ENGINEERING

CHEMISTRY - II

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Chapter 7

COMBUSTION OF FUELS

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7.1 INTRODUCTION

❖ ***Combustion is a process of rapid exothermic oxidation, in which a fuel burns in the presence of oxygen with the evolution of heat and light.***

❖ Aim of combustion is to get the maximum amount of heat from a combustible substance in the shortest time. Most of the combustible substances are enriched with carbon and hydrogen.

- During combustion they undergo thermal decomposition to give simpler products, which are oxidised to CO_2, H_2O, etc.,

$$C + O_2 \longrightarrow CO_2 \; ; \quad \text{Exothermic.}$$

$$H_2 + \tfrac{1}{2}O_2 \longrightarrow H_2O \; ; \quad \text{Exothermic.}$$

- Since the above reactions are exothermic, large quantity of heat is given out.

7.2 CALORIFIC VALUE

➡ The efficiency of a fuel can be understood by its calorific value. The calorific value of a fuel is defined as ***"the total amount of heat liberated, when a unit mass of fuel is burnt completely."***

Units of calorific values

➡ The quantity of heat can be measured by the following units:

1. Calorie.

2. Kilocalorie.
3. British Thermal Unit (B.T.U).
4. Centigrade Heat Unit (C.H.U).

- ***Calorie***: *It is defined as the amount of heat required to raise the temperature of 1 gram of water through* 1°C *(15 to* 16°C*).*

7.3 HIGHER AND LOWER CALORIFIC VALUES

7.3.1 Higher (or) Gross calorific value (GCV)

- It is defined as ***the total amount of heat produced, when a unit quantity of the fuel is completely burnt and the products of combustion are cooled to room temperature***.

- When a fuel containing hydrogen is burnt, the hydrogen is converted into steam. If the combustion products are cooled to room temperature, the steam gets condensed into water and latent heat is evolved. Thus, the latent heat of condensation of steam is also included in gross calorific value.

7.3.2 Lower (or) Net Calorific Value (NCV)

- It is defined as ***the net heat produced, when a unit quantity of the fuel is completely burnt and the products of combustion are allowed to escape***.

$$\therefore\ NCV = GCV - \text{Latent heat of condensation of water vapour produced.}$$

$$= GCV - \text{Mass of hydrogen} \times 9 \times \text{Latent heat of condensation of water vapour.}$$

- 1 part by weight of H_2 produces 9 parts by weight of H_2O as follows. The latent heat of steam is 587 cal/gm.

$$H_2 \quad + \quad O \quad \longrightarrow \quad H_2O$$

2 gms   16 gms   18 gms

1   8   9

Thus,

$$NCV = GCV - \frac{9}{100} H \times 587$$

$$= GCV - 0.09H \times 587$$

where

$$H = \% \text{ of } H_2 \text{ in the fuel.}$$

7.4 THEORETICAL CALCULATION OF CALORIFIC VALUE

Dulong's formula

- Dulong's formula for the theoretical calculation of calorific value is

GCV (or) HCV

$$= \frac{1}{100}\left[8080\ C + 34500\left(H - \frac{O}{8}\right) + 2240\ S\right] \text{kcal/kg}$$

- where C,H,O and S represent the % of the corresponding elements in the fuel.

- It is based on the assumption that the calorific values of C, H and S are found to be 8080, 34500 and 2240 kcal, when 1 kg of the fuel is burnt completely. However, all the oxygen in the fuel is assumed to be present in combination with hydrogen in the ratio H : O as 1:8 by weight. So the

surplus hydrogen available for combustion is $H - \frac{O}{8}$

$$\therefore \text{N C V (or) L C V} = \boxed{\left[\mathbf{HCV} - \frac{\mathbf{9}}{\mathbf{100}}\mathbf{H} \times \mathbf{587}\right] \mathbf{kcal/kg}}$$

7.4.1 Problems based on calorific value

Problem-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/gm.

(A.U. June 2007)

Solution

(i) Gross calorific value (GCV)

$$= \frac{1}{100}\left[8080 \times \%\,C + 34500\left(\%\,H - \frac{\%\,O}{8}\right) + 2240 \times \%\,S\right] \text{kcal/kg}$$

$$= \frac{1}{100}\left[8080 \times 85 + 34500\left(8 - \frac{0}{8}\right) + 2240 \times 1\right] \text{kcal/kg}$$

$$= \frac{1}{100} [\ 6,86,800 + 2,76,000 + 2240\ ]\ \text{kcal/kg}$$

$$= \frac{1}{100} [\ 9,65,040\ ]\ \text{kcal/kg}$$

$$= 9,650.4\ \text{kcal/kg.}$$

(ii) Net Calorific Value (NCV)

$$= GCV - \frac{9}{100} H \times 587\ \text{kcal/kg}$$

$$= 9650.4 - \frac{9}{100} \times 8 \times 587\ \text{kcal/kg}$$

$$= 9650.4 - 422.64$$

$$= 9227.76\ \text{kcal/kg.}$$

Problem-2

Calculate the gross and net calorific values of a coal sample having the following composition C = 80% ; H = 7% ; O = 3% ; S = 3.5% ; N = 2.5% and ash 4.4%.

Solution

(i) GCV

$$= \frac{1}{100}\left[8080 \times \%\,C + 34500\left(\%H - \frac{\%\,O}{8}\right) + 2240 \times \%\,S\right] \text{k. cal/kg}$$

$$= \frac{1}{100}\left[8080 \times 80 + 34500\left(7 - \frac{3}{8}\right) + 2240 \times 3.5\right] \text{k cal/kg}$$

$= [8080 \times 0.80 + 345(7 - 0.375) + 22.40 \times 3.5]$ k cal/kg

$= [6464 + 2285.6 + 78.4]$ k. cal/kg

$= 8828.0$ k. cal/kg .

(ii) NCV

$= GCV - [0.09H \times 587]$ k. cal/kg

$= 8828 - [0.09 \times 7 \times 587]$ k. cal/kg

$= [8828 - 369.8]$ k. cal/kg

$= 8458.2$ k. cal/kg .

Problem-3

On analysis, a coal sample has the following composition by weight; C = 85%; O = 3%; S = 0.5% and ash = 3%. Net calorific value was found to be 8,400 kcal/kg. Calculate the percentage of hydrogen and gross calorific value of coal.

Solution

$$GCV = [\ NCV + 0.09H \times 587\ ]\ \text{kcal/kg}$$

$$= [\ 8{,}400 + 0.09H \times 587\ ]\ \text{kcal/kg}$$

$$= [\ 8{,}400 + 52.8\ H\ ]\ \text{kcal/kg} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$GCV = \frac{1}{100}\left[\ 8080 \times \%\ C + 34{,}500\left(\%H - \frac{\%O}{8}\right) + 2240 \times \%\ S\ \right] \text{kcal/kg}$$

$$= \frac{1}{100}\left[8080 \times 85 + 34{,}500\left(H - \frac{3}{8} \right) + 2240 \times 0.5 \right] \text{kcal/kg}$$

$$= \frac{1}{100} [\ 686800 + 34500H - 12937.5 + 1120\ ] \text{ kcal/kg}$$

$$= [\ 6{,}868 + 345H - 129.4 + 11.2\ ] \text{ kcal/kg}$$

$$= 6{,}749.8 + 345\ H \text{ kcal/kg} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Equation (2) is substituted in equation (1)

$$6749.8 + 345\ H = 8400 + 52.8\ H$$

$$345\ H - 52.8\ H = 8400 - 6749.8$$

$$292.2\ H = 1650.2$$

$$H = \frac{1650.2}{292.2}$$

$$H = 5.647$$

$$\% \text{ of H} = 5.647 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Equation (3) is substituted in equation (1)

$$\therefore \text{GCV} = (8400 + 52.8 \times 5.647)$$

$$= 8698.16 \text{ kcal/kg}$$

Problem-4

Calculate the net and gross calorific value of a coal sample having following composition: C = 82%, H = 8%, O = 5%, N = 1.4% and ash = 3.6%. (APJAKTU, Jan. 2016).

Solution

(i) GCV

$$= \frac{1}{100}\left[8080 \times \% \text{ C} + 34500\left(\% \text{ H} - \frac{\% \text{O}}{8}\right) + 2240 \times \% \text{ S}\right] \text{kcal/kg}$$

$$= \frac{1}{100}\left[8080 \times 82 + 34500\left(8 - \frac{5}{8}\right) + 0\right] \text{kcal/kg}$$

$$= \frac{1}{100}[662560 + 254437.5]$$

$$= 9169.98 \text{ kcal/kg}$$

(ii) NCV

$$= GCV - \frac{9}{100} H \times 587 \text{ kcal/kg}$$

$$= 9169.98 - \frac{9}{100} \times 8 \times 587$$

$$= 8747.34 \text{ kcal/kg}$$

Problem-5

Calculate the gross and net calorific value of a fuel having following composition 82% C, 8% H, 5% O, 2.5% S,1.4% N and 2.1% ash.

(APJAKTU, July 2016)

Solution

We know that,

GCV = 1/100 [8080C + 34500 (H – O/8) + 2240S] kcal/kg

$$= 1/100\,[8080 \times 82 + 34500\,(8 - 5/8) + 2240 \times 2.5]$$

$$= 9225.97 \text{ kcal/kg}$$

$$NCV = GCV - 0.09H \times 587 \text{ kcal/kg}$$

$$NCV = 9225.97 - 0.09 \times 8 \times 587 = 8803.3 \text{ kcal/kg}$$

Problem-6

A coal sample has 80% of carbon, 9% of hydrogen, 6% of sulphur and remaining is ash. Calculate the HCV and LCV of the coal sample.

(JNTU(H), June 2017)

Solution

(i) Higher Calorific Value (HCV)

$$= \frac{1}{100}\left[8080 \times \%\,C + 34500\left(\%\,H - \frac{\%\,O}{8}\right) + 2240 \times \%\,S\right] \text{kcal/kg}$$

$$= \frac{1}{100}\left[\ 8080 \times 80 + 34500\left(9 - \frac{0}{8}\right) + 2240 \times 6\ \right] \text{kcal/kg}$$

$$= \frac{1}{100}\ [\ 64{,}6400 + 3{,}10{,}500 + 13440\ ]\ \text{kcal/kg}$$

$$= \frac{1}{100}\ [\ 9{,}70{,}340\ ]\ \text{kcal/kg}$$

$$= 9{,}703.4\ \text{kcal/kg.}$$

(ii) Lower Calorific Value (LCV)

$$= GCV - \frac{9}{100} H \times 587\ \text{kcal/kg}$$

$$= 9703.4 - \frac{9}{100} \times 9 \times 587\ \text{kcal/kg}$$

$$= 9703.4 - 475.47$$

$$= 9227.93\ \text{kcal/kg.}$$

7.5 IGNITION TEMPERATURE (IT)

It is defined as, *"the lowest temperature to which the fuel must be heated, so that it starts burning smoothly".* Ignition temperature of coal is about 300□C. In the case of liquid fuels, the ignition temperature is called the flash point, which ranges from 200 – 450^{O}C. For gaseous fuels, the ignition temperature is in the order of 800^{O}C.

7.5.1 Spontaneous Ignition Temperature (SIT)

It is defined as *"the minimum temperature at which the fuel catches fire (ignites) spontaneously without external heating".*

If the ignition temperature of a fuel is low it can catch fire very quickly. On the other hand if the ignition temperature is high it is difficult to ignite the fuel. If the heat evolved in a system is unable to escape, temperature of the system goes on increasing and when SIT is reached, the system burns on its own.

7.6 EXPLOSIVE RANGE OR LIMITS OF INFLAMMABILITY

All gaseous fuels have two limits called upper limit and lower limit. These limits represents percentage by volume of fuel present in fuel-air mixture.

1. Lower limit represents the smallest proportion of combustible gas (fuel).
2. Upper limit represents the largest proportion of combustible gas.

The range covered by these limits is termed as explosive range of the fuels. For continuous burning the amount of fuel present in the fuel-air mixture should not go below the lower limit or above the upper limit.

The explosive range of petrol is 2-4.5. This means that when the concentration of petrol vapour in petrol-air mixture is between 2 and 4.5 by volume, the mixture will burn on ignition. When the concentration of petrol vapour in petrol-air mixture is below 2% (lower limit) or above 4.5% (upper limit) by volume, the mixture will not burn on ignition. Some of the limits of inflammability are given in the following table. 7.1.

Table 7.1: The limits of inflammability of hydrogen, acetylene, natural gas

Gas	Lower limit of inflammability	Upper limit of inflammability
Hydrogen	4	74
Acetylene	3	80
Natural gas	5	14

Thus, explosive range (or) explosive limit is the limiting composition of a gas-air mixture beyond which the mixture will not ignite and continue to burn is called explosive range (or) explosive limit.

7.7 FLUE GAS ANALYSIS (ORSAT METHOD)

The mixture of gases (like CO_2, O_2, CO, etc) coming out from the combustion chamber is called flue gases. The analysis of a flue gas would give an idea about the complete or incomplete combustion process. The analysis of flue gases 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 $CaCl_2$ is connected through 3-way stop cock. The other end of this tube is connected with a graduated burette. The burette is surrounded by a water-jacket to keep the temperature of 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 (fig 7.1) The horizontal tube is also connected with three different absorption bulbs 1, 2, and 3 for absorbing CO_2, O_2 and CO.

Bulb	Reagent	Function
1	Potassium hydroxide solution.	Absorbs only CO_2
2	Alkaline pyrogallol solution.	Absorbs CO_2 and O_2
3	Ammoniacal cuprous chloride solution.	Absorbs CO_2, O_2 and CO

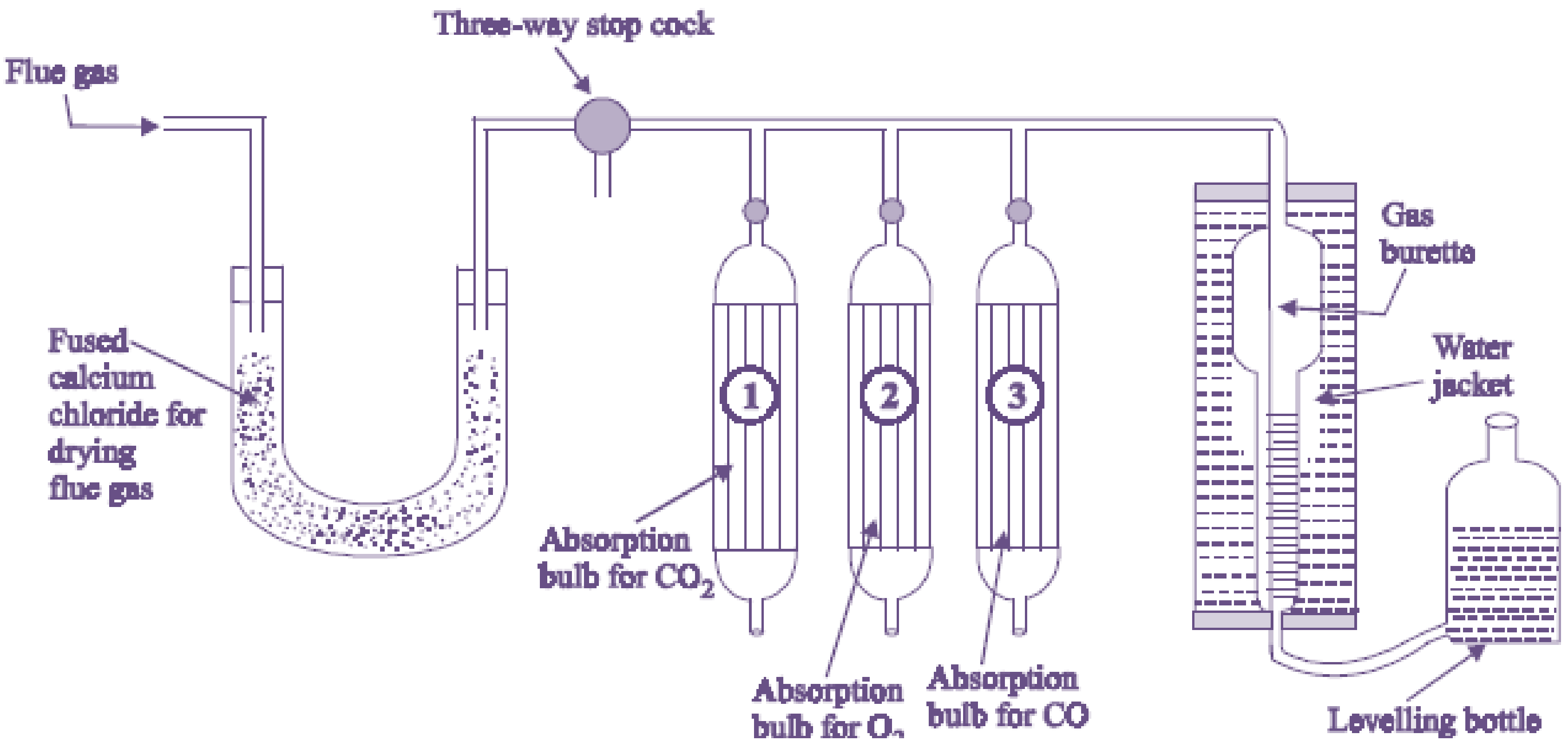
Working

The 3-way stop-cock is opened to the atmosphere and the reservoir is raised, till the burette is completely filled with water and air is excluded from the burette. The 3-way stop-cock is now connected to the flue gas supply and the flue gas is sucked into the burette and the volume of flue gas is adjused to 100 cc by raising and lowering the reservoir. Then the 3-way stop cock is closed.

(a) Absorption of CO_2

The stopper of the absorption bulb-1, containing KOH solution, is opened and all the gas is passed into the bulb-1 by raising the level of water in the burette. The gas enters into the bulb-1, where CO_2 present in the flue gas is absorbed by KOH.

The gas is again sent to the burette. This process is repeated several times to ensure complete absorption of CO_2. The decrease in volume of the flue gas in the burette indicates the volume of CO_2 in 100 cc of the flue gas.



Three-way stop cock
Flue gas
Fused calcium chloride for drying flue gas
1
2
3
Gas burette
Water jacket
Absorption bulb for CO_2
Absorption bulb for O_2
Absorption bulb for CO
Levelling bottle

(b) Absorption of O_2

Stop-cock of bulb-1 is closed and stop cock of bulb-2 is opened. The gas is again sent into the absorption bulb-2, where O_2 present in the flue gas is absorbed by alkaline pyrogallol. The decrease in volume of the flue gas in the burette indicates the volume of O_2.

(c) Absorption of CO

Now stop-cock of bulb-2 is closed and stop-cock of bulb-3 is opened. The remaining gas is sent into the absorption bulb-3, where CO present in the flue gas is absorbed by ammoniacal cuprous chloride. The decrease in volume of the flue gas in the burette indicates the volume of CO. The remaining gas in the burette after the absorption of CO_2, O_2 & CO is taken as nitrogen.

Significance (or) uses of flue gas analysis

1. Flue gas analysis gives an idea about the complete or incomplete combustion process.
2. If the flue gases contain considerable amount of CO, it indicates that incomplete combustion is occuring and it also indicates that the short supply of O_2.
3. If the flue gases contain considerable amount of O_2, it indicates that complete combustion is occuring and also it indicates that the excess of O_2 is supplied.

Precautions

1. Care must be taken in such a way that, the reagents in the absorption bulb 1, 2 and 3 should be brought to the etched marked level one by one by raising and lowering reservoir bottle.
2. All the air from the reservoir bottle is expelled to atmosphere by lifting the reservoir bottle.
3. It is essential that CO_2, O_2 and CO are absorbed in that order only.
4. As the CO content in flue gas is very small, it should be measured quite carefully.

7.8 ANNA UNIVERSITY QUESTIONS

1. Explain: Gross and Net calorific value. *(A.U. Dec 06)*
2. Define gross and net calorific values of a fuel. How are they related. *(A.U. June 2006)*
3. Calculate the gross and net calorific value of coal having the following compositions. Carbon - 85%, hydrogen - 8%, sulphur - 1%, nitrogen - 2% and ash - 4%. *(A.U. May 2007)*
4. How the flue gas analysis is carried out? Explain with neat diagram. Mention the significane of such analysis. *(TCY A.U. July, Dec 2009)(TNV & Chen A.U. May 2009)(A.U Dec 2012)*
5. With a neat diagram explain the analysis of flue gas by Orsat apparatus and mention the precautions to be followed during the analysis. *(Chen A.U. Dec 2009)*
6. Explain the flue gas analysis by orsat method with suitable diagram. *(A.U. May 2017)*


THANK
YOU!