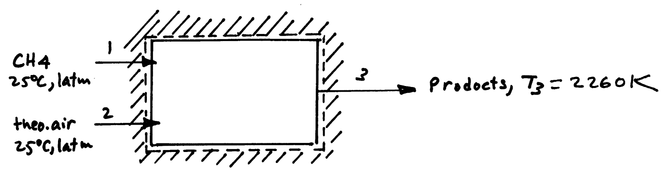
PROBLEM 13.61

KNOWN: CH4 at 25°C, 1atm enters an insulated reactor operating at steady state and burns with the theoretical amount of air entering at 25°C, 1atm. The products, which contain CO_2, CO, H_2O, O_2, and N_2 exit at 2260K.

FIND: Determine the fractions of the entering carbon that burn to CO_2, CO.

SCHEMATIC & GIVEN DATA:



ASSUMPTIONS: (1) The control volume shown in the accompanying figure operates at steady state with $\dot{Q}_{cv} = \dot{W}_{cv} = 0$ and negligible effects of kinetic and potential energy. (2) Combustion is with the theoretical amount of air. 3.76 moles of N_2 accompany each mole of O_2 in the air. N_2 is inert. (3) The combustion air and combustion products can be modeled as ideal gases.

ANALYSIS: The reaction equation takes the form

$$CH_4 + 2\,O_2 + 7.52\,N_2 \rightarrow x\,CO_2 + (1-x)\,CO + 2H_2O + \left(\frac{1-x}{2}\right)O_2 + 7.52\,N_2$$

At steady state, an energy rate balance reduces to read

$$0 = \frac{\dot{Q}_{cv}}{\dot{n}_{CH4}}^{\,0} - \frac{\dot{W}_{cv}}{\dot{n}_{CH4}}^{\,0} + (\bar{h}_{CH4})_1 + [2\bar{h}_{O_2} + 7.52\bar{h}_{N_2}]_2 - [x\bar{h}_{CO_2} + (1-x)\bar{h}_{CO} + 2\bar{h}_{H_2O} + (\tfrac{1-x}{2})\bar{h}_{O_2} + 7.52\bar{h}_{N_2}]_3$$

with $\bar{h} = \bar{h}_f^\circ + \Delta\bar{h}$, and noting that $\bar{h}_f^\circ = 0$ for O_2 and N_2

$$0 = (\bar{h}_f^\circ)_{CH4} + [0] - x[\bar{h}_f^\circ + \Delta\bar{h}]_{CO_2} - (1-x)[\bar{h}_f^\circ + \Delta\bar{h}]_{CO} - 2[\bar{h}_f^\circ + \Delta\bar{h}]_{H_2O} - (\tfrac{1-x}{2})(\Delta\bar{h})_{O_2} - 7.52(\Delta\bar{h})_{N_2}$$

With data from Tables A-23, 25

$$0 = (-74{,}850) - x[-393{,}520 + (116{,}594 - 9364)] - (1-x)[-110{,}530 + (74{,}882 - 8669)] - 2[-241{,}820 + (96089 - 9904)] - (\tfrac{1-x}{2})[77781 - 8682] - 7.52[74220 - 8669]$$

or

$$0 = (-74{,}850) - x[-286{,}290] - (1-x)[-44{,}317] - 2[-155{,}635] - (\tfrac{1-x}{2})(69{,}099) - 492{,}944$$

$$0 = (-74{,}850) - (-44{,}317) - 2(-155{,}635) - \frac{69{,}099}{2} - 492{,}944 - x(-286{,}290 + 44{,}317 - \frac{69{,}099}{2})$$

$$x = \frac{(-74{,}850) + 44{,}317 + 2(155{,}635) - 69{,}099/2 - 492{,}944}{(-286{,}290 + 44{,}317 - 69{,}099/2)}$$

$$= \frac{-246{,}757}{-276{,}523} = 0.892 \Rightarrow$$ 89.2% of carbon to CO_2, 10.8% of carbon to CO ←