SCHOOL OF ENGINEERING
MECHANICAL ENGINEERING
LRESE-Laboratory of Renewable Energy Sciences and Engineering

Thermodynamics and energetics I: examples lecture, chapter 7

1.

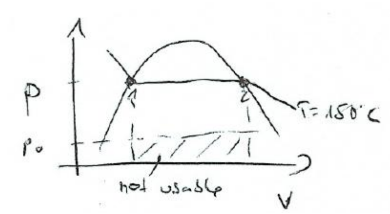
$$ex = u - u_0 + p_0(v - v_0) - T_0(s - s_0) \overset{\text{ideal gas}}{=} u - u_0 + \frac{\tilde{R}}{M}\left(\frac{p_0 T}{p} - T_0\right) - T_0\left(s^0(T) - s^0(T_0) - \frac{\tilde{R}}{M} ln\left(\frac{p}{p_0}\right)\right)$$, with $s^0(T) = \int_{T_{ref}}^{T} \frac{c_p}{T} dT$

$$ex = 880.35 - 214.07 + \frac{8.314}{29}\left(\frac{1.01}{7}1140 - 300\right) - 300\left(3.11883 - 1.70203 - \frac{8.314}{29} ln\left(\frac{7}{1.013}\right)\right) = 368.91\text{kJ/kg}$$

2.

$$ex_2 - ex_1 = u_2 - u_1 + p_0(v_2 - v_1) - T_0(s_2 - s_1)$$
$$= 2559.5 - 631.68 + 10^5(0.3928 - 1.0905 \cdot 10^{-3})/1000 - 293(6.8379 - 1.8418)$$
$$= 502.38\text{kJ/kg}$$

$$\frac{Ex_q}{m} = \left(1 - \frac{T_0}{T}\right)\frac{Q}{m} \overset{\text{1st law}}{=} \left(1 - \frac{T_0}{T}\right)\left(u_2 - u_1 + \frac{W}{m}\right)$$
$$= \left(1 - \frac{T_0}{T}\right)\left(u_2 - u_1 + p(v_2 - v_1)\right) = 649.5\text{kJ/kg}$$



$$\frac{Ex_w}{m} = \frac{W}{m} - p_0(v_2 - v_1) = p(v_2 - v_1) - p_0(v_2 - v_1)$$
$$= 147.21\, k\text{J/kg}$$

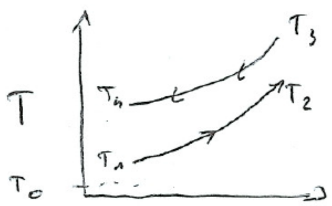
$$\frac{Ex_d}{m} = -\Delta ex + \frac{Ex_q}{m} - \frac{Ex_w}{m} = 0 \rightarrow \text{since reversible}$$

3.

1st law: $0 = \cancel{\dot{Q}}^{=0} - \cancel{\dot{W}}^{=0} + \dot{m}(h_1 - h_2) + \dot{m}(h_3 - h_4) \rightarrow$

$h_4 = h_3 + h_1 - h_2 = 1068.89 + 617.5 - 888.27 = 798.15\text{kJ/kg}$

$\rightarrow T_4 = 778\text{K}$



Exergy balance: $0 = \sum\left(1 - \frac{T_0}{T_j}\right)\cancel{\dot{Q}_j}^{=0} - \cancel{\dot{W}}^{=0} + \dot{m}\left(ex_{f,1} - ex_{f,2}\right) + \dot{m}\left(ex_{f,3} - ex_{f,4}\right) - \dot{E}x_d$

$$\dot{m}\left(ex_{f,1} - ex_{f,2}\right) = \dot{m}\left(h_1 - h_2 - T_0(s_1 - s_2)\right)$$
$$= \dot{m}\left(h_1 - h_2 - T_0\left(s(T_1) - s(T_2) - \frac{\tilde{R}}{M} ln\left(\frac{p_1}{p_2}\right)\right)\right) = -14.1\text{MW}$$
$$\dot{m}\left(ex_{f,3} - ex_{f,4}\right) = \dot{m}\left(h_3 - h_4 - T_0(s_3 - s_4)\right)$$
$$= \dot{m}\left(h_3 - h_4 - T_0\left(s(T_3) - s(T_4) - \frac{\tilde{R}}{M} ln\left(\frac{p_3}{p_4}\right)\right)\right) = 16.93\text{MW}$$
$$\dot{E}x_d = \dot{m}\left(ex_{f,1} - ex_{f,2}\right) + \dot{m}\left(ex_{f,3} - ex_{f,4}\right) = 2.83\text{MW}$$

Alternative:

2nd law: $0 = \sum \cancel{\frac{\dot{Q}_j}{T_j}}^{=0} + \sum \dot{m}s_i - \sum \dot{m}s_e + \dot{\sigma} \rightarrow \dot{\sigma} = \dot{m}(s_4 - s_3) + \dot{m}(s_2 - s_1) = \dot{m}\left(s(T_4) - s(T_3) - \frac{\tilde{R}}{M} ln\left(\frac{p_4}{p_3}\right)\right) + \dot{m}\left(s^0(T_2) - s^0(T_1) - \frac{\tilde{R}}{M} ln\left(\frac{p_2}{p_1}\right)\right) = 9.431\text{kJ/kg}$

$$\dot{E}x_d = T_0\dot{\sigma} = 2.83\text{MW}$$

4.

$h_1 = 3105.6$kJ/kg; $s_1 = 7.53$kJ/kg/K → $h_{2,s} = 2743$kJ/kg

Isentropic efficiency: $(h_1 - h_2) = \eta_{t,s}\left(\frac{\dot{W}}{\dot{m}}\right)_s = \eta_{t,s}\left(h_1 - h_{2,s}\right)$ → $h_2 = 2833.7$kJ/kg;

$$\frac{\dot{W}}{\dot{m}} = (h_1 - h_2) = 271.95\text{kJ/kg} \rightarrow s_2 = 7.74\text{kJ/kg/K}$$

2nd law: $s_2 - s_1 = \frac{\dot{\sigma}}{\dot{m}} = 0.211$kJ/kg/K

Exergy balance: $ex_{f,1} - ex_{f,2} = \frac{\dot{W}}{\dot{m}} + T_0\frac{\dot{\sigma}}{\dot{m}} = 335.25$kJ/kg

Exergy efficiency: $\varepsilon_{ex} = \frac{\dot{W}/\dot{m}}{ex_{f,1} - ex_{f,2}} = 81\%$