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

EPFL

Thermodynamics and energetics I: examples lecture, chapter 9

1. $M = \sum_{i=1}^{j} y_i M_i = y_{N2}M_{N2} + y_{O2}M_{O2} + y_{Ar}M_{Ar} + y_{CO2}M_{CO2}$

$$= 0.7808 \cdot 28.02 + 0.2095 \cdot 32.00 + 0.0093 \cdot 39.94 + 0.0003 \cdot 44.01 = 28.97 \frac{\text{kg}}{\text{kmol}}$$

2. a) Mixture changes isentropically, therefore: $\tilde{s}_2 - \tilde{s}_1 = y_{O2}\Delta\tilde{s}_{O2} + y_{CO2}\Delta\tilde{s}_{CO2} = 0$

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$$y_{O2}\left(\tilde{s}^0_{O2}(T_2) - \tilde{s}^0_{O2}(T_1) - \tilde{R}ln\left(\frac{p_2}{p_1}\right)\right) + y_{CO2}\left(\tilde{s}^0_{CO2}(T_2) - \tilde{s}^0_{CO2}(T_1) - \tilde{R}ln\left(\frac{p_2}{p_1}\right)\right) = 0$$

$$y_{O2}\tilde{s}^0_{O2}(T_2) + y_{CO2}\tilde{s}^0_{CO2}(T_2) = y_{O2}\tilde{s}^0_{O2}(T_1) + y_{CO2}\tilde{s}^0_{CO2}(T_1) + (y_{O2} + y_{CO2})\tilde{R}ln\left(\frac{p_2}{p_1}\right)$$

$$0.2\tilde{s}^0_{O2}(T_2) + 0.8\tilde{s}^0_{CO2}(T_2) = 233.42 \text{ kJ/kmol/K}$$

We need to do iteration:
At T_2=510K: 0.2(221.206)+0.8(235.700)=232.80 kJ/kmol/K
At T_2=530K: 0.2(221.812)+0.8(236.575)=233.62 kJ/kmol/K
And then we can interpolate to get T_2=517.6K

b) For each component change of entropy is calculated via idealized expressions:
O2: $\Delta\tilde{s}_{O2} = \tilde{s}^0_{O2}(T_2) - \tilde{s}^0_{O2}(T_1) - \tilde{R}ln\left(\frac{p_2}{p_1}\right)$=3.69 kJ/kmol/K
CO2: $\Delta\tilde{s}_{CO2} = \tilde{s}^0_{CO2}(T_2) - \tilde{s}^0_{CO2}(T_1) - \tilde{R}ln\left(\frac{p_2}{p_1}\right)$=-0.92 kJ/kmol/K

c) Energy balance for open system at steady state, no work and heat transfer, potential energy changes neglected: $0 = h_1 - h_2 + \frac{V_1^2 - V_2^2}{2} \rightarrow V_2 = \sqrt{V_1^2 + 2(h_1 - h_2)}$
Enthalpy change: $h_1 - h_2 = \frac{\tilde{h}_1 - \tilde{h}_2}{M} = \frac{1}{M}\left[y_{O2}\left(\tilde{h}_1 - \tilde{h}_2\right)_{O2} + y_{CO2}\left(\tilde{h}_1 - \tilde{h}_2\right)_{CO2}\right]$
Apparent molecular weight: $M = \sum_{i=1}^{j} y_i M_i$=41.6 kg/kmol
Enthalpy change of mixture: $h_1 - h_2$=194.7 kJ/kg $\rightarrow V_2$=624 m/s

3. a) The saturation pressure at 21 °C is (from table or database) p_g=0.02487 bar
$p_{v1} = \phi p_g$=0.01741 bar, $\omega_1 = 0.622\frac{p_{v1}}{p - p_{v1}}$ =0.11 kg_{vapor}/kg_{dryair}

b) The dew point temperature is the saturation temperature corresponding to p_{v1}. From table or database, T=15.3 °C.

c) Mass of water vapor at initial state: 1kg = $m_a + m_{v1}$ and $\omega_1 = \frac{m_{v1}}{m_a}$
$\rightarrow m_{v1} = \frac{1kg}{\frac{1}{\omega_1}+1}$ =0.0109 kg_{vapor}
Mass of dry air: m_a=1kg-m_{v1}=0.9891 kg_{dryair}
The mass of water vapor at the final state is:
Saturation pressure at 5 °C is (from table or database) p_g=0.00872 bar
$p_{v2} = \phi p_g$=0.00872 bar (ϕ=100%), $\omega_2 = 0.622\frac{p_{v2}}{p - p_{v2}}$ =0.0054 kg_{vapor}/kg_{dryair}
$m_{v2} = m_a\omega_1$=0.0053 kg_{vapor}
Condensed mass of water vapor: $m_w = m_{v1} - m_{v2}$=0.0056 $kg_{condensate}$

4. Heating moist air

a) Mass balances: $\dot{m}_{a1} = \dot{m}_{a2} = \dot{m}_a$ and $\dot{m}_{v1} = \dot{m}_{v2} = \dot{m}_v$

Energy balance at steady state, no work transfer, no kinetic and potential energy changes:

$$0 = \dot{Q}_{cv} + (\dot{m}_a h_{a1} + \dot{m}_v h_{v1}) - (\dot{m}_a h_{a2} + \dot{m}_v h_{v2})$$
$$\dot{Q}_{cv} = \dot{m}_a(h_{a2} - h_{a1}) + \dot{m}_v(h_{v2} + h_{v1})$$
$$\dot{Q}_{cv} = \dot{m}_a(h_{a2} - h_{a1}) + \dot{m}_v\left(h_{g2} + h_{g1}\right)$$
$$\dot{Q}_{cv} = \dot{m}_a(h_{a2} - h_{a1}) + \omega\dot{m}_a\left(h_{g2} + h_{g1}\right)$$

With $\dot{m}_a = \frac{\dot{V}_a}{v_{a1}} = \frac{\dot{V}_a}{\frac{\bar{R}}{M}T/p_{v1}} = \frac{\dot{V}_a}{\frac{\bar{R}}{M}T/(\phi_1 p_{g1})}$=182.9 kg/min

$\omega = 0.622\frac{p_{v1}}{p-p_{v1}}$ =0.00616 kg_{vapor}/kg_{dryair} → $\dot{Q}_{cv}$=3’717 kJ/min

b) $\phi_2 = \frac{p_{v2}}{p_{g2}}$=23.1%