Module 9: Fules

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Module outline:
Introduction
Fuels
Classification of fuels
Determination of calorific values
Analysis of coal
Biogas
Biomass

9.1. INTRODUCTION

Fuel is a combustible substance, containing carbon as main constituent, which on proper burning gives large amount of heat, which can be used economically for domestic and industrial purposes. Wood, charcoal, coal, kerosene, petrol, diesel, producer gas, oil gas, etc. are some of the fuels.

During the process of combustion of a fuel (like coal), the atoms of carbon, hydrogen etc. combines with oxygen with the simultaneous liberation of heat at a rapid rate. This energy is liberated due to the "rearrangement of valency electrons" in these atoms, resulting in the formation of new compounds (like CO_2, H_2O, etc.) are called as products of combustion. These new compounds have less energy (or heat content) in them and, therefore, the energy (or heat) released during the combustion process is the difference in the energy of the reactants (C, H, and O, etc. of fuel) and that of the products formed.

$$Fuel + O_2 \longrightarrow Products + Heat$$

High energy contents   Low energy contents
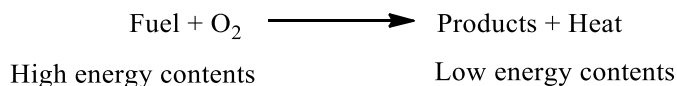
The primary or main sources of fuels are coals and petroleum oils, the amounts of which are dwindling day-by-day. These are stored fuels available in earth's crust and are generally called as 'fossil fuels'.

9.2 CLASSIFICATION OF FUELS

Fuels are classified on the basis of either occurrence or physical state.

9.2.1. On the Basis of Occurrence

On the basis of occurrence, fuels are classified as follows – primary or natural fuels and secondary or artificial or manufactured fuels.

1. **Primary or Natural Fuels:** Fuels which occur in nature as such and can be used directly without processing or after little processing which does not change the chemical composition of parent fuel are known as primary fuels. For example, fossil fuels like wood, coal, petroleum, natural gas, crude oil, etc.

2. **Secondary or Artificial or Manufactured Fuels:** The fuels which are derived from the primary fuels by chemical processing are known as secondary fuels. For example, coke, charcoal, kerosene, coal gas, diesel, etc.

9.2.2. On the Basis of Physical State

On the basis of physical states, fuels are classified as solid fuels, liquid fuels and gaseous fuels.
1. **Solid Fuels:** Those fuels which satisfy the characteristic features of a solid substance are called solid fuels.
2. **Liquid Fuels:** Those fuels which satisfy the characteristic features of a liquid substance are called liquid fuels.
3. **Gaseous Fuels:** Those fuels which satisfy the characteristic features of a gaseous substance are called gaseous fuels.

Examples of Fuels Based on Classifications

Occurrence → Physical state ↓	Natural Fuels	Artificial Fuels
Solid Fuels	Wood, coal, oil shale	Charcoal, coke, straw, briquettes
Liquid Fuels	Petroleum	Oils, coal tars, alcohols
Gaseous Fuels	Natural gas	Coal gas, producer gas, water gas, hydrogen, acetylene, oil gas

9.3. CHARACTERISTICS OF A GOOD FUEL

1. A good fuel should possess high calorific value.
2. An ideal fuel should have moderate ignition temperature.
3. The fuel should have low moisture content.
4. A fuel should have low content of non-combustible matter.
5. A fuel must be renewable in nature.
6. A fuel must be easily accessible.
7. A fuel must be easy to handle.
8. A fuel must be convenient to store and safe to transport.
9. A good fuel must be economical.
10. Combustion should be easily controllable.
11. The fuel should burn in air with efficiency, without much smoke.

9.4. CALORIFIC VALUE

Calorific value of a fuel is the total quantity of heat liberated, when a unit mass (or volume) of the fuel is burnt completely.

Units of Calorific Value: Units of calorific value for solid, liquid and gaseous fuels are given below.

Units of calorific values

System	Solid/ Liquid Fuels	Gaseous Fuels
CGS	Calories/ gm	Calories/ cm^3
MKS	kcal/ kg	kcal/ m^3
B.T.U.	B.T.U./ lb	B.T.U./ ft^3

9.5. UNITS OF HEAT

1. **Calorie:** It is the amount of heat required to raise the temperature of one gram of water through one degree centigrade (15-16^oC).
2. **Kilocalorie (or Kilogram Centigrade Units):** It may be defined as the quantity of heat required to raise the temperature of one kilogram of water through one degree centigrade. Thus:

$$1 \text{ kal} = 1,000 \text{ cal}$$

3. **British Thermal Unit (B.Th.U. or B.T.U.)** It is defined as the quantity of heat required to raise the temperature of one pound of water through one degree Fahrenheit (60-61^oF). This is the English system unit.

$$1 \text{ B.Th.U} = 252 \text{ cal} = 0.252 \text{ kcal}$$

or $$1 \text{kacl} = 3.968 \text{ B.Th.U.}$$

4. **Centigrade Heat Unit (C.H.U):** It is the quantity of heat required to raise the temperature of one pound of water through one degree centigrade.

$$1 \text{ kcal} = 3.968 \text{ B.Th.U.} = 2.2 \text{ C.H.U.}$$

9.6. CLASSIFICATION OF CALORIFIC VALUE

The calorific value has been classified on the basis of combustion product. There are two types of calorific values depending on the fact whether the steam produced as a result of combustion is allowed to cool down at room temperature or is allowed to escape.

Higher or Gross Calorific Value (HCV or GCV): The total amount of heat produced, when unit mass/ volume of the fuel has been burnt completely and the product of the combustion have been cooled to room temperature (i.e., 15^oC or 60^oF).

Lower or Net Calorific Value (LCV or NCV): The net heat produced, when unit mass/ volume of the fuel is burnt completely and the product are permitted to escape.

LCV = HCV – Latent heat of water vapour formed

LCV = HCV – Mass of hydrogen × 9 × latent heat of steam

or   NCV = GCV - Mass of hydrogen × 9 × latent heat of steam

because 1 part by mass of hydrogen produces 9 parts by mass of water. The latent heat of steam is 587 kcal/ kg or 1,060 B.Th.U./ lb of water vapour formed at room temperature (i.e., $15^{o}C$).

9.7.   DETERMINATION OF CALORIFIC VALUE USING BOMB CALORIMETER

Bomb calorimeter is used to find the calorific value of solid and liquid fuels.

Bomb Calorimeter
Bomb calorimeter consists of a cylindrical stainless steel vessel known as bomb and a lid is there screwed firmly on the bomb (Figure 9.1). The lid contains two electrodes and an oxygen inlet valve. One electrode is provided with a small ring which contains a stainless steel or nickel or silica crucible. The bomb is placed in a copper calorimeter containing a known weight of water. The copper calorimeter is provided with an electrically operated stirrer and a Beckmann's thermometer, which can read accurately temperature difference up to 1/ 100th of a degree. This calorimeter is surrounded by an air jacket and then a water jacket to prevent heat losses due to radiation.
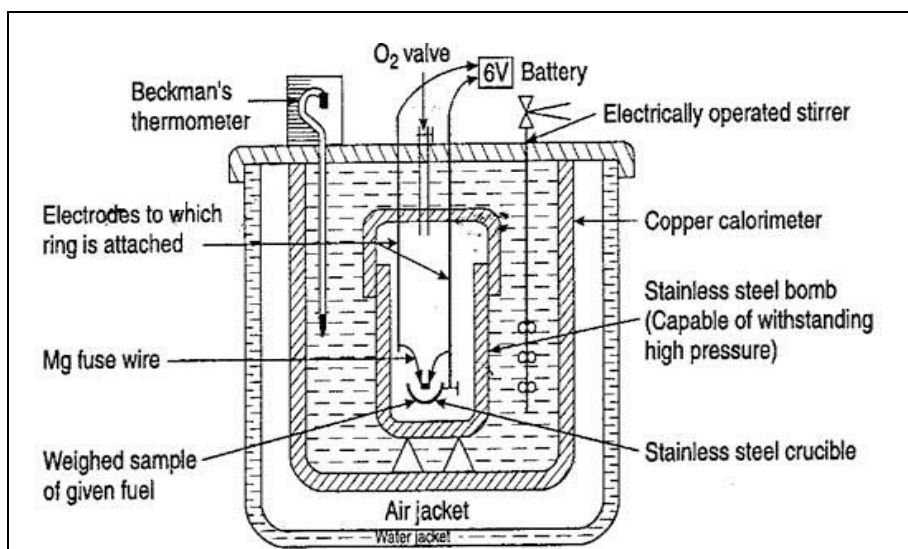

Fig. 9.1 Bomb calorimeter

Working: A known mass (about 0.5 to 1.0 g) of the given fuel is taken in clean crucible. The crucible is then supported over the ring. A fine magnesium wire, touching the fuel sample, is then stretched across the electrodes. The bomb lid is tightly screwed and bomb filled with oxygen to 25-atmospheric pressure. The bomb is then lowered into copper calorimeter, containing a known mass of water. The stirrer is worked and initial temperature of water is noted. The electrodes are then connected to 6-volt battery and circuit completed. The sample burns and heat is liberated. Uniform stirring of water is continued and the maximum temperature attained is recorded.

Calculation
Let   x = mass in g of fuel sample taken in crucible

W = mass of water in the calorimeter
w = water equivalent in g of calorimeter, stirrer, thermometer, bomb, etc.
t_1 = initial temperature of water in calorimeter
t_2 = final temperature of water in calorimeter
L = higher calorific value in fuel in cal/ g
∴∴   Heat liberated by burning of fuel = xL

Heat absorbed by water and apparatus, etc. = $(W + w) (t_2 - t_1)$
According to the law of conservation of energy
Heat liberated by the fuel = heat absorbed by water and apparatus, etc.
        ∴ $xL = (W + w) (t_2 - t_1)$

or   HCV of fuel (L) $\Box$ $\dfrac{(W + w)\,(t_2 - t_1)}{x}$ cal/ g (or kcal/ kg)

To calculate net calorific value following procedure is required

If   H = percentage of hydrogen in fuel

$$H_2 + 1/_2 O_2 \longrightarrow H_2O$$

2 gm   18 gm

1 gm   9 gm

i.e., weight of water produced from 1 gm H_2 = 9 gm

Then,   9H/ 100g = Mass of H_2O from 1 g of fuel = 0.09 H g

$\therefore$ Heat taken by water in forming steam

$\therefore$ LCV = HCV – Latent heat of water formed

LCV = (L – 0.09 H × 587) cal/ g   (Latent heat of steam = 587 cal/g)

Corrections: To get more accurate results, the following corrections are applied:

i.   **Fuse wire correction (C_F):** The heat liberated, as measured above, includes the heat given out by ignition of the fuse wire.

ii.   **Cotton thread correction (C_T):** If fuel is ignited with the help of a cotton or cotton thread, it will give extra heat and that must be subtracted from the obtained value. This is calculated from the weight of the dry cotton thread used.

iii.   **Acid correction (C_A):** Fuels containing S and N are oxidised, under high pressure and temperature of ignition, to H_2SO_4 and HNO_3 respectively.

$$S + 2 H + 2 O_2 \longrightarrow H_2SO_4 + Heat$$

$$2 N + 2 H + 3 O_2 \longrightarrow 2 HNO_3 + Heat$$

Formations of these acids are exothermic reactions. So the measured heat also includes the heat given out during the acid formation. The amount of these acids is analysed from washing of bomb by titration; while H_2SO_4 alone is determined by precipitation as $BaSO_4$. The correction for 1 mg of S is 2.25 cal; while for 1 mL of N/ 10 HNO_3 formed is 1.43 cal.

iv.   **Cooling correction C_C):** Time taken to cool the water in calorimeter from maximum temperature to room temperature is noted. From the rate of cooling (dt^o/ minute) and the actual time taken for cooling (t minutes), the cooling correction of dt × t is added to the rise in temperature.

$\Box$ $L = \dfrac{(W + w)\,(t_2 - t_1 + \text{cooling correction}) - [\text{Acid + fuse corrections + thread correction}]}{\text{Mass of fuel (x)}}$ cal/ g (or kcal/ kg)

Note: Dulong's formula for calculating the calorific values is given as:

$$\text{Gross calorific values (GCV)} = \frac{1}{100}\left[8080C + 34{,}500\left(H - \frac{O}{8}\right) + 2{,}240S\right] \text{kcal/ kg}$$

Where, C, H, O and S are the percentage of carbon, hydrogen , oxygen and sulphur respectively.

$$\text{Net calorific values (LCV)} = \left[HCV - \frac{9}{100}H \Box 587\right] \text{kcal/ kg}$$

$$= [HCV - 0.09H \Box 587] \text{kcal/ kg}$$

Example 9.1. The following data is obtained in a bomb calorimeter experiment:

Weight of fuel = 1.029g   Weight of water in calorimeter = 2200g

Water equivalent of calorimeter = 570g   Observed rise in temperature = 2.3^oC

Cooling correction = 0.047^oC Acid correction = 62.2 calories

Fuse wire correction = 3.8 calories   Cotton thread correction = 1.6 calories

Calculate the GCV of fuel sample. If the fuel contains 6.0% of hydrogen, determine NCV. (Latent heat of steam = 580 cal/g)

Solution: Given that

x = 1.029 g   W = 2200g

w = 570g $t_2 - t_1 = 2.3^0C$

$C_C = 0.047^0C$ $C_A = 62.6$ cal

$C_T = 1.6$ cal $C_F = 3.8$ cal

$$GCV = \frac{(W + w)(t_2 - t_1 + \text{cooling correction}) - [\text{Acid} + \text{fuse corrections} + \text{thread correction}]}{\text{Mass of fuel }(x)} \text{ cal/ g (or kcal/ kg)}$$

$$GCV = \frac{(2200 + 570)(2.3 + 0.047) - (62.6 + 3.8 + 1.6)}{1.029} = 6251.88 \text{ cal/g}$$

$$NCV = GCV - 0.09 \times H \times 580$$
$$= 6251.88 - 0.09 \times 6 \times 580$$
$$= 5938.68 \text{ cal/g}$$

Example 9.2. A sample of coal contained 92%C, 5% H and 3% ash. When this coal was tested in a laboratory for its calorific value in a bomb calorimeter, the following data were obtained:

Weight of coal burnt = 0.95g   Weight of water taken in calorimeter = 2000g

Water equivalent of calorimeter = 700g   Rise in temperature = 2.48^0C

Cooling correction = 0.02^0C   Fuse wire correction = 10 cal

Acid correction = 60 cal

Calculate the net and gross calorific values of the coal in cal/g (Latent heat of steam is 580 cal/g)

Solution.

Weight of fuel (x) = 0.95g

Water in calorimeter (W) = 2000g

Water equivalent of calorimeter (w) = 700g

Rise in temperature ($t_2 - t_1$) = 2.48^oC

Cooling correction (C_C) = 0.02^oC

Acid Correction (C_A) = 60 cal

Fuse wire correction (C_F) = 10 cal

Since

$$GCV = \frac{(W + w)(t_2 - t_1 + \text{cooling correction}) - [\text{Acid} + \text{fuse corrections} + \text{thread correction}]}{\text{Mass of fuel }(x)} \text{ cal/ g (or kcal/ kg)}$$

$$GCV = \frac{(2000 + 700)(2.48 + 0.02) - (60 + 10)}{0.95} = 7031.58 \text{ cal/g}$$

$$NCV = GCV - 0.09 \times H \times 580$$
$$= 7031.58 - 0.09 \times 5 \times 580$$
$$= 6770.58 \text{ cal/g}$$

Example 9.3. 0.72g of fuel containing 80% carbon when burnt in air in a bomb calorimeter, increases the temperature of water from 27.30C to 29.1 0C. If the calorimeter contains 250 g of water and its water equivalent is 150 g. Calculate HCV of fuel. Give answer in kJ/kg.

Solution: Given

Weight of fuel (x) = 0.72g

Water in calorimeter (W) = 250g

Water equivalent of calorimeter (w) = 150g

Initial temperature t_1 = 27.3^oC

Final Temperature t_2 = 29.1^oC

$$\text{HCV of fuel} \square \frac{(W + w)(t_2 - t_1)}{x} \text{ cal/ g}$$

$$\text{HCV of fuel} \square \frac{(250 + 150)(29.1 - 17.3)}{0.72} = 1,000 \text{ cal/ g}$$

$$\text{HCV of fuel} \square \frac{4.18 \square 1000 \square 10^{-3}}{10^{-3}} = 4180 \text{ kJ/kg}$$

Example 9.4. A coal has following composition by weight: C = 92%, O = 2%, S = 0.5% N = 0.5% and ash = 1.5 %. The NCV of coal was found to be 9,430 kcal/ kg. Calculate the percentage hydrogen and GCV of coal. The latent heat of steam is 587cal/g.

Solution: According to Dulong's formula for GCV

$$\text{Gross calorific values (HCV)} = \frac{1}{100}\left[8080C + 34{,}500\left(H - \frac{O}{8}\right) + 2{,}240S\right] \text{kcal/ kg}$$

$$\text{Gross calorific values (HCV)} = \frac{1}{100}\left[8080 \times 92 + 34{,}500\left(H - \frac{2}{8}\right) + 2{,}240 \times 0.5\right] \text{kcal/ kg}$$

= [7433.60 + 345 H − 86.25 + 11.20] kcal/ kg

= [7358.55 + 345 H] --- (1)

Since,

GCV = (Net calorific value + 0.09H × 587) kcal/ kg

= 9430 + 0.09H × 587

GCV = 8490.5 + 52.2H ---(2)

From (1) and (2) we get

[7358.55 + 345H] = [9430 + 52.83 H]

292.17 H = 2071.45

H = **7.09%**

From equation (1) we have

GCV = (7358.55 + 345 H) kcal/ kg

= 7358.55 + (345 × 7.09) kcal/ kg

= 9804.6 kcal/ kg

Example 9.5. Calculate the GCV and NCV of coal having the following compositions: C = 85%, H = 8%, S = 1%, N = 2% and ash 4% and latent heat of steam is 587 cal/g.

Solution. O = 100 – (85 + 8 + 1 + 2 + 4) = 0

According to Dulong's formula for GCV

$$\text{Gross calorific values (HCV)} = \frac{1}{100}\left[8080C + 34{,}500\left(H - \frac{O}{8}\right) + 2{,}240S\right] \text{kcal/ kg}$$

$$\text{Gross calorific values (HCV)} = \frac{1}{100}\left[8080 \times 85 + 34{,}500\left(8 - \frac{0}{8}\right) + 2{,}240 \times 1\right] \text{kcal/ kg}$$

= 6868 + 345 + 22.4

= 7335.4 cal/ g

NCV = GCV - 0.09 × H × 587

= 7235.4 - 0.09 × 8 × 587

= 6812.76 cal/ g

9.8. COALS

Coal is a highly carbonaceous matter that has been formed as a result of alternation of vegetable matters (e.g., plants) under certain favourable conditions. It is chiefly composed of C, H, N and O, besides non-combustible inorganic matter. Therefore the various types of coals are:

1. Peat: The average composition is C = 57%, H = 5.7%, N = 2%, O = 35.3%.
2. Lignites (brown coals): The average composition is C = 67%, H = 5%, N = 1.5%, O = 26.5%.
3. Bituminous coals (common coals): The average composition is C = 77-90%, H = 5%, N = 2%, O = 4-16.2%.
4. Anthracite: The average composition is C = 93.3%, H = 3%, N = 0.7%, O = 3%

9.9. ANALYSIS OF COAL

In order to assess the quality of coal, the following two type of analysis are made.
A. Proximate analysis
B. Ultimate analysis

9.9.1. Proximate Analysis

It is the simplest type of analysis of coal which includes the determination of moisture, volatile matter, ash and fix carbon. This analysis gives valuable information for accessing the application of a fuel for a particular domestic and industrial use.

i. **Moisture:** A known weight of air-dried coal sample is heated at 105-110°C for one hour in a silica crucible. The crucible is then cooled into desiccators and weighted.

$$\text{Percentage of moisture} = \frac{\text{Loss in weight}}{\text{Wt. of coal sample taken}} \times 100$$

ii. **Volatile matter:** The coal sample is heated at 925°C ± 20°C in an electric furnace (muffle furnace) for seven minutes. The crucible is cooled in desiccators and weighted. The percentage of volatile matter is calculated by using the formula.

$$\text{Percentage of volatile matter} = \frac{\text{Loss in weight due to removal of volatile matter}}{\text{Wt. of coal sample taken}} \times 100$$

iii. **Ash:** The non-combustible material left after the burning of coal is known as ash. The coal sample is heated gradually at 700 ± 50°C for half an hour. The crucible is then taken out, cooled and weighted. The ash content is calculated by using the formula.

$$\text{Percentage of ash} = \frac{\text{Weight of ash left}}{\text{Wt. of coal sample taken}} \times 100$$

iv. **Fixed carbon:** Fixed carbon in the coal can be determined as follows:

$$\text{Percentage of fixed carbon} = 100 - \% \text{ of (moisture + volatile matter ash)}$$

9.9.2. Ultimate analysis

This analysis involves in the following determinations:

1. **Carbon and Hydrogen:** about 1-2 g of accurately weighed coal sample is burnt in a current of oxygen in a combustion apparatus. C and H of the coal are converted into CO_2 and H_2O respectively. The gaseous products of combustion are absorbed respectively in KOH and $CaCl_2$ tubes to known weights. The increase in weights of these are then determined.

$$C + O_2 \longrightarrow CO_2$$
$$12 \qquad\qquad 44$$

$$H_2 + 1/2 O_2 \longrightarrow H_2O$$
$$2 \qquad\qquad 18$$

$$2KOH + CO_2 \longrightarrow K_2CO_3 + H_2O$$

$$CaCl_2 + 7H_2O \longrightarrow CaCl_2[H_2O]$$
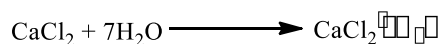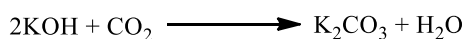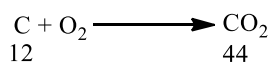
$$\therefore \quad \text{Percentage of C} = \frac{\text{Increase in weight of KOH tube} \times 12 \times 100}{\text{Weight of coal sample taken} \times 44}$$

$$\text{and} \quad \text{Percentage of H} = \frac{\text{Increase in weight of CaCl}_2 \text{ tube} \times 2 \times 100}{\text{Weight of coal sample taken} \times 18}$$

2. **Nitrogen:** About 1 g of accurately weighed powdered coal is heated with concentrated H_2SO_4 along with K_2SO_4 (catalyst) in a long necked flask (called Kjeldahl's flask). After the solution become clear, it is treated with excess of KOH and the liberated ammonia is distilled over and absorbed in a known volume of standard acid solution. The unused acid is then determined by back titration with standard NaOH solution. From the volume of acid used by ammonia liberated, the percentage of N in coal is calculated as follows:

$$\text{Percentage of N} = \frac{\text{Volume of acid used} \times \text{normality} \times 1.4}{\text{Weight of coal sample taken}}$$

3. **Sulphur:** Sulphur is determined from the washings obtained from the known mass of coal, used in a bomb calorimeter for determination of a calorific value. During the determination, S is converted into sulphate. The washings are treated with barium chloride solution, when barium sulphate is precipitated. This precipitate is filtered, washed and heated to constant weight.

$$\text{Percentage of S} = \frac{\text{Weight of BaSO}_4 \text{ obtained} \times 32 \times 100}{\text{Weight of coal sample taken in bomb} \times 233}$$

4. **Ash** determination is carried out as in proximate analysis.

5. **Oxygen:** It is obtained by difference

$$\text{Percentage of O} = 100 - \text{Percentage of (C + H + S + N + ash)}$$

Example 9.6. A sample of coal was analysed as follows:

Exactly 1.51 g of coal sample was weighed into a silica crucible. After heating for 1 hour at 110°C, the residue weighed 1.415g. The crucible was the heated strongly for 7 minutes at 950°C. The residue was weighed 0.528g. The crucible was then heated until a constant weight of residue was obtained. The last residue was found to be 0.254g. Calculate the percentage of above analysis.
(Even sem. 2010 – 2011)

Solution.

$$\text{Percentage of moisture} = \frac{\text{Loss in weight}}{\text{Wt. of coal sample taken}} \times 100$$

$$= \frac{1.51 - 1.415}{1.51} \times 100 = 6.29\%$$

$$\text{Percentage of volatile matter} = \frac{\text{Loss in weight due to removal of volatile matter}}{\text{Wt. of coal sample taken}} \times 100$$

$$= \frac{1.415 - 0.528}{1.51} \times 100 = 58.4\%$$

$$\text{Percentage of ash} = \frac{\text{Weight of ash left}}{\text{Wt. of coal sample taken}} \times 100$$

$$= \frac{0.254}{1.51} \times 100 = 16.82\%$$

$$\text{Percentage of fixed carbon} = 100 - \% \text{ of (moisture + volatile matter ash)}$$

$$= 100 - (6.29 + 58.74 + 16.82) = 18.15\%$$

Example 9.7. 3.25g of coal was Kjehldalized and NH_3 gas thus evolved was absorbed in 45 ml of 0.1N H_2SO_4. To neutralize excess acid, 11.5 ml of 0.1 N NaOH was required. Determine the percentage of nitrogen in fuel.

Solution.

$$\text{Percentage of N} = \frac{\text{Volume of acid used} \times \text{normality} \times 1.4}{\text{Weight of coal sample taken}}$$

$$= \frac{(45 - 11.5) \times 0.1 \times 1.4}{3.25} = 1.44\%$$

Example 9.8. 0.2g of coal sample was analysed in bomb calorimeter for sulphur. The weight of $BaSO_4$ precipitate was found to be 0.05g. Calculate the percentage of sulphur in the coal sample.

Solution.

$$\text{Percentage of S} = \frac{\text{Weight of } BaSO_4 \text{ obtained} \times 32 \times 100}{\text{Weight of coal sample taken in bomb} \times 233}$$

$$\text{Percentage of S} = \frac{0.05 \times 32 \times 100}{0.2 \times 233} = 3.45\%$$

9.10. COMBUSTION OF FUEL

Combustion is a chemical process accompanied by the liberation of heat and light. It is necessarily an exothermic reaction. For example

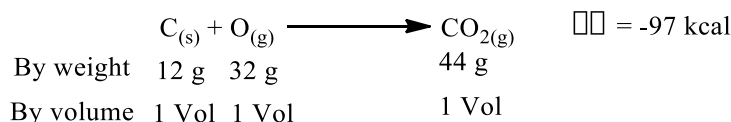$$C_{(s)} + O_{(g)} \longrightarrow CO_{2(g)} \qquad \Delta H = \text{-97 kcal}$$
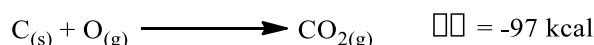
To ensure complete combustion, the substance must be brought to its ignition temperature. Ignition temperature is defined as the minimum temperature at which the substance ignites and burns without further addition of heat from outside.

9.11. CALCULATION OF AIR REQUIRED FOR COMBUSTION

The amount of oxygen and air required for complete combustion of a given quantity of the fuel can be calculated on the basis of following principles.

1. Substances always undergo complete combustion by well defined overall chemical reactions i.e., substances always combine in definite proportions. For example the combustion of carbon is represented by the following balanced equations;

$$C_{(s)} + O_{(g)} \longrightarrow CO_{2(g)} \qquad \Delta H = \text{-97 kcal}$$

By weight   12 g   32 g   44 g

By volume   1 Vol 1 Vol   1 Vol

2. In actual practice, the combustion is carried out in presence of air. Therefore, from the amount of oxygen required (as calculated on the basis of above reaction), amount of air is calculated. The basis of this calculation is the fact that air contains 21% of oxygen by volume and 23% of oxygen by weight.

Thus 1 m^3 of oxygen is supplied by $1 \times \dfrac{100}{21} = 4.76$ m^3 of air.

Similarly 1 kg of oxygen is supplied by $1 \times \dfrac{100}{23} = 4.76$ kg of air.

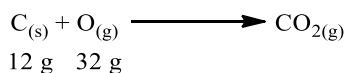3. Mean molecular weight of air is taken as 28.94 g mol^{-1}

Example 9.9. Calculate the weight and volume of air for complete combustion of 3 kg of carbon.
Solution:

$$C_{(s)} + O_{(g)} \longrightarrow CO_{2(g)}$$
$$12 \text{ g} \quad 32 \text{ g}$$

Since, weight of oxygen required to burn 12 kg of carbon = 32 kg

Therefore, weight of oxygen required to burn 1 kg of carbon = $\dfrac{32}{12}$ = 2.67 kg

Weight of oxygen required to burn 1 kg of carbon = $\dfrac{32}{12} \times 3$ = 8 kg

Weight of air required to burn 3 kg of carbon = $8 \times \dfrac{100}{23}$ = 34.78 kg of air

Again, 32g of air occupy 22.4 litres of volume at NTP

Therefore, 8 x 1000g of air will occupy = $\dfrac{22.4 \times 8 \times 1000}{32}$ $\dfrac{22.4 \times 8\,1000}{32}$ = 5600 litres

Thus, the volume of air required for complete combustion of 3 kg of carbon
= $\dfrac{100}{21} \times 5600$ = 2666.7 litres or 26.67 m^3

Example 9.10. Calculate the volume of air required for complete combustion of 1 m^3 of gaseous fuel having the composition: CO = 48%; CH$_4$ = 8%; H$_2$ = 40%; C$_2$H$_2$ = 2%; N$_2$ = 1% and remaining being ash.
Solution:

Constituent	Amount	Combustion Reaction	Volume of O$_2$ Required
CO	0.48	$CO + 0.5\,O_2 \longrightarrow CO_2$ 1 mole 0.5 mole	$0.48 \times 0.5 = 0.24$ m^3
CH$_4$	0.08	$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$ 1 mole 2 mole	$0.08 \times 2 = 0.16$ m^3
H$_2$	0.40	$H_2 + 0.5\,O_2 \longrightarrow H_2O$ 1 mole 0.5 mole	$0.40 \times 0.5 = 0.20$ m^3
C$_2$H$_2$	0.02	$C_2H_2 + 5/2\,O_2 \longrightarrow 2CO_2 + H_2O$ 1 mole 5/2 mole	$0.02 \times 5/2 = 0.05$ m^3

Total volume of oxygen required = 0.24 + 0.16 + 0.20 + 0.05 = 0.65 m^3

Volume of air required = $0.65 \times \dfrac{100}{21}$

9.12. BIOGAS

Biogas is produced by the degradation of biological matter by the bacterial action (of anaerobic bacteria) in the absence of free oxygen.

Examples
i. Natural gas is a biogas, which results after a long period decay of animal and vegetable matters, buried inside the earth.
ii. Gobar gas (or dung gas), which is produced by the anaerobic fermentation of cattle dung.
iii. Biogas can also be produced from the sewage waste and other organic wastes.

9.13. CONSTITUENTS OF BIOGAS

The average composition of biogas is:

i. CH$_4$ (methane) – 50-60% (a combustible gas).
ii. CO$_2$ – 30-40% (a non-combustible gas).
iii. H$_2$ – 5-10% (a combustible gas).
iv. N$_2$ – 2-6% (a non-combustible gas).
v. H$_2$S – trace (a combustible gas).

Out of these, the constituent methane (an extremely good fuel) makes biogas as an excellent fuel.

9.14. RAW MATERIALS FOR BIOGAS

Animal dung, poultry wastes, vegetable wastes, waste paper and cotton clothes, plant waste (grass, husk, leaves, skins, weeds), human excreta, bird's excreta, etc.

9.15. MANUFACTURE OF DUNG (OR GOBAR GAS) GAS

It is produced by the anaerobic degradation of cattle dung. It is carried out in gobar gas plant which consists of well-shaped underground tank (called digester). Covered with dome-shaped roof both made of brick and cement. The dome of the digester is fixed so that it acts as gas holder (or gas strong tank) for the biogas produced. At the top the dome, there is a gas outlet pipe and gas valve. On the left side of the digester, there is a sloping inlet chamber and on the right side, there is a rectangular outlet chamber, both made of brick and cement. Fresh cattle dung + water slurry is introduced from the inlet chamber; whole spent dung slurry gets collected in the outlet chamber. The inlet chamber is connected to the mixing tank; while the outlet chamber is connected to the overflow tank.
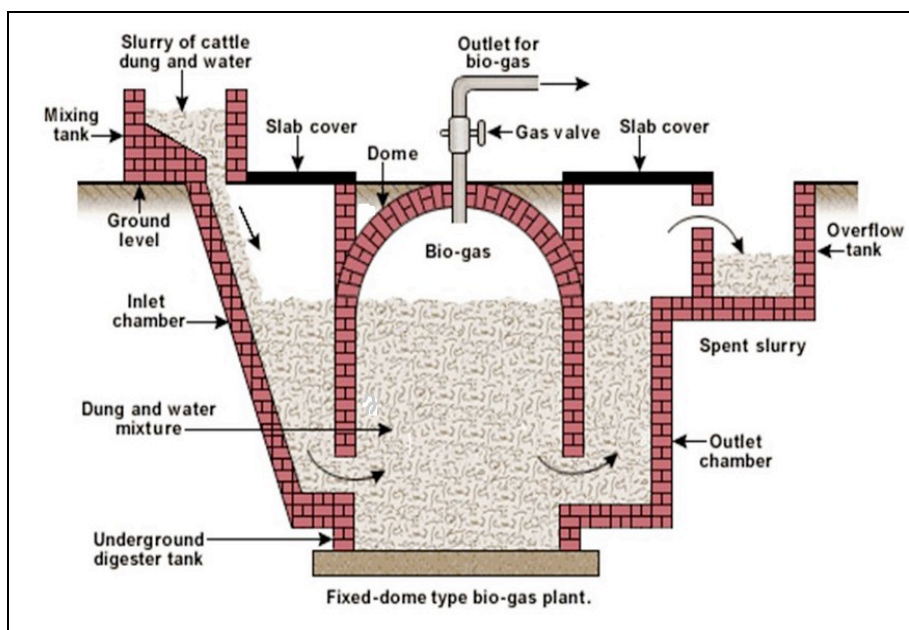

Fig. 9.1. Gobar gas

Working: Slurry (made by mixing cattle dung and water in equal proportion in mixing tank) is fed into the digester tank via the inlet chamber, till the slurry level becomes nearly equal to the cylindrical top level. In about 50-60 days, the biogas plan starts functioning. During this time period, the cattle dung undergoes fermentation in the presence of anaerobic bacteria with gradual evolution of biogas, which starts collecting in dome-shaped space. As the time passes, more and more biogas collects inside the dome, thereby exerting pressure on the slurry in the digester tank and this in-turn forces the spent slurry to the overflow tank via outlet chamber. From the overflow tank, the spent slurry is withdrawn periodically and used as good manure. From time to time, fresh slurry is fed to the digester so as to get regular supply of biogas. The biogas collected in dome is taken out through the outlet pipe by opening the gas valve and then used as fuel gas.

Note: Fixed-dome type biogas plant is also known as Janta gobar gas plant. Such a plant is quite cheap, since only bricks and cement are used for its construction. There is no danger of corrosion of such a plant.

9.16. USES OF BIOGAS

   i.   For cooking food.
   ii.   As a fuel to run engines.
   iii. As an illuminate in villages.

9.17. ADVANTAGES OF BIOGAS

   i.   Its calorific value is high.
   ii.   Biogas production is very economical.
   iii. The gas has all advantages of gaseous fuel like cleanliness, absence of smoke, flexibility, etc.
   iv.   It does not contain poisonous gas, CO, as an ingredient.
   v.   It provides simultaneously excellent yield of good manure.
   vi.   It involves no storage problem, since biogas can be supplied through pipes directly from the biogas plant.

9.18. LIMITATION OF BIOGAS

It is necessary to have the gas lamp or stove or burner within 10 meters of the plant.

9.19. BIOMASS

Biomass is the waste organic matter (mostly from the dead plants and animals) which used either as a source of energy (by burning or biogas production) and/ or as a chemical feedstock.

Biomass refers to all materials that are produced by photosynthesis and potentially useful as energy sources and for the production of organic chemicals.

Example: Wood, cattle dung, bagasse (remaining part of sugarcane) poultry wastes, vegetable wastes, waste paper, waste cotton clothes, plant wastes (grass, husk, leaves, skins, weeds), human excreta, bird's excreta, dead animals, sewage, etc.

Biomass consists of carbon compounds which may be used as source of energy by causing either of the following methods:

1. Biomass such as wood, cattle dung, bagasse, plant wastes, agricultural wastes, dry vegetable wastes, etc. is used directly in Chulhas for getting energy. However, by doing so a lot of heat energy is wastes and lot of smoke etc. is liberated, thereby causing blackening of utensils and houses. Moreover, it liberates poisonous gas carbon monoxide and leaves ash as residue.

2. Biomass is converted into biogas, which is used for heating and lighting purposes. By burning biogas much large amount of heat is liberated.

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EXERCISE

1. Write short note on electrode potential.
2. What is standard electrode potential?
3. Describe the construction and working of galvanic cell.
4. Explain the function of salt bridge.
5. What do you understand by electrochemical series?
6. Discuss the working principle of secondary batteries.
7. Derive Nernst equation for the calculation of cell emf.
8. Describe the construction of lead storage battery.
9. What is electrochemical corrosion? Write down the mechanism involved in the said reaction.
10. Describe the process of galvanization of iron? How does it prevent the corrosion of iron?
11. Explain the mechanism of hydrogen evolution and oxygen absorption in electrochemical corrosion. Give figures.

12.   What is corrosion? Describe the mechanism of electrochemical corrosion by (i) Hydrogen evolution (ii) Oxygen absorption
13.   Explain sacrificial anodic and impressed cathodic protection method for prevention of corrosion.
14.   Explain why pure metal rod half immersed vertically in water starts corroding at the bottom?
15.   Discuss any four method of corrosion control.
16.   Define the term corrosion. Discuss in brief the electrochemical theory of corrosion.
17.   What are the factors which affect corrosion?
18.   What is corrosion of metals? Explain the basic reason of metallic corrosion.
19.   How is corrosion prevented by cathodic protection?
20.   Define corrosion.
21.   Write a short note on corrosion inhibitors.
22.   Discuss the mechanism of electrochemical corrosion.