MCG 2131 - Problem Set 1

All from 9th edition of Borgnakke & Sonntag, Fundamentals of Thermodynamics.
Equivalent problem numbers for the 8th edition are given where these exist.

1. Textbook Problem 11.18 (8th edition 11.19).

Properties for the refrigerants used are in Table A.5. Convert mass fraction to mol:

$x_i = M\, Y_i / M_i$, and $M = (\Sigma (Y_i / M_i))^{-1} = 86.2$ kg/kmol, so that

$x_{R32} = 0.381$; $x_{R125} = 0.180$; and $x_{R134a} = 0.439$.

$R = \bar{R} / M = 0.0964$ kJ/kg K (alternatively, $R = \Sigma\, Y_i R_i$)

$C_P = \Sigma\, Y_i C_{Pi} = 0.8299$ kJ/kg K; $C_V = C_P - R = 0.7334$ kJ/kg K
(alternatively, $C_V = \Sigma\, Y_i C_{Vi}$)

2. Textbook Problem 11.17.

Write gas law for each component i:

$\dot{m}_i = p_i \dot{V} / R_i T$

$R_{C2H6} = 0.2765$ kJ/kg K, $R_{C3H8} = 0.1886$ kJ/kg K, $R_{C4H10} = 0.1430$ kJ/kg K.

$\dot{m}_{C2H6} = 0.1851$ kg/s, $\dot{m}_{C3H8} = 1.176$ kg/s, $\dot{m}_{C4H10} = 0.477$ kg/s

3. (a) Mol fractions: for each component calculate Y_i / M_i , then divide by $\Sigma\, Y_i / M_i$.

Answers: $\mathbf{x_{H2} = 0.242}$, $\mathbf{x_{CO} = 0.388}$, $\mathbf{x_{CO2} = 0.154}$, $\mathbf{x_{N2} = 0.216}$.

(b) Write gas law for mixture as a whole. Mixture gas constant $R = \mathcal{R} / M$, and mixture molecular mass $M = 1 / \Sigma (Y_i / M_i)$.

Answer: **M = 24.23 kg/kmol, v = 1.006 m³/kg.**

(c) First law, closed system, no work, assume const. sp. heat:

$q_{12} = 0 = u_2 - u_1 = C_V (T_2 - T_1)$

Mixture specific heat $C_V = \sum Y_i C_{V\,i} = 0.9056$ kJ/kg K, $\mathbf{q_{12} = 72.4}$ **kJ/kg.**

(d) First law, no heat transfer, assume const sp. ht

$0 = w_{12} + u_2 - u_1 = w_{12} + C_V (T_2 - T_1)$

Isentropic, const sp. ht: $s_2 - s_1 = 0 = C_P \ln (T_2 / T_1) - R \ln (P_2 / P_1)$

or $T_2 = T_1 (P_2 / P_1)^{(k - 1)/k}$

$k = C_P / C_V = 1.379$, $\mathbf{T_2 = 552\ K, w_{12} = -234.5\ kJ/kg}$

4. Textbook Problem 11.49 (8th edition 11.39).

First law for system: Q = W = 0, therefore $U_2 = U_1$

$$m\, u_2 = m_{O2}\, u_{O22} + m_{CO2}\, u_{CO22} = m_{O2}\, u_{O21} + m_{CO2}\, u_{CO21}$$

Assume constant specific heat:

$$m_{O2}\, C_{VO2}\, (T_2 - T_{O21}) + m_{CO2}\, C_{VCO2}\, (T_2 - T_{CO21}) = 0.$$

for O_2, $C_P = 0.922$ kJ/kg K, $C_V = 0.662$ kJ/kg K, $R = 0.2598$ kJ/kg K
for CO_2, $C_P = 0.842$ kJ/kg K, $C_V = 0.653$ kJ/kg K, $R = 0.1889$ kJ/kg K

Solve $\mathbf{T_2 = 334.5\ K}$

Final pressure $P_2 = m\, R\, T_2 / V_2$

- mixture gas constant $R = \Sigma\, Y_i\, R_i$, Y_i 's from given masses, R= 0.211 kJ/kg K
- total volume = sum of initial volumes, each volume from gas law from each component in initial state ($V_i = m_i\, R_i\, T_i / P_i$), which gives $V = 8.785\ m^3$

then $\mathbf{P_2 = 306\ kPa}$

(b) Second law, adiabatic

$$0 + S_{GEN} = S_2 - S_1$$

Total entropy change

$$S_2 - S_1 = \Delta S = m_{O2}\, \Delta s_{O2} + m_{CO2}\, \Delta s_{CO2}$$

$$= m_{O2} [\, C_{PO2} \ln (T_2 / T_{O21}) - R_{O2} \ln (p_{O22} / P_{O21})] + \\ + m_{CO2} [\, C_{PCO2} \ln (T_2 / T_{CO21}) - R_{CO2} \ln (p_{CO22} / P_{CO21})]$$

- final partial pressures from gas laws for components at final state $p_i = m_i\, R_i\, T_2 / V_2$

- then $\mathbf{S_{GEN} = \Delta S = 5.720\ kJ/K}$

5. Textbook Problem 11.47

First law, adiabatic, no work, neglect KE and PE

$$0 + \dot{m}_{ST}\, h_{ST\,1} + \dot{m}_{O2}\, h_{O2\,1} = (\dot{m}_{ST} + \dot{m}_{O2}\,)\, h_2 = \dot{m}_{ST}\, h_{ST\,2} + \dot{m}_{O2}\, h_{O2\,2}$$

since $h_2 = \Sigma\, Y_i\, h_i = \Sigma\, \dot{m}_i\, h_i / \Sigma\, \dot{m}_i$
Assume constant sp. heat:

$\dot{m}_{ST}\, C_{P\,ST}\, (T_{1\,ST} - T_2) = \dot{m}_{O2}\, C_{P\,O2}\, (T_2 - T_{1\,O2})$

$C_{P\,ST} = 1.872$ kJ/kg K, $C_{P\,O2} = 0.922$ kJ/kg K, $T_{1\,ST} = 673$K, $T_{1\,O2} = 400$ K

Solve: $\mathbf{T_2 = 546}$ **K.**

Second law, adiabatic, constant pressure (makes pressure terms 0), assume constant specific heat:

$$0 + \dot{S}_{GEN} = (\dot{m}_{ST} + \dot{m}_{O2})\, s_2 - \dot{m}_{ST}\, s_{ST\,1} - \dot{m}_{O2}\, s_{O2\,1}$$

$$= \dot{m}_{ST}\, (C_{P\,ST} \ln (T_2 / T_{ST\,1}) - R_{ST} \cdot 0) + \dot{m}_{O2}\, (C_{P\,O2} \ln (T_2 / T_{O2\,1}) - R_{O2} \cdot 0)$$

$\mathbf{\dot{S}_{GEN} = 0.282}$ **kJ/s K**