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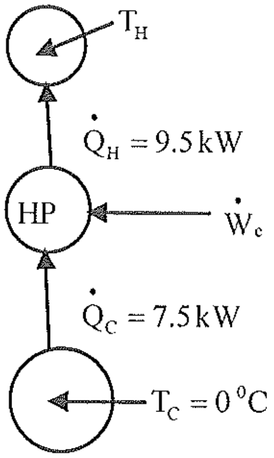
Çankaya University
Faculty of Engineering
Mechanical Engineering Department
ME 211 Thermodynamics I
Closed Notes and Bookes
Fall 2016
Final Exam

1) A reversible heat pump cycle operating at steady state receives energy at the rate $\dot{Q}_C = 7.5\,\mathrm{kW}$ from a cold reservoir at temperature $T_C = 0\,^0\mathrm{C}$ and discharges energy at the rate $\dot{Q}_H = 9.5\,\mathrm{kW}$ to a hot reservoir at temperature T_H . Determine the value of T_H and the coefficient of performance of heat pump.



$$\gamma = \frac{\dot{Q}_H}{\dot{Q}_H - \dot{Q}_C} = \frac{9{,}5}{9{,}5 - 7{,}5} = 4{,}75$$

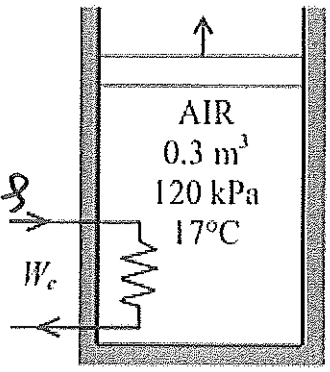
$$\gamma = \frac{T_H}{T_H - T_c}$$

$$4{,}75 = \frac{T_H}{T_H - 273} \rightarrow T_H = 345{,}8\ \mathrm{K}$$

2) An insulated piston–cylinder device initially contains 300 L of air at 120 kPa and 17 °C. Air is now heated for 15 min by a 200-W resistance heater placed inside the cylinder. The pressure of air is maintained constant during this process. Determine the entropy production term σ . Hint: you may use $c_p = 1.02\,kJ/kg.K$ or you can use Air Tables.

$m = \frac{P_1 V_1}{R T_1}$

$= 0.4325\ kg$



closed system $\Delta KE = 0$

$\Delta PE = 0 \quad Q = 0$

$\cancel{Q}^{0} - W = m(u_2 - u_1)$

$-(W_e + W_p) = m(u_2 - u_1)$

$W_p = mp(v_2 - v_1)$

$-(-W_e) = m(h_2 - h_1)$

$W_e = mc_p(T_2 - T_1)$

$W_e = (200\,\frac{J}{s})(15\,min)(\frac{60\,s}{min}) = 180\,kJ$

$T_2 = \frac{W_e}{mc_p} + T_1 = \frac{180}{(1.02)(0.4325)} + 290$

$= 698\,K \approx 700\,K$

$\Delta S = \cancel{\int \frac{\delta Q}{T}}^{0} + \sigma \qquad \sigma = m(s_2 - s_1)$

$\sigma = m[c_p \ln \frac{T_2}{T_1} - \cancel{R \ln P_2/P_1}^{0}]$

$= (0.4325)(1.02) \ln \frac{698}{290} = 0.387\ \frac{kJ}{K}$

Method 2:

$T_1 = 290\,K$ $h_1 = 290.16\,\frac{kJ}{kg}$

$W_e = m\,(h_2 - h_1)$

$180 = (0,4325)(h_2 - 290,16)$

$h_2 \cong 706\,kJ/kg \longrightarrow T_2 \approx 690\,K$

$T_1 = 290K$ $s_1^0 \cong 1.66802\,kJ/kg\,K$

$T_2 \cong 700K$ $s_2^0 = 2,57277\,kJ/kg\,K$

$\sigma = m\left[s_2^0 - s_1^0 - \underset{0}{\cancel{R \ln P_2/P_1}}\right)$

$= (0,4325)(2,57277 - 1.66802)$

$= 0,3913\,kJ/K$

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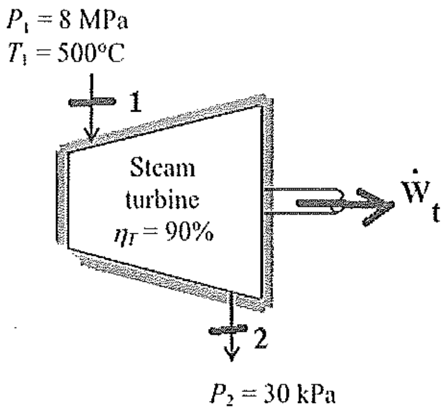
3) Steam enters an adiabatic turbine at 8 MPa and 520 ^{0}C with a mass flow rate of 3 kg/s and leaves at 30 kPa. The isentropic efficiency of the turbine is 0.90. Neglecting the kinetic and potential energy change of the steam,

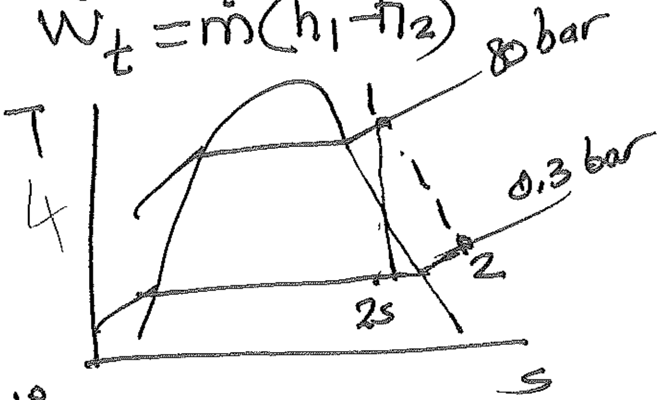


SSSF
$\Delta KE = 0$
$\Delta PE = 0$

$$-\dot{W}_t = \dot{m}(h_2 - h_1) \quad 2$$

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

(a) Show the cess on the T-s diagram
(b) determine wer output of the turbine.
(c) [illegible]



① $P_1 = 80$ bar $\rightarrow T_{SAT} = 295{,}1°C$
$T_1 = 520°C \quad T_1 > T_{SAT}$ superheated
$h_1 = 3447{,}7$ kJ/kg
$s_1 = 6{,}7871$ kJ/kgK

5

(2s) $P_{2s} = 0{,}3$ bar
$s_{2s} = s_1 = 6{,}7871$

$s_{2s} = s_f + x_{2s} s_{fg}$
$6{,}7871 = 0{,}9439 + x_{2s}(7.6686 - 0{,}9439)$
$x_{2s} \cong 0{,}87$ 5

$$h_{2s} = h_f + x_{2s} h_{fg} = 289.23 + 0{,}87(2336{,}1)$$
$$= 2321{,}6 \text{ kJ/kg} \quad 4$$

3

$$\eta_t = \frac{h_1 - h_2}{h_1 - h_{2s}} \rightarrow h_2 = h_1 - \eta_t(h_1 - h_{2s})$$

$$h_2 = 3447.7 - 0.9\,(3477.7 - 2321.6)$$

$$= 2434.2 \text{ kJ/kg}$$

5

$$\dot{W}_t = 3\,(3447.7 - 2434.2) \approx 3040 \text{ kW}$$

Water: (Table A.2)

$T_1 = 15°C \Rightarrow$ (comp. liq.) $h_1 = h_f = \underline{62,99}$ kJ/kg, $s_1 = 0,2245$

$T_2 = 23°C \Rightarrow h_2 = h_f = \underline{96,52 \text{ kJ/kg}}$, $s_2 = 0,3393$ kJ/kgK kJ/kgK.

R-22:

$P_3 = 12$ bar, $T_3 = 90°C$ (table A.9)
$h_3 = \underline{308,7}$ kJ/kg, $s_3 = 1,0363$ kJ/kgK } superheated

$T_4 = 28°C$, $P_4 = 12$ bar (compressed liq.) ⑩
$h_4 = h_f = \underline{79,05 \text{ kJ/kg}}$, $s_4 = s_f = 0,2936$ kJ/kgK

a) $$0 = \underset{0}{\cancel{\dot Q_{cv}}} - \underset{0}{\cancel{\dot W_{cv}}} + \dot m_w \left[(h_1 - h_2) + \cancel{\frac{V_1^2 - V_2^2}{2}} + g\cancel{(z_1 - z_2)} \right]$$
$$+ \dot m_{Ref} \left[(h_3 - h_4) + \cancel{\frac{V_3^2 - V_4^2}{2}} + g\cancel{(z_3 - z_4)} \right]$$

$$\Rightarrow \dot m_w (h_1 - h_2) + \dot m_{ref} (h_3 - h_4) = 0$$

$$\dot m_w = \dot m_{ref} \frac{(h_4 - h_3)}{(h_1 - h_2)} = 150 \cdot \frac{(79,05 - 308,7)}{(62,99 - 96,52)}$$ ⑦

$$\dot m_w = 150 \cdot 6,85 = 1027,36 \text{ kg/h}$$

$\underline{\underline{\dot m_w = 0,285 \text{ kg/s}}}$ $\left(m_{ref} = \frac{150}{3600} = 0,042 \text{ kg/s} \right)$

b) $$\dot 0 = \sum_j \underset{0}{\cancel{\frac{\dot Q_j}{T_j}}} + m_1 s_1 + m_3 s_3 - m_2 s_2 - m_4 s_4 + \dot\sigma_{cv}$$

⑧

$$\Rightarrow m_w (s_1 - s_2) + m_{ref} (s_3 - s_4) + \dot\sigma_{cv} = 0$$

$$0 = 0,285 (0,224 - 0,3393) + 0,042 (1,0363 - 0,2936) + \dot\sigma_{cv}$$

$\Rightarrow \underline{\underline{\dot\sigma_{cv} = 0,0017 \text{ kJ/K}}}$.   6,12 kWh/K

$\text{kW} = \frac{\text{kJ}}{\text{s}}$