

PROBLEM 2-1

GIVEN: Air with a molar composition of 79% N_2 and 21% O_2

FIND: The mass fraction of O_2 and N_2 in the air

APPROACH: This a simple conversion problem using:

$$MW_{mix} = \sum X_i MW_i \quad \text{and} \quad Y_i = X_i \frac{MW_i}{MW_{mix}}$$

Given the molar composition: $X_{N_2} = 0.79$ and $X_{O_2} = 0.21$

mixture molecular weight:

$$\begin{aligned} MW_{mix} &= \sum X_i MW_i = X_{N_2} MW_{N_2} + X_{O_2} MW_{O_2} \\ &= 0.79(28.013) + (0.21)(32) = 28.85 \text{ kg/kmol} \end{aligned}$$

mass fraction of O_2 and N_2

$$Y_{O_2} = X_{O_2} \left(\frac{MW_{O_2}}{MW_{mix}} \right) = 0.21 \left(\frac{32}{28.85} \right) = 0.233$$

$$Y_{N_2} = X_{N_2} \left(\frac{MW_{N_2}}{MW_{mix}} \right) = 0.79 \left(\frac{28.013}{28.85} \right) = 0.767$$

Comments: Note that $Y_{O_2} > X_{O_2}$ since $MW_{O_2} > MW_{mix}$ and that $\sum Y_i = 1$ as would be expected.

PROBLEM 2-2

GIVEN: The following mixture:

| Species | # MOLES | X_i | Y_i | MW_i |
|------------------|---------|----------------------|----------------------|--------|
| CO | 0.095 | 0.002 | 0.002 | 28.010 |
| CO ₂ | 6 | 0.127 | 0.195 | 44.011 |
| H ₂ O | 7 | 0.149 | 0.094 | 18.016 |
| N ₂ | 34 | 0.722 | 0.707 | 28.013 |
| NO | 0.005 | 106×10^{-6} | 111×10^{-6} | 30.006 |
| TOTAL: | 47.1 | 1.0 | 1.0 | |

- FIND: a) The mole fraction, mole%, and ppm of NO in the mixture
 b) Determine the MW of the mixture
 c) Determine the mass fraction of each constituent

$$a) X_i = \frac{N_i}{\sum N_i} = \frac{N_{NO}}{N_{CO} + N_{CO_2} + N_{H_2O} + N_{N_2} + N_{NO}} = \frac{0.005}{0.095 + 6 + 7 + 34 + 0.005}$$

$$X_{NO} = 106 \times 10^{-6} \text{ kmol/kmol-mix}$$

$$\text{MOLE \%} = X_i \cdot 100 = 0.0106 \%$$

$$\text{PPM} = \frac{\#NO}{\text{TOT \#}} (1 \times 10^6) = \frac{N_{NO} \cdot A}{\sum N_i \cdot A} (1 \times 10^6) = X_{NO} (1 \times 10^6) = 106 \text{ ppm}$$

where $A \equiv$ Avogadro's Number

$$b) MW_{mix} = \sum X_i MW_i = X_{CO} MW_{CO} + X_{CO_2} MW_{CO_2} + X_{H_2O} MW_{H_2O} + X_{N_2} MW_{N_2} + X_{NO} MW_{NO}$$

where X_{CO} , X_{CO_2} , X_{H_2O} , and X_{N_2} are found in the same manner as X_{NO} was found

$$MW_{mix} = (0.002)(28.010) + (0.127)(44.011) + (0.149)(18.016) + 0.722(28.013) + (106 \times 10^{-6})(30.006)$$

$$MW_{mix} = 28.6 \text{ kg/kmol-mix}$$

$$c) Y_i = X_i \frac{MW_i}{MW_{mix}} \quad \left(\frac{kg_i}{kg_{mix}} \right)$$

| | | |
|-------------------|---|------------------------|
| CO: | $Y = (0.002)(28.01/28.6)$ | = 0.002 |
| CO ₂ : | $Y = (0.127)(44.011/28.6)$ | = 0.195 |
| H ₂ O: | $Y = (0.149)(18.016/28.6)$ | = 0.094 |
| N ₂ : | $Y = (0.722)(28.013/28.6)$ | = 0.707 |
| NO: | $Y = (106 \times 10^{-6})(30.006/28.6)$ | = 111×10^{-6} |

COMMENTS: Note that $\text{ppm}_i = X_i (1 \times 10^6)$ and that $\sum X_i = 1$ and $\sum Y_i = 1$ can often be used to check your calculations

PROBLEM 2-3

GIVEN : mixture with 5 kmole H_2 and 3 kmole O_2

FIND : x_{H_2} , x_{O_2} , MW_{mix} , Y_{H_2} , Y_{O_2}

SOLUTION :

$$a) \quad x_i = \frac{N_i}{N_{tot}} \quad ; \quad x_{H_2} = \frac{5}{5+3} = \boxed{0.625}$$

$$x_{O_2} = 1 - x_{H_2} = 1 - 0.625 = \boxed{0.375}$$

$$b) \quad MW_{mix} = \sum x_i MW_i = x_{H_2} MW_{H_2} + x_{O_2} MW_{O_2} \\ = 0.625(2.016) + 0.375(31.999)$$

$$\boxed{MW_{mix} = 13.260}$$

$$c) \quad Y_i = x_i \frac{MW_i}{MW_{mix}} \quad ; \quad Y_{H_2} = 0.625 \frac{2.016}{13.260} = \boxed{0.095}$$

$$Y_{O_2} = 1 - Y_{H_2} = 1 - 0.095 = \boxed{0.905}$$

COMMENT : Even though the mole fraction of H_2 is large, its low molecular weight results in its having a small mass fraction.

PROBLEM 2-4

GIVEN: $O_2 - CH_4$ mixture @ 300 K & 100 kPa;
 $x_{O_2} = 0.2$

FIND: Y_{CH_4} , N_{CH_4}/V

ASSUMPTIONS: ideal gas mixture

SOLUTION:

$$\begin{aligned} a) \quad Y_{CH_4} &= x_{CH_4} \frac{MW_{CH_4}}{MW_{MIX}} \\ &= x_{CH_4} \frac{MW_{CH_4}}{x_{CH_4} MW_{CH_4} + (1 - x_{CH_4}) MW_{O_2}} \\ &= 0.2 \frac{16.043}{0.2(16.043) + 0.8(31.999)} = \frac{0.2(16.043)}{28.008} \end{aligned}$$

$$\boxed{Y_{CH_4} = 0.111}$$

$$b) \quad P_{CH_4} V = N_{CH_4} R_u T ; \quad P_{CH_4} = x_{CH_4} P$$

$$N_{CH_4}/V = \frac{x_{CH_4} P}{R_u T}$$

$$= \frac{(0.2) 100 \cdot 10^3}{8315 (300)} = \boxed{8.018 \cdot 10^{-3} \frac{\text{kmol}}{\text{m}^3}}$$

COMMENT: Careful treatment of units is required in part b.

PROBLEM 2-5

GIVEN: N_2 -Ar mixture with $N_{N_2} = 3 N_{Ar}$;
 $T = 500 \text{ K}$; $P = 250 \text{ kPa}$

FIND: x_i , MW_{mix} , Y_i , N_{N_2}/V

ASSUMPTION: ideal gas mixture

SOLUTION:

$$a) x_{N_2} = \frac{N_{N_2}}{N_{mix}} = \frac{3 N_{Ar}}{3 N_{Ar} + N_{Ar}} = \frac{3}{4} = \boxed{0.75}$$

$$x_{Ar} = 1 - 0.75 = \boxed{0.25}$$

$$b) MW_{mix} = \sum x_i MW_i$$

$$= 0.75(28.014) + 0.25(39.948)$$

$$\boxed{MW_{mix} = 30.998}$$

$$c) Y_{N_2} = x_{N_2} \frac{MW_{N_2}}{MW_{mix}} = 0.75 \frac{28.014}{30.998} = \boxed{0.678}$$

$$\boxed{Y_{Ar} = 1 - Y_{N_2} = 0.322}$$

$$d) P_{N_2} V = N_{N_2} R_u T ; P_{N_2} = x_{N_2} P_{tot}$$

$$N_{N_2}/V = \frac{x_{N_2} P_{tot}}{R_u T} = \frac{(0.75) 250 \cdot 10^3}{8315 (500)} = \boxed{0.0451 \text{ kmol } N_2 / m^3}$$

COMMENT: Careful treatment of units is required in part d.

PROBLEM 2-6

GIVEN: CO_2 - O_2 mixture with $x_{\text{CO}_2} = 0.1$; $x_{\text{O}_2} = 0.9$;
 $T = 400 \text{ K}$

FIND: Standardized enthalpy of mixture

ASSUMPTION: Ideal-gas behavior

SOLUTION: This is a straight forward application of Eqn. 2.15a combined with the definition of standardized enthalpy (Eqn. 2.34).

$$\begin{aligned}\bar{h}_{\text{CO}_2} &= \bar{h}_{f,\text{CO}_2}^\circ + \Delta \bar{h}_{s,\text{CO}_2} = -393,546 + 4003 \text{ (Table A.2)} \\ &= -389,543 \text{ kJ/kmol}\end{aligned}$$

$$\bar{h}_{\text{O}_2} = \bar{h}_{f,\text{O}_2}^\circ + \Delta \bar{h}_{s,\text{O}_2} = 0 + 3031 = 3031 \text{ kJ/kmol} \text{ (Table A.11)}$$

$$\begin{aligned}\bar{h}_{\text{mix}} &= \sum x_i \bar{h}_i = x_{\text{CO}_2} \bar{h}_{\text{CO}_2} + x_{\text{O}_2} \bar{h}_{\text{O}_2} \text{ (Eqn. 2.15a)} \\ &= 0.1(-389,543) + 0.9(3031)\end{aligned}$$

$$\boxed{\bar{h}_{\text{mix}} = -36,226 \text{ kJ/kmol}_{\text{mix}}}$$

COMMENT: The use of the Appendix A tables made this problem simple. Note that the same information is available as curvefit equations in Table A-13.