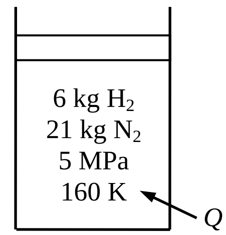
13-72 Heat is transferred to a gas mixture contained in a piston cylinder device. The initial state and the final temperature are given. The heat transfer is to be determined for the ideal gas and non-ideal gas cases.

Properties The molar masses of H_2 and N_2 are 2.0, and 28.0 kg/kmol. (Table A-1).

Analysis From the energy balance relation,



$$E_{in} - E_{out} = \Delta E$$
$$Q_{in} - W_{b,out} = \Delta U$$
$$Q_{in} = \Delta H = \Delta H_{H_2} + \Delta H_{N_2} = N_{H_2}(\bar{h}_2 - \bar{h}_1)_{H_2} + N_{N_2}(\bar{h}_2 - \bar{h}_1)_{N_2}$$

since W_b and ΔU combine into ΔH for quasi-equilibrium constant pressure processes

$$N_{H_2} = \frac{m_{H_2}}{M_{H_2}} = \frac{6\text{ kg}}{2\text{ kg/kmol}} = 3\text{ kmol}$$
$$N_{N_2} = \frac{m_{N_2}}{M_{N_2}} = \frac{21\text{ kg}}{28\text{ kg/kmol}} = 0.75\text{ kmol}$$

(*a*) Assuming ideal gas behavior, the inlet and exit enthalpies of H_2 and N_2 are determined from the ideal gas tables to be

$$H_2: \quad \bar{h}_1 = \bar{h}_{@160\text{ K}} = 4{,}535.4\text{ kJ/kmol}, \qquad \bar{h}_2 = \bar{h}_{@200\text{ K}} = 5{,}669.2\text{ kJ/kmol}$$
$$N_2: \quad \bar{h}_1 = \bar{h}_{@160\text{ K}} = 4{,}648\text{ kJ/kmol}, \qquad \bar{h}_2 = \bar{h}_{@200\text{ K}} = 5{,}810\text{ kJ/kmol}$$

Thus, $Q_{ideal} = 3\times(5{,}669.2 - 4{,}535.4) + 0.75\times(5{,}810 - 4{,}648) = \mathbf{4273\ kJ}$

(*b*) Using Amagat's law and the generalized enthalpy departure chart, the enthalpy change of each gas is determined to be

H_2:

$$\left.\begin{aligned} T_{R_1,H_2} &= \frac{T_{m,1}}{T_{cr,H_2}} = \frac{160}{33.3} = 4.805 \\ P_{R_1,H_2} = P_{R_2,H_2} &= \frac{P_m}{P_{cr,H_2}} = \frac{5}{1.30} = 3.846 \\ T_{R_2,H_2} &= \frac{T_{m,2}}{T_{cr,H_2}} = \frac{200}{33.3} = 6.006 \end{aligned}\right\} \begin{aligned} Z_{h_1} &\cong 0 \\ Z_{h_2} &\cong 0 \end{aligned} \qquad \text{(Fig. A-29)}$$

Thus H_2 can be treated as an ideal gas during this process.

N_2:

$$\left.\begin{aligned} T_{R_1,N_2} &= \frac{T_{m,1}}{T_{cr,N_2}} = \frac{160}{126.2} = 1.27 \\ P_{R_1,N_2} = P_{R_2,N_2} &= \frac{P_m}{P_{cr,N_2}} = \frac{5}{3.39} = 1.47 \\ T_{R_2,N_2} &= \frac{T_{m,2}}{T_{cr,N_2}} = \frac{200}{126.2} = 1.58 \end{aligned}\right\} \begin{aligned} Z_{h_1} &= 1.3 \\ Z_{h_2} &= 0.7 \end{aligned} \qquad \text{(Fig. A-29)}$$

Therefore,

$$(\bar{h}_2 - \bar{h}_1)_{H_2} = (\bar{h}_2 - \bar{h}_1)_{H_2,ideal} = 5{,}669.2 - 4{,}535.4 = 1{,}133.8\text{kJ/kmol}$$
$$(\bar{h}_2 - \bar{h}_1)_{N_2} = R_u T_{cr}(Z_{h_1} - Z_{h_2}) + (\bar{h}_2 - \bar{h}_1)_{ideal}$$
$$= (8.314\text{kPa}\cdot\text{m}^3\text{/kmol}\cdot\text{K})(126.2\text{K})(1.3 - 0.7) + (5{,}810 - 4{,}648)\text{kJ/kmol} = 1{,}791.5\text{kJ/kmol}$$

Substituting,

$$Q_{in} = (3\text{ kmol})(1{,}133.8\text{ kJ/kmol}) + (0.75\text{ kmol})(1{,}791.5\text{ kJ/kmol}) = \mathbf{4745\ kJ}$$