ/min. Neglecting the changes in kinetic and potential energies, determine the rate of entropy generation during this process?



$\Delta KE = 0$
$\Delta PE = 0$
SSSF
$\sum \dot m_i = \sum \dot m_e$
$\dot m_1 + \dot m_2 = \dot m_3$

$$0 = \sum \frac{\dot Q_j}{T_j} + \sum \dot m_i s_i - \sum \dot m_e s_e + \dot\sigma_{cv}$$

$$\frac{\dot Q_{cv}}{T} + \dot m_1 s_1 + \dot m_2 s_2 - \dot m_3 s_3 + \dot\sigma_{cv} = 0$$

$$\dot\sigma_{cv} = \dot m_3 s_3 - \left[\dot m_1 s_1 + \dot m_2 s_2 + \frac{\dot Q_{cv}}{T} \right]$$

2) $\dot Q_{cv} - \cancel{\dot W_{cv}}^{\,0} = \sum \dot m_e h_e - \sum \dot m_i h_i$

$$\dot Q_{cv} = \dot m_3 h_3 - [\dot m_1 s_1 + \dot m_2 s_2]$$

$P_1 = 2$ bar, $T_1 = 10°C$] $h_1 = h_f = 42.022$ kJ/kg ← compressed Liquid
$s_1 = s_f = 0.1511$ kJ/kgK

$P_2 = 2$ bar → $T_{SAT} = 120.°C$ superheated $T_2 > T_{SAT}$
$T_2 = 150°C$ $h_2 = 2870.7$ kJ/kg
$s_2 = 7.5081$ kJ/kg K

(3) $P_3 = 2$ bar, $T_3 = 55°C$) $T_3 < T_{SAT}$ compressed liquid (10)

$h_3 = h_f = 230.26$ kJ/kg

$s_3 = s_f = 0.7680$ kJ/kg K

a) from energy balance $\dot{m}_2 = 9.692$ kg/min

b) from entropy balance

$\dot{\sigma}_{cv} = 18.6 \frac{kJ}{min\,K}$