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

This simplified drawing shows many of a refinery's most important processes.
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)

$LHV = HHV - LH \text{ of steam } (9H/100 + M/100)$
Combustion

\[ C + O_2 = CO_2 + 32,790 \text{ kJ/kg of carbon}, \]
Heat of formation at 25°C is 393.7 kJ/mol [Perry p-2-188]

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

\[ S + O_2 = SO_2 + 9260 \text{ kJ/kg of sulfur} \]

Calcination

\[ CaCO_3 = CaO + CO_2 - 1830 \text{ kJ/kg of CaCO}_3 \]
\[ = MgO + CO_2 - 1183 \text{ kJ/kg of MgCO}_3. \]

Sulfation

\[ CaO + SO2 + 1/2 O2 = CaSO4 + 15141 \text{ kJ/kg S}. \]
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 $2 \times 16 = 32$ kg
- 1 kmol of a gas occupies 22.4 nm$^3$ at 0°C 1 atm
1. \( C + O_2 = CO_2 \) kJ/kg carbon
2. \( H_2 + \frac{1}{2} O_2 = H_2O \)
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
   \[ V_{O2} = (1.866C + 5.56H + 0.7S - 0.7O) \text{ Nm}^3/\text{kg} \]
5. Since air contains 21% oxygen by volume, the air required is \( V_{Air} = V_{O2}/0.21 \)
   \[ = 8.89 (C + 0.375S) + 26.5 H - 3.3O \text{ Nm}^3/\text{kgf} \]
Limestone required for S capture

- Limestone required for unit mass of fuel

\[ R = \text{Calcium to Sulfur molar ratio} \]

- If appreciable amount of CaO is present in coal ash replace \( R \) with \( R' \)

\[
Lq = \frac{100S}{32X_{\text{ca}c\text{o}3}} R
\]

\[
R' = \left[ R - \frac{32X_{\text{ca}o}}{56S} \right]
\]
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

\[ V_G = V_g + (\text{exair}-1)V_{\text{air}}(1+X_m) \text{ Nm}^3/\text{kg}_{\text{Fuel}} \]
AIR REQUIRED/mass fuel burnt

- Theoretical dry air requirement
  \[ M_{da} = [11.53 \text{ C} + 34.34 (\text{H} - \text{O}/8) + 4.34 \text{ S} + \text{A.S}] \text{ kg/kg coal} \]
  where \( A = 2.38 \) for S-capture;
  \( = 0 \) for no S-capture

- Actual dry air required
  \[ T_{da} = \text{Excess air Coeff.} \times M_{da} \text{ kg/kg} \]

- Actual wet air required
  \[ M_{wa} = T_{da} (1 + Xm). \]
### TYPICAL EXCESS AIR COEFFICIENT

<table>
<thead>
<tr>
<th>PF</th>
<th>Slag tap</th>
<th>Bubbling</th>
<th>CFB</th>
<th>Oil &amp; Gas</th>
<th>Oil &amp; Gas</th>
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</thead>
<tbody>
<tr>
<td>Anthracite</td>
<td>Bituminus</td>
<td>All fuels</td>
<td>All fuel</td>
<td>Negative pressure</td>
<td>Positive pressure</td>
</tr>
<tr>
<td>1.2-1.25</td>
<td>1.15-1.2</td>
<td>1.3-1.5</td>
<td>1.2</td>
<td>1.08-1.07</td>
<td>1.05-1.07</td>
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Solid Waste Produced

- Solid residues = Ash + Spent sorbents
- Spent sorbents = CaSO$_4$ + CaO + MgO + inert

$$L_w = 136 \left( \frac{S}{32} \right) E_{sor} + 56 \left( \frac{LqX_{caco3}}{100} - \frac{SE_{sor}}{32} \right) + \frac{40LqX_{mgco3}}{84} + LqX_{inert}$$

$$Wa = [L_w + ASH + (1 - Ec) - Xcao],$$

- Gas product = CO$_2$ + H$_2$O + N$_2$ + O$_2$ + SO$_2$ + Fly ash
Flue gas volume per kg fuel

- $V_{\text{CO}_2} = 1.866C + 0.7 \ \text{RS} \ \text{Nm}^3/\text{kg}_{\text{Fuel}}$
- $V_{\text{SO}_2} = 0.7S \ (1 - Esor) \ \text{Nm}^3/\text{kg}_{\text{Fuel}}$
- $V_{\text{N}_2} = 0.79 \ V_{\text{AIR}} + 0.8 \ N \ \text{Nm}^3/\text{kg}_{\text{Fuel}}$

where $V_{\text{AIR}}$ is the volume of air required per kg fuel

- $V_{\text{H}_2\text{O}} = 11.1H + 1.24W + 1.6Xm \cdot V_{\text{AIR}} \ \text{Nm}^3/\text{kg}_{\text{Fuel}}$

- Flue gas volume, $V_g = V_{\text{CO}_2} + V_{\text{SO}_2} + V_{\text{N}_2} + V_{\text{H}_2\text{O}} \ \text{Nm}^3/\text{kg}_{\text{Fuel}}$
Mass of gaseous products/kg fuel

- Carbon dioxide produced per kg fuel
  \[ W_{CO2} = 3.66C + \frac{44SR}{32} \left[ 1 + \frac{100X_{mgco3}}{84X_{caco3}} \right] \]

- Nitrogen
  \[ N_2 = N + 0.768M_{da} \cdot \text{EAC} \]

- Oxygen
  \[ O = O + 0.231M_{da}(\text{EAC} - 1) + (1 - E_{\text{sor}}) S/2 \]
  In case of no sulfur capture last term is zero

- Sulfur-dioxide
  \[ 2S(1 - E_{\text{sor}}) \]

- Fly ash
  \[ a_c \times \text{ASH}; \]
  where \( a_c \) = fraction of ash as fly ash
Mass of flue gas

- Total mass of flue gas per unit mass of fuel burnt
  \[ W_c = M_{wa} - 0.231M_{da} + 3.66C + 9H + M_f + L_q X_{ml} + N + O + 2.5S(1 - E_{sor}) + a_c ASH + 1.375SR \left[ 1 + 1.19 \frac{X_{MgCO_3}}{X_{CaCO_3}} \right] \]

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
  \[ = 33,823 \, \text{C} + 144249(\text{H-O/8}) + 9418S \, \text{kJ/kg} \]

- Lower heating value
  \[ \text{LHV} = \text{HHV} - 22604\text{H} - 2581\text{M} \, \text{kJ/kg} \]
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