Problem # 1

Part 1

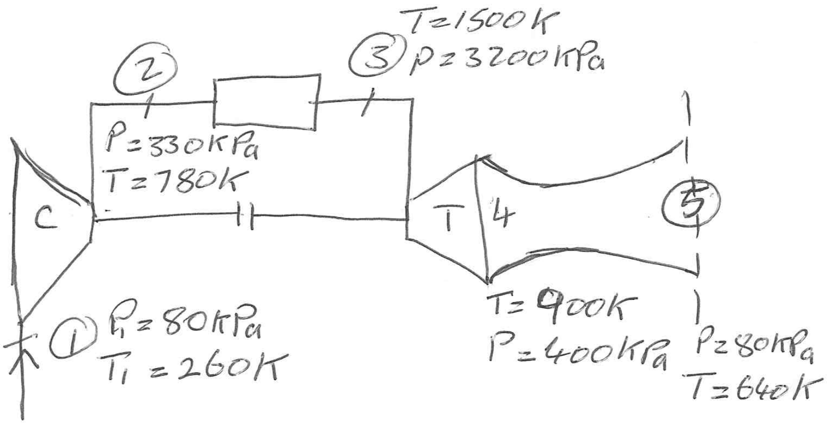

Figure 1: Problem 1 schematic diagram

$*1^{st}$ law - compressor and turbine

$$W_C = h_2 - h_1 = 800.28 - 260.32 = 539.36 kJ/kg \tag{1}$$

$$W_T = h_3 - h_4 = 1635.8 - 935.15 = 702.65 kJ/kg \tag{2}$$

$*1^{st}$ law - nozzle

$$h_4 = h_5 + \frac{1}{2}V_5^2 \tag{3}$$

$\Rightarrow$

$$V_5 = \sqrt{2000(933.15 - 649.53)} = 753 m/s \tag{4}$$

Part 2

$$W_T = W_C \Rightarrow h_2 - h_1 = h_3 - h_{4n} \tag{5}$$

$\Rightarrow$

$$h_{4n} = 1635.8 - 800.28 + 260.32 = 1095.84 kJ/kg \tag{6}$$

From air tables $T_{4n} = 1043.45K$. Now we need to get T_{5n} and V_{5n}.
The nozzle polytroic index, n:

$$\frac{T_5}{T_4} = \left(\frac{P_5}{P_4}\right)^{\frac{n-1}{n}} = \frac{T_{5n}}{T_{4n}} \Rightarrow T_{5n} = T_{4n}\left(\frac{T_5}{T_4}\right) \tag{7}$$

$\Rightarrow$

$$T_{5n} = 1043.45\left(\frac{649.53}{933.15}\right) = 726.15K \Rightarrow h_{5n} = 742kJ/kg \tag{8}$$

$\Rightarrow$

$$V_{5n} = \sqrt{2000(1095.84 - 742)} = 841.24m/s \tag{9}$$

$$\eta = \frac{\frac{1}{2}V_{5n}^2}{h_3 - h_2} = \frac{\frac{1}{2\times 1000}(841.24)^2}{(1635.8 - 800.28)} = 42.35\% \tag{10}$$

Problem # 2

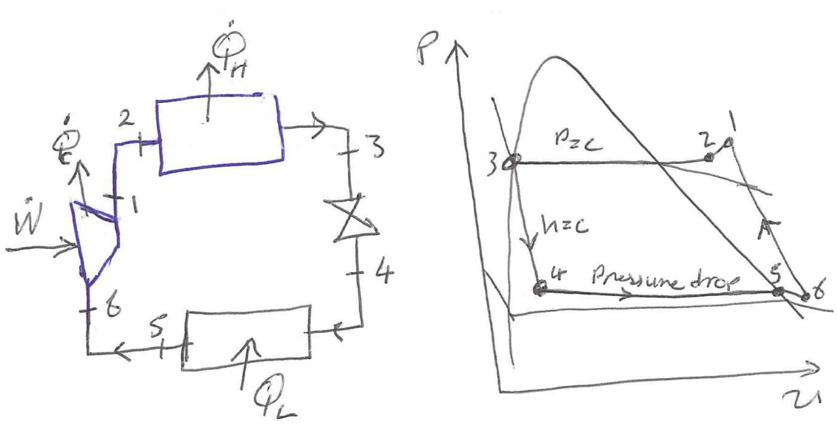

Figure 2: Problem 2 schematic diagram

<u>1^{st} law - Compressor</u>

$$\dot{W}_C - \dot{Q}_C + \dot{m}(h_6 - h_1) = 0; \quad (\dot{W}_{C-in} - \dot{Q}_{C-out}) \tag{11}$$

$\Rightarrow$

$$\dot{Q}_C = 5 + 0.05(284 - 377) = 0.35kW(out) \tag{12}$$

<u>1^{st} law - Condenser</u>

$$\dot{Q}_H = \dot{m}(h_2 - h_3) = 0.05(367 - 134) = 11.65kW(out) \tag{13}$$

<u>1^{st} law - Evaporator</u>

$$\dot{Q}_L = \dot{m}(h_5 - h_4) = 0.05(280 - 134) = 7.3kW(in) \tag{14}$$

COP - Heat Pump

$$COP = \frac{\dot{Q}_H}{\dot{W}_C} = \frac{11.65}{5} = 2.33 \tag{15}$$

Problem # 3

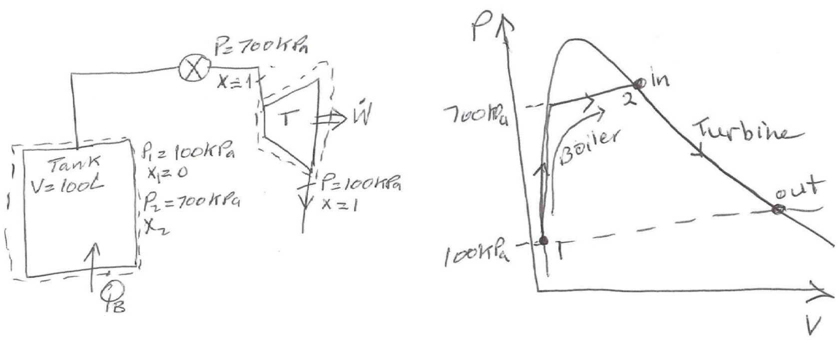

Figure 3: Problem 3 schematic diagram

Boiler tank control volume.
Continuity

$$\Delta m_{CV} = m_i - m_e; \quad m_i = 0 \tag{16}$$

$\Rightarrow$

$$m_2 - m_1 = -m_e \;\; or \;\; m_e = m_1 - m_2 \tag{17}$$

$$m_1 = \frac{V}{v_1} = \frac{0.1}{0.001043} = 95.877kg \tag{18}$$

$$m_2 = \frac{V}{v_2} = \frac{0.1}{0.2729} = 0.366kg \tag{19}$$

$\Rightarrow$

$$m_e = 95.877 - 0.366 = 95.511kg \tag{20}$$

1^{st} law - Boiler

$$\Delta E_{CV} = Q_B - \dot{m}_e h_e \tag{21}$$

$\Rightarrow$

$$m_2 u_2 - m_1 u_1 = Q_B - (m_1 - m_2) h_e \tag{22}$$

$\Rightarrow$

$$Q_B = m_2u_2 - m_1u_1 + m_eh_e = 224871kJ \tag{23}$$

<u>1^{st} law - Steam Turbine</u>

$$\Delta E_{CV} = -W + m_e(h_{in} - h_{out}); \quad \Delta E_{CV} = 0 \tag{24}$$

$\Rightarrow$

$$W = m_e(h_{in} - h_{out}) = 8405kJ \tag{25}$$

System's thermal efficiency, η_{th}

$$\eta_{th} = \frac{W}{Q_B} = \frac{8405}{224871} = 3.7\% \tag{26}$$

Problem # 4

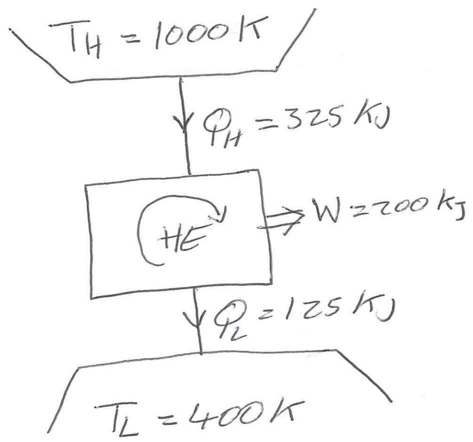

Figure 4: Problem 4 schematic diagram

<u>2^{nd} law - Carnot</u>

$$\eta_{cr} = 1 - \frac{T_L}{T_H} = 1 - \frac{400}{1000} = 0.6 \tag{27}$$

$$\eta_{HE} = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H} = \frac{200}{325} = 0.615 \tag{28}$$

It is <u>impossible</u> to have a real engine with efficiency higher than the reversible engine that works between same temperature limits.
<u>ALSO</u>
<u>2^{nd} law - Entropy</u>

$$\frac{Q_H}{T_H} - \frac{Q_L}{T_L} + S_{gen} = \Delta S_{CV} = 0 \quad (Cycle) \tag{29}$$

$\Rightarrow$

$$S_{gen} = \frac{125}{400} - \frac{325}{1000} = -0.0125kJ/kg \tag{30}$$

It is impossible to construct an engine with $S_{gen} < 0$

Problem # 5

Entropy generation for silicon

$$\Delta s_{sil} = C_{sil} ln\left(\frac{T_2}{T_1}\right) = 712 * ln\left(\frac{70 + 273.15}{15 + 273.15}\right) = 124.377\, J/(kg.K) \tag{31}$$

Entropy generation for Copper

$$\Delta s_{cu} = C_{cu} ln\left(\frac{T_2}{T_1}\right) = 390 * ln\left(\frac{70 + 273.15}{15 + 273.15}\right) = 68.128\, J/(kg.K) \tag{32}$$

Entropy generation for PVC

$$\Delta s_{PVC} = C_{PVC} ln\left(\frac{T_2}{T_1}\right) = 960 * ln\left(\frac{70 + 273.15}{15 + 273.15}\right) = 167.7\, J/(kg.K) \tag{33}$$

Total entropy generation

$$\Delta S_T = m_{sil}\Delta s_{sil} + m_{cu}\Delta s_{cu} + m_{PVC}\Delta s_{PVC} \tag{34}$$

$\Rightarrow$

$$\Delta S_T = 0.05 * 124.377 + 0.02 * 68.128 + 0.05 * 167.7 = 15.966 J/K \tag{35}$$