UNIT 5 FUELS

Structure

5.1 INTRODUCTION

Fuels are substances used for burning purposes while the term combustion pertains to burning mechanism. Energy can be obtained by burning of the fuels. It can also be obtained by nuclear reactions. In addition to these, there are a number of other alternative ways by virtue of which energy is obtained from the substances.

Fuel are a combustible substances containing carbon as the main constituent which on burning provides heat that can be used for both domestic and industrial needs. Charcoal, coal, wood, kerosene, petrol, diesel, water gas, producer gas and oil gas are some examples of fuels. On burning, energy obtained is equivalent to the energy difference between the fuel and the products.

$$\text{Fuel} + O_2 \rightarrow \text{Products} + \text{Heat}$$

Thus, the products are of lesser energy content than the fuel.

The main sources of fuels are coal and petroleum oils. Both these fuels are stored in earth's crust and are commonly known as **fossil fuels**.

In this unit, we will first discuss the classification of fuels. Then the calorific value of a fuel would be explained. We would then list the characteristics of a good fuel. This would be followed by discussion on the determination of calorific value. Finally, we would explain in detail some solid, liquid and gaseous fuels.

Objectives

After studying this unit, you should be able to

- define fuels,

- give the necessity of fuels in our daily life,

- classify fuels as solid, liquid or gaseous,

- list important characteristics of a good fuel,

- explain the determination of calorific values by bomb calorimeter and Boy's gas calorimeter,

- describe the various of types solid fuels such as coals and coke,

- discuss the origin, mining and refining of petroleum or crude oil,

- explain liquid fuels such as synthetic petrol, diesel and kerosene, and

- give composition and importance of gaseous fuels such as natural gas, water gas, coal gas, oil gas and biogas etc.

5.2 CLASSIFICATION OF FUELS

Fuels can be classified on the basis of their

    (i)   occurrence, and

    (ii)   state of aggregation.

As per the first classification, they may be further divided as *primary* and *secondary* fuels. **Primary** fuels which are also known as natural fuels are obtained from nature as such. Their examples are coal, wood, petroleum and natural gas etc. **Secondary** or artificial fuels are prepared from primary fuels. The examples of secondary fuels are coke, charcoal, diesel, kerosene, producer gas and water gas.

Figure 5.1 : Classification of Fuels

Primary solid fuels are available in nature and can be used as such straight away or after a minor processing like washing, cleaning or drying etc. Now-a-days, wood in general is not in practice as a source of energy unless it is available very economically. The use of wood also leads to deforestation which affects the environment. In place of wood, other materials like coke, charcoal and coal etc. are preferred. As a fuel, wood has less calorific value.

Figure 5.1 summarizes the classification of fuels and their examples.

5.3 CALORIFIC VALUE OF FUELS

The **calorific value** of a fuel is defined as the amount of heat liberated when a unit mass (or volume) of the fuel is burnt completely. It is expressed in terms of unit of heat in a number of ways as follows :

(i) **Calorie**

It is the amount of heat required to raise the temperature of 1 gm of water by 1^oC (i.e., 15^oC to 16^oC).

(ii) **Kilo Calorie**

It is the unit in metric system. It is defined as the amount of the heat required to raise the temperature of 1 kg of water by 1^oC (i.e., 15^oC to 16^oC).

(iii) **British Thermal Unit (B. Th. U)**

It is the amount of heat required to raise the temperature of 1 pound of water by 1^oF (i.e., $60 – 61^oF$).

$$1 \text{ B. Th. U.} = 252 \text{ Calories}$$

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

(iv) **Centigrade Heat Unit (C. H. U)**

It is the amount of heat required to raise the temperature of 1 pound of water by 1^oC (i.e., $15^oC – 16^oC$)

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

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

In case of solid or liquid fuels, the calorific value is expressed either in terms of cal./gm or kcal/kg or B. Th. U./lb. In case of gaseous fuels, the unit of calorific value is kcal/m^3 or B. Th. U./ft^3.

The caloric values of fuels are expressed using following two terms :

(i) Higher or gross calorific value, and

(ii) Lower or net calorific value.

Higher or Gross Calorific Value (HCV)

It is concerned with the hydrogen containing fuels which on burning get converted into steam. The products of combustion get cooled down to room temperature and the latent heat of condensation is also included in calculation but in true sense HCV is the total amount of heat produced when unit mass (or volume) of the fuel is burnt completely and the products of combustion were cooled to temperature 15^oC or 60^oF.

Lower or Net Calorific Value (LCV)

When any fuel is burnt, water or moisture is not condensed and it escapes along with hot combustion which means that a lesser amount of heat is available. LCV can be understood as the net amount of heat obtained on burning completely one unit mass (or volume) of fuel when the products are permitted to escape. Hence

LCV = HCV – Latent Heat of water/moisture vapour formed

SAQ 1

(a)   What are the units of calorific value of a fuel?

(b)   Differentiate between HCV and LCV.

5.4 CHARACTERISTICS OF A GOOD FUEL

A fuel which fullfills the following requirements is known as a good fuel.

(i)   It should have a high calorific value per unit mass or volume. It should generate large amount of heat under end use conditions.

(ii)   It should not evolve harmful gases or substances like CO_X, NO_X, and SO_2 etc.

(iii)   It should not be associated with higher amount of non-combustible materials like ash, clinker etc.

(iv)   It should have moderate ignition temperature. Low ignition temperature is dangerous for storage as well as transportation since it can create fire hazards. On the other hand, high ignition temperature causes difficulty in ignition.

(v)   It should not give any unpleasant odour.

(vi)   It should have moderate velocity of combustion.

(vii) It should be readily available in bulk at economical rate.

(viii) It should burn with efficiency without producing much smoke.

(ix)   In case of solid fuel, the size should be uniform so that the combustion may take place in regular way.

(x)   It should be easy to handle and transport.

SAQ 2

Write down five characteristics of 'good fuel'.

5.5 COMPARISON BETWEEN SOLID, LIQUID AND GASEOUS FUELS

Every fuel in its aggregation of state is associated some merits and demerits. We will now list the merits and demerits of solid, liquid and gaseous fuels.

5.5.1 Solid Fuels

Merits

    (i)   Their cost of production is low.

    (ii)   They are easy to store and transport.

    (iii)   They have high calorific value.

    (iv)   They have moderate ignition temperature.

    (v)   They have good adsorption for gases.

Demerits

    (i)   They have high ash content.

    (ii)   Their thermal efficiency is low.

    (iii)   They burn with clinker formation.

    (iv)   They produce harmful waste products.

    (v)   They have high moisture content but their moisture content is lower than liquid or gaseous fuels.

    (vi)   They cannot be used as internal combustion engine fuels.

    (vii)   A good amount of heat goes waste.

    (viii)   Their combustion is not easily controllable.

5.5.2 Liquid Fuels

The following are some merits and demerits of liquid fuels.

Merits

    (i)   Liquid fuels do not give any non-combustible matter after burning.

    (ii)   They can also be used in internal combustion (IC) engines.

    (iii)   They have moderate ignition temperature.

    (iv)   They need less amount of air for their complete combustion.

    (v)   They are economical.

    (vi)   Combustion is easily controllable in case of liquid fuels.

    (vii)   They have less moisture content.

    (viii)   They possess high calorific value.

    (ix)   Their supply can be easily regulated.

    (x)   They can be easily stored for long period.

Demerits

    (i)   Their storage is costlier than solid fuels.

    (ii)   Their cost is much higher than solid ones.

    (iii)   They produce bad odour.

    (iv)   There is a great risk of fire hazards with liquid fuels.

    (v)   They are inflammable.

5.5.3 Gaseous Fuels

The following are some merits and demerits of gaseous fuels.

Merits

(i) Gaseous fuels can be transported easily through pipes to the place of their consumption. Thus, their transportation cost is minimized.

(ii) They burn easily.

(iii) Gaseous fuels leave no non-combustible matter after burning.

(iv) They can be used as internal combustion engine fuels.

(v) They are very economical.

(vi) They have high calorific value.

(vii) They burn without soot.

(viii) Their combustion can easily be controlled.

(ix) In case of gaseous fuels, uniform mixing with air can be carried out and hence environmental pollution can be avoided.

(x) They do not need any special burners.

Demerits

(i) They are highly inflammable and therefore there are greater chances of fire hazards.

(ii) They need more space for their storage, thereby their storage is a costly affair.

5.6 DETERMINATION OF CALORIFIC VALUE

The calorific values can be determined using Bomb calorimeter and Boy's gas calorimeter. In this section you will study about them in detail.

5.6.1 Bomb Calorimeter

Bomb calorimeter is used to determine the calorific value of solid and liquid fuels. The apparatus is shown in Figure 5.2.

Figure 5.2 : Bomb Calorimeter

Construction

The Bomb is made of steel in which the combustion of fuel is allowed. It has a lid which can be screwed to the body of bomb so as to provide a perfect gas tight seal. The lid is provided with two stainless steel electrodes and an oxygen inlet valve. A small ring is attached to one of the electrodes. A stainless steel or nickel crucible is supported with this ring. This bomb is placed in a copper calorimeter which is surrounded by air jacket or water jacket so that no heat loss takes place due to radiation. The apparatus also contains an electrically operated stirrer and Beckman's thermometer which gives temperature upto $1/100^{th}$ degree centigrade.

Function

A definite mass (0.5 to 1.0 g) of the fuel under testing is taken in a clean crucible. The crucible is then supported over the ring. A good quality magnesium wire touching the fuel is placed across the electrodes. The bomb is placed across the electrodes. The bombs lid is tightly screwed. The bomb is filled with oxygen and the pressure inside is created upto 25 atm. The bomb is lowered in copper calorimeter which contains a known amount of water. The initial temperature of water is recorded and then the electrodes are connected to a 6 volt battery and circuit is completed. The fuel sample burns and the heat is released. The water is stirred uniformly and the maximum temperature attained by the water is recorded.

Calculations

Let m = mass (in gms) of fuel sample,

W = mass (in gms) of water in calorimeter,

w = water equivalent (in gms) of calorimeter,

t_1 = initial temperature of water,

t_2 = final temperature of water, and

L = higher calorific value (HCV) in fuel (cal/gm).

Then, the total heat liberated by burning of fuel = $m \times L$.

The heat taken by water and the system = $(W + w) (t_2 - t_1)$

As we know that heat liberated = heat taken, hence

Heat liberated by the fuel = Heat taken by the water and system

$$m \times L = (W + w) (t_2 - t_1)$$

or $$L = \frac{(W + w) (t_2 - t_1)}{m} \ \text{cal/gm.}$$

It is the HCV of the fuel taken for testing.

LCV = HCV – Latent heat of water produced.

The latent heat of water $= 0.09 \times 587$ cal/gm

(Latent heat of steam is 587 cal/gm).

5.6.2 Boy's Gas Calorimeter

The calorific value of liquid and gaseous fuels can be determined by Boy's Gas calorimeter. The apparatus is shown in Figure 5.3.

Figure 5.3 : Boy's Gas Calorimeter

Construction

The apparatus consists of a suitable gas burner in which a known volume of gas at known pressure can undergo combustion at a uniform rate of 3-4 litres per minute. Around the burner, there is a combustion chamber with a copper tubing coiled inside as well as outside. Water is passed through this coil at constant rate continuously. To determine the colorific value correctly, the whole system is kept insulated.

Function

A definite volume of gas is taken in the gas burner at definite pressure. The gas is burnt at constant rate to produce a large amount of heat. The rise in temperature in the water circulation is recorded accurately with the help of thermometer. When the steady situation with respect to rate of fuel burning and water circulation is attained, then the following observations are taken.

(i) The volume of gas burnt in a given time

(ii) The quality of water circulated through the coil

(iii) Mass of water condensed during that time

(iv) The rise in temperature

Calculation

(i) Using the above observations, we can calculate HCV and LCV of liquid fuels and gaseous fuels as follows :

V = volume of gas burnt in time 't'.

W = mass of water circulated in time 't'.

T_1 and T_2 are initial and final temperatures of water, respectively.

L = Higher calorific value of fuel (cal/gm)

m = mass of water condensed in time 't'.

(ii) Heat given by the combustion of fuel = $V \times L$

(iii) Heat taken by the circulated water $= W(T_2 - T_1)$.

Assuming that there is no loss of heat, we can say that

$$\text{Heat given} = \text{Heat taken}$$

$$V \times L = W(T_2 - T_1)$$

$$\text{HCV} = L = \frac{W(T_2 - T_1)}{V}$$

LCV = HCV – Latent heat of water produced

$$= \left(L - \frac{m}{V} 587 \right) \text{Kcal/m}^3 .$$

5.7 SOLID FUELS

We will now discuss two solids fuels, viz., coal and coke.

5.7.1 Coal

Coal is a highly carbonaceous matter and is used as a fuel. It is found in nature as a result of several decomposition stages of vegetable matter under the influence of heat and pressure in limited supply of air. It consists of mainly C, H, N, O and some non-combustible inorganic matter. There are several theories which predict the coal formation but out of these two main theories are :

 (i)   Situ Theory, and

 (ii) Transportation Theory (Drift Theory).

Situ Theory

This theory hints that the coal formation took place at the place of vegetation which is known as pure form of the coal.

Transportation Theory (Drift Theory)

This theory hints that vegetables, trees and organic matter etc. have been undergone transportation to deep depressions which decomposed gradually under high pressure and temperature with the evolution of gases like CH_4, C_2H_6, CO_2 etc. In this way, the coal got deposited in the form of thick layers.

Classification of Coal by Rank

Coal is classified on the basis of following characteristics :

 (i)   Less hydrogen, nitrogen, oxygen, sulphur contents and more carbon content

 (ii) Less moisture content

 (iii) High calorific value

 (iv) Moderately hard

 (v)   Less volatile matter

The successive stages of transformation of vegetable matter into coal are wood, peat, lignite, bituminous and anthracite.

 (i)   **Peat**

It is found as brown fibrous jelly like material. It is considered that it is the first stage of wood coalification. It is not an economical fuel. It is in practice dug by manpower. Peat variety contains 80-90% water (moisture). The average composition of air dried peat coal is as follows : C = 57%, H = 6%, O = 35% and ash content 2 to 6%. The calorific value of this coal is about 5500 kcal/kg (on air dry basis). In India, it is found in Nilgiri Hills (South India).

(ii) **Lignite**

It is considered as the second stage of coalfication of wood. It contains less moisture than peat coal. It is soft and brown coloured variety of coal. It is in compact texture and gets broken down in small pieces easily. In our country, it is found in Kashmir, Rajasthan, Assam and in Tamil Nadu (at Neyveli). The average composition of lignite (on air dry basis) is as C = 60 to 70%, O = 20%, H = 5% and ash = 2%. Lignite coal is a very good domestic fuel. It is mainly used in the manufacture of producer gas and in steam generation as boiler fuel. On air dry basis, its calorific value ranges between 6400-7150 kcal/kg.

(iii) **Bituminous Coals**

These coals are available in pitch blank to dark grey colours. These are good quality coals. The average composition of bituminous coals (on air dry basis) is as follows : C = 88%, H = 4.5 and O (N, S) 13.5%. Their calorific value is higher than peat and lignite coals. This value varies from 7000 to 8500 kcal/kg. The bituminous coal deposits are found in Madhya Pradesh, Orissa, Bihar and West Bengal. These coals are very much used in industries, household needs and in the manufacturing of metallurgical coke and coal gas.

(iv) **Anthracite**

Anthracite is the coal of the highest rank. It is considered as the purest form of the coal. It contains (on air dry basis) 92-96% carbon and has the lowest amount of volatile matter. It is the hardest form of coal and has good lustrous appearance. It gives intense local heating. It gives no smoke during burning. It provides high calorific value of 8700 kcal/kg. In India, its deposits are found in Kashmir and in eastern Himalayan region.

Selection of Coal

The selection of coal is carried out on the basis of following points :

(i) **Calorific Value**

The coal should have high calorific value so that its small quantity may provide a large amount of heat. High calorific value coal reduces the cost of its transportation and storage.

(ii) **Coking Quality**

We know that coke is obtained by high carbonization process of coal which is heated in large size ovens in the absence of air. Then coal is converted into soft, plastic and tube of large coherent masses which are known as coking coals.

(iii) **Calorific Intensity**

It is based on the gaseous products of the coal combustion. It depends upon the following factors :

(a) Nature,

(b) Quantity, and

(c) Specific heat

The calorific intensity may be defined as the maximum temperature obtainable on the complete combustion of coal in the presence of excess air. Mathematically, it is represented as follows :

$$\text{Flame Temperature} = \frac{\text{Heat of combustion} + \text{Sensible Heat of air}}{\sum (\text{Combustion products} \times \text{Specific heats})}$$

If any fuel burns without flame then it is of high calorific intensity. On the other hand, if it burns with a flame then total heat is distributed to a large area which decreases the calorific intensity.

(iv) **Moisture Content**

A good quality coal on an average should have low percent of moisture to prevent the heat loss.

(v) **Ash Content**

The ash content of coal should be low so that cost of coal transportation and disposal of ash is less. Low ash content coal shall give more heating value.

(vi) **Size of Coal**

To give maximum heat, the size of the coal should be uniform.

(vii) **Sulphur and Undesirable Contents**

The sulphur and undesirable contents in the coal should be low. During the combustion of coal, these substances produce unpleasant odour as well as pollute the environment in one way or the other.

5.7.2 Coke

It is obtained as residue in the retorts during the dry distillation of coal. The good coke should have the following characteristics.

(i) It should possess low ash content.

(ii) It should possess low moisture content.

(iii) It should have high calorific value.

(iv) It should be moderate in size i.e., it should be neither too big nor too small in size.

(v) It should have no or low undesirable contents like S, P, N etc.

(vi) The coke should have good combustibility so that it can be easily burnt.

(vii) It should be moderately hard and compact.

(viii) It should have good porosity so that oxygen can pass through for complete combustion.

The coke is one of the prime materials to manufacture the coal gas. It is also used as a reducing agent in the manufacturing of metallurgical coke.

Manufacturing of Metallurgical Coke

The metallurgical coke is manufactured in two ways :

(i)   Beehive oven process, and

(ii)   Otto Hoffmann's Byproduct oven process.

(a)   **Beehive Oven Process**

The oven employed in this process is a dome shaped structure made of bricks. It is about 4 m wide and 2.5 m high with two openings – one at the top to feed the coal charge and other on the side to let in air as well as for coke discharge. This oven is shown in Figure 5.4.

Figure 5.4 : Beehive Oven

In this process, the coal is fed through the opening at the top and the charge is levelled to provide about 0.6 m deep layer. The air is sent through the side opening and the coal is ignited. The volatile matter is allowed to escape through the partly closed opening on the side. Combustion is allowed to proceed in gradually low supply of air to get slow carbonization from the top layer to bottom layer. The process may last for nearly 4-5 days when the carbonization is complete. The hot coke is raked out through the side and quenched with water. The yield is about 80%. To prevent the wastage of heat, several ovens in series may be arranged. The byproducts in this process are not recoverable.

(b)   **Otto Hoffmann's Byproduct Oven Process**

This process is beneficial than the previous one because a number of by products like coal gas, ammonia, benzol oil, tar etc. are obtained. One of the by products, i.e. coal gas can be used for heating. The structure of the ovens is as follows. It consists of a number of narrow silica chambers, each about 10 – 12 m in length, 3 – 4 m in height and about 0.4 – 0.5 m in width. These are erected side by side with vertical flues between them to form a sort of battery. To introduce the charge, every oven has a hole at the top of it and there is a refractory lined cast iron door at each end for coke discharge. The functioning of oven is based on the heat regenerative principle. The ovens are shown in Figure 5.5.

In this process, finely powdered coal is introduced through the hole (at the top) of oven chamber which is then tightly closed so that the supply of air may be prevented at both ends. Then, the ovens are heated to about 1200°C using producer gas. The required air for the combustion of the coal is preheated in regenerators flanking the retorts. At the same time flue gases leave their acquired heat to one generator, the other heater is used for

preheating the incoming air. This cycle continues until all the volatile matter gets away. It takes nearly 18-20 hours for the carbonization of the coal on the completion of this carbonization process. The red hot coke is taken out into a truck by massive ram. It is then quenched with water. The coke may also be cooled down with the help of inert gases in a separate chamber. The cooling with inert gases is said to be *dry quenching* which provide cleaner and stronger coke. It also consists of less dust content than water cooled coke. The yield in this process is about 70-75%.

Figure 5.5 : Otto Hoffmann's Byproduct Oven Process

Recovery of Byproducts

In this process, following byproducts are obtained :

(i)   Ammonia

(ii) H_2S

(iii) Naphthalene

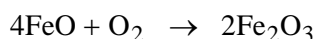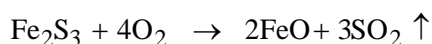(iv) Benzene

(v)   Tar, etc.

Recovery of Ammonia

The gases coming out from chamber are allowed to pass through another tower where water is sprayed. The gaseous ammonia gets absorbed in water and becomes available as NH_4OH.

Recovery of H_2S

The gases are allowed to pass through a column packed with moist Fe_2O_3 which retains H_2S. This can be represented as follows :

$$Fe_2O_3 + H_2S \rightarrow Fe_2O_3 + 3H_2O$$
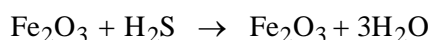
When whole of Fe_2O_3 is converted into Fe_2S_3, the purifier on exposure to the atmosphere regenerates Fe_2O_3.

$$Fe_2S_3 + 4O_2 \rightarrow 2FeO + 3SO_2 \uparrow$$

$$4FeO + O_2 \rightarrow 2Fe_2O_3$$

Recovery of Naphthalene

Naphthalene gets condensed when gases are allowed to come in contact with cold water after the recovery of ammonia.

Recovery of Benzene

When the gases after above recoveries are allowed to come in contact with petroleum, then benzene and other homologues are taken off.

Recovery of Tar

The tar is recovered after ammonia recovery.

SAQ 3

(a)   What is metallurgical coke?

(b)   Arrange peat, lignite, bituminous and anthracite coal in increasing order of calorific value.

(c)   Which one is the highest ranking coal?

5.8 LIQUID FUELS

There are a number of liquid fuels. Some are derived from petroleum (crude oil) and some are obtained by synthesis.

5.8.1 Petroleum or Crude Oil

The term *petroleum* is combination of *petra* (meaning rock) and *oleum* (meaning oil). It is a dark greenish brown coloured viscous oil. It occurs under the earth crust and is found floating on the layer of brine. It is associated with gases called natural gases. Petroleum or crude oil is mainly composed of various hydrocarbons like paraffins, cycloparaffins, olefins, naphthalenes, aromatics etc. The average composition of crude petroleum is as follows :

C = 79 – 81%, H = 11.5 – 14.8%, S = 0.1 – 3.3% and N & O = 0.1 – 0.5%.

(a)   **Origin of Petroleum**

There are various theories of origin of petroleum. One of them is modern theory which tells that the petroleum has resulted from the partial decomposition of marine animals and vegetable matter of prehistoric forests. The phenomenon the earth (like volcanic eruptions etc.) burried these materials under the earth where they had undergone changes under the influence of high pressure and temperature. The conversion of these materials into various hydrocarbons occurred either under the influence of

radioactive substances or by bacterial decomposition (anaerobic type) in reducing conditions.

(b) **Mining of Petroleum**

The crude oil is found in porous strata beneath the impervious rock at 500 to 15000 ft depth. It is taken out to the surface by drilling holes in the earth crust and sinking pipes upto the oil bearing surface of rocks. In some cases, the hydrostatic pressure of natural gases push the crude oil to come to the surface through these holes. On the other hand, in some cases, it is drawn to the surface by mechanically pumping. The mining of petroleum is shown in Figure 5.6.

Figure 5.6 : Mining of Petroleum

(c) **Refining of Petroleum**

Petroleum is refined using a number of processes which separate the crude oil into different components. These processes are explained below :

(i) *Fractional Distillation*

Fractional distillation of the crude oil gives various fractions thereby separating lighter and heavier portions. The crude oil is heated in a furnace to about $400^{o}C$ in an iron retort which has high temperature in its lower part while low temperature in its upper part or we can say that its upper part is relatively cooler. It is shown in Figure 5.7. In this distillation, higher boiling fractions condense first while lower boiling fractions get condensed turn by turn. The details of each fractions obtained are given in Table 5.1.

Figure 5.7 : Fractional Distillation of Petroleum

Table 5.1 : Details of Fractions of Crude Oil

Name of Fraction	Boiling Range	Composition of Hydrocarbons	Uses
Uncondensed gas	Below 30°C	C_1 to C_4	As domestic or industrial fuel under the name LPG (liquefied petroleum gas)
Petroleum ether	30 - 70°C	C_5 to C_7	As a solvent
Gasoline or petrol or motor spirit	40 - 120°C	C_5 to C_9	As motor fuel, solvent and in dry cleaning
Naphtha or solvent spirit	120 - 180°C	C_9 to C_{10}	As solvent and in dry cleaning
Kerosene oil	180 - 250°C	C_{10} to C_{16}	As an illuminant, jet engine fuel and for preparing laboratory gas
Diesel oil or fuel or gas oil	250 - 320°C	C_{10} to C_{18}	Diesel engine fuel
Heavy oil This on refractionation gives :	320 - 400°C	C_{17} to C_{30}	For getting gasoline by cracking process
(a) Lubricating oil	---	---	As lubricant
(b) Petroleum jelly (vaseline)	---	---	As lubricant and in cosmetics and medicines
(c) Grease	---	---	As lubricants
(d) Paraffin wax	---	---	In candles, boot polishes, wax paper, etc.
Residue may be either :	Above 400°C	C_{30} and above	
(a) Asphalt, or	---	---	Water-proofing of roofs and road making
(b) Petroleum coke	---	---	As a fuel and in moulding arc light rods

Later on the uncondensed gases are liquefied and are known as LPG (Liquefied Petroleum Gas). LPG comprises of mainly components from alkane series, alongwith very small amounts of mecaptans and aromatics which causes odd small therein.

(ii) *Separation of Water and Other Impurities*

The crude oil makes stable emulsion with brine water. With the help of two highly charged electrodes, this emulsion breaks and the water droplets get aggregated to form bigger water drops which separate out from the oil. To remove the colour and other impurities, it is passes through various columns of adsorbents like kieselghur clay etc. Finally, pure oils are obtained.

(iii) *Removal of Sulphur and other Compounds*

The oil is treated with the oxide of copper which reacts with sulphur and its compounds to form sulphide of copper. Copper sulphide so obtained is filtered out.
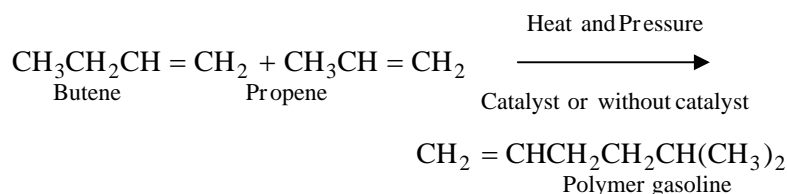
5.8.2 Synthetic Petrol

Petrol can be synthesized in following ways :

(i) Polymerization

(ii) Fischer Tropsch Process

(iii) Bergius Process

(i) **Polymerization**

The cracking of heavy oils provide the gases containing alkanes and olefins such as CH_4, C_2H_6, C_3H_8, C_4H_{10}, C_3H_6, and C_4H_8 etc. At high temperature and high pressure, this gaseous mixture undergoes polymerization with or without the presence of catalyst and forms higher hydrocarbons.

This product resembles with gasoline and is known as polymer gasoline. It may be represented by the following reaction :

$$CH_3CH_2CH = CH_2 + CH_3CH = CH_2 \xrightarrow[\text{Catalyst or without catalyst}]{\text{Heat and Pressure}}$$

Butene   Propene

$$CH_2 = CHCH_2CH_2CH(CH_3)_2$$

Polymer gasoline

(ii) **Fischer Tropsch Process**

In this process, water gas $(CO + H_2)$ is mixed with H_2 gas. The hydrogen sulphide present is removed by passing this mixture through ferric oxide. This purified gaseous mixture is compressed to a high pressure of 25 atm. Then, the mixture is passed through a converter which contains a catalyst (a mixture of 5 parts thorium oxide, 8 parts magnesium oxide, 100 parts cobalt and 200 parts kieselhgur clay). The converter works at a temperature of 200-300°C. The reactions provide a mixture of saturated and unsaturated hydrocarbons as follows :

$$n\,CO + 2n\,H_2 \ \rightarrow \ C_nH_{2n} + n\,H_2O$$

$$n\,CO + (2n + 1)\,H_2 \ \rightarrow \ C_nH_{2n+2} + n\,H_2O$$
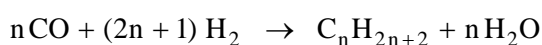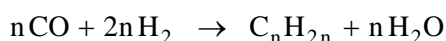
The hot gaseous mixture so obtained is cooled down which results in a liquid resembling to the crude oil. Gasoline and high boiling oil are obtained by fractional distillation of this oil. The process is shown in Figure 5.8.

Figure 5.8 : Fischer-Tropsch Process

(iii) **Bergius Process**

A good quality coal (low ash content) in powdered form is mixed with heavy oil to make a paste and a catalyst (tin or nickel oleate) is also added. This mixture is heated in presence of H_2 at about 450^oC under a pressure of about 200 atm for 1.5 hrs. In this reaction, hydrogen combines with coal to make saturated hydrocarbons which after decomposition get converted into low boiling liquid hydrocarbons. The gases coming out are condensed to the liquid which resembles the crude oil. The crude oil so obtained on fractionation provides (i) Gasoline, (ii) Middle oil, and (iii) Heavy oil.

This process is shown in Figure 5.9.

Figure 5.9 : Bergius Process

5.8.3 Diesel Engine Fuel

This fuel consists of long chain hydrocarbons. We know that in a diesel engine, the fuel is exploded under heat and pressure. The fuel should get ignited at a temperature below the compression temperature. Its suitability is decided by *cetane number* which is known as the percentage of hexadecane in a mixture of α-methyl naphthalene and hexadecane. Cetane number is the measure of the ease with which a fuel ignites. Its ignition is adjusted with the help of additives.

5.8.4 Kerosene as a Fuel

It is a fraction of petroleum which is obtained in between $180\text{-}250^oC$. It is used for domestic purposes mainly as a fuel in stoves and as an illuminant also. It has the quality of vaporization before its combustion. In the excess of air, it burns with a blue flame without any smoke. Kerosene oil with low sulphur content with the excess of air is used as a fuel for jet engines.

SAQ 4

(a) Name any three liquid fuels.

(b) What is synthetic petrol?

(c) Explain the use of kerosene as a fuel.

5.9 GASEOUS FUELS

There are a good number of gaseous fuels out of which some important or commonly used gaseous fuels are the following ones :

(i) **Liquid Petroleum Gas (LPG)**

It is supplied under pressure in cylinders under commercial names like Bharat Gas, Hindustan Petroluem Gas or Indane Gas etc. The main constituents of LPG are lower hydrocarbons upto C_4 like n - and isobutane, propane and isobutylene. It is mainly obtained as a byproduct during cracking of heavy oils or from natural gas. It is a low cost fuel and therefore, it is used as industrial as well as domestic fuel. It is highly knocking resistant and therefore, it burns cleanly without forming any residue. It can also be used in the engines working under high compression ratios. It can be used in certain vehicles like trucks, tractors etc. as a fuel but now-a-days a craze is being propogated to use LPG as a substitute of petrol. After blending it with TML (tetramethyl lead), it can be used as a main part of diesel fuel for railway locomotives. It has the calorific value of nearly 28,000 cal/gm.

(ii) **Natural Gas**

It is associated with petroleum deposits. It is obtained from the well dug in oil bearing regions. Natural gas occurs alongwith petroleum. It is known as wet gas which is treated to remove propane, butane, propene and butene and is used as LPG. On the other hand, when the gas is associated with crude oil, it is known as dry gas.

After removal of objectionable constituents like water, H_2S, CO_2, N_2 and dust etc. and heavier liquefiable hydrocarbons (propane, butane, propene and butene etc.), the approximate composition of natural gas is $CH_4 = 70-90\%$, $C_2H_6 = 4-9\%$, $H_2 = 2-3\%$ and rest part is a mixture of CO and CO_2.

It is an excellent domestic fuel and it can be transported over a large distance through pipes. It is also used as a raw material for the manufacture of carbon black. It has calorific value nearly 12500 cal/gm.

(iii) **Water Gas**

It is the mixture of carbon monoxide and hydrogen gases $(CO + H_2)$. Its method of production is quite simple. It is obtained by passing steam and air alternatively over a bed of red hot coal or coke which is maintained at about 900^oC in a reactor. The steam is passed in from the bottom in the coke charge and the water gas is formed as follows :

$$C + H_2O \rightarrow CO + H_2 - 31 \text{ kcal}$$

The reaction is an endothermic one, hence to maintain the temperature, steam supply is stopped and air supply is allowed by virtue of which the following reactions of endothermic nature occur :

$$C + O_2 \rightarrow CO_2 + 94 \text{ kcal}$$

$$2C + O_2 \rightarrow 2CO_2 + 53 \text{ kcal}$$
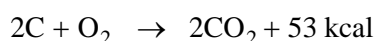
When the temperature rises upto 1000^oC, then air supply is stopped and again steam supply is revived to continue the formation of water gas.
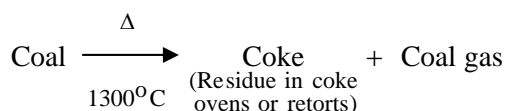
It has the composition as follows : $CO = 41\%$, $H_2 = 50\%$, CO_2 and $N_2 = 3-10\%$. It has the calorific value of nearly 3000 cal/gm. Water gas burns with a blue flame. In general, it is used as a source of hydrogen gas.

(iv) **Producer Gas**

It is a mixture of carbon monooxide and nitrogen $(CO + N_2)$. It is obtained by passing air and steam over incandescent coal or coke in a reactor. The average composition of this gas is as follows : $CO = 22-30\%$, $N_2 = 50-55\%$, $H_2 = 8-10\%$ and $CO_2 = 3-5\%$. It exhibits a calorific value of approximately 1350 cal/gm. It is used for heating open hearth furnaces and muffle furnaces etc. It is also used in some metallurgical operations as a reducing agent.

(v) **Coal Gas**

It is a mixture of methane and hydrogen $(CH_4 + H_2)$. It is produced when coal is carbonized or heated in the absence of air at about $1300^{o}C$ in coke ovens or gas retorts.

$$Coal \xrightarrow[1300^oC]{\Delta} \underset{\substack{\text{(Residue in coke} \\ \text{ovens or retorts)}}}{Coke} + Coal\ gas$$

It has the average composition as follows : $CH_4 = 45-50\%$, $H_2 = 30-40\%$, $C_2H_2 = 2\%$, $C_2H_4 = 3\%$, $CO + CO_2 = 8\%$, N_2 and others 2%. It is used as a domestic fuel. It is also used as a reducing agent in metallurgical operations.

(vi) **Oil Gas**

It is obtained by the cracking of kerosene oil. It is a mixture of hydrogen and lower hydrocarbons. Its manufacturing process is quite simple and is shown in Figure 5.10. The average composition of gas is as $CH_4 = 25-30\%$, $H_2 = 50-55\%$, $CO + CO_2 = 10-15\%$. It has the calorific value of nearly 5000 cal/gm.

Figure 5.10 : Oil Gas Production

To produce oil gas, the retort is heated to red hot stage and then stream of kerosene oil is allowed to fall on heated retort. As soon as the oil comes in contact with red hot bottom of the retort, it is converted into lower gaseous hydrocarbons. A golden yellow coloured gas results which is collected and stored in gas holders. It is in general used as a laboratory gas.

(vii) **Biogas**

It is obtained by the degradation of biological matter by the bacterial action in the presence of free oxygen. Natural gas is a biogas which is produced after a long period decay of animal and vegetable matters burried inside the earth. Gobar gas is produced the anaerobic fermentation of cattle dung. Biogas can be produced from the sewage and other organic waste materials. Its average composition is $CH_4 = 50-60\%$, $CO = 30-35\%$, $H_2 = 4-8\%$ and $N_2 +$ other gases $2 - 6\%$. Biogas is used for cooking food, for running the engines and for illumination in rural areas.

SAQ 5

(a)   Write the full form of LPG.

(b)   What is the composition of LPG?

(c)   Enlist at least five gaseous fuels.

(d)   What is biogas?

(e)   Differentiate water gas and producer gas.

(f)   What are the uses of biogas?

5.10 SUMMARY

Fuels are the most important commodities now-a-days. In the absence of fuels, we cannot think of our survival. There are so many parameters to select a fuel for a particular requirement. The calorific value of a fuel is one of the deciding parameters. The knowledge of petroleum (crude oil) mining and its refining is valuable one. Various gaseous fuels provide a tool for different purposes. Now-a-days, biogas and gobar gas are in very much common use in rural areas. It is due to the easy availability of cattle dung. Biogas fullfills a number of needs of villagers. Finally, we should optimally use the fuels because the wastage of fuel leads to the quicker consumption of reserves as well as it affects the economy.

5.11 ANSWERS TO SAQs

SAQ 1

(a)   Units of calorific value of a fuel are calorie, kilocalorie, British Thermal Unit and Centigrade Heat Unit.

(b)   HCV is the total amount of heat produced when unit mass (or volume) of the fuel is burnt completely and the products of combustion were cooled to $15^{o}C$ (or $60^{o}F$).

LCV is the net amount of heat obtained on burning completely one unit mass (or volume) of fuel when products are permitted to escape.

LCV = HCV – Latent heat of moisture / Water vapour formed.

SAQ 2

Any five characteristics as given in Section 5.4.

SAQ 3

(a)   Coke used for metallurgical processes.

(b)   Peat, lignite, bituminous, anthracite.

(c)   Anthracite.

SAQ 4

(a)   Kerosene, Diesel engine fuel, Synthetic petrol.

(b)   Petrol obtained by synthetic processes which is used as a fuel.

(c)   Kerosene is used as a fuel for domestic purposes. It burns without smoke. Kerosene with low sulphur content is used as a fuel for jet engines.

SAQ 5

(a)   Liquified petroleum gas.

(b)   It contains normal butane and isobutene, propane and isobutylene.

(c)   LPG, Natural gas, Water gas, Producer gas, Coal gas.

(d)   Gas obtained by the degradation of biological matter by bacterial action in the presence of free oxygen.

(e)   Water gas is a mixture of $CO + H_2$ whereas producer gas is $CO + N_2$.

(f)   It is used for cooking food, running engines and illumination.

What is the raw material of biogas?

SAQ 1

    (d)   Define a fuel.

    (e)   Name the types of various coals.

    (f)   What is the origin of petroleum?

    (g)   What is jet engine fuel?

    (h)   What is the raw material of biogas?

Objectives type Questions

    (i)   A good fuel should have

        a.   moderatic ignition temperature,

        b.   high ignition temperature,

        c.   high calorific value,

        d.   both (i) and (iii).

    (j)   Peat is

        (i)   Brown gelly like mass,

        (ii)   Pitch black coal,

        (iii)   Soft brown coloured coal,

        (iv)   Last stage of 'coalification'.

    (k)   Which of the following statement is true

        (i)   Coke burns with a long flame,

        (ii)   Coke burns with a short flame,

        (iii)   Coke possesses better strength than coal,

(iv) Sulphur content of coke is higher than that of coal from which it is obtained.

(l) Which of the following in coal decreases its calorific value

    (i) Hydrogen,

    (ii) Oxygen,

    (iii) Carbon,

    (iv) Suluphur.

(m) Bomb calorimeter is used for determining the calorific value of

    (i) Gaseous fuel,

    (ii) Liquid fuel,

    (iii) Solid fuel,

    (iv) Both (ii) and (iii).

(n) Gas with least calorific value is

    (i) Coal gas,

    (ii) Producer gas,

    (iii) Natural gas,

    (iv) Water gas.

(o) Which of the following is biogas

    (i) Water,

    (ii) Coal gas,

    (iii) Producer gas,

    (iv) Natural gas.

(p) Bergius process of synthetic petrol involves

    (i) passing water gas over heated powdered coke under pressure,

    (ii) catalytic hydrogeneration of coal,

    (iii) heating coal under pressure,

    (iv) cracking of heavy oil.

Answers of Objectives Question

SAQ 1

    (a) (iv)

    (b) (i)

    (c) (ii)

    (d) (ii)

    (e) (iv)

    (f) (ii)

    (g) (iv)

(h) (ii)

Descriptive Question

SAQ 1

(a) Give details of gross calorific value and low calorific value.

(b) Give details of fuels classification.

(c) Describe the manufacture of coal gas and biogas.

(d) What do you mean by synthetic petrol? Write about is preparation.

(e) Discuss the refining of crude oil and give its products.

(f) What do you understand with the mining of petroleum?

(g) Discuss the production of metallurgical coke by the Otto-Hoffman's oven.

(h) What is coke? Describe its production by Beehive coke oven method.

(i) Explain the origin of petroleum.

(j) Write notes on
   (i)   Diesel Engine Fuel
   (ii) Kerosene as a fuel
   (iii) Oil gas
   (iv) Coal gas

(k) Discuss the characteristics of a good fuel.

(l) Write in brief about following coals
   (i)   Peat
   (ii) Lignites
   (iii) Bituminous
   (iv) Anthracite