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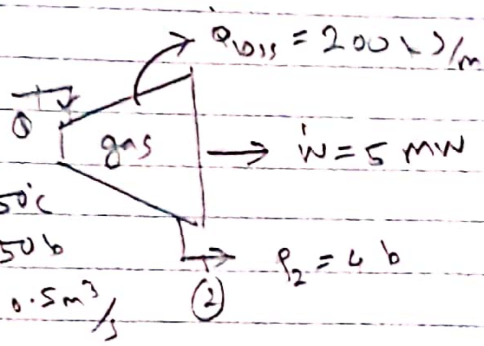
Q1 (a) Assumptions for steady flow
- All properties of ~~syste~~ CV are constant
- All properties at inlet/outlet ~~are~~ are constant
- All heat/work interactions are constant.

(b)



$T_1 = 650°C$
$P_1 = 50\ b$
$\dot{V}_1 = 0.5\ m^3/s$

$c_p = 1.15\ kJ/kg.K \quad k = 1.3$

(i) $\dot{m} = \frac{P\dot{V}}{RT}$ (ideal gas)

$= \frac{P_1 \dot{V}_1}{RT_1}$

$k = \frac{c_p}{c_v} \rightarrow c_v = 0.8846\ kJ/kg.K$

$R = c_p - c_v = 0.2654\ kJ/kg.K$

$= \frac{(50\times10^2\ kPa)\ 0.5\ m^3/s}{0.2654\ (650+273)}$

$= 10.21\ kg/s$

(ii) T_2 from SSSF

$\dot{Q} - \dot{W} = \sum_{out} \dot{m}(h + ke + pe) - \sum_{in} \dot{m}(h + ke + pe)$

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

$3.333 - 5000 = \dot{m}c_p(T_2 - T_1)$

$\rightarrow T_2 = 497.28\ K$

$= 224.28\ °C$ //

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(iii) $\frac{\vec{V}_2}{\vec{V}_1}$ for $\dot{m} = \frac{A\vec{V}}{v}$

$$\dot{m} = \frac{A_1 \vec{V}_1}{v_1} = \frac{A_2 \vec{V}_2}{v_2} \qquad (A_1 = A_2)$$

$$\frac{\vec{V}_2}{\vec{V}_1} = \frac{v_2}{v_1}$$

$$= \frac{RT_2/P_2}{RT_1/P_1}$$

$$= \frac{497.28/400}{923/5000}$$

$$= 6.7346$$

(iv) $\dot{V}_2 = \frac{\dot{m} RT_2}{P_2}$

$$= 3.3673 \ m^3/s$$

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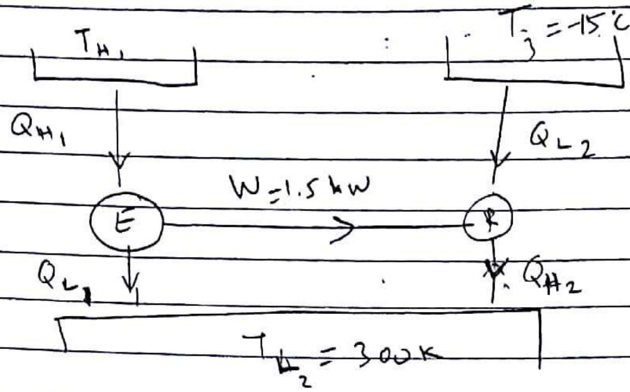
Q2.



$\eta_E = \eta_{Carnot} = 60\%$

(i) $\eta_{Carnot} = 0.6 = \dfrac{T_{H_1} - T_{L_2}}{T_{H_1}} = 1 - \dfrac{T_{L_2}}{T_{H_1}}$

$= 1 - \dfrac{300}{T_{H_1}}$ 4

$\therefore T_{H_1} = 750\ K$ //

$\eta = 0.6 = \dfrac{W}{Q_{H_1}} = \dfrac{1.5\ kW}{Q_{H_1}}$

3

$\therefore Q_{H_1} = 2.5\ kW$ *

$Q_{L_1} = Q_{H_1} - W = 1\ kW$ * 3

(ii) Carnot refrigerator

$COP_R = \dfrac{T_L}{T_H - T_L} = \dfrac{T_3}{T_{L_2} - T_3}$

$= \dfrac{(-15+273)}{300-(-15+273)}$ 4

$= 6.14$ *

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$COP_R = 6.4 = \frac{\dot{Q}_{L2}}{\dot{W}} = \frac{\dot{Q}_{L}}{1.5 kW}$

3

$\therefore \dot{Q}_{L2} = 9.21 kW$

$\dot{Q}_{H2} = \dot{Q}_{L2} + \dot{W} = 10.71 kW$ 3

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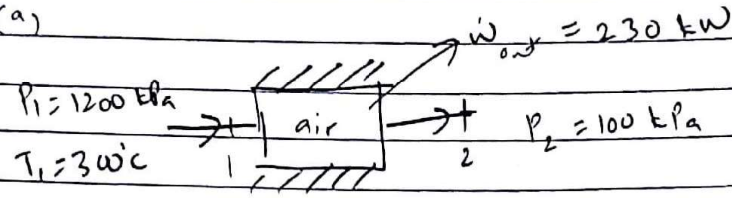
Q3 (a)



$\dot{m} = 1$ kg/s

validity of device.

Assuming isentropic ($W_{max,out}$)

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

$$\frac{T_2}{573} = \left(\frac{100}{1200}\right)^{\left(\frac{0.4}{1.4}\right)}$$

$\rightarrow T_2 = 281.72$ K

4

$\dot{W}_{max}$ by 1st Law

$\dot{Q} - \dot{W} = \dot{m}(\Delta h + \Delta ke + \Delta pe)$

$-\dot{W}_{max} = 1\,(C_p\,(T_2 - T_1))$

$= 1.005\,(281.72 - 573)$

4

$\dot{W}_{max} = 292.74$ kW

$\dot{W}_{out} < \dot{W}_{max}$ (valid!)

2

– different approach: check S_{gen}

1st Law: $\dot{Q} - \dot{W} = \dot{m}(\Delta h + \Delta ke + \Delta pe)$

$-230 \text{ kW} = 1 \text{ kg/s}\; C_p\,(T_2 - T_1)$

$\therefore T_2 = 344.14$ K

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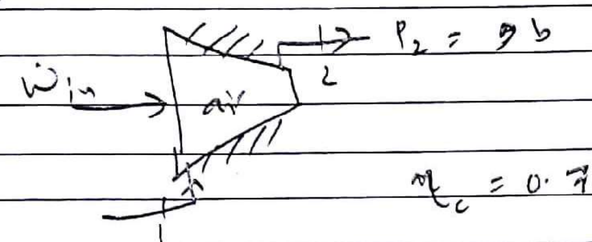
$$\frac{dS_{cv}}{dt}^{0} = \sum \frac{\dot{Q}}{T}^{0} + \dot{m}(s_1 - s_2) + \dot{S}_{gen}$$

$$0 = 1\left(c_p \ln \frac{T_1}{T_2} - R \ln \frac{P_1}{P_2}\right) + \dot{S}_{gen}$$

$$= 1.005 \ln\left(\frac{573.}{344.14}\right) - 0.287 \ln\left(\frac{1200}{100}\right) + \dot{S}_{gen}$$

$$\dot{S}_{gen} = 0.2008 \ \frac{kW}{K} > 0 \ \text{(valid!)}$$

(b)



$\eta_c = 0.75$

$T_1 = 30°C$

$P_1 = 1$ b

(i) $T_{2a} = ?$

$$\frac{T_{2s}}{T_1} = \left(\frac{P_2}{P_1}\right)^{\left(\frac{k-1}{k}\right)}$$

$$T_{2s} = 303\left(\frac{9}{1}\right)^{\left(\frac{0.4}{1.4}\right)} = 567.6 \text{ K}$$ 2

$$\eta_c = 0.75 = \frac{T_{2s} - T_1}{T_{2a} - T_1} = \frac{567.6 - 303}{T_{2a} - 303}$$ 3

$$\therefore T_{2a} = 655.8 \text{ K} \ \#$$

(ii) $$\frac{dS_{cv}}{dt}^{0} = \sum \frac{\dot{Q}}{T}^{0} + \dot{m}(s_1 - s_2) + s_{gen}$$

$$s_{gen} = s_2 - s_1 = c_p \ln \frac{T_{2a}}{T_1} - R \ln \frac{P_2}{P_1}$$ 5

$$= 1.005 \ln\left(\frac{655.8}{303}\right) - 0.287 \ln(9)$$

$$= 0.1454 \ \frac{kJ}{kg.K} \ \#$$

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