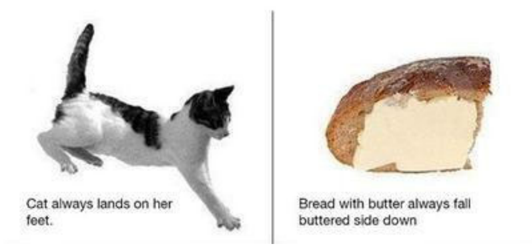
Common Algebra Mistakes I Have Seen

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

1



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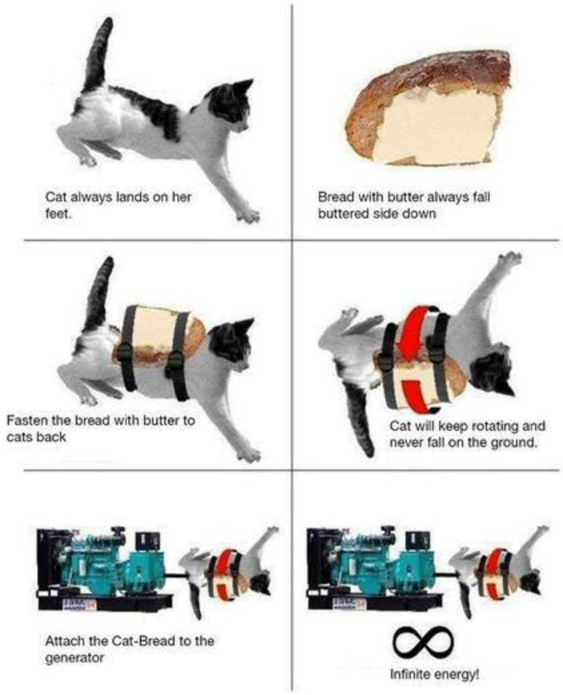


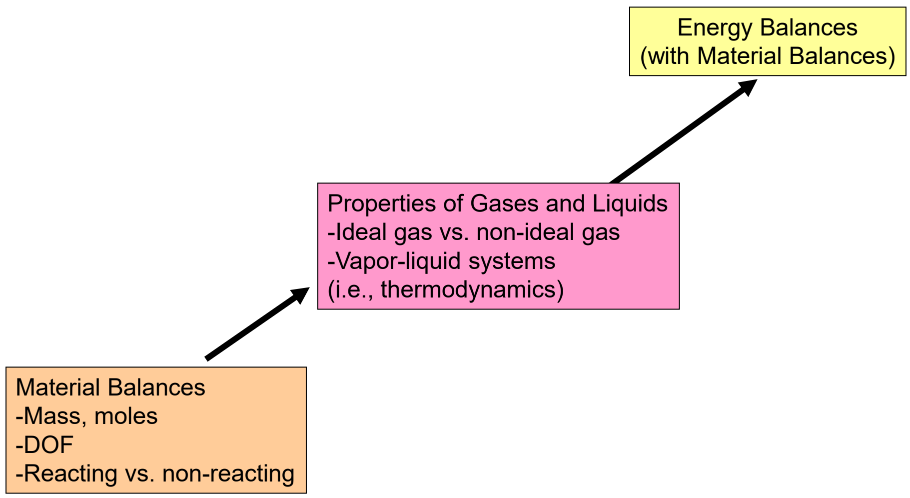
3

Review

- What is different about a DOF analysis when reactions are present?
- When doing the DOF analysis for the overall system and a reactor is present, what do you do?
- When do you use ξ and when do you use element balances?

4

Where are we?
Where are we going?



5

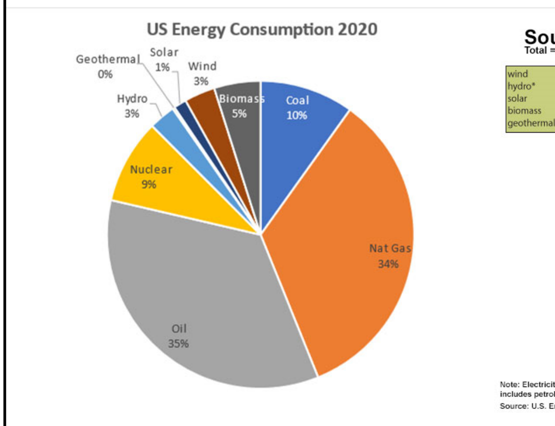
Class 12
Combustion

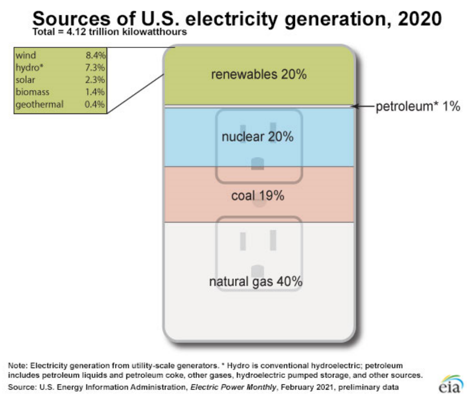
- Terminology
  - Theoretical O_2, air
  - % Excess Air
  - Wet vs. Dry Basis
- Examples

6

U.S. Energy Consumption

(What % of use is through combustion?)





83.5% uses combustion!

60% uses combustion!

http://www.eia.gov/totalenergy/ (2020)

7

Things to Remember About Combustion Problems ★

- Stoichiometric air requirement
  - All C ⇒ CO_2
  - All H ⇒ H_2O
  - All N ⇒ N_2
  - All S ⇒ 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

8

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**

9

Oxygen in Fuel Example

10

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: $$93.75\frac{mol\,O_2}{\min}\left(\frac{1\,mol\,air}{0.21\,mol\,O_2}\right)=446.4\frac{mol\,air}{\min}$$

11

Mix of 2 Different Fuels
(Fatherly Advice)

- Wanted: Stoichiometric air requirement when a mix of 2 different fuels is used

Advice:

- Write stoichiometric equation for each fuel separately
- Do NOT combine into one stoichiometric equation!

Example: 2 mol/s of CH_4, 0.3 mol/s of C_3H_8

- $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ Need 4 mol/s O_2
- $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$ Need 1.5 mol/s O_2

12

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

13

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

14

Review Dry Basis

Volunteer needed!

15

Excel File Demo

16

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

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

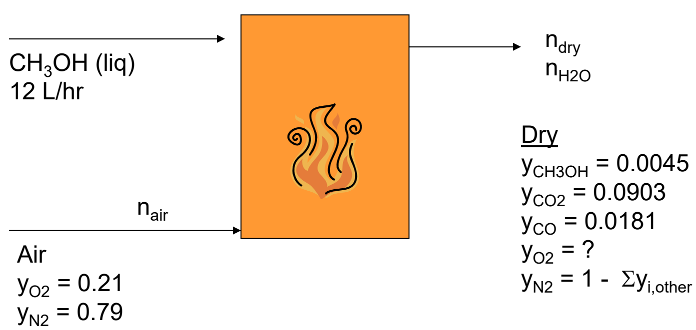
The trick:

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

17

Problem 4.93

(4.71 in 3rd Edition)



$CH_3OH + 1.5\ O_2 \rightarrow CO_2 + 2H_2O$

(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

18

Problem 4.71 (Cont.)

1. Find molar flow rate of methanol

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

(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}; y_{CH3OH}, y_{CO2}, y_{CO}: Dry basis

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

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

19

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

20

Explosion Videos

- Stadium of Fire (July, 1989)
  - 1 million firecrackers gone wrong
  - (https://www.youtube.com/watch?v=JQhji939inc)
- Pepcon plant explosion
  - Ammonium Perchlorate for the space shuttle
  - NH_4ClO_4
  - (https://www.youtube.com/watch?v=cPVpzjxRjPk)
- Bleve explosions
  - boiling liquid expanding vapor explosions
  - (https://www.youtube.com/watch?v=NuPVEsQaGB0)

21