UNIT - V

FUELS AND COMBUSTION

5.5. Combustion ,

5.5.1 Flue gas analysis by Orsat method

5.5 Combustion

Combustion or burning is a high temperature exothermic redox chemical reaction between a fuel (the reductant) and an oxidant, usually atmospheric oxygen, that produces oxidized, often gaseous products, in a mixture termed as smoke. Combustion does not always result in fire, because a flame is only visible when substances undergoing combustion vapourise, but when it does, a flame is a characteristic indicator of the reaction. While the activation energy must be overcome to initiate combustion (e.g., using a lit match to light a fire), the heat from a flame may provide enough energy to make the reaction self-sustaining. Combustion is often a complicated sequence of elementary radical reactions. Solid fuels, such as wood and coal, first undergo endothermic pyrolysis to produce gaseous fuels whose combustion thensupplies the heat required to produce more of them. Combustion is often hot enough that incandescent light in the form of either glowing or a flame is produced. A simple example can be seen in the combustion of hydrogen and oxygen into water vapor, a reaction commonly used to fuel rocket engines. This reaction releases 242 kJ/mol of heat and reduces the enthalpy accordingly (at constant temperature and pressure):

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

Combustion of an organic fuel in air is always exothermic because the double bond in O_2 is much weaker than other double bonds or pairs of single bonds, and therefore the formation of the stronger bonds in the combustion products CO_2 and H_2O results in the release of energy. The bond energies in the fuel play only a minor role, since they are similar to those in the combustion products; e.g., the sum of the bond energies of CH_4 is nearly the same as that of CO_2. The heat of combustion is approximately −418 kJ per mole of O_2 used up in the combustion reaction, and can be estimated from the elemental composition of the fuel.

Uncatalyzed combustion in air requires relatively high temperatures. Complete combustion is

stoichiometric concerning the fuel, where there is no remaining fuel, and ideally, no residual oxidant. Thermodynamically, the chemical equilibrium of combustion in air is overwhelmingly on the side of the products. However, complete combustion is almost impossible to achieve, since the chemical equilibrium is not necessarily reached, or may contain un burnt products such as carbon monoxide, hydrogen and even carbon (soot or ash). Thus, the produced smoke is usually toxic and contains unburned or partially oxidized products. Any combustion at high temperatures in atmospheric air, which is 78 percent nitrogen, will also create small amounts of several nitrogen oxides, commonly referred to as NOx, since the combustion of nitrogen is thermodynamically favored at high, but not low temperatures. Since burning is rarely clean, fuel gas cleaning or catalytic converters may be required by law.

Fires occur naturally, ignited by lightning strikes or by volcanic products. Combustion (fire) was the first controlled chemical reaction discovered by humans, in the form of campfires and bonfires, and continues to be the main method to produce energy for humanity. Usually, the fuelis carbon, hydrocarbons, or more complicated mixtures such as wood that contains partially oxidized hydrocarbons. The thermal energy produced from combustion of either fossil fuels such as coal or oil, or from renewable fuels such as firewood, is harvested for diverse uses such as cooking, production of electricity or industrial or domestic heating. Combustion is also currently the only reaction used to power rockets. Combustion is also used to destroy (incinerate) waste, both nonhazardous and hazardous.

Oxidants for combustion have high oxidation potential and include atmospheric or pure oxygen, chlorine, fluorine, chlorine tri-fluoride, nitrous oxide and nitric acid. For instance, hydrogen burns in chlorine to form hydrogen chloride with the liberation of heat and light characteristic of combustion. Although usually

not catalyzed, combustion can be catalyzed by platinum or vanadium, as in the contact process.

Calorific value:

The total quantity of heat of liberated when unit mass of fuel is burnt completely.

Units for calorific value:

i) Calorie / gram

ii) Kilocalorie / kg

iii) British thermal unit (for solid or liquid fuels)

1. Higher calorific value (HCV) or Gross calorific value (GCV):

The total amount of heat produced when unit mass of the fuel is burnt completely and the products of combustion are cooled to room temperature.

2. Lower calorific value (LCV) or Net calorific value (NCV)

The net heat produced when unit mass of the fuel is burnt completelyand the products of combustion are allowed to escape.

Dulong's formula for GCV is,

GCV or HCV = [8080 C + 34500 (H) + 2240 S] kcal / kg

Where C, H, O & S represents the % of the corresponding elements.

Dulong's formula for NCV is,

NCV = GCV – 0.09H x 587 kcal / kg. (H = % of H2 in thefuel) Problems based on calorific value

1. Calculate the gross and net calorific values of coal having the following compositions, carbon = 85%, hydrogen = 8%, sulphur = 1%, nitrogen =2%, ash = 4%, latent heat of steam = 587 cal/g.

- **Gross calorific value:**

GCV or HCV = [8080 C + 34500 (H -) + 2240 S] kcal /kg

= [8080 x 85 + 34500 (8 -) + 2240 x 1] kcal /kg

= [686800 + 276000 + 2240] kcal /kg

GCV or HCV= 9650.4 kcal / kg.

- **Net calorific value:**

$= 9650.4 - 8 \times 587$

$= 9650.4 - 422.64$

NCV = 9227.76 kcal / kg

Ignition Temperature:

- The minimum temperature at which a fuel starts to burn is called its ignition temperature. It is otherwise called autogenous ignition temperature.
- Some fuels have low ignition temperature and some have high ignition temperature.
- The fuels that have low ignition temperature are highly inflammable andburn quickly at the spark of fire.
- While some fuels that have high ignition temperature do not burn quickly. They require heating to burn.
- For example kerosene oil does not burn unless it is heated up to its ignition temperature.
- For liquid fuels it is called as Flash point that ranges from 200 – 450^{0}C.
- Ignition temperature for coal is 300^{0}C.
- Ignition temperature for gaseous fuels is 400^{0}C - 600^{0}C.

Spontaneous Ignition Temperature (SIT):

- It is defined as, “the minimum temperature at which the fuel catches fire spontaneously without external heating”.
- It is otherwise known as Self Ignition Temperature.
- This temperature is sometimes referred to as the kindling point of the fuel. Raising the temperature of a fuel to its auto-ignition point provides the energy required to initiate the chemical reaction needed for combustion.
- The auto-ignition temperature for a given fuel decreases as the pressure increases or as the oxygen concentration increases.
- When the system reaches Spontaneous Ignition Temperature, the system burns on its own.
- The self ignition temperature of diesel is 210°C and that of petrol varies from 247°C to 280°C.

Explosive Range:

Before a fire or explosion can occur, three conditions must be met simultaneously. A fuel and oxygen must exist in certain proportions, along with an ignition source. The ratio of fuel and oxygen that is required varies with each combustible gas or vapour.

- The minimum concentration of a particular combustible gas or vapour necessary to support its combustion in air is defined as the Lower Explosive Limit (LEL) for that gas. Below this level, the mixture is too "lean" to burn.
- The maximum concentration of a gas or vapour that will burn in air is defined as the Upper Explosive Limit (UEL). Above this level, the mixture is too "rich" to burn.
- The range between the LEL and UEL is known as the flammable range for that gas or vapour.

Flue gas analysis by Orsat method:

- Flue gas is the mixture of gases (like CO_2, O_2& CO) coming out fromthe combustion chamber.
- The analysis of a flue gas would give an idea about the complete or incomplete combustion process.
- The analysis of flue gas is carried out by using Orsat's apparatus.

Description of Orsat's apparatus:

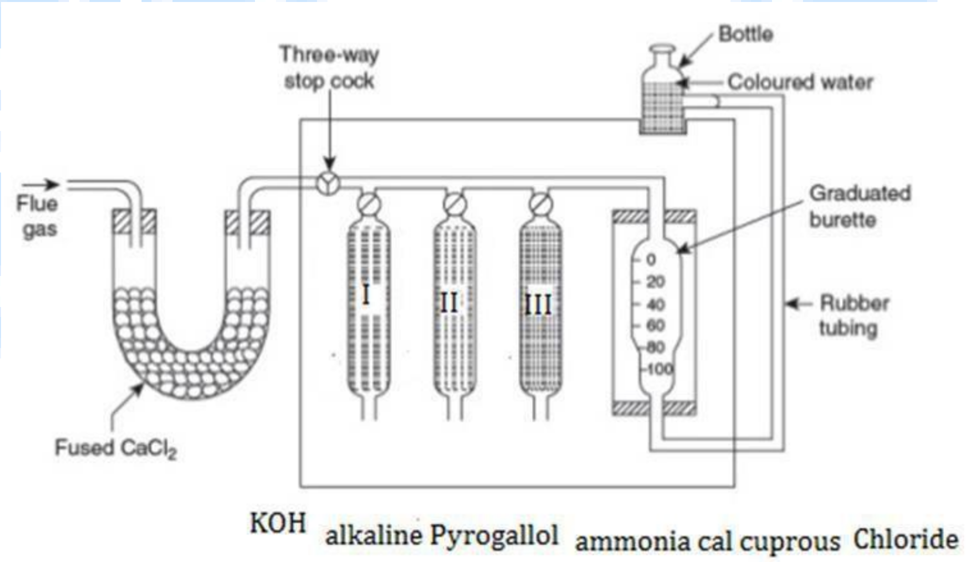
- It consists of a horizontal tube.
- At one end of this tube, 'U' tube containing fused CaCl2 is connected through 3 – way stop cock.
- The other end of the tube is connected with a graduated burette.
- The burette is surrounded by a water jacket (keeps the temperature of the gas constant).
- The lower end of the burette is connected to a water reservoir by means of a rubber tube.
- The level of water in the burette can be raised or lowered by raising or lowering the reservoir.

- The horizontal tube is connected with three different absorption bulbs 1, 2 and 3 for absorbing CO_2, O_2 and CO.

Bulb - 1 contains KOH and it absorbs CO_2 only.

Bulb - 2 contains alkaline pyrogallol and it absorbs CO2and O2.

Bulb - 3 contains ammoniacal cuprous chloride and itabsorbs CO_2, O_2 and CO.



Working:

- The three way stop cock is opened to the atmosphere and the burette is completely filled with water and air is sent out.
- The burette is filled with flue gas to 100cc by raising or lowering the reservoir. Now the 3- way stop cock is closed.

1. Absorption of CO2:

- The Bulb-1 is filled with the flue gas is by raising the level of water in the burette.
- Here CO_2 is absorbed by KOH. The gas is again sent to the burette.

- The process is repeated several times to ensure complete absorption ofCO_2.
- The decrease in volume of the flue gas = the volume of CO_2 in 100cc of the flue gas.

2. **Absorption of O_2:**

- Bulb-1 is closed and Bulb-2 is opened.
- The gas enters into Bulb-2 where O_2 is absorbed by alkaline pyrogallol.
- The decrease in volume of the flue gas = the volume of O_2.

3. **Absorption of CO:**

- Bulb 2 is closed and Bulb-3 is opened.
- The remaining gas is sent into Bulb-3, where CO is absorbed by ammonical cuprous chloride.
- The decrease in volume of flue gas = the volume of CO.
- The remaining gas in the burette is taken as nitrogen.

Significance:

i) It gives an idea about the complete or incomplete combustion.

ii) If the flue gas contains high amount of CO, it shows in complete Combustion and short supply of O_2.

iii) If the flue gas contain high amount of O_2, it indicates complete combustion and excess supply of O_2.