13-31 The partial pressures of a gas mixture are given. The mole fractions, the mass fractions, the mixture molar mass, the apparent gas constant, the constant-volume specific heat, and the specific heat ratio are to be determined.

Properties The molar masses of CO_2, O_2 and N_2 are 44.0, 32.0, and 28.0 kg/kmol, respectively (Table A-1). The constant-volume specific heats of these gases at 300 K are 0.657, 0.658, and 0.743 kJ/kg·K, respectively (Table A-2a).

Analysis The total pressure is

$$P_{\text{total}} = P_{\text{CO2}} + P_{\text{O2}} + P_{\text{N2}} = 12.5 + 37.5 + 50 = 100 \text{ kPa}$$

Partial pressures
CO_2, 12.5 kPa
O_2, 37.5 kPa
N_2, 50 kPa

The volume fractions are equal to the pressure fractions. Then,

$$y_{\text{CO2}} = \frac{P_{\text{CO2}}}{P_{\text{total}}} = \frac{12.5}{100} = \mathbf{0.125}$$

$$y_{\text{O2}} = \frac{P_{\text{O2}}}{P_{\text{total}}} = \frac{37.5}{100} = \mathbf{0.375}$$

$$y_{\text{N2}} = \frac{P_{\text{N2}}}{P_{\text{total}}} = \frac{50}{100} = \mathbf{0.50}$$

We consider 100 kmol of this mixture. Then the mass of each component are

$$m_{\text{CO2}} = N_{\text{CO2}} M_{\text{CO2}} = (12.5 \text{ kmol})(44 \text{ kg/kmol}) = 550 \text{ kg}$$
$$m_{\text{O2}} = N_{\text{O2}} M_{\text{O2}} = (37.5 \text{ kmol})(32 \text{ kg/kmol}) = 1200 \text{ kg}$$
$$m_{\text{N2}} = N_{\text{N2}} M_{\text{N2}} = (50 \text{ kmol})(28 \text{ kg/kmol}) = 1400 \text{ kg}$$

The total mass is

$$m_m = m_{\text{N2}} + m_{\text{O2}} + m_{\text{Ar}} = 550 + 1200 + 1400 = 3150 \text{ kg}$$

Then the mass fractions are

$$\text{mf}_{\text{CO2}} = \frac{m_{\text{CO2}}}{m_m} = \frac{550 \text{ kg}}{3150 \text{ kg}} = \mathbf{0.1746}$$

$$\text{mf}_{\text{O2}} = \frac{m_{\text{O2}}}{m_m} = \frac{1200 \text{ kg}}{3150 \text{ kg}} = \mathbf{0.3810}$$

$$\text{mf}_{\text{N2}} = \frac{m_{\text{N2}}}{m_m} = \frac{1400 \text{ kg}}{3150 \text{ kg}} = \mathbf{0.4444}$$

The apparent molecular weight of the mixture is

$$M_m = \frac{m_m}{N_m} = \frac{3150 \text{ kg}}{100 \text{ kmol}} = \mathbf{31.50 \text{ kg/kmol}}$$

The constant-volume specific heat of the mixture is determined from

$$\begin{aligned} c_v &= \text{mf}_{\text{Co2}} c_{v,\text{CO2}} + \text{mf}_{\text{O2}} c_{v,\text{O2}} + \text{mf}_{\text{N2}} c_{v,\text{N2}} \\ &= 0.1746 \times 0.657 + 0.3810 \times 0.658 + 0.4444 \times 0.743 \\ &= \mathbf{0.6956 \text{ kJ/kg} \cdot \text{K}} \end{aligned}$$

The apparent gas constant of the mixture is

$$R = \frac{R_u}{M_m} = \frac{8.314 \text{ kJ/kmol} \cdot \text{K}}{31.50 \text{ kg/kmol}} = \mathbf{0.2639 \text{ kJ/kg} \cdot \text{K}}$$

The constant-pressure specific heat of the mixture and the specific heat ratio are

$$c_p = c_v + R = 0.6956 + 0.2639 = \mathbf{0.9595 \text{ kJ/kg} \cdot \text{K}}$$

$$k = \frac{c_p}{c_v} = \frac{0.9595 \text{ kJ/kg} \cdot \text{K}}{0.6956 \text{ kJ/kg} \cdot \text{K}} = \mathbf{1.379}$$