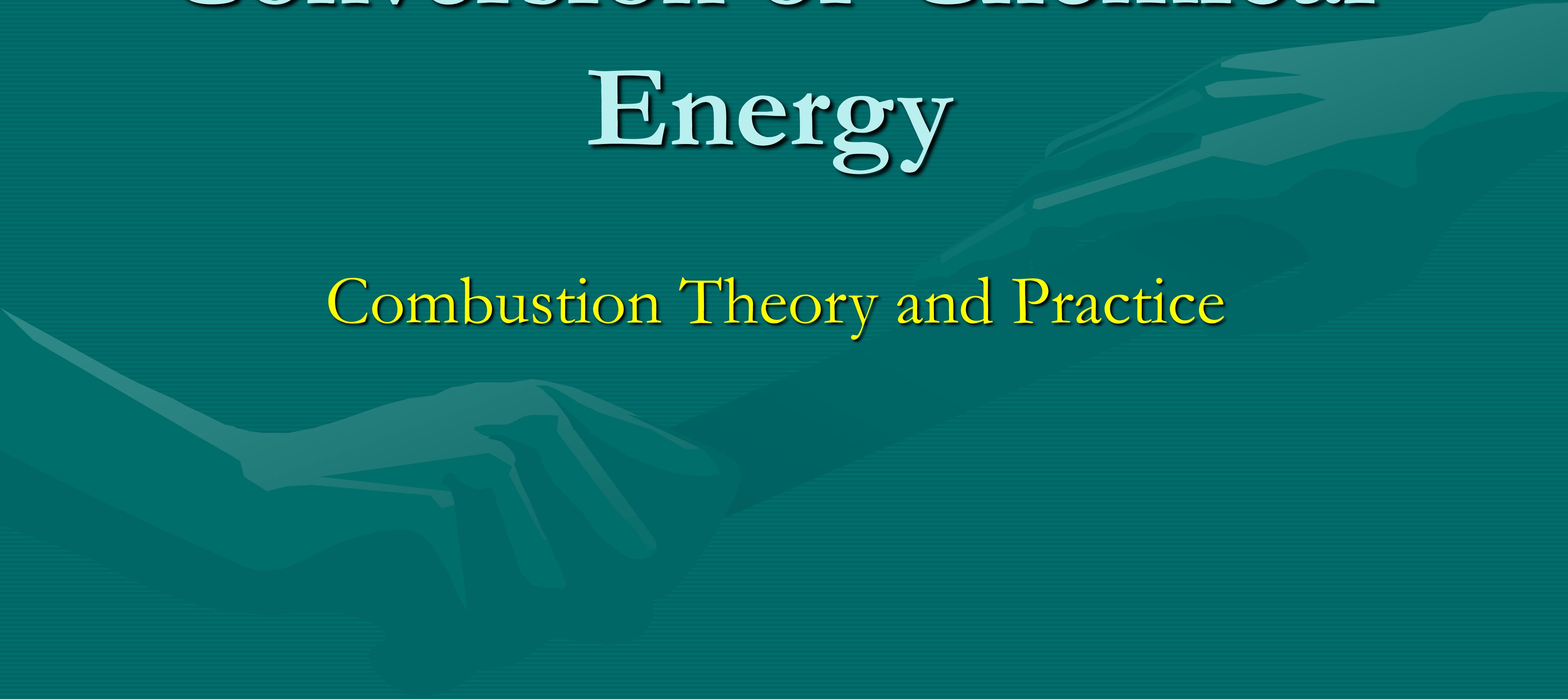
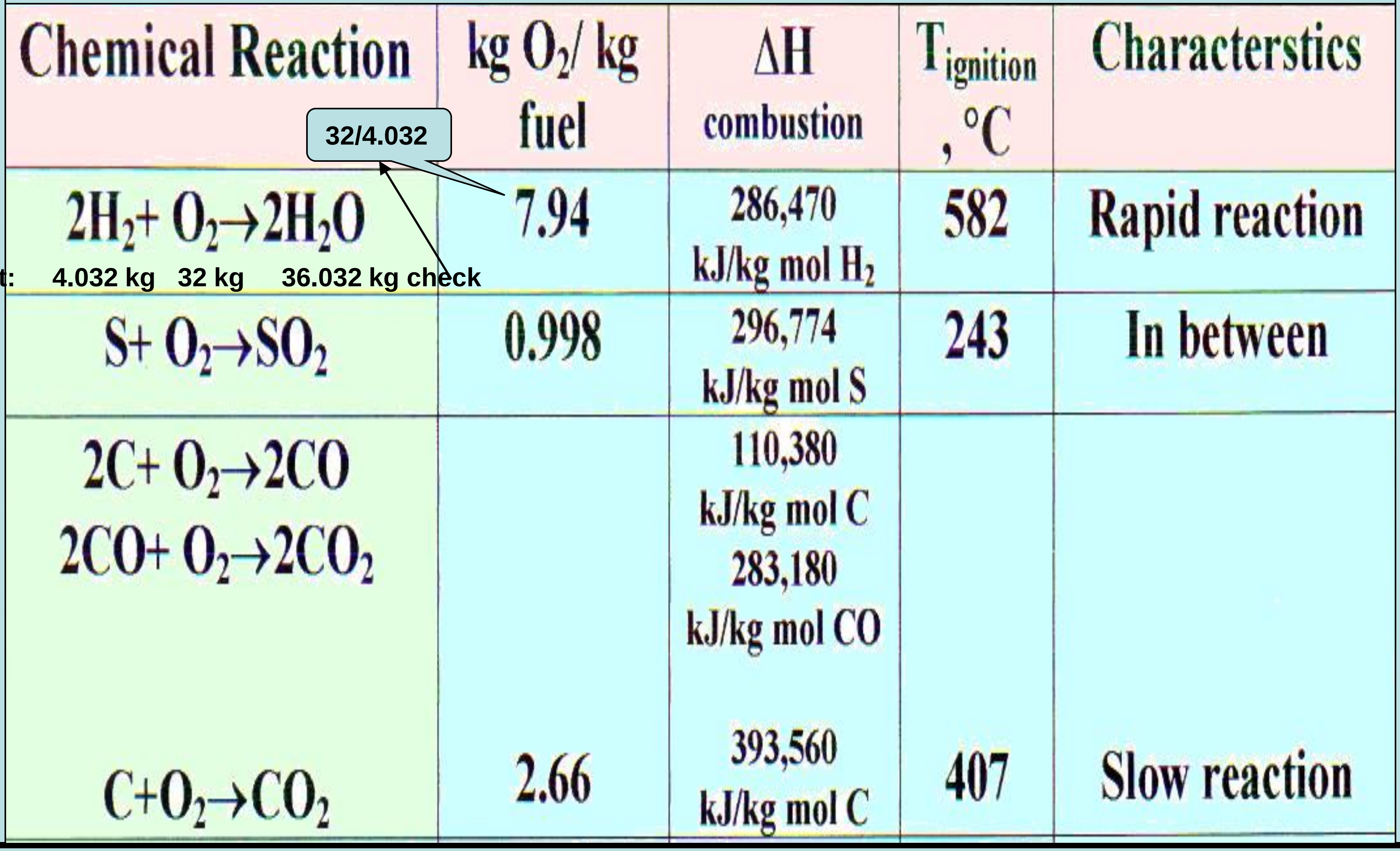
Conversion of Chemical Energy

Combustion Theory and Practice



Conversion of Chemical energy



Chemical Reaction	kg O_2/ kg fuel	ΔH combustion	$T_{ignition}$, °C	Characterstics
$2H_2 + O_2 \rightarrow 2H_2O$	7.94	286,470 kJ/kg mol H_2	582	Rapid reaction
$S + O_2 \rightarrow SO_2$	0.998	296,774 kJ/kg mol S	243	In between
$2C + O_2 \rightarrow 2CO$ $2CO + O_2 \rightarrow 2CO_2$		110,380 kJ/kg mol C 283,180 kJ/kg mol CO		
$C + O_2 \rightarrow CO_2$	2.66	393,560 kJ/kg mol C	407	Slow reaction

32/4.032

Mwt: 4.032 kg 32 kg 36.032 kg check

Dissociation reactions take place at high temp. $O_2 \rightarrow 2O$ $N_2 \rightarrow 2N$ $2CO_2 \rightarrow 2CO + O_2$ $N_2 + O_2 \rightarrow 2NO$ $N_2 + 2O_2 \rightarrow 2NO_2$				These reactions are endothermic. NO_X causes atmospheric Pollution Temp. must be kept low to minimize dissociation

- Theoretical (Stoichiometric) air-fuel ratio is the minimum air requirement for the complete fuel combustion.
- The basis of A/F ~ volumetric or gravimetric or mole ratio, based on "as burned" fuel analysis.
- A/F ratio can be determined by making O_2 balance on the combustible reactants.

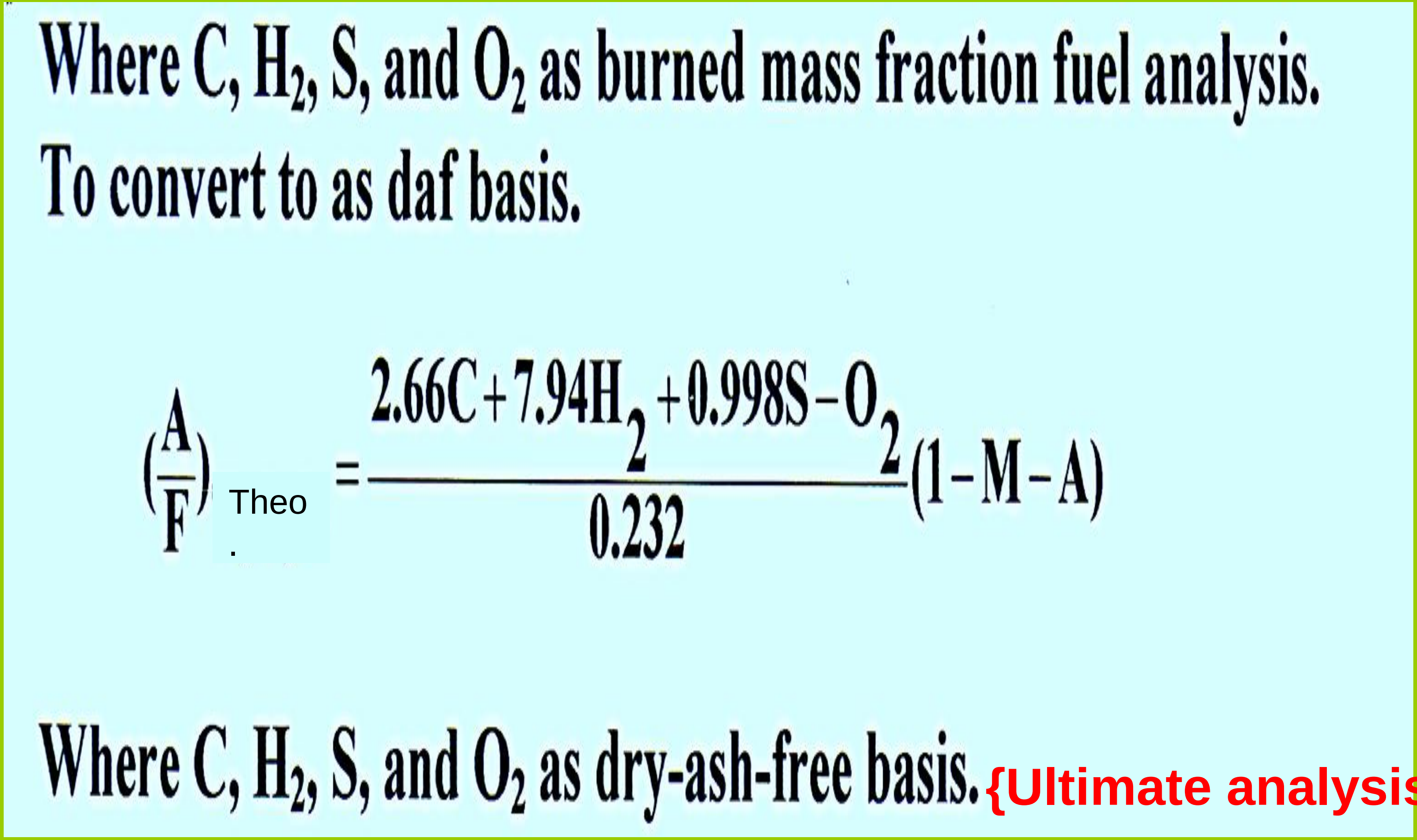
Note: Derivations based on mass balance calculations ~ See Principle course

$$\left(\frac{A}{F}\right)_{\text{Theo.}} = \frac{2.66C + 7.94H_2 + 0.998S - O_2}{0.232}$$

(kg O2 / kg fuel)

(kg O_2 / kg air)

Kg air/kg fuel
Dry Air basis



Where C, H_2, S, and O_2 as burned mass fraction fuel analysis.

To convert to as daf basis.

$$\left(\frac{A}{F}\right)_{\text{Theo.}} = \frac{2.66C + 7.94H_2 + 0.998S - O_2}{0.232}(1 - M - A)$$

Where C, H_2, S, and O_2 as dry-ash-free basis. **{Ultimate analysis}**

- For gaseous and liquid fuels, it is preferable to work with molar quantities rather than mass fraction

Let Z is the number of atoms of a given element in a mole of fuel.

For examples; C_8H_{18} , $Z_C=8$, $Z_H= 18$

$50\%\ CH_4$, $40\%\ C_2H_6$, $5\%\ H_2S$, $5\%\ O_2$

$Z_C= 0.5(1)+0.4(2)=1.3$

$Z_H= 0.5(4)+0.4(6)+0.05(2)=4.5$

$Z_S=0.05(1)=0.05$

$Z_O=0.05(2)=0.1$

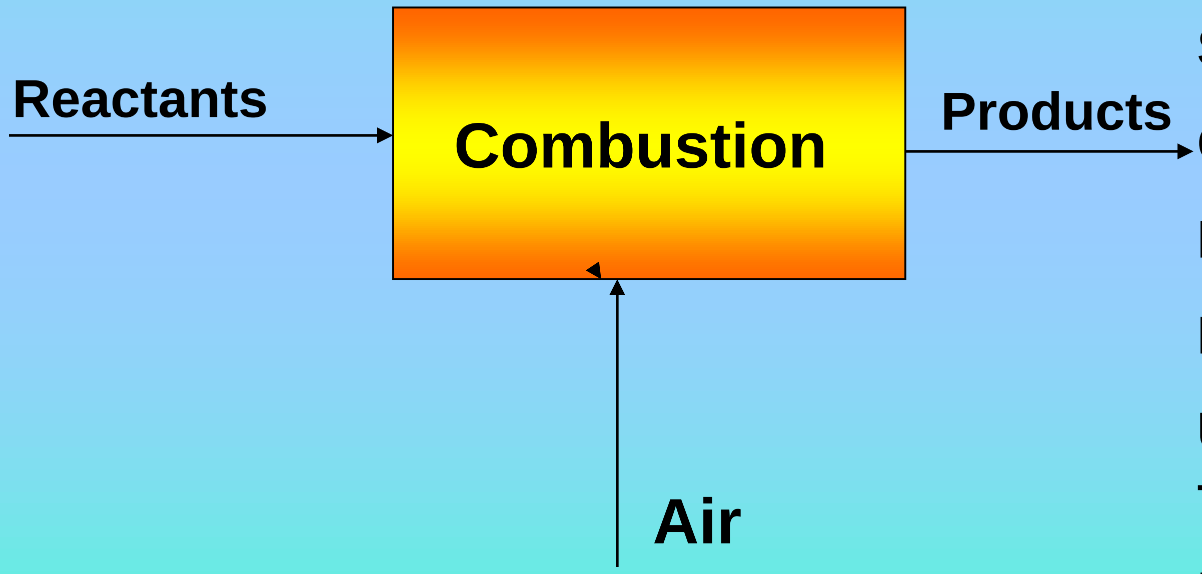
Note the effective chemical formula of the gas mixture is $C_{1.3}H_{4.5}O_{0.1}S_{0.05}$

Therefore,

$$\left(\frac{A}{F}\right)_{\text{Theo, mol}} = \frac{Z_C + \frac{Z_H}{4} + Z_S - Z_O}{0.21} \qquad /$$

$$\left(\frac{A}{F}\right)_{\text{Theo, mass}} = \frac{28.97\left(\frac{A}{F}\right)_{\text{Theo, mol}}}{\text{Mwt of fuel}} \qquad //$$

Combustion Process



Reactants

Combustion

Air

Products

CO

CO_2

H_2O

SO_2

O_2

N_2

NO_x

Unburned fuel

Hydroxyls

Aldehydes

Ash particles

Actual combustion process

Conditions of proper combustion

- Proper mixing of Reactant ‘ M ‘
- Sufficient air ‘ A ‘
- Sufficient temperature ‘ T ‘
- Sufficient time for the Reaction ‘ T ’
- Sufficient reactant density To propagate the flame ‘ρ’

5 requisites MATTρ

Can only be assured by providing excess air. However, excess air must be as minimum as we can because too much excess air increases the losses and increases NO_x emissions.

Good combustion

How can we express the amount of air for any combustion process?

There are two ways:

$$1.\ \text{Dilution coefficient, DC} = \frac{(\mathrm{A/F})_{\mathrm{act}}}{(\mathrm{A/F})_{\mathrm{theo}}} \qquad ///$$

$$2.\ \%\ \text{excess air} = \frac{(\mathrm{A/F})_{\mathrm{act}} - (\mathrm{A/F})_{\mathrm{theo}}}{(\mathrm{A/F})_{\mathrm{theo}}}\ \mathrm{x}\,100 \qquad ////$$

$$= (\mathrm{DC} - 1)100 \qquad /////$$

Estimation of actual Air-to-Fuel ratio $(A/F)_{act}$

- $(A/F)_{act}$ is estimated from an experimental measurements of the gaseous components of the flue gas.
- Experimental measurements are:

1. GC analyzer ‘Gas Chromatography’
2. Orsat flue-gas analyzer
3. Other techniques

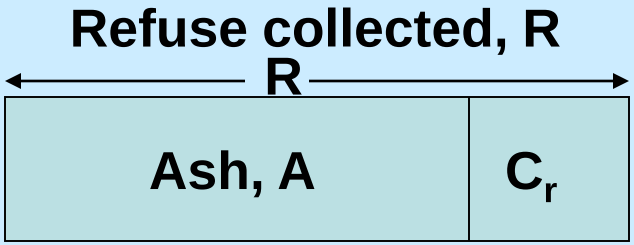
How to get the $(A/F)_{act}$ for solid fuel?

- In addition to gaseous analysis, *refuse analysis is required.*
- *Refuse analysis* concerns with the experimental determination of the HHV value of the refuse.
- *Refuse analysis* has two ways of expressing:

1. the amount of energy per unit mass of refuse kJ/kg or Btu/lb
2. mass fraction of unburned carbon or percent combustible in refuse.

Note: *Refuse means the substance which remains in combustor after combustion.*

Percent combustible in the refuse

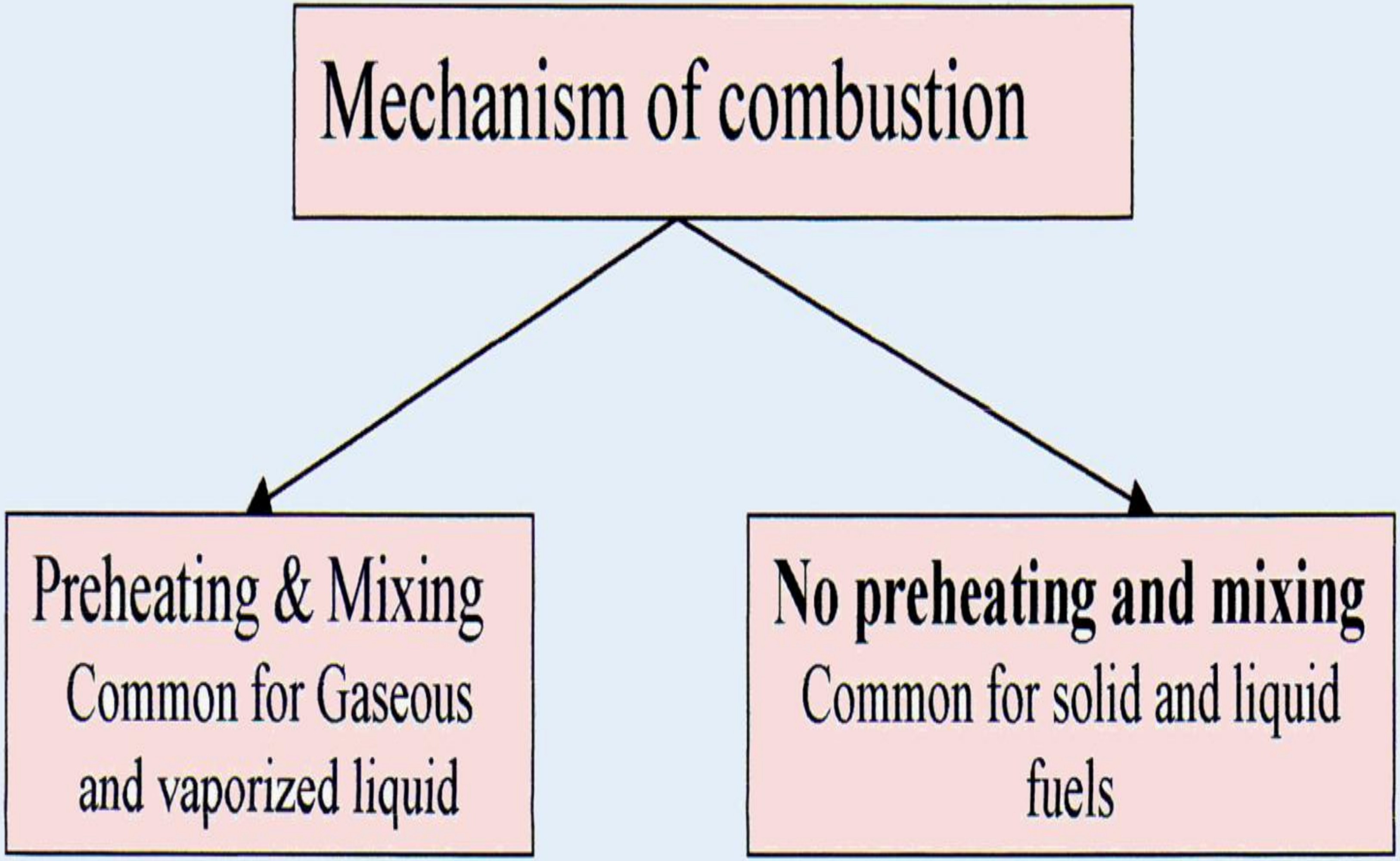


$$R = A + C_r$$

R: mass of refuse collected per unit mass of coal burned.

C_r: mass of unburned carbon in the refuse per unit mass of coal burned.

$$\% \text{ combustible} = 100\,(\text{HHV})_{\text{refuse}} / (\text{HHV})_{\text{carbon}}$$
$$= 100\,(\text{HHV})_{\text{refuse}}/32778 \text{ SI units}$$
$$= 100\,(\text{HHV})_{\text{refuse}}/14093 \text{ British units}$$



Mechanism of combustion

Preheating & Mixing
Common for Gaseous and vaporized liquid

No preheating and mixing
Common for solid and liquid fuels

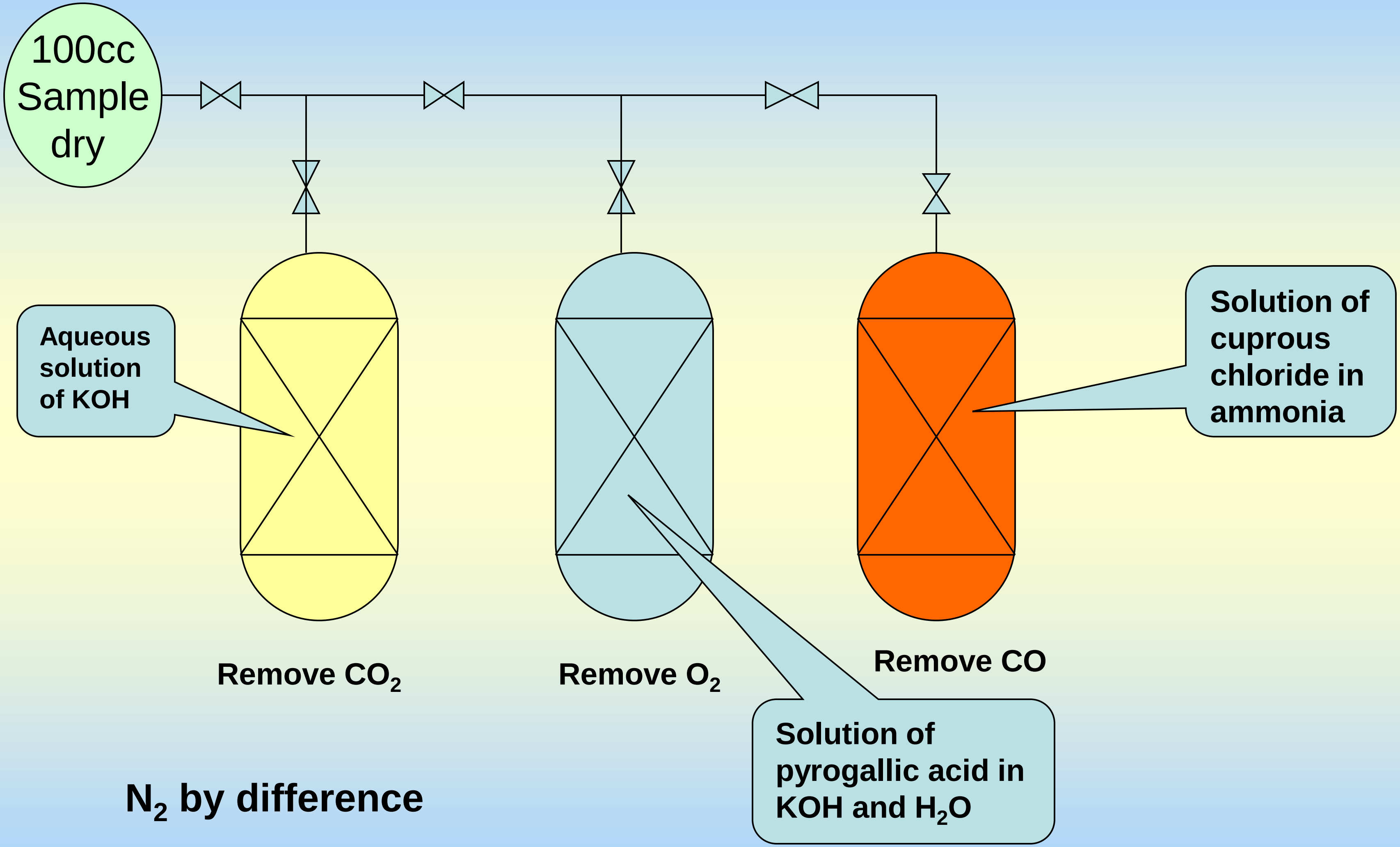
Premixed flame

- Fuel and O_2 are mixed and heated before ignition
- O_2 has a good opportunity to react with hydrocarbons to form hyroxylates. Hence, these hydroxylates are converted into aldehydes. Finally, aldehydes are burned to give CO_2 and H_2O.
- The flame formed in this case is blue or non-luminous flame.
- Example: Bunsen burner or gas stove burner

Un-premixed flame

- In this type, premixing dose not take place.
- Time of mixing of fuel and oxidant is very short.
- Heating of fuel and air is rapid.
- As a result the hydrocarbons are cracked into lighter compounds and into carbon and hydrogen.
- Combustion takes place between the elements of C and H_2.
- In general, C yields a yellow flame and H_2 yields invisible flame. Both of them yield a luminous flame or yellow flame.
- Example: the type of mechanism is predominant in solid combustion and liquid fuel

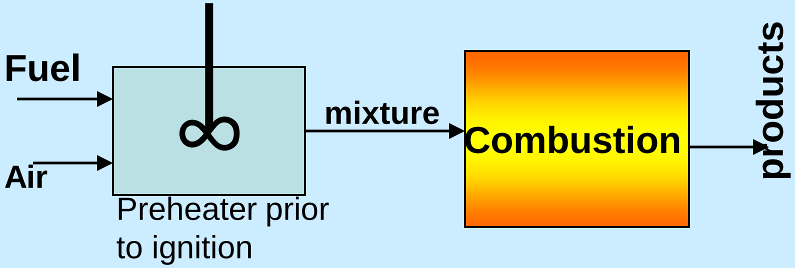
The concept of orsat analysis



N_2 by difference

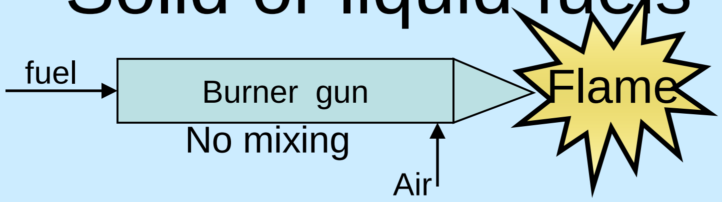
Summary
Mechanism of combustion

- Gaseous fuels or vaporized liquids.



- H.C $\xrightarrow{\text{heat}}$ hydroxylated compounds ‘aldehydes’
- O_2 + aldehydes → flame

- Solid or liquid fuels



- H.C → lighter H.C and into the basic elements C and H_2
- $C + O_2$ $H_2 + O_2$