

Homework Set #3, Thermodynamics II

Due:3-18-97

A large tank is separated into two compartments, with one compartment containing O_2 and the other compartment containing N_2 . The state conditions are indicated below. At some point, the partition is removed and the gases mix. Calculate the ending conditions, including all the mole fractions, pressures, temperatures, and entropy generation.

O_2 is designated by A, N_2 is designated by B

$$\begin{array}{lll}
 P_A := 100 \cdot \text{kPa} & P_B := 100 \cdot \text{kPa} & M_A := 32 \cdot \frac{\text{kg}}{\text{kmole}} \\
 T_A := 300 \cdot \text{K} & T_B := 300 \cdot \text{K} & \\
 V_A := 0.5 \cdot \text{m}^3 & V_B := 0.3 \cdot \text{m}^3 & M_B := 28 \cdot \frac{\text{kg}}{\text{kmole}}
 \end{array}$$

From the first law and ideal gas law, one can easily show that the process is constant temperature and constant pressure. The entropy generation is:

$$S_{\text{gen}} = (N_B \cdot s_{A,2} + N_B \cdot s_{B,2}) - (N_A \cdot s_{A,1} + N_B \cdot s_{B,1}) = N_A \cdot (s_{A,2} - s_{A,1}) + N_B \cdot (s_{B,2} - s_{B,1})$$

$$\Delta s_X = s_2 - s_1 = c_p \cdot \ln\left(\frac{T_2}{T_1}\right) - \frac{R_u}{M_X} \cdot \ln\left(\frac{y_{X,2} \cdot P_2}{y_{X,1} \cdot P_1}\right)$$

$$N_A := \frac{P_A \cdot V_A}{R_u \cdot T_A} \quad N_A = 0.02 \quad N_B := \frac{P_B \cdot V_B}{R_u \cdot T_B} \quad N_B = 0.012$$

$$N_m := N_A + N_B$$

$$y_{A,2} := \frac{N_A}{N_m} \quad y_{A,2} = 0.625 \quad y_{B,2} := \frac{N_B}{N_m} \quad y_{B,2} = 0.375$$

$$S_{\text{gen}} := N_A \cdot (-R_u \cdot \ln(y_{A,2})) + N_B \cdot (-R_u \cdot \ln(y_{B,2})) \quad S_{\text{gen}} = 0.176 \cdot \frac{\text{kJ}}{\text{K}}$$

Second part changes the initial conditions for the nitrogen:

$$\begin{array}{lll}
 P_A := 100 \cdot \text{kPa} & P_B := 200 \cdot \text{kPa} & M_A := 32 \cdot \frac{\text{kg}}{\text{kmole}} \\
 T_A := 300 \cdot \text{K} & T_B := 600 \cdot \text{K} & \\
 V_A := 0.5 \cdot \text{m}^3 & V_B := 0.3 \cdot \text{m}^3 & M_B := 28 \cdot \frac{\text{kg}}{\text{kmole}}
 \end{array}$$

In this case, the first law must be used to calculate T_2 and then the ideal gas law to calculate P_2

$$U_1 - U_2 = 0 = (N_A \cdot u_{A,1} + N_B \cdot u_{B,1}) - (N_A \cdot u_{A,2} + N_B \cdot u_{B,2}) = N_A \cdot (u_{A,1} - u_{A,2}) + N_B \cdot (u_{B,1} - u_{B,2})$$

Using constant specific heats:

$$T_2 = \frac{N_A \cdot c_{v,A} \cdot T_A + N_B \cdot c_{v,B} \cdot T_B}{N_A \cdot c_{v,A} + N_B \cdot c_{v,B}}$$

$$N_A = 0.02 \quad N_B := \frac{P_B \cdot V_B}{R_u \cdot T_B} \quad N_B = 0.012$$

$$N_m := N_A + N_B$$

$$y_{A,2} := \frac{N_A}{N_m} \quad y_{A,2} = 0.625 \quad y_{B,2} := \frac{N_B}{N_m} \quad y_{B,2} = 0.375$$

$$c_{v,A} := 0.696 \cdot \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \quad c_{v,B} := 0.752 \cdot \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

$$c_{p,A} := 0.956 \cdot \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \quad c_{p,B} := 1.049 \cdot \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

$$T_2 := \frac{N_A \cdot c_{v,A} \cdot T_A + N_B \cdot c_{v,B} \cdot T_B}{N_A \cdot c_{v,A} + N_B \cdot c_{v,B}} \quad T_2 = 417.992 \cdot \text{K}$$

$$M_m := y_{A,2} \cdot M_A + y_{B,2} \cdot M_B \quad M_m = 30.5 \cdot \frac{\text{kg}}{\text{kmole}}$$

$$P_2 := N_m \cdot R_u \cdot \frac{T_2}{V_A + V_B} \quad P_2 = 139.331 \cdot \text{kPa}$$

$$S_{\text{gen}} = (N_B \cdot s_{A,2} + N_B \cdot s_{B,2}) - (N_A \cdot s_{A,1} + N_B \cdot s_{B,1}) = N_A \cdot (s_{A,2} - s_{A,1}) + N_B \cdot (s_{B,2} - s_{B,1})$$

$$\Delta s_A := c_{p,A} \cdot M_A \cdot \ln\left(\frac{T_2}{T_A}\right) - R_u \cdot \ln\left(\frac{y_{A,2} \cdot P_2}{P_A}\right) \quad \Delta s_A = 11.297 \cdot \frac{\text{kJ}}{\text{kmole} \cdot \text{K}}$$

$$\Delta s_B := c_{p,B} \cdot M_B \cdot \ln\left(\frac{T_2}{T_B}\right) - R_u \cdot \ln\left(\frac{y_{B,2} \cdot P_2}{P_B}\right) \quad \Delta s_B = 0.543 \cdot \frac{\text{kJ}}{\text{kmole} \cdot \text{K}}$$

$$S_{\text{gen}} := N_A \cdot \Delta s_A + N_B \cdot \Delta s_B \quad S_{\text{gen}} = 0.233 \cdot \frac{\text{kJ}}{\text{K}}$$

$$\text{kPa} \equiv 1000 \cdot \text{Pa}$$

$$\text{kmole} \equiv 1000 \cdot \text{mole}$$

$$\text{kJ} \equiv 1000 \cdot \text{joule}$$

$$R_u \equiv 8.314 \cdot \frac{\text{kJ}}{\text{kmole} \cdot \text{K}}$$