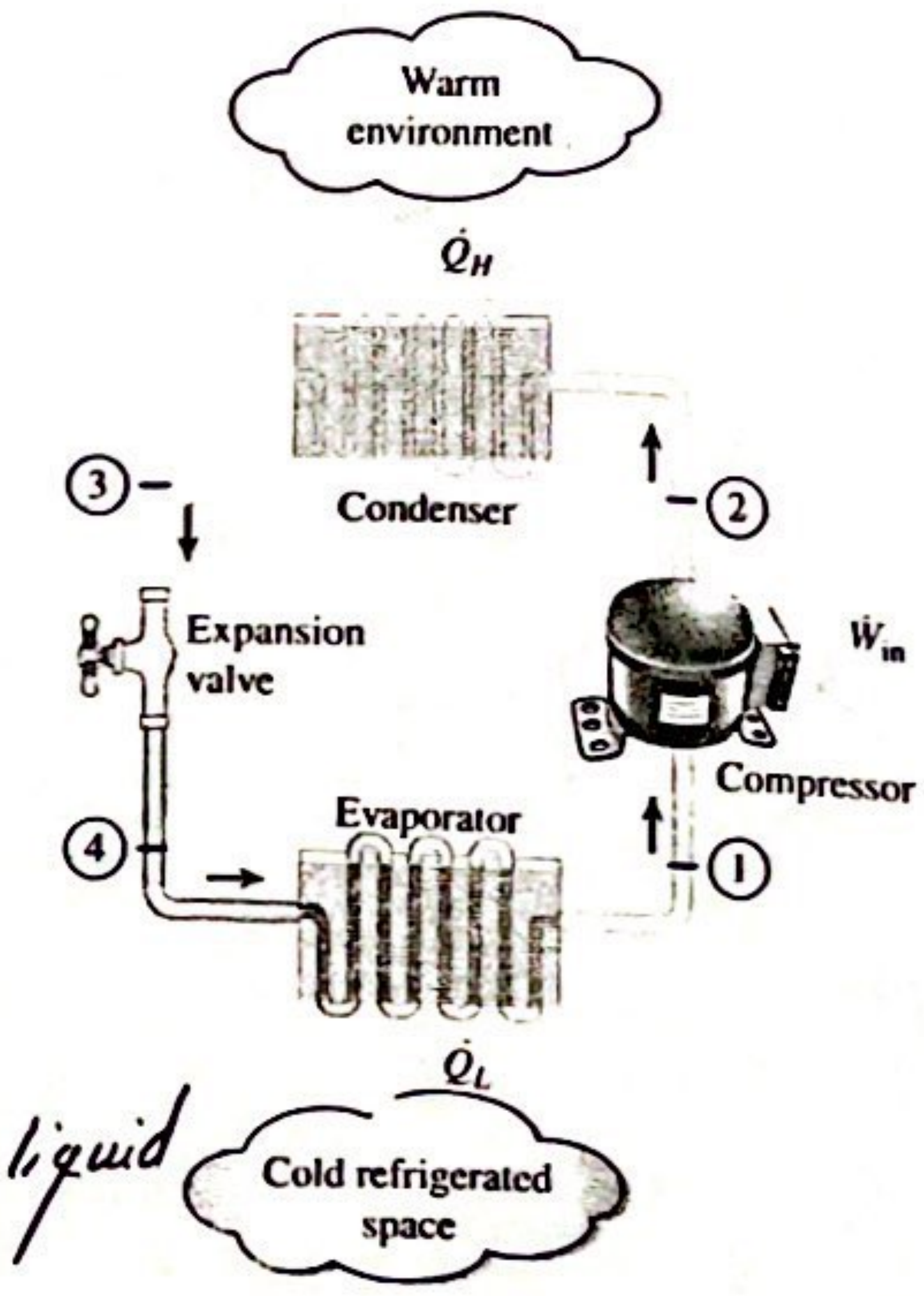
Review Problems for Midterm Exam 2:

1- A refrigerator uses refrigerant- 134a as its working fluid and operates on the vapor-compression refrigeration cycle. The Refrigerant enters the compressor at a rate of 0.025 kg/s at 200 kPa and 0 ˚C and leaves the condenser at 1400 kPa and 48 ˚C. The isentropic efficiency of the compressor is 88%, determine: a) the refrigeration capacity in ton of refrigeration, b) the power input, c) the coefficient of performance.



① $\begin{cases} P_1 = 200 \text{ kPa} \\ T_1 = 0\,^\circ C \end{cases}$ $T_{sat\ at\ 2\,bar} = -10.09\,^\circ C$

$T > T_{sat}$ Therefore super heat

$\begin{cases} h_1 = 250.1 \text{ kJ/kg} \\ s_1 = 0.9582 \text{ kJ/kg·K} \end{cases}$

② $\begin{cases} P_2 = 1400 \text{ kPa } (14 \text{ bar}) \\ s_{2s} = s_1 \end{cases} \Rightarrow h_{2s} = 292.65 \text{ kJ/kg}$

③ $\begin{cases} P_3 = 14 \text{ bar} \\ T_3 = 48\,^\circ C \end{cases}$ $T_{sat\ at\ 14\,bar} = 52.43\,^\circ C$

$T < T_{sat} \rightarrow$ subcooled or compressed liquid

$h_3 \simeq h_{f\ at\ 48\,^\circ C} = 118.35 \text{ kJ/kg}$ $\qquad h_4 = h_3$

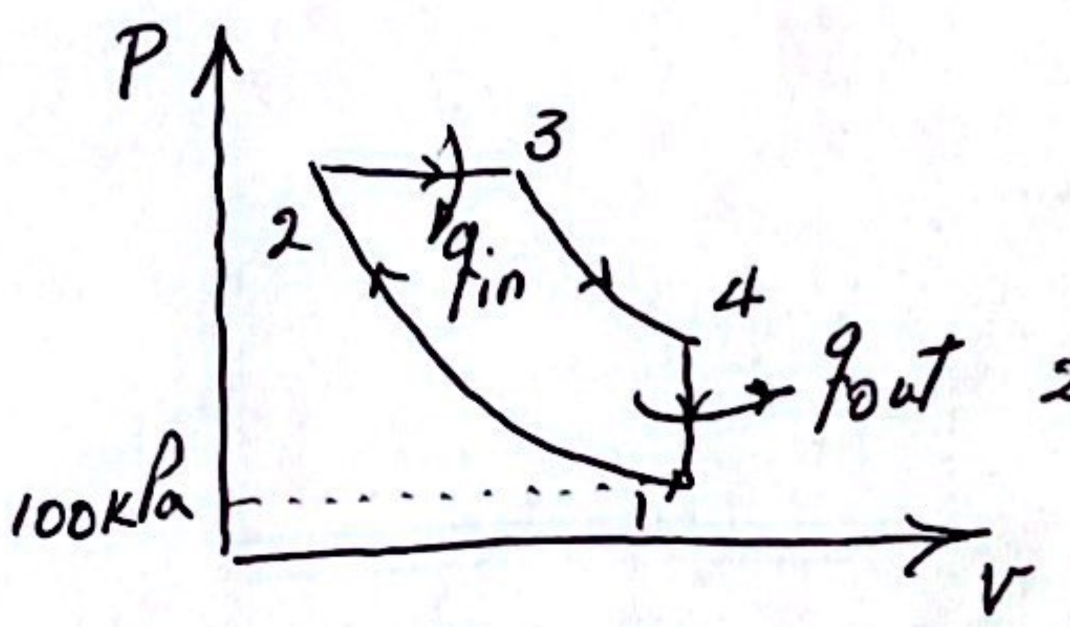
$$\eta_c = \frac{w_s}{w_a} = \frac{h_{2s} - h_1}{h_2 - h_1} \Rightarrow h_2 = h_1 + \frac{h_{2s} - h_1}{\eta_c} = 250.1 + \frac{292.65 - 250.1}{0.88} = 298.45 \text{ kJ/kg}$$

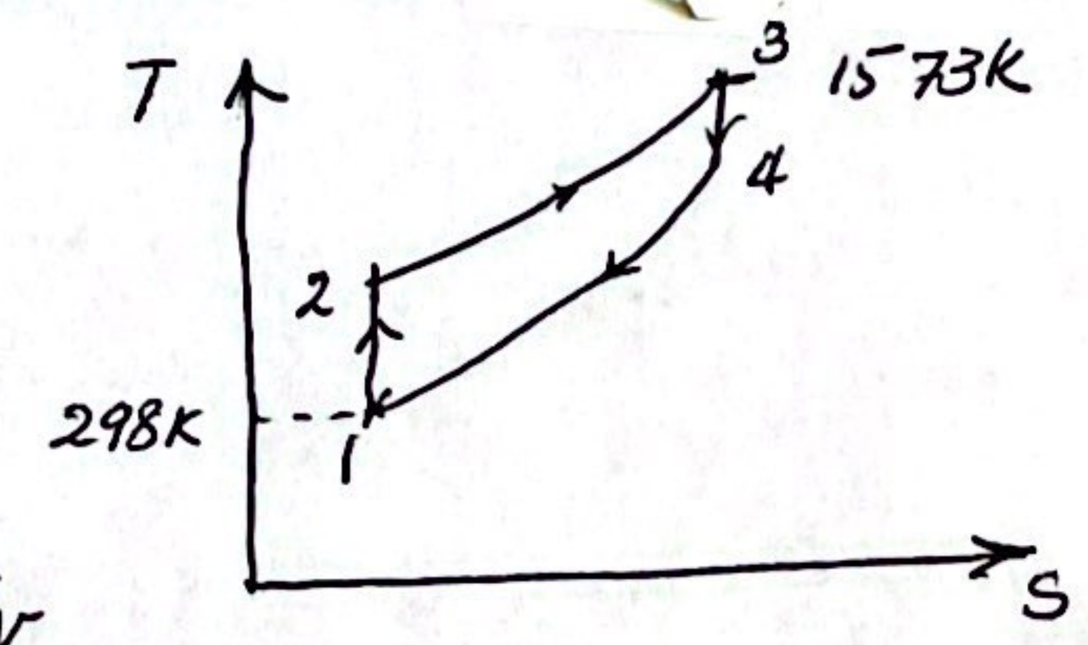
$$\dot{Q}_{in} = \dot{m}(h_1 - h_4) = 0.025(250.1 - 118.35) = 3.294 \text{ kW} = 0.938 \text{ ton of ref}$$

$$\dot{W}_c = \dot{m}(h_2 - h_1) = 0.025(298.45 - 250.1) = 1.209 \text{ kW}$$

$$COP = \frac{\dot{Q}_{in}}{\dot{W}_c} = \frac{3.294}{1.209} = 2.725$$

2- An air-standard Diesel cycle has a compression ratio of 18. At the beginning of compression, the pressure is 100 kPa, and the temperature is 25°C. At the end of the combustion process, the temperature is 1300°C. Draw the P-v and T-s diagrams and determine a) the temperature at the other states, b) the input heat, c) the output heat, d) the thermal efficiency of the cycle. Assume constant specific heats for air and k = 1.4.





From table A.20

$k = 1.4 \rightarrow c_p = 1.005 \ \frac{kJ}{kg \cdot K}$

$c_v = 0.718$

$r = V_1/V_2 = 18$

Process 1-2

$\Delta S = 0 \Rightarrow T_1 V_1^{k-1} = T_2 V_2^{k-1} \Rightarrow T_2 = T_1 (r)^{k-1} = 298(18)^{1.4-1} = 946.95\ K$

Process 2-3 $\rightarrow$ P = Const $\quad P_2 = P_3$

$P_3 V_3 = mRT_3$
$P_2 V_2 = mRT_2$ $\Rightarrow V_3/V_2 = T_3/T_2 = \frac{1573}{946.95} = 1.66 = r_c$ cutoff ratio

Process 3-4 $\Delta S = 0$ $\Rightarrow T_4 V_4^{k-1} = T_3 V_3^{k-1}$ $\quad T_4 = T_3 (V_3/V_4)^{k-1} = T_3 \left[\frac{V_3}{V_2} \times \frac{V_2}{V_4} \right]^{k-1}$

$= T_3 \left[r_c \times \frac{1}{r} \right]^{k-1} = 1573 \left(\frac{1.66}{18} \right)^{1.4-1} = 606.26K$

$q_{2-3} - w_{2-3} = u_3 - u_2 \Rightarrow q_{2-3} = P(V_3 - V_2) + (u_3 - u_2) = (P_3V_3 + u_3) - (P_2V_2 + u_2)$

$= h_3 - h_2 = c_p(T_3 - T_2) = 1.005(1573 - 946.95)$

$= 629.18$ kJ/K

$q_{4-1} - \cancel{w_{4-1}}^{\,0} = u_4 - u_1$

$q_{4-1} = u_4 - u_1 = c_v(T_4 - T_1) = 0.718(606.26 - 298) = 221.33$ kJ/kg

$\eta_{TH} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{q_{4-1}}{q_{2-3}} = 1 - \frac{221.33}{629.18} = 0.6482\ (64.82\%)$

Also:

$\eta_{TH} = 1 - \frac{1}{r^{k-1}} \left[\frac{r_c^k - 1}{k(r_c - 1)} \right] = 1 - \frac{1}{18^{1.4-1}} \left[\frac{1.66^{1.4} - 1}{1.4(1.66-1)} \right] = 0.6482$ (64.81%)

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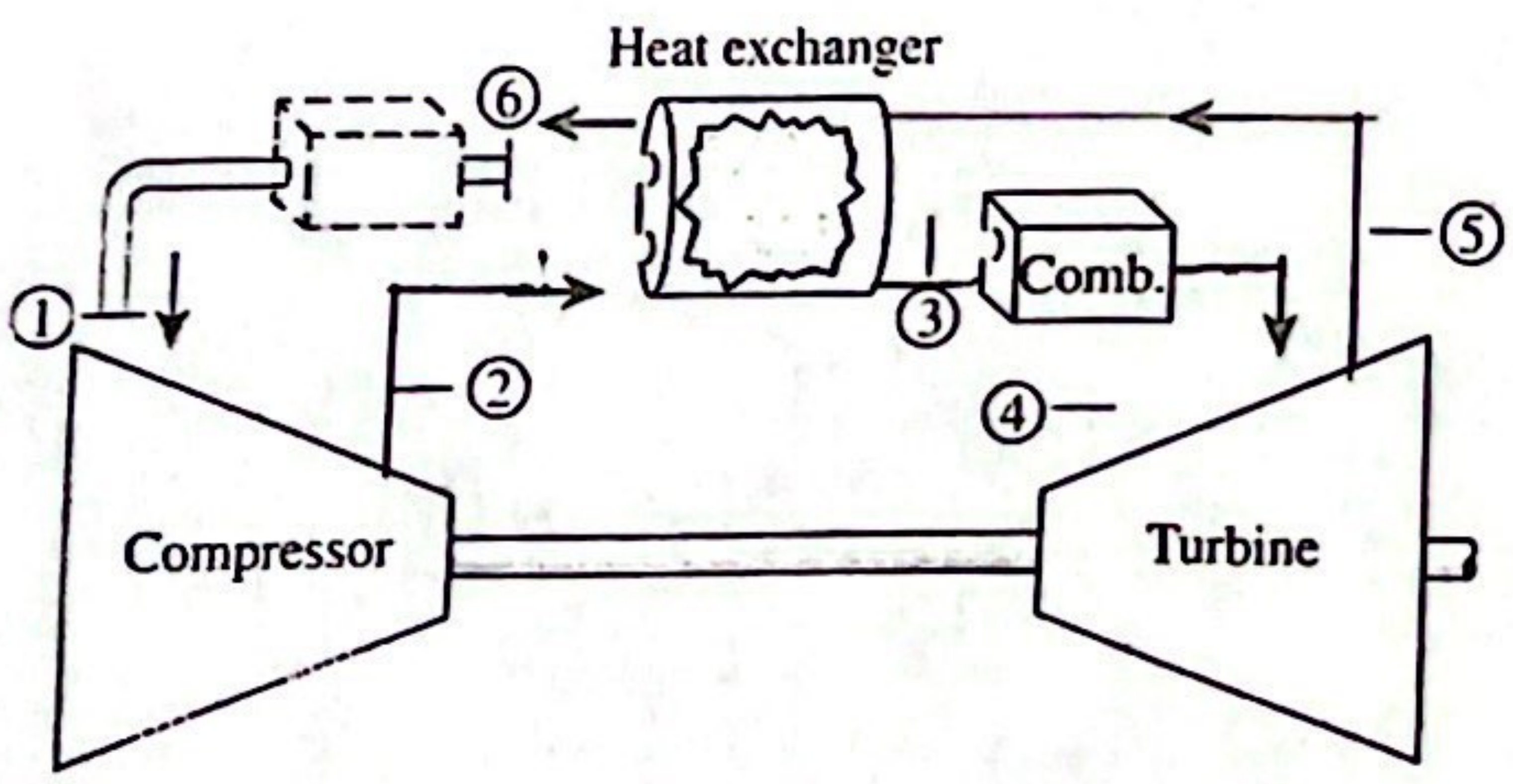
3-A gas turbine engine operates on the ideal Brayton cycle with regeneration. Air enters the compressor at 100 kPa and 300 K. The compressor pressure ratio is 8 and the maximum cycle temperature is 1100 K. The mass flow rate of air is 0.5 kg/s. Assuming isentropic efficiencies of compressor and turbine are 80% and 85% respectively and the effectiveness of regenerator is 90%, draw the T-s diagram and determine a) the rate of heat addition, b) the net output power, c) the efficiency of the cycle. $K = 1.4$

$$\begin{cases} P_1 = 100\,kPa \\ T_1 = 300K \end{cases} \qquad P_2/P_1 = 8 \qquad T_4 = 1100K$$



$$\frac{T_{2S}}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \Rightarrow T_{2S} = 300(8)^{\frac{1.4-1}{1.4}} = 543.42\,K$$

$$\frac{T_{5S}}{T_4} = \left(\frac{P_5}{P_4}\right)^{\frac{k-1}{k}} \Rightarrow T_{5S} = 1100\left(\frac{1}{8}\right)^{\frac{1.4-1}{1.4}} = 607.27\,K$$

$$\eta_c = \frac{w_s}{w_a} = \frac{h_{2s}-h_1}{h_2-h_1} = \frac{c_p(T_{2s}-T_1)}{c_p(T_2-T_1)} \Rightarrow T_2 = T_1 + \frac{(T_{2s}-T_1)}{\eta_c} = 300 + \frac{543.42-300}{0.8} = 604.275\,K$$

$$\eta_t = \frac{w_a}{w_s} = \frac{h_4-h_5}{h_4-h_{5s}} \Rightarrow \frac{c_p(T_4-T_5)}{c_p(T_4-T_{5s})} \Rightarrow T_5 = T_4 - \eta_t(T_4-T_{5s}) = 1100-0.85(1100-607.27) = 681.18\,K$$

$$\eta_{reg} = \frac{h_3-h_2}{h_5-h_2} = \frac{c_p(T_3-T_2)}{c_p(T_5-T_2)} \Rightarrow T_3 = T_2 + \eta_{reg}(T_5-T_2) = 604.275 + 0.9(681.18-604.275) = 673.49\,K$$

$$\dot{Q}_{in} = \dot{m}(h_4-h_3) = \dot{m}\,c_p(T_4-T_3) = 0.5\times1.005(1100-673.49) = 214.32\,kW$$

$$\dot{W}_{net} = \dot{m}(w_t - w_c) = \dot{m}\left[(h_4-h_5)-(h_2-h_1)\right] = \dot{m}\,c_p\left[(T_4-T_5)-(T_2-T_1)\right]$$

$$= 0.5\times1.005\left[(1100-681.18)-(604.275-298)\right] = 57.56\,kW$$

$$\eta_{TH} = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{57.56}{214.32} = 0.268\ (26.8\%)$$