# FUELS & COMBUSTION CALCULATIONS

Unit 5

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# TYPES OF FUELS

- FOSSIL FUELS
  *Solid fuels (COAL)*
  *Liquid fuels (OIL)*
  *Gaseous fuels (NATURAL GAS)*

- NUCLEAR FUELS
- RENEWABLE FUELS (BIOMASS)
- WASTE FUELS (MUNICIPAL WASTES)

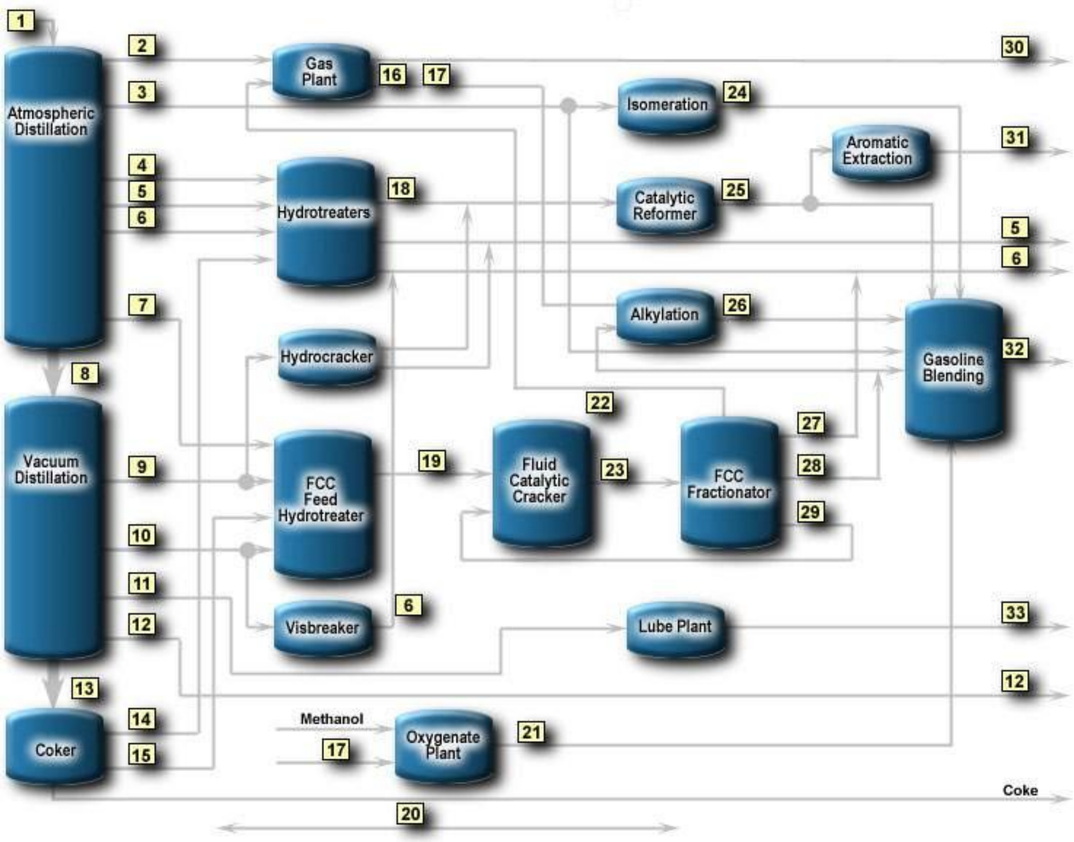
# SOLID FUELS PROPERTIES

- HEATING VALUE
- ULTIMATE ANALYSIS
- PROXIMATE ANALYSIS
- ASH DEFORMATION POINTS
  - Initial deformation temp.
  - Softening temp.
  - Hemispherical temp
  - Fluid temp.

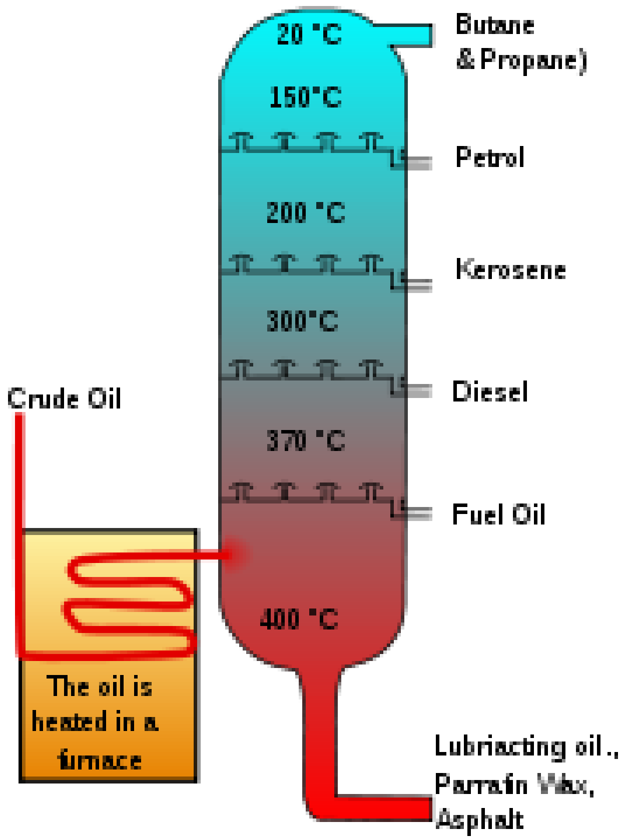
# LIQUID FUELS PROPERTIES

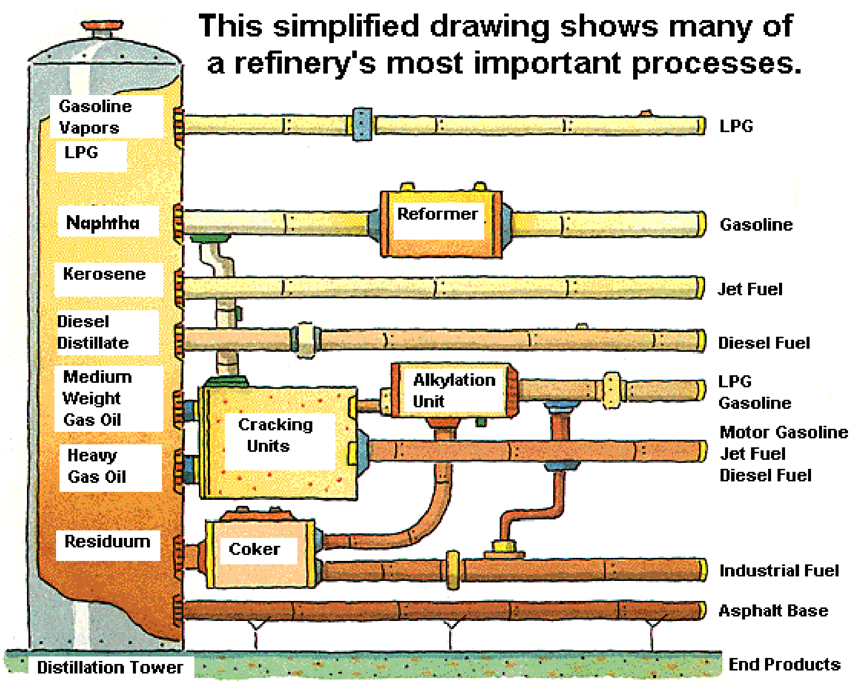
- HEATING VALUE
- FLASH POINT
- IGNITION POINT (SELF, FORCED)
- VISCOSITY
- POUR POINT
- SULFUR
- ASH

# Refinery process



# Distillation



# GASEOUS FUEL

## PROPERTIES

- HEATING VALUE
- COMPOSITION
- DENSITY

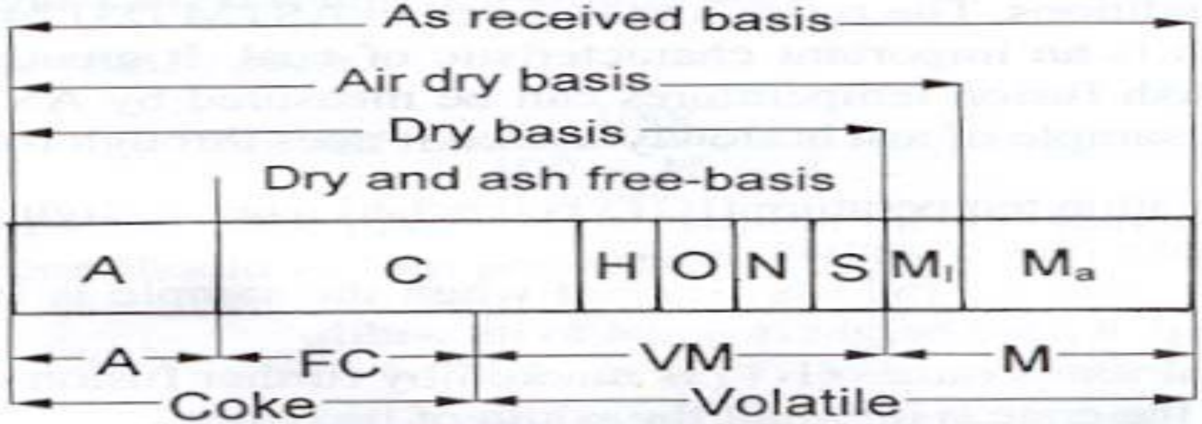
# BASIS OF ANALYSIS

- AS RECEIVED

Ultimate $C + H + O + N + S + A + M = 100$

Proximate $VM + FC + M + A = 100$

- AIR DRY $[100C/(100-M_a)]$
- DRY ASH FREE $[100C/(100-M-A)]$



# HEATING VALUE

- HIGHER HEATING VALUE (GROSS)
- LOWER HEATING VALUE (NET)

LHV = HHV – LH of steam (9H/100+M/100)

# II-1 CHEMICAL REACTIONS

- **Combustion**

$C + O_2 = CO_2$ **+ 32,790** kJ/kg of carbon,

Heat of formation at 25C is 393.7 kJ/mol [Perry p-2-188]

$mC_n H_m + (n + m/4)O_2 = nCO_2 + m/2\ H_2O$ **+ Q**

$S + O_2 = SO_2$ **+ 9260** kJ/kg of sulfur

- **Calcination**

$CaCO_3 = CaO + CO_2$ – 1830 kJ/kg of $CaCO_3gCO_3$

$= MgO + CO_2$ – 1183 kJ/kg of $MgCO_3$.

- **Sulfation**
- CaO + SO2 + 1/2 O2 = CaSO4 **+ 15141** kJ/kg S.

# Basic Stoichiometry

- $C + O_2 = CO_2$ **+ *q***
- 1 kmol of carbon combines with 1 kmol of oxygen to produce 1 kmol of carbon dioxide and release *q* amount of heat.
- 1 kmol of reactant = *M* kg of the reactant when *M* is the molecular weight of the reactant. So mass of one kmol of oxygen ($O_2$) is

  $$2x16 = 32 \text{ kg}$$
- 1 kmol of a gas occupies 22.4 $nm^3$ at $0^0C$ 1 atm

# BASIC EQUATION

1. $C + O_2 = CO_2$ kJ/kg carbon
2. $H_2 + ½\ O_2 = H_2O$
3. $S + O_2 = SO_2$

4. Adding oxygen requirements of above eqns and subtracting the oxygen in fuel we get the total oxygen required

   $V_{O2} = (1.866C + 5.56H + 0.7S - 0.7O)$ $Nm^3/kg$

5. Since air contains 21% oxygen by volume, the air required is $V_{Air} = V_{O2}/0.21$

   $= 8.89\ (C + 0.375S) + 26.5\ H - 3.3O$ $Nm^3/kgf$

# Limestone required for S capture

- Limestone required for unit mass of fuel

  [*R* = Calcium to Sulfur molar ratio]

$$Lq = \frac{100S}{32X_{caco3}} R$$

- If appreciable amount of CaO is present in coal ash replace *R* with *R'*

$$R' = \left[ R - \frac{32X_{cao}}{56S} \right]$$

# EXCESS AIR

- Owing to imperfect mixing combustion always needs a little extra oxygen. It is known as excess air.
- Excess air coefficient = Actual air/ Theoretical air
- Total excess air at exit = excess air at entry + leakage (negative draft)
- Flue gas volume

$V_G = Vg + (exair-1)V_{air}(1+X_m)\ Nm^3/kg_{Fuel}$

# AIR REQUIRED/mass fuel burnt

- Theoretical dry air requirement
- $M_{da}$= [11.53 C + 34.34 (H – O/8) + 4.34 S+ A.S] kg/kg coal

  where $A$ = 2.38 for S-capture;

  = 0 for no S-capture
- Actual dry air required
- $T_{da}$ = Excess air Coeff. X $M_{da}$ kg/kg
- Actual wet air required
- $M_{wa}$ = Tda (1 + Xm).

# TYPICAL EXCESS AIR COEFFICIENT

| PF | Slag tap | Bubbling | CFB | Oil & Gas | Oil & Gas |
|---|---|---|---|---|---|
| Anthracite | Bituminus | All fuels | All fuel | Negative pressure | Positive pressure |
| 1.2-1.25 | 1.15-1.2 | 1.3-1.5 | 1.2 | 1.08-1.07 | 1.05-1.07 |

# SOLID WASTE PRODUCED

- Solid residues = Ash + Spent sorbents
- Spent sorbents = $CaSO_4$+CaO+MgO+inert
- $$Lw = 136\left(\frac{S}{32}\right)E_{sor} + 56\left(\frac{LqX_{caco3}}{100} - \frac{SE_{sor}}{32}\right) + \frac{40LqX_{mgco3}}{84} + LqX_{inert}$$
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*Wa* = [*Lw* + *ASH* + (1 – *Ec*) – *Xcao*],

- Gas product = $CO_2$+$H_2O$+$N_2$+$O_2$+$SO_2$+Fly ash

# Flue gas volume per kg fuel

- $V_{Co2}$= 1.866*C*+*0.7 RS* $Nm^3/kg_{Fuel}$
- $V_{SO2}$ = 0.7*S* (1-*Esor*) $Nm^3/kg_{Fuel}$
- $V_{N2}$=0.79 $V_{AIR}$+ 0.8 *N* $Nm^3/kg_{Fuel}$

  where $V_{air}$ is the volume of air required per kg fuel
- $V_{H2O}$= 11.1*H*+1.24*W*+1.6*Xm* .$V_{AIR}$ $Nm^3/kg_{Fuel}$
- Flue gas volume, $V_g = V_{co2}+V_{so2}+V_{N2}+ V_{H2O}$ $Nm^3/kg_{Fuel}$

# Mass of gaseous products/kg fuel

- Carbon dioxide produced per kg fuel

$$W_{CO2} = 3.66C + \frac{44SR}{32}\left[1 + \frac{100X_{mgco3}}{84X_{caco3}}\right]$$

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$N_2$ = $N + 0.768M_{da}.EAC$

- Oxygen = $O + 0.231M_{da}(EAC - 1) + (1 - E_{sor})S/2$

  In case of no sulfur capture last term is zero

- Sulfur-dioxide = $2S(1 - E_{sor})$

- Fly ash = $a_c \times ASH$;

  where $a_c$ = fraction of ash as fly ash

# Mass of flue gas

- Total mass of flue gas per unit mass of fuel burnt

$$W_c = M_{wa} - 0.231M_{da} + 3.66C + 9H + M_f + L_q X_{ml}$$

$$+N + O + 2.5S(1 - E_{sor}) + a_c ASH +$$

$$1.375SR\left[1 + 1.19\frac{X_{MgCO_3}}{X_{CaCO_3}}\right]$$

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where $M_{wa}$ is the weight of wet air per unit fuel. For no sulfur capture $E_{sor} = 0 = R = L_q$ , and *2.5S* should be *2.0S*

# Heating Value (approximate)

- Higher heating value
- = 33,823 C+144249(H-O/8)+9418S kJ/kg

- Lower heating value
- LHV = HHV – 22604H -2581M kJ/kg

# Problem

Composition of #2 heating oil is given as: C- 86.4%, H-13.33%, S – 0.15%; O – 0.04%, N – 0.06%, Ash – 0.02%.

- Find
- A) Composition of the fuel on) Dry ash free basis
- B) Higher heating value
- C) Lower heating value
- D) amount of dry air required to burn 1 kg fuel
- E) If the amount of air in flue gas is 5% what was the amount of air used /kg fuel