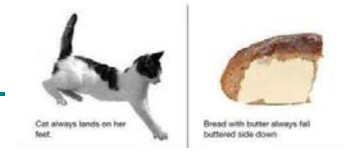
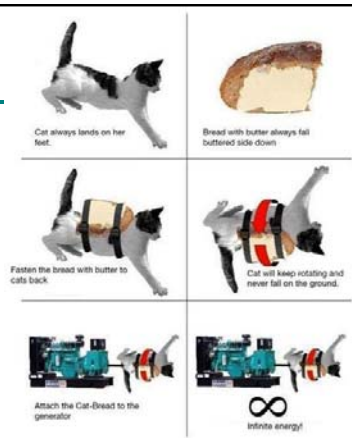
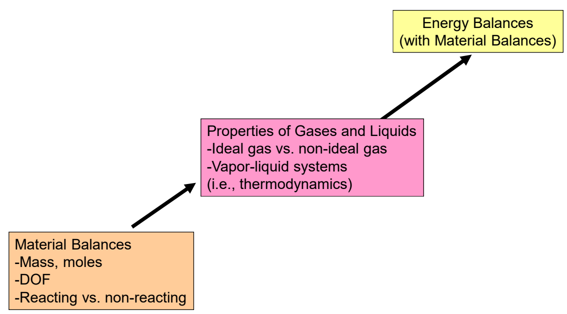
Common Algebra Mistakes I Have Seen

$$(a+b)^2 \neq a^2 + b^2$$
$$exp(a+b) \neq \exp(a) + \exp(b)$$
$$\frac{1}{a+b} \neq \frac{1}{a} + \frac{1}{b}$$
$$\sqrt{\frac{a^2}{b^2}} \neq \frac{\sqrt{a}}{b}$$
$$\frac{a+b}{b} \neq 1 + b$$
$$\ln(a) - \ln(b) \neq \ln(a-b)$$





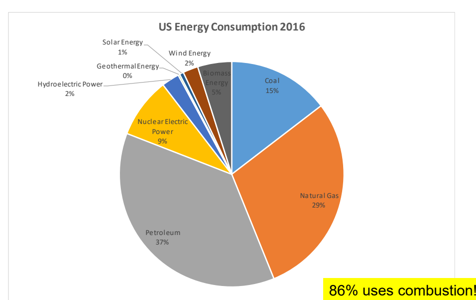
Where are we?
Where are we going?



Class 15
Combustion

- Terminology
  - Theoretical O_2, air
  - % Excess Air
  - Wet vs. Dry Basis
- Examples

US Energy Consumption
(What % of use is through combustion?)



http://www.eia.gov/totalenergy/ (2017)

Things to Remember About Combustion Problems

- Stoichiometric air requirement
  - All C $\Rightarrow CO_2$
  - All H $\Rightarrow H_2O$
  - All N $\Rightarrow N_2$
  - All S $\Rightarrow SO_2$
  - It may not fully combust, or it may form other products, but this is how the stoichiometric air requirements are calculated!
- Oxygen in the fuel affects stoichiometric conditions
- Often have excess air
- Don't forget the N_2!!!
  - Affects mole fractions

Example

- Consider the methane combustion reaction:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

- If there is not enough O_2, the following reaction occurs:

$$CH_4 + 3/2\ O_2 \rightarrow CO + 2H_2O$$

- **What is the stoichiometric requirement of O_2 to burn 10 moles of CH_4?**
  - **20 moles of O_2!!! You always consider complete combustion to CO_2 when computing the stoichiometric requirement**

Oxygen in Fuel Example

What is the stoichiometric O_2 requirement of a stream of 50 mol/min of methanol?

- $CH_3OH + 1.5\ O_2 \Rightarrow CO_2 + 2\ H_2O$

Remember

$$50\frac{mol\ CH_3OH}{\min}\left(\frac{1.5\ mol\ O_2}{mol\ CH_3OH}\right) = 75\frac{mol\ O_2}{\min}$$

- What if we want 25% excess air?
  - Excess O_2 = 1.25 × O_2, stoich = 1.25 × 75 mol/min = 93.75 mol O_2/min
  - Excess air: $93.75\frac{mol\ O_2}{\min}\left(\frac{1\ mol\ air}{0.21\ mol\ O_2}\right) = 446.4\frac{mol\ air}{\min}$

Example: Petroleum Coke

- Leftover hydrocarbon after refining
- Dirty, smelly, nasty
- Has energy content
- Gasified in China to make chemicals

http://www.alibaba.com/product-free/10256813/Petroleum_Coke/showimage.html

What is the theoretical air requirement of 100 lbs/hr of petroleum coke?

- Pet coke is 95 wt% C, 4% H, and 1% O
- $C + O_2 \rightarrow CO_2$
- $2H + 0.5\ O_2 \rightarrow H_2O$

$$\left(95\frac{lbs\ C}{hr}\right)\left(\frac{lbmol\ C}{12\ lbs\ C}\right)\left(\frac{lbmol\ O_2}{lbmol\ C}\right)\left(\frac{lbmol\ air}{0.21\ lbmol\ O_2}\right)\left(\frac{29\ lb\ air}{lbmol\ air}\right) = 1093\frac{lbs\ air}{hr}$$

$$\left(4\frac{lbs\ H}{hr}\right)\left(\frac{lbmol\ H}{1\ lbs\ H}\right)\left(\frac{0.5\ lbmol\ O_2}{2\ lbmol\ H}\right)\left(\frac{lbmol\ air}{0.21\ lbmol\ O_2}\right)\left(\frac{29\ lb\ air}{lbmol\ air}\right) = 138\frac{lbs\ air}{hr}$$

$$\left(1\frac{lbs\ O}{hr}\right)\left(\frac{lbmol\ O}{16\ lbs\ O}\right)\left(\frac{lbmol\ O_2}{2\ lbmol\ O}\right)\left(\frac{lbmol\ air}{0.21\ lbmol\ O_2}\right)\left(\frac{29\ lb\ air}{lbmol\ air}\right) = 4.3\frac{lbs\ air}{hr}$$ ← Subtract

Total Air requirement = 1093 + 138 – 4.3 = 1227 lbs air/hr

Review Dry Basis

Hint on Using Dry Basis

$$\dot{n}_{tot} = \dot{n}_{dry} + \dot{n}_{H_2O}$$

$$y_{i,dry} = \frac{\dot{n}_i}{\dot{n}_{dry}}$$

So it may seem obvious, but

$$\dot{n}_i = y_{i,dry}\,\dot{n}_{dry}$$

The trick:

- If given mole fraction on a dry basis, you will likely need to compute $\dot{n}_{dry}$

Problem 4.71

(4.93 in 4th Edition)

CH_3OH (liq)
12 L/hr

n_{dry}
n_{H2O}

n_{air}

Air
$y_{O2} = 0.21$
$y_{N2} = 0.79$

Dry
$y_{CH3OH} = 0.0045$
$y_{CO2} = 0.0903$
$y_{CO} = 0.0181$
y_{O2} = ?
$y_{N2} = 1 - \Sigma y_{i,other}$

$CH_3OH + 1.5\ O_2 \rightarrow CO_2 + 2H_2O$
(CO formation equation not needed if we do element balances)

DOF	
U (n_{air}, n_{dry}, n_{H2O}, y_{O2})	= 4
Elem (C,H,O)	= 3
NR (N_2)	= 1
OE	= 0
DOF	0

Problem 4.71 (Cont.)

1. Find molar flow rate of methanol

$$\left(12\frac{lit\ CH_3OH}{hr}\right)(0.792)\left(1\frac{g}{cm^3}\right)\left(1000\frac{cm^3}{lit}\right)\left(\frac{mol}{32g}\right) = 297\frac{mol\ CH_3OH}{hr}$$

(S.G.)

2. Find the stoich. O_2 req't

Note: we don't know the actual air flow rate, but need the stoichiometric amount to find the % excess air once we find $n_{O2,in}$.

297 mol CH_3OH (1.5 mol O_2/mol CH_3OH) = 445.5 mol O_2/hr

3. Elemental C balance (in = out)

$$\left(297\frac{mol\ CH_3OH}{hr}\right)\left(\frac{1C}{mol\ CH_3OH}\right) = n_{dry}\left[(0.0045)\left(\frac{1C}{mol\ CH_3OH}\right) + (0.0903)\left(\frac{1C}{mol\ CO_2}\right) + (0.0181)\left(\frac{1C}{mol\ CO}\right)\right]$$

wanted: n_{dry}
Dry basis: y_{CH3OH}, y_{CO2}, y_{CO}

n_{dry} = 297/0.1129 = 2631 mol/hr

4-6. Balances on H, O, N_2 (see spreadsheet)

So… What Did You Learn Today?

- Stoichiometric air requirement
  - All C $\Rightarrow CO_2$
  - All H $\Rightarrow H_2O$
  - All N $\Rightarrow N_2$
  - All S $\Rightarrow SO_2$
- Don't forget to add in the N_2
- Don't forget the O in the fuel
- Compute n_{dry} if mole fractions are given on a dry basis