Class 3

• Happy Monday!
• Terminology
  – Densities, MW, mole and mass fractions, flow rates, and temperatures
  – Pressure stuff next class
• Convert mass fraction to mole fraction
  – Using a basis

Business

• For those who added the class late the info materials are on my web page

• Please help me get to know you!
  – I may end up writing a letter of recommendation for you sometime

Error in 4th Edition
(early printing)

• See pdf file

Specific Gravity (SG)

• Definition: Density/Reference Density
• Typical Reference Density = water at 4°C
  – Value: 1 g/cm³, 1000 kg/m³ or 62.43 lbm/ft³
• SG given at particular temperature (does not have to be the reference temperature)
• To get density from SG:
  \[ \rho_A = (SG_A)(\rho_{H_2O,ref}) \]
  \[ SG_A = \frac{\rho_A}{\rho_{H_2O,ref}} \]

A. Terminology Handout

1. Find a friend and go over the sheet
2. Write or remember questions
Practice on SG

1. Look up the SG of Toluene in the back of your book (Table B.1)
   - Is this for a gas or a liquid?
   - What is the density in lbm/ft³?
   - What does the "(20°/4°)" in the column heading mean? (see page 44)
2. Look up the SG of water in Table B.1
   - Note the superscript (also on sulfuric acid)

Mole and Mass Fractions

- Must know what these represent physically!
- Must be able to interchange between the two
- Nomenclature differences: Web and book
  - Web uses $x_i$ for mole fraction, $w_i$ for mass fraction
- Remember: Not all the mole (or mass) fractions are independent. If you have "n" species then "n-1" of the mole fractions are independent. Why????

Please specify which type of moles!!!

- You have seen MW expressed in g/mol
  - What about kg/kg-mol?
  - Also lbm/lb-mol
    - $\text{MW}_{\text{carbon}} = 12 \text{ g/mol} = 12 \text{ lbm/lb-mol} = 12 \text{ kg/kg-mol}
- Is the concept of lb-mol new?
  - The book uses "mol" to mean "g-mol"
  - How do you convert from g-mol to lb-mol?
    - 1 lb-mol = 454 g-mol (just like 454 grams in a lbm)
    - 1 lb-mol ≠ 1 g-mol
  - How many g-mols are in a kg-mol?
    - 1 kg-mol = 1000 g-mol

Think-Pair-Share

- Composition of air is approximately:
  - 79% $N_2$, 21% $O_2$
- How do you find the mass fraction of $O_2$ in the air?
  - Method
  - Value

B. Class Exercise

- Convert mole fractions to mass fractions
- Why?
  - Most instruments measure mole fractions
  - Balances are done on mass fractions
    - Mass is conserved
    - Moles are not always conserved
  - $\text{H}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{H}_2\text{O}$
    - 1.5 moles \hspace{1em} 1 mole

Conversion from Mole to Mass Fraction

<table>
<thead>
<tr>
<th>Compound</th>
<th>$y_i$ (mole fraction)</th>
<th>$n_i$ (mol)</th>
<th>$M_i$ (g/mol)</th>
<th>$m_i$ (g)</th>
<th>$x_i$ (mass fraction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{CO}_2$</td>
<td>0.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\text{CH}_4$</td>
<td>0.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\text{C}_2\text{H}_6$</td>
<td>0.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\text{H}_2\text{O}$</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conversion from Mole to Mass Fraction

1. Assume a basis of 100 gmols
2. Calculate number of moles of each species
3. Find MW's
4. Calculate mass of each species
5. Normalize to find mass fractions

<table>
<thead>
<tr>
<th>Compound</th>
<th>$y_i$ (mole fraction)</th>
<th>$n_i$ (mol)</th>
<th>$M_i$ (g/mol)</th>
<th>$m_i$ (g)</th>
<th>$x_i$ (mass fraction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$</td>
<td>0.20</td>
<td>20</td>
<td>44</td>
<td>880</td>
<td>0.358</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>0.50</td>
<td>50</td>
<td>16</td>
<td>800</td>
<td>0.325</td>
</tr>
<tr>
<td>C$_2$H$_6$</td>
<td>0.20</td>
<td>20</td>
<td>30</td>
<td>600</td>
<td>0.244</td>
</tr>
<tr>
<td>H$_2$O</td>
<td>0.10</td>
<td>10</td>
<td>18</td>
<td>180</td>
<td>0.073</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1.00</td>
<td>100</td>
<td><strong>2460</strong></td>
<td></td>
<td>1.000</td>
</tr>
</tbody>
</table>

C. Average Molecular Weight

Formula: $\bar{M} = \sum y_i M_i \frac{mol_{i,s}}{mol_{i,s}} \frac{g_{i,s}}{mol_{i,s}} \frac{mol_{i,u}}{mol_{i,u}} = \frac{g_{i,u}}{mol_{i,u}}$

Units: mol$_{i,s}$ g$_{i,s}$ mol$_{i,u}$ mol$_{i,u}$, g$_{i,u}$ mol$_{i,u}$

Should this be mole or mass fraction?

How Do You Convert From Mass Fraction To Mole Fraction?

- Basis: 100 grams
- Compute mass of each species
- Divide by MW$_i$ to get moles$_i$
- Sum number of moles
- Compute mole fraction
Example Problem

A coal gasifier produces 5000 lbm/hr of syngas, composed of 35 mol% CO and 65 mol% H₂.

Find: Mass flow rate of CO in lb/hr.

Strategies:

a. Find species mass fractions,
   Get species mass flow rates

b. Find MW avg,
   Convert mass flow rate to total molar flow rate,
   Get species molar flow rate,
   Convert back to species mass flow rate

Which Has More H:
A m³ of liquid H₂ or a m³ of gasoline?

1. Approximate gasoline as iso-octane (C₈H₁₈)
2. Find densities & MWs
   • Iso-octane (6 kmol/m³ at 298 K)
   • H₂ (35 kmol/m³ at 20 K)
3. Find kmols of H per m³
   • (18 mol H/mol iso-octane) × (6 kmol iso-octane/m³) = 108 kmol/m³
   • (2 mol H/mol H₂) × (35 kmol/m³) = 70 kmol/m³

Dry Basis
Given yᵢ on a wet basis, compute yᵢ on a dry basis

<table>
<thead>
<tr>
<th>compound</th>
<th>yᵢ</th>
<th>Mᵢ (g/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>0.015</td>
<td>44</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.820</td>
<td>16</td>
</tr>
<tr>
<td>C₂H₆</td>
<td>0.040</td>
<td>30</td>
</tr>
<tr>
<td>H₂O</td>
<td>0.125</td>
<td>18</td>
</tr>
</tbody>
</table>

Assume basis of 100 gmoles of “wet” gas

<table>
<thead>
<tr>
<th>compound</th>
<th>nᵢ</th>
<th>yᵢ'</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>1.5</td>
<td>1.5/87.5 = 0.017</td>
</tr>
<tr>
<td>CH₄</td>
<td>82.0</td>
<td>82/87.5 = 0.937</td>
</tr>
<tr>
<td>C₂H₆</td>
<td>4.0</td>
<td>4/87.5 = 0.046</td>
</tr>
<tr>
<td>H₂O</td>
<td>12.5</td>
<td></td>
</tr>
</tbody>
</table>

Total | 100.0 |
Total (dry) | 87.5 | 1.000 |

Temperature Scales

°C K
-273.15 0 100
0 273.15 373.15

°F
-459.67 32 212
0 491.67 671.67

°R

Note: we do not use the degree symbol on the Kelvin scale!

°C °F

Thermocouples provide digital temperature values

Temperature
Temperature Conversions
(Eqns. 3.5-1 thru 4)

\[
\begin{align*}
T(K) &= T(\degree C) + 273.15 \\
T(\degree R) &= T(\degree F) + 459.67 \\
T(\degree R) &= 1.8 \times T(K) \\
T(\degree F) &= 1.8 \times T(\degree C) + 32
\end{align*}
\]

Homework Hints

- 3.3 – Work book problem available
- 3.10 – Archimedes principle
- 3.16 – A slurry is a mixture of liquid and fine solids
- 3.28 – Hint is given to define error