School of Mechanical & Aerospace Engineering
MA3010 – Thermodynamics & Heat Transfer
AY22S1 – CA 1 Solution Guide

1. A completely reversible refrigerator is removing heat from a 4°C (T_L) refrigerated space at a rate of 5400 kJ/h (Q_L) and rejecting the waste heat to the environment at 27°C (T_H). What is the power consumption of the refrigerator (W_{in})?

$$\mathrm{COP_R} = \frac{1}{\frac{T_H}{T_L} - 1}$$
$$W_{in} = \frac{Q_L}{\mathrm{COP_R}}{}_{\#}$$

2. What is the power consumed (W) for a reversible and adiabatic compression of 2 kg/s ($\dot{m}$) of oxygen from 100 kPa (P_1) and 50°C (T_1) to 1.2 MPa (P_2) and 355°C (T_2)? Assume an average temperature of 500 K.

reversible and adiabatic = isentropic, use $n = k$
$$W = \dot{m}\frac{nRT_1}{n-1}\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right]_{\#} = \dot{m}c_{p,avg}(T_2 - T_1)_{\#}$$

3. 250 ml (V) of hot tea (ρ = 1000 kg/m3, c = 4.18 kJ/kg·K) cools from 80°C (T_1) to 27°C (T_2). What is the entropy change (ΔS) of this process?

$$m = \rho V$$
$$\Delta S = mc\ln\frac{T_2}{T_1}{}_{\#}$$

4. A tank is filled with saturated moist air at 30°C (T) and the total pressure in the tank is 150 kPa (P). If the mass of water vapour in the tank is 800 g (m_v), calculate the mass of dry air (m_a).

saturated moist air, $\phi = 100\%$
$$P_g = P_{sat@T}$$
$$\omega = 0.622\frac{\phi P_g}{P - \phi P_g} = \frac{m_v}{m_a}$$
$$m_a = \frac{m_v}{\omega}{}_{\#}$$

5. An ideal gas mixture consists of 2.5 kmol (N_{N2}) of nitrogen and 4.2 kmol (N_{O2}) of oxygen. Determine the specific heat at constant pressure ($c_{p,m}$) of the mixture at a temperature of 350 K.

$$m_{\mathrm{O_2}} = N_{\mathrm{O_2}}M_{\mathrm{O_2}}$$
$$m_{\mathrm{N_2}} = N_{\mathrm{N_2}}M_{\mathrm{N_2}}$$

$$\mathrm{mf}_{\mathrm{O}_2} = \frac{m_{\mathrm{O}_2}}{m_{\mathrm{O}_2} + m_{\mathrm{N}_2}}$$
$$\mathrm{mf}_{\mathrm{N}_2} = 1 - \mathrm{mf}_{\mathrm{O}_2}$$
$$c_{p,m} = \mathrm{mf}_{\mathrm{O}_2} \times c_{p,O_2} + \mathrm{mf}_{\mathrm{N}_2} \times c_{p,N_2}{}_{\#}$$

Using the mole fraction version to obtain specific heat per kmol is also acceptable but the answer and values used must be in terms of kJ/kmol·K.

$$y_{O_2} = \frac{N_{O_2}}{N_{O_2} + N_{N_2}}$$
$$y_{N_2} = 1 - y_{O_2}$$
$$\bar{c}_{p,m} = y_{\mathrm{O}_2} \times \bar{c}_{p,O_2} + y_{\mathrm{N}_2} \times \bar{c}_{p,N_2}{}_{\#}$$

6. Carbon dioxide is compressed steadily at a rate of 1.5 kg/s ($\dot{m}$) by an adiabatic compressor from 100 kPa (P_1) and 30°C (T_1) to 500 kPa (P_2). If the compressor consumes 185 kW (W_a) of power during operation, calculate its isentropic efficiency (η_c). Assume an average temperature of 400 K.

$$T_{2s} = T_1 \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$$
$$W_{isen} = -\dot{m}\frac{nRT_1}{n-1}\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right], n = k$$
$$\eta_c = \frac{W_{isen}}{W_a}{}_{\#} = \frac{\dot{m}c_p(T_{2s} - T_1)}{W_a}{}_{\#}$$

7. An inventor has developed a new heat engine that taps into a geothermal energy source at 150°C (T_H) while rejecting the waste heat to the environment at 10°C (T_L). It is claimed that the engine produces 2 kW (W_{out}) of power with a heat rejection rate of 12000 kJ/h (Q_L). Is this claim valid?

$$\eta_{TH} = \frac{W_{out}}{Q_H} = \frac{W_{out}}{W_{out} + Q_L}$$
$$\eta_{TH,\mathrm{Carnot}} = 1 - \frac{T_L}{T_H}$$

if $\eta_{TH} \leq \eta_{TH,\mathrm{Carnot}}$, claim is valid, otherwise, claim is invalid

Alternatively, comparisons between power produced and heat rejection rates are acceptable as well.

8. 3.3 kg (m) of saturated liquid R134a at 600 kPa (P_1) evaporates into vapour at 100 kPa (P_2) and 30°C (T_2). Calculate the entropy change of R134a (ΔS).

$s_1 = s_f$ at pressure, P_1 (saturated liquid)

s_2 = properties at T_2, P_2 (superheated vapour)

$$\Delta S = m(s_2 - s_1)_{\#}$$