MAK 212 - TERMODİNAMİK
CRN: 21688, 21689, 21690, 21691, 21692
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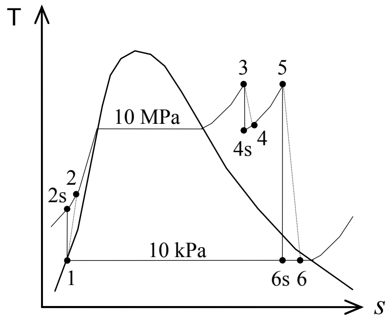
<u>**1**</u> (a) From the steam tables,

$$h_1 = h_{f@10kPa} = 191.83 kJ/kg$$

$$v_1 = v_{f@10kPa} = 0.00101 m^3/kg$$



$$\begin{aligned} w_{p,in} &= v_1(P_2 - P_1)/\eta_p \\ &= (0.00101 m^3/kg)(10{,}000 - 10 kPa)\left(\frac{1 kJ}{1 kPa\cdot m^3}\right)/(0.95) \\ &= 10.62 kJ/kg \end{aligned}$$

$$h_2 = h_1 + w_{p,in} = 191.83 + 10.62 = 202.45 kJ/kg$$

$$\left.\begin{aligned} P_3 &= 10 MPa \\ T_3 &= 500^\circ C \end{aligned}\right\} \begin{aligned} h_3 &= 3373.7 kJ/kg \\ s_3 &= 6.5966 kJ/kg\cdot K \end{aligned}$$

$$\left.\begin{aligned} P_{4s} &= 1 MPa \\ s_{4s} &= s_3 \end{aligned}\right\} h_{4s} = 2782.5 kJ/kg$$

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} \longrightarrow \begin{aligned} h_4 &= h_3 - \eta_T(h_3 - h_{4s}) \\ &= 3373.7 - (0.80)(3373.7 - 2782.5) = 2900.74 kJ/kg \end{aligned}$$

$$\left.\begin{aligned} P_5 &= 1 MPa \\ T_5 &= 500^\circ C \end{aligned}\right\} \begin{aligned} h_5 &= 3478.5 kJ/kg \\ s_5 &= 7.7622 kJ/kg\cdot K \end{aligned}$$

$$\left.\begin{aligned} P_{6s} &= 20 kPa \\ s_{6s} &= s_5 \end{aligned}\right\} \begin{aligned} x_{6s} &= \frac{s_{6s} - s_f}{s_{fg}} = \frac{7.7622 - 0.6493}{7.5009} = 0.948 \ (\text{atturbineexit}) \\ h_{6s} &= h_f + x_{6s} h_{fg} = 191.83 + (0.948)(2392.8) = 2460.2 kJ/kg \end{aligned}$$

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} \longrightarrow \begin{aligned} h_6 &= h_5 - \eta_T(h_5 - h_{6s}) \\ &= 3478.5 - (0.80)(3478.5 - 2460.2) \\ &= 2663.86 kJ/kg > h_g \ (\text{superheated vapor}) \end{aligned}$$

From steam tables at 10 kPa we read T_6 = **87.5°C**.

(b) $$w_T = (h_3 - h_4) + (h_5 - h_6) = 3373.7 - 2900.74 + 3478.5 - 2663.86 = 1287.6 kJ/kg$$

$$q_{in} = (h_3 - h_2) + (h_5 - h_4) = 3373.7 - 202.45 + 3478.5 - 2900.74 = 3749.0 kJ/kg$$

$$w_{net} = w_T - w_{p,in} = 1287.6 - 10.62 = 1277.0 kJ/kg$$

Thus the thermal efficiency is

$$\eta_{th} = \frac{w_{net}}{q_{in}} = \frac{1277.0 kJ/kg}{3749.0 kJ/kg} = \mathbf{34.1\%}$$

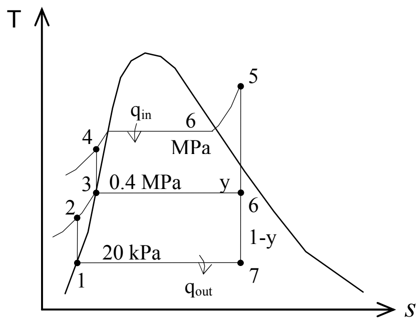
(c) The mass flow rate of the steam is

$$\dot{m} = \frac{\dot{W}_{net}}{w_{net}} = \frac{150{,}000\, kJ/s}{1277.0\, kJ/kg} = \mathbf{117.5\ kg/s}$$

2 (a) From the steam tables,

$$h_1 = h_{f@20kPa} = 251.40 kJ/kg$$

$$v_1 = v_{f@20kPa} = 0.001017 m^3/kg$$



$$w_{pI,in} = v_1(P_2 - P_1)$$
$$= (0.001017 m^3/kg)(400 - 20 kPa)\left(\frac{1 kJ}{1 kPa \cdot m^3}\right)$$
$$= 0.39 kJ/kg$$

$$h_2 = h_1 + w_{pI,in} = 251.40 + 0.39 = 251.79 kJ/kg$$

$$\left.\begin{array}{l} P_3 = 0.4 MPa \\ sat.liquid \end{array}\right\} \begin{array}{l} h_3 = h_{f@0.4MPa} = 604.74 kJ/kg \\ v_3 = v_{f@0.4MPa} = 0.001084 m^3/kg \end{array}$$

$$w_{pII,in} = v_3(P_4 - P_3)$$
$$= (0.001084 m^3/kg)(6000 - 400 kPa)\left(\frac{1 kJ}{1 kPa \cdot m^3}\right)$$
$$= 6.07 kJ/kg$$

$$h_4 = h_3 + w_{pII,in} = 604.74 + 6.07 = 610.81 kJ/kg$$

$$\left.\begin{array}{l} P_5 = 6 MPa \\ T_5 = 450^\circ C \end{array}\right\} \begin{array}{l} h_5 = 3301.8 kJ/kg \\ s_5 = 6.7193 kJ/kg \cdot K \end{array}$$

$$\left.\begin{array}{l} P_6 = 0.4 MPa \\ s_6 = s_5 \end{array}\right\} \begin{array}{l} x_6 = \dfrac{s_6 - s_f}{s_{fg}} = \dfrac{6.7193 - 1.7766}{5.1193} = 0.9655 \\ h_6 = h_f + x_6 h_{fg} = 607.74 + (0.9655)(2133.8) = 2664.93 kJ/kg \end{array}$$

$$\left.\begin{array}{l} P_7 = 20 kPa \\ s_7 = s_5 \end{array}\right\} \begin{array}{l} x_7 = \dfrac{s_7 - s_f}{s_{fg}} = \dfrac{6.7193 - 0.8320}{7.0766} = 0.8319 \\ h_7 = h_f + x_7 h_{fg} = 251.40 + (0.8319)(2358.3) = 2213.3 kJ/kg \end{array}$$

The fraction of steam extracted is determined from the steady-flow energy equation applied to the feedwater heater. Noting that $\dot{Q} \cong \dot{W} \cong \Delta ke \cong \Delta pe \cong 0$,

$$\sum \dot{m}_i h_i = \sum \dot{m}_e h_e \longrightarrow \dot{m}_6 h_6 + \dot{m}_2 h_2 = \dot{m}_3 h_3 \longrightarrow y h_6 + (1 + y) h_2 = 1(h_3)$$

where y is the fraction of steam extracted from the turbine ($= \dot{m}_6 / \dot{m}_3$). Solving for y,

$$y = \frac{h_3 - h_2}{h_6 - h_2} = \frac{604.74 - 251.79}{2664.93 - 251.79} = 0.1463$$

Then,

$$q_{in} = h_5 - h_4 = 3301.8 - 610.81 = 2691.0 kJ/kg$$
$$q_{out} = (1 - y)(h_7 - h_1) = (1 - 0.1463)(2213.3 - 251.4) = 1674.9 kJ/kg$$

and

$$w_{net} = q_{in} - q_{out} = 2691.0 - 1674.9 = \mathbf{1016.1\ kJ/kg}$$

(b) The thermal efficiency is determined from

$$\eta_{th} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{1674.9\, kJ/kg}{2691.0\, kJ/kg} = \mathbf{37.8\%}$$

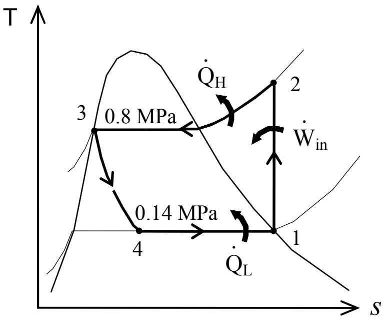
3 (a) In an ideal vapor-compression refrigeration cycle, the compression process is isentropic, the refrigerant enters the compressor as a saturated vapor at the evaporator pressure, and leaves the condenser as saturated liquid at the condenser pressure. From the refrigerant tables,

$$\left.\begin{array}{l} P_1 = 140kPa \\ sat.vapor \end{array}\right\} \begin{array}{l} h_1 = h_{g@140kPa} = 236.04kJ/kg \\ s_1 = s_{g@140kPa} = 0.9322kJ/kg \cdot K \end{array}$$

$$\left.\begin{array}{l} P_2 = 0.8MPa \\ s_2 = s_1 \end{array}\right\} h_2 = 272.05kJ/kg$$

$$\left.\begin{array}{l} P_3 = 0.8MPa \\ sat.liquid \end{array}\right\} h_3 = h_{f@0.8MPa} = 93.42kJ/kg$$

$$h_4 \cong h_3 = 93.42kJ/kg \ (throttling)$$



The quality of the refrigerant at the end of the throttling process is

$$x_4 = \left(\frac{h_4 - h_f}{h_{fg}}\right)_{@140kPa} = \frac{93.42 - 25.77}{210.27} = \mathbf{0.322}$$

(b) The COP of the refrigerator is determined from its definition,

$$\mathrm{COP_R} = \frac{q_L}{w_{in}} = \frac{h_1 - h_4}{h_2 - h_1} = \frac{236.04 - 93.42}{272.05 - 236.04} = \mathbf{3.96}$$

(c) The power input to the compressor is determined from

$$\dot{W}_{in} = \frac{\dot{Q}_L}{\mathrm{COP_R}} = \frac{5\ \mathrm{kW}}{3.96} = \mathbf{1.26\ kW}$$

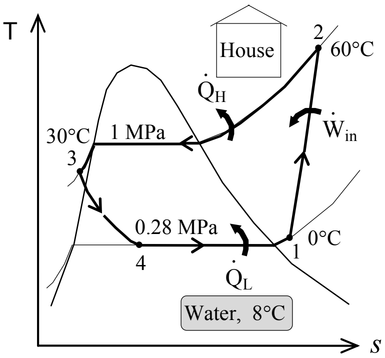
4 (a) From the refrigerant tables,

$$\left.\begin{array}{l} P_1 = 280kPa \\ T_1 = 0^\circ C \end{array}\right\} h_1 = 247.64kJ/kg$$

$$\left.\begin{array}{l} P_2 = 1.0MPa \\ T_2 = 60^\circ C \end{array}\right\} h_2 = 291.36kJ/kg$$

$$\left.\begin{array}{l} P_3 = 1.0MPa \\ T_3 = 30^\circ C \end{array}\right\} h_3 \cong h_{f@30^\circ C} = 91.49kJ/kg$$

$$h_4 \cong h_3 = 91.49kJ/kg \ (throttling)$$



The mass flow rate of the refrigerant is

$$\dot{m}_R = \frac{\dot{Q}_H}{q_H} = \frac{\dot{Q}_H}{h_2 - h_3} = \frac{60{,}000/3{,}600kJ/s}{(291.36 - 91.49)kJ/kg} = 0.0834kg/s$$

Then the power input to the compressor becomes

$$\dot{W}_{in} = \dot{m}(h_2 - h_1) = (0.0834kg/s)(291.36 - 247.64)kJ/kg = \mathbf{3.65kW}$$

(b) The rate of hat absorption from the water is

$$\dot{Q}_L = \dot{m}(h_1 - h_4) = (0.0834kg/s)(247.64 - 91.49)kJ/kg = \mathbf{13.02kW}$$

(c) The electrical power required without the heat pump is

$$\dot{W}_e = \dot{Q}_H = 60{,}000/3{,}600\ \mathrm{kJ/s} = 16.67\ \mathrm{kW}$$

Thus,

$$\dot{W}_{increase} = \dot{W}_e - \dot{W}_{in} = 16.67 - 3.65 = \mathbf{13.02\ kW}$$