13-53 The volume fractions of components of a gas mixture are given. This mixture is heated while flowing through a tube at constant pressure. The heat transfer to the mixture per unit mass of the mixture is to be determined.

Assumptions All gases will be modeled as ideal gases with constant specific heats.

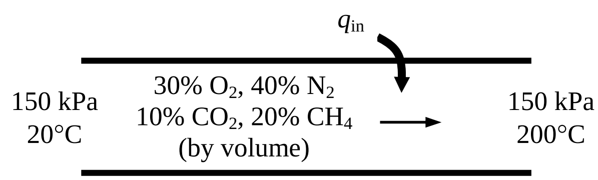
Properties The molar masses of O_2, N_2, CO_2, and CH_4 are 32.0, 28.0, 44.0, and 16.0 kg/kmol, respectively (Table A-1). The constant-pressure specific heats of these gases at room temperature are 0.918, 1.039, 0.846, and 2.2537 kJ/kg·K, respectively (Table A-2a).

Analysis We consider 100 kmol of this mixture. Noting that volume fractions are equal to the mole fractions, mass of each component are

$$
\begin{aligned}
m_{\mathrm{O2}} &= N_{\mathrm{O2}} M_{\mathrm{O2}} = (30\ \mathrm{kmol})(32\ \mathrm{kg/kmol}) = 960\ \mathrm{kg} \\
m_{\mathrm{N2}} &= N_{\mathrm{N2}} M_{\mathrm{N2}} = (40\ \mathrm{kmol})(28\ \mathrm{kg/kmol}) = 1120\ \mathrm{kg} \\
m_{\mathrm{CO2}} &= N_{\mathrm{CO2}} M_{\mathrm{CO2}} = (10\ \mathrm{kmol})(44\ \mathrm{kg/kmol}) = 440\ \mathrm{kg} \\
m_{\mathrm{CH4}} &= N_{\mathrm{CH4}} M_{\mathrm{CH4}} = (20\ \mathrm{kmol})(16\ \mathrm{kg/kmol}) = 320\ \mathrm{kg}
\end{aligned}
$$

The total mass is

$$
\begin{aligned}
m_m &= m_{\mathrm{O2}} + m_{\mathrm{N2}} + m_{\mathrm{CO2}} + m_{\mathrm{CH4}} \\
&= 960 + 1120 + 440 + 320 \\
&= 2840\ \mathrm{kg}
\end{aligned}
$$



Then the mass fractions are

$$
\begin{aligned}
\mathrm{mf}_{\mathrm{O2}} &= \frac{m_{\mathrm{O2}}}{m_m} = \frac{960\ \mathrm{kg}}{2840\ \mathrm{kg}} = 0.3380 \\
\mathrm{mf}_{\mathrm{N2}} &= \frac{m_{\mathrm{N2}}}{m_m} = \frac{1120\ \mathrm{kg}}{2840\ \mathrm{kg}} = 0.3944 \\
\mathrm{mf}_{\mathrm{CO2}} &= \frac{m_{\mathrm{CO2}}}{m_m} = \frac{440\ \mathrm{kg}}{2840\ \mathrm{kg}} = 0.1549 \\
\mathrm{mf}_{\mathrm{CH4}} &= \frac{m_{\mathrm{CH4}}}{m_m} = \frac{320\ \mathrm{kg}}{2840\ \mathrm{kg}} = 0.1127
\end{aligned}
$$

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

$$
\begin{aligned}
c_p &= \mathrm{mf}_{\mathrm{O2}} c_{p,\mathrm{O2}} + \mathrm{mf}_{\mathrm{N2}} c_{p,\mathrm{N2}} + \mathrm{mf}_{\mathrm{CO2}} c_{p,\mathrm{CO2}} + \mathrm{mf}_{\mathrm{CH4}} c_{p,\mathrm{CH4}} \\
&= 0.3380 \times 0.918 + 0.3944 \times 1.039 + 0.1549 \times 0.846 + 0.1127 \times 2.2537 \\
&= 1.1051\ \mathrm{kJ/kg \cdot K}
\end{aligned}
$$

An energy balance on the tube gives

$$
q_{\mathrm{in}} = c_p (T_2 - T_1) = (1.1051\ \mathrm{kJ/kg \cdot K})(200 - 20)\ \mathrm{K} = \mathbf{199\ kJ/kg}
$$