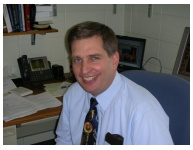
Class 2

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

1

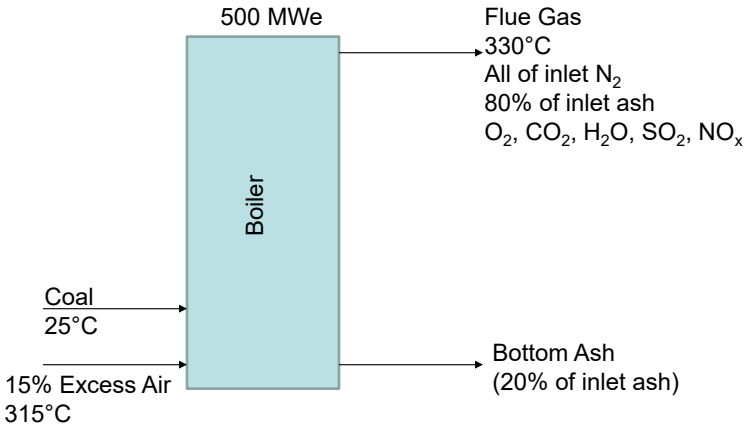
Business

- For those who added the class late the info materials are on my web page and on Learning Suite
- Please help me get to know you!
  - I may end up writing a letter of recommendation for you sometime



2

HW Review
(Case Study)



3

TA Schedule
(now posted on web page)

	M	Tu	W	Th	F
8		Parker		Parker	
9					
10					
11					
noon	Dawson				
1		Parker		Parker	
2	Dawson		Dawson		Dawson
3					
4					
5					
6					

Also note that Parker's cell # was changed in the syllabus, and final exam is Dec. 13

4

- Today: Terminology, using a basis
- Next time: Pressure, manometers
- Then: Mass and mole balances
- Then: Thermodynamics, vapor pressure, humidity, energy, heat capacities
- Then: Energy balances

5

Error in 4th Edition

(early printing)

- See pdf file

6

Answers to the quiz!

- Densities are sometimes expressed as a linear function of temperature, such as

$$\rho = \rho_0 + \frac{a}{T}$$

where ρ is the density in g/cm^3 and T is in Kelvin. What must the units be of the constants ρ_0 and a?

ρ_0 has units of g/cm^3

aT has units of g/cm^3, so a has units of $\frac{g \cdot K}{cm^3}$

7

A. Terminology Handout

1. Go over the sheet (with a neighbor if possible)
2. Write or remember questions

8

Chemical Engineering Terms

Symbol	Quantity
ρ	Density (g/cm^3)
S.G.	Specific gravity (ρ/ρ_{water})
$\hat{V}$	Specific volume (cm^3/g)
$\dot{m}$	Mass flow rate (g/s)
$\dot{n}$	Molar flow rate (gmol/s)
	g-mol vs lb-mol
$\dot{V}$ or $\dot{v}$	Volumetric flow rate (m^3/s)
MW	Molecular weight (g/gmol)
x_A	Mass fraction of species A (other definitions as well) ($mass_A/mass_{mix}$)
y_A	Mole fraction of species A (other definitions as well) (mol_A/mol_{mix})
$\overline{MW}$	Mixture molecular weight (g/gmol)
	Using a basis
C_A	Molar concentration (mol_A/cm^3); also called molarity
c_A	Mass concentration (g_A/cm^3); also called partial density ρ_A
T	Temperature scales (°C, K, °F, °R)

9

Specific Gravity (SG)

- Definition: Density/Reference Density
- Typical Reference Density = water at 4°C
  - Value: 1 g/cm^3, 1000 kg/m^3 or 62.43 lb_m/ft^3
- SG given at a particular temperature (does not have to be the reference temperature)
- SG is unitless, which is why we use it
- To get density from SG:

$$\rho_A = (SG_A)(\rho_{H_2O,ref})$$

$$SG_A = \frac{\rho_A}{\rho_{H_2O,ref}}$$

10

Practice on SG

1. Look up the SG of Toluene in the back of your book (Table B.1) 0.866
   - Is this for a gas or a liquid?
   - What is the density in lb_m/ft^3? $0.866 \times 62.4\ lb_m/ft^3$
   - 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)

11

Mole and Mass Fractions

y_A x_A

- 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?????

12

Please specify which type of moles!!!

- You have seen MW expressed in g/mol
  - What about kg/kg-mol?
  - Also lb_m/lb-mol
    - MW_{carbon} = 12 g/mol = 12 lb_m/lb-mol = 12 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 lb_m)
    - 1 lb-mol ≠ 1 g-mol
  - How many g-mols are in a kg-mol?
    - 1 kg-mol = 1000 g-mol

13

Think-Pair-Share

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

14

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

$H_2 + ½\ O_2 \rightarrow H_2O$

1.5 moles 1 mole

Gas chromatograph to measure gas phase mole fraction (y_i)

15

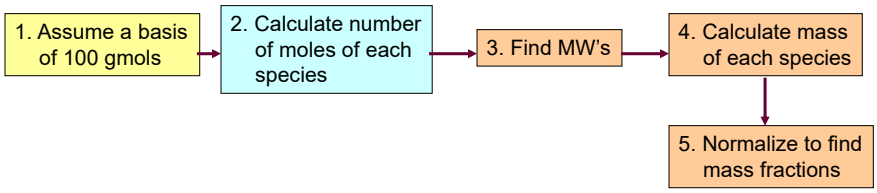
Conversion from Mole to Mass Fraction

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

Compound	y_i (mole fraction)	n_i (mol)	M_i (g/mol)	m_i (g)	x_i (mass fraction)
CO_2	0.20				
CH_4	0.50				
C_2H_6	0.20				
H_20	0.10				
	1.00				

16

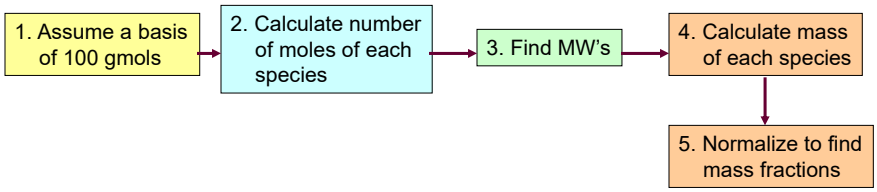
Conversion from Mole to Mass Fraction



Compound	y_i (mole fraction)	n_i (mol)	M_i (g/mol)	m_i (g)	x_i (mass fraction)
CO_2	0.20	20			
CH_4	0.50	50			
C_2H_6	0.20	20			
H_20	0.10	10			
Total	1.00	100			

17

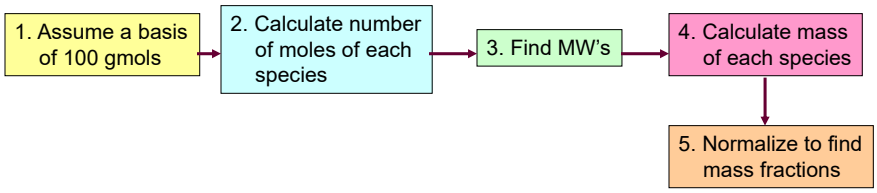
Conversion from Mole to Mass Fraction



Compound	y_i (mole fraction)	n_i (mol)	M_i (g/mol)	m_i (g)	x_i (mass fraction)
CO_2	0.20	20	44.0		
CH_4	0.50	50	16.0		
C_2H_6	0.20	20	30.0		
H_20	0.10	10	18.0		
Total	1.00	100			

18

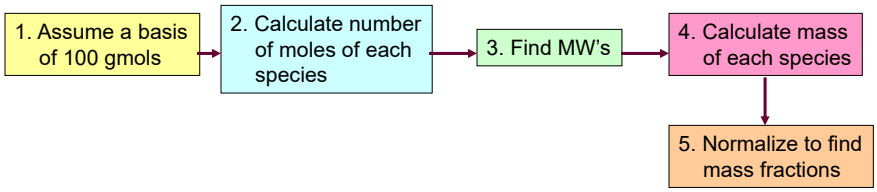
Conversion from Mole to Mass Fraction



Compound	y_i (mole fraction)	n_i (mol)	M_i (g/mol)	m_i (g)	x_i (mass fraction)
CO_2	0.20	20	44	880	
CH_4	0.50	50	16	800	
C_2H_6	0.20	20	30	600	
H_20	0.10	10	18	180	
Total	1.00	100		2460	

19

Conversion from Mole to Mass Fraction



Compound	y_i (mole fraction)	n_i (mol)	M_i (g/mol)	m_i (g)	x_i (mass fraction)
CO_2	0.20	20	44	880	0.358
CH_4	0.50	50	16	800	0.325
C_2H_6	0.20	20	30	600	0.244
H_20	0.10	10	18	180	0.073
Total	1.00	100		2460	1.000

20

C. Average Molecular Weight

Formula:

$$\overline{M} = \sum y_i M_i$$

Units:

$$\frac{mol_A}{mol_{mix}}\frac{g_A}{mol_A} + \frac{mol_B}{mol_{mix}}\frac{g_B}{mol_B} = \frac{g_{mix}}{mol_{mix}}$$

Should this be mole or mass fraction?

21

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

22

Example Problem

A coal gasifier produces 5000 lb_m/hr of syngas, composed of
35 mol% CO and
65 mol% H_2.

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

23

Example Problem
35 mol% CO
65 mol% H_2
$\dot{m}_{tot}$ = 5000 lb_m/hr
Find: $\dot{m}_{CO}$

Strategy 1. Calculate mass of each component

Basis: 100 mols total

$$(35\ mols\ CO)\left(\frac{28\ g\ CO}{mol\ CO}\right) = 980\ g\ CO$$

$$(65\ mols\ H_2)\left(\frac{2\ g\ H_2}{mol\ H_2}\right) = 130\ g\ H_2$$

1110 g tot

$$x_{CO} = \frac{980}{1110} = 0.883$$

$$\dot{m}_{CO} = 0.883 \cdot 5000\frac{lb_m}{hr} = 4414\frac{lb_m\ CO}{hr}$$

Strategy 2. Calculate $\overline{MW}$ to get $\dot{n}_{tot}$

$$\overline{MW} = \sum y_i MW_i = 0.35 \cdot 28 + 0.65 \cdot 2 = 11.1\ \ g/gmol$$

$$\dot{n}_{tot} = \left(5000\frac{lb_m}{hr}\right)\left(\frac{lbmol}{11.1\ lb_m}\right) = 450.45\frac{lbmol\ mix}{hr}$$

$$\dot{n}_{CO} = \left(450.45\frac{lbmol\ mix}{hr}\right)\left(\frac{0.35\ lbmol\ CO}{lbmol\ mix}\right)$$

$$\dot{n}_{CO} = 157.66\frac{lbmol\ CO}{hr}$$

$$\dot{m}_{CO} = \left(157.66\frac{lbmol\ CO}{hr}\right)\left(\frac{28\ lb_m\ CO}{lbmol\ CO}\right) = 4414\frac{lb_m\ CO}{hr}$$

24

Which Has More H:

A m^3 of liquid H_2 or a m^3 of gasoline?

1. Approximate gasoline as iso-octane (C_8H_{18})
2. Find densities & MWs
   - Iso-octane (6 kmol/m^3 at 298 K)
   - H_2 (35 kmol/m^3 at 20 K)
3. Find kmols of H per m^3
   - (18 kmol H/kmol iso-octane) × (6 kmol iso-octane/m^3) = 108 kmol/m^3
   - (2 mol H/mol H_2) × (35 kmol/m^3) = 70 kmol/m^3

25

Dry Basis

Given y_i on a wet basis, compute y_i on a dry basis

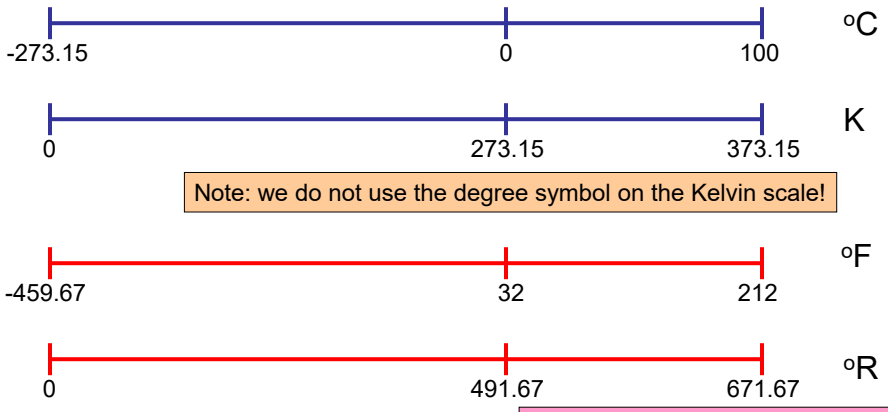
compound	y_i	M_i (g/mol)
CO_2	0.015	44
CH_4	0.820	16
C_2H_6	0.040	30
H_2O	0.125	18

Assume basis of 100 gmols of "wet" gas

compound	n_i	y_i'
CO_2	1.5	1.5/87.5 = 0.017
CH_4	82.0	82/87.5 = 0.937
C_2H_6	4.0	4/87.5 = 0.046
H_2O	12.5	--------
Total	100.0	
Total (dry)	87.5	1.000

26

Temperature Scales



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

Rankine scale may be new for you

Should be able to convert between scales!!
You must use an absolute temperature scale when you multiply or divide temperatures!!!

27

Temperature Conversions
(Eqns. 3.5-1 thru 4)

$T(K) = T(°C) + 273.15$

$T(°R) = T(°F) + 459.67$

$T(°R) = 1.8\ T(K)$

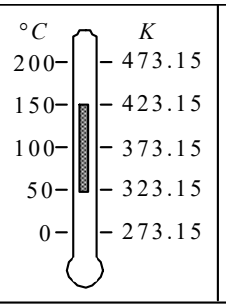
$T(°F) = 1.8\ T(°C) + 32$

28

Temperature

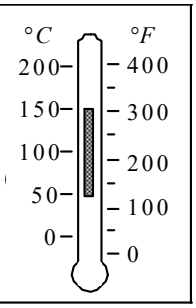
$T(K) = T(°C) + 273.15$

$1°C\ (diff.) = 1K\ (diff.)$

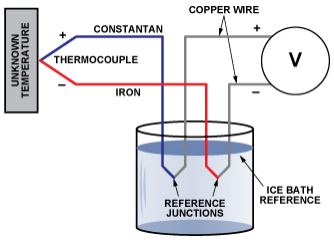


$T(°F) = 1.8T(°C)+32$

$1.8\,\Delta T(°C) = \Delta T\ (°F)$

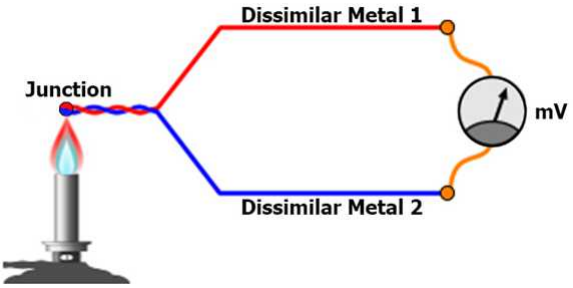


Thermocouples provide digital temperature values



29

Thermocouples

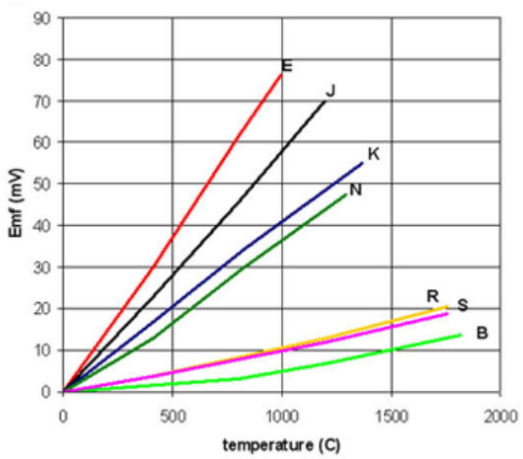


A thermocouple is a sensor used to measure temperature. Thermocouples consist of two wire legs made from dissimilar metals which are fixed together at one end, creating a junction. When this junction experiences a change in temperature a voltage is created, this voltage can then be measured and referenced back to the temperature. This is also known as the "Seebeck Effect".

https://www.sterlingsensors.co.uk/thermocouples

30

Types of Thermocuples



31

Types of Thermocouples

T/C Type	Conductor +	Conductor −	T/C Junction Continuous Temperature range °C	INTERNATIONAL IEC 584-3:1989 BS 4937 PT30:1993	(FORMER) UNITED KINGDOM BS 1843:1952	FRANCE NFE-18001	GERMANY DIN43714	JAPAN JIS C 1610-1981	USA ANSI MC 96.1	Cable Code
E	Ni-CR	Cu-Ni Constantan	0 to +800							EX
J	Fe	Cu-Ni Constantan	0 to +750							JX
K	Ni-Cr	Ni-Al	0 to +1100							KX
N	Ni-Cr-Si Nicrosil	Ni-Si-Mg Nisil	0 to +1100							NX NC
R	Pt-13Rh	Pt	0 to +1600							RCA
S	Pt-10Rh	Pt	0 to +1600							SCA
T	Cu	Cu-Ni Constantan	-185 to +300							TX
B	Pt-30Rh	Pt-6Rh	+200 to +1700							BX

32

Homework Hints

- 3.1 – Volume & Density
- 3.2 – Archimedes principle
- 3.3 – A slurry is a mixture of liquid and fine solids
- 3.4 – Non-ideal volume of liquid mixture

33