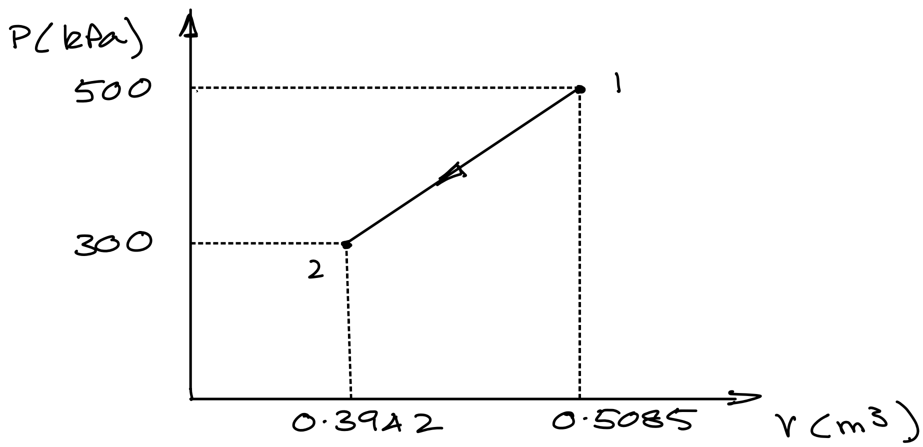
CHE 260 MID-TERM SOLUTION-2023

(1) For CO_2 $R = 0.18892 \ kJ/kg\,K$

$$V_1 = \frac{mRT_1}{P_1} = \frac{2\,kg \times 0.18892\,\frac{kJ}{kg\,K} \times 673\,K}{500\,kPa} = 0.5085\,m^3$$

$$V_2 = \frac{mRT_2}{P_2} = \frac{2\,kg \times 0.18892\,kJ/kg\,K \times 313\,K}{300\,kPa} = 0.3942\,m^3$$



$$W_{12} = -\int_{V_1}^{V_2} P\,dV = \frac{1}{2}(P_1+P_2)(V_1-V_2)$$

$$= \frac{1}{2}(500+300)\,kPa\,(0.5085-0.3942)\,m^3$$

$$W_{12} = 45.72\ kJ$$

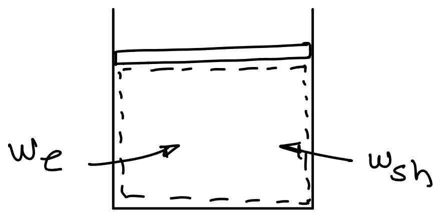
$$Q_{12} + W_{12} = m\,c_v\,(T_2 - T_1)$$

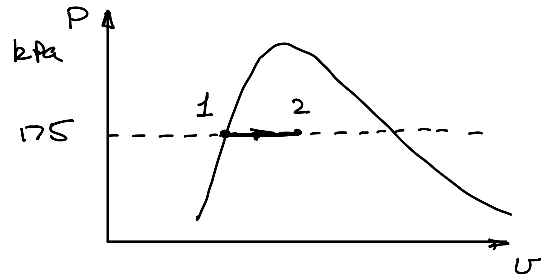
$$c_v = 0.6529\ kJ/kg\,K.$$

$$Q_{12} = 2\,kg \times 0.6529\,kJ/kg\,K\,(40-400)^\circ C - 45.72\,kJ$$

$$Q_{12} = -515.8\ kJ$$

(2)





For a constant Pressure Process

$$W_e + W_{sh} = \Delta H = m(h_2 - h_1)$$

At P = 175 kPa, sat liquid $\left.\right\}$ $h_1 = h_f = 486.99$ kJ/kg, $v_1 = v_f = 0.001057$ m³/kg

$P_2 = 175$ kPa, $x_2 = 0.5$ $\left.\right\}$ $h_f = 486.99$ kJ/kg, $h_g = 2700.6$ kJ/kg.

$$h_2 = h_f + x_2(h_g - h_f)$$
$$= 486.99 + 0.5(2700.6 - 486.99)$$
$$= 1593.8 \text{ kJ/kg}$$

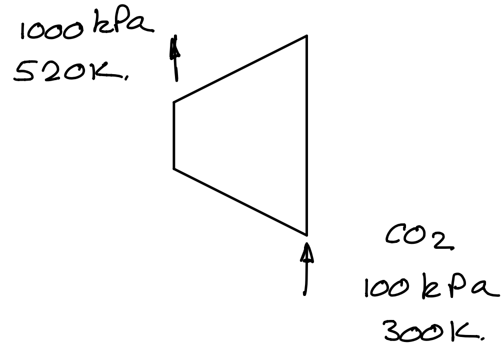
$$m = \frac{V_1}{v_1} = \frac{5\times10^{-3}\,\text{m}^3}{0.001057\,\text{m}^3/\text{kg}} = 4.730 \text{ kg}$$

$$\overbrace{V_e I \Delta t}^{W_e} + W_{sh} = m(h_2 - h_1)$$

$$\frac{V_e (8A)(45\times60\,s)}{1000\ \text{J/kJ}} + 400\,\text{kJ} = 4.730\,\text{kg}\,(1593.8 - 486.99)\frac{\text{kJ}}{\text{kg}}$$

$$V_e = 223.9\ \text{V}$$

(3)



For CO_2 $\quad c_p = 0.842\ \frac{kJ}{kgK}$ $\quad \gamma = 1.289$.

$R = 0.1889\ kJ/kgK.$

$$w_a = h_2 - h_1 = c_p(T_2 - T_1)$$

$$= 0.842\ \frac{kJ}{kgK}(520K - 300K) = 185.24\ \frac{kJ}{kg}$$

For isentropic compression

$$T_{2s} = T_1\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = 300K\left(\frac{1000\ kPa}{100\ kPa}\right)^{\frac{0.289}{1.289}}$$

$$T_{2s} = 502.7\ K$$

$$w_s = c_p(T_{2s} - T_1) = 0.842\ \frac{kJ}{kgK}(502.7\ K - 300\ K)$$

$$= 170.67\ kJ/kg$$

$$\eta_t = \frac{w_s}{w_a} = \frac{170.67}{185.24} = 0.9213$$

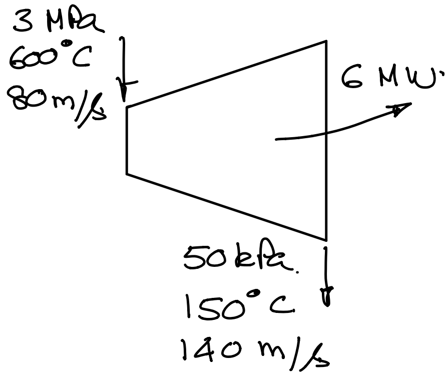
$$\eta_t = 92.1\%.$$

$$s_{gen} = s_2 - s_1 = c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}$$

$$= 0.842 \ln\left(\frac{520K}{300K}\right) - 0.1889 \ln\left(\frac{1000}{10}\right)$$

$$s_{gen.} = 0.0282\ kJ/kgK$$

(4)



3 MPa, 600°C: $h_1 = 3682.3 \ \frac{kJ}{kg}$, $s_1 = 7.5085 \ \frac{kJ}{kg\,K}$

50 kPa, 150°C: $h_2 = 2780.1 \ \frac{kJ}{kg}$, $s_2 = 7.9401 \ \frac{kJ}{kg\,K}$

a) $$\dot{W} = \dot{m}\left[(h_2 - h_1) + \frac{V_2^2 - V_1^2}{2}\right]$$

$$-6000 \ \frac{kJ}{s} = \dot{m}\left[(2780.1 - 3682.3)\frac{kJ}{kg} + \frac{\left(140\frac{m}{s}\right)^2 - \left(80\frac{m}{s}\right)^2}{2 \times 1000 \ J/kJ}\right]$$

$$\dot{m} = 6.699 \ kg/s$$

b) For isentropic process $s_{2s} = s_1 = 7.5085 \ kJ/kg\,K$

At 50 kPa $s_f = 1.0910 \ kJ/kg\,K$, $h_f = 340.49 \ kJ/kg$

$s_g = 7.5939 \ kJ/kg\,K$, $h_g = 2645.9 \ kJ/kg$

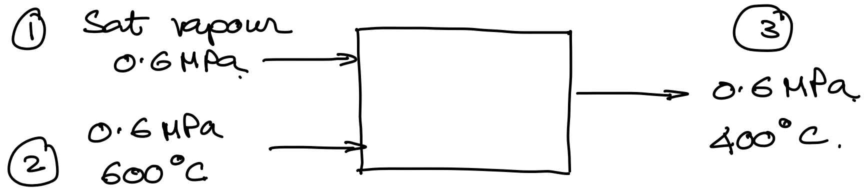
$$x_{2s} = \frac{s_{2s} - s_f}{s_g - s_f} = \frac{7.5085 - 1.0910}{7.5939 - 1.0910} = 0.9869$$

$$h_{2s} = h_f + x_{2s}(h_g - h_f)$$
$$= 340.49 + 0.9869(2645.9 - 340.49) = 2615.7 \ \frac{kJ}{kg}$$

$$\dot{W}_s = \dot{m}\left[(h_{2s} - h_1) + \frac{V_2^2 - V_1^2}{2}\right]$$
$$= 6.699\left[(2615.7 - 3682.3) + \frac{140^2 - 80^2}{2 \times 1000}\right] = -7100.9 \ kW$$

$$\eta_t = \frac{\dot{W}_a}{\dot{W}_s} = \frac{-6000 \ kW}{-7100.9 \ kW} = 0.855$$

(5)



1) sat vapour, 0.6 MPa, $h_1 = 2756.2 \ \mathrm{kJ/kg}$, $s_1 = 6.7593 \ \frac{\mathrm{kJ}}{\mathrm{kg\,K}}$

2) 0.6 MPa, 600°C, $h_2 = 3701.7 \ \frac{\mathrm{kJ}}{\mathrm{kg}}$, $s_2 = 8.2695 \ \frac{\mathrm{kJ}}{\mathrm{kg\,K}}$

3) 0.6 MPa, 400°C, $h_3 = 3270.8 \ \frac{\mathrm{kJ}}{\mathrm{kg}}$, $s_3 = 7.7097 \ \frac{\mathrm{kJ}}{\mathrm{kg\,K}}$

Mass Balance $\quad \dot{m}_3 = \dot{m}_1 + \dot{m}_2.$

Energy Balance $\quad \dot{m}_3 h_3 = \dot{m}_1 h_1 + \dot{m}_2 h_2.$

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

$$\Rightarrow \dot{m}_3 (h_3 - h_2) = \dot{m}_1 (h_1 - h_2)$$

$$\Rightarrow \frac{\dot{m}_1}{\dot{m}_3} = \frac{h_3 - h_2}{h_1 - h_2} = \frac{3270.8 - 3701.7}{2756.2 - 3701.7} = 0.456$$

Entropy balance. $\quad \dot{m}_3 s_3 = \dot{m}_1 s_1 + \dot{m}_2 s_2 + \dot{S}_{gen}$

$$\dot{S}_{gen}/\dot{m}_3 = s_3 - \dot{m}_1/\dot{m}_3 \, s_1 - \dot{m}_2/\dot{m}_3 \, s_2$$

$$\dot{S}_{gen}/\dot{m}_3 = 7.7097 - 0.456 \times 6.7593 - 0.544 \times 8.2695$$
$$= 0.129 \ \mathrm{kJ/kg\,K}.$$