

CHARACTERISTICS OF A GOOD FUEL

(1) **High calorific value** : A fuel should possess high calorific value, since *the amount of heat liberated and temperature attained* thereby depends upon the calorific value of fuel.

(2) **Moderate ignition temperature** : *Ignition temperature is the lowest temperature to which the fuel must be pre-heated so that it starts burning smoothly.* Low ignition temperature is dangerous for storage and transport of fuel, since it can cause fire hazards. On the other hand, high ignition temperature causes *difficulty in kindling* (or igniting) the fuel, but the fuel is safe during storage, handling and transport. Hence, an ideal fuel should have "moderate" ignition temperature.

(3) **Low moisture content** : The moisture content of the fuel *reduces the heating value* and involves in a loss of money, because it is paid for at the same rate as the fuel. Hence, fuel should have low moisture content.

(4) **Low non-combustible matter content** : After combustion, the non-combustible matter remains, generally, in the form of *ash or clinker*. The non-combustible matter also *reduces the heating value*, besides additional cost of storage, handling and disposal of the waste products produced. Each per cent of non-combustible matter in fuel means a heat loss of about 1.5%. Hence, a fuel should have low content of non-combustible matter.

(5) **Moderate velocity of combustion** : If the rate of combustion is *low*, then the required high temperature may *not* be possible, because a part of the heat liberated may get radiated, instead of raising the temperature. On the other hand, *too high* combustion rates are also *not* required.

(6) **Products of combustion should not be harmful** : Fuel, on burning, should *not* give out objectionable and harmful gases. In other words, the gaseous products of a combustion should not pollute the atmosphere. CO , SO_2 , H_2S , PH_3 , etc., are some of the harmful gases.

(7) **Low cost** : A good fuel should be readily available in bulk at a cheap rate.

(8) **Easy to transport** : Fuel must be easy to handle, store and transport at a low cost. Solid and liquid fuels can easily be transported from one place to another. On the other hand, transportation of gaseous fuels is costly and can even cause fire hazards.

(9) **Combustion should be easily controllable**, *i.e.*, *combustion of the fuel should be easy to start or stop, when required.*

(10) **Should not undergo spontaneous combustion** : Spontaneous ignition can cause *fire hazards.*

(11) **Storage cost in bulk should be low.**

(12) **Should burn in air with efficiency, without much smoke.**

(13) In case of solid fuel, the *size should be uniform* so that combustion is *regular.*

COMPARISON BETWEEN SOLID, LIQUID AND GASEOUS FUELS

(A) Solid Fuels : Advantages : (1) They are easy to transport. (2) They are convenient to store, without any risk of spontaneous explosion. (3) *Their cost of production is low.* (4) *They possess moderate ignition temperatures.*

Disadvantages : (1) Their ash content is *high.* (2) Their large proportion of heat is wasted during combustion. In other words, their *thermal efficiency is low.* (3) They **burn with**

clinker formation. (4) Their combustion operations *cannot* be controlled easily. (5) Their cost of handling is *high*. (6) Their calorific value is *lower* as compared to that of liquid fuels. (7) They require *large excess of air* for complete combustion. (8) They *cannot* be used as internal combustion engine fuels.

(B) Liquid Fuels : Advantages : (1) They possess *higher calorific value* per unit mass than solid fuels. (2) They burn without forming dust, ash, clinkers, etc. (3) Their firing is *easier* and also fire can be extinguished easily by stopping the liquid fuel supply. (4) They are *easy to transport* through pipes. (5) They can be stored indefinitely, without *any loss*. (6) The flame produced by burning liquid fuels can easily be *controlled* by adjusting the liquid fuel supply. (7) Liquid fuels are, generally, handled by *pipes* and one man can easily regulate a large number of furnaces simultaneously. (8) They are *clean in use* and economic in labour. (9) Loss of heat to chimney is *very low*, due to greater cleanliness. (10) They require *less excess of air* for complete combustion. (11) They require *less furnace space* for combustion. (12) There is *no wear and tear* of grate bars and cleaning of fires, etc., unlike solid fuels. (13) They can be used as *internal combustion fuels*.

Disadvantages : (1) The cost of liquid fuel is relatively much *higher* as compared to solid fuels. (2) *Costly special storage tanks* are required for storing liquid fuels. (3) There is a *greater risk of fire hazards*, particularly in case of a highly inflammable and volatile liquid fuel. (4) They give *bad odour*. (5) For efficient burning of liquid fuels, *specially constructed burners and spraying apparatus* are required. (6) Choking of sprayers (during liquid fuel combustion) is a drawback of oil firing.

(C) Gaseous Fuels : Advantages : (1) They can be *conveyed easily* through pipelines to the actual place of need, thereby eliminating manual labour in transportation. (2) They can be *lighted at moment's notice*. (3) They have *high* heat content and hence, help us in having *higher temperatures*. (4) They can be *pre-heated* by the heat of hot waste gases, thereby affording economy in heat. (5) Their combustion can readily be *controlled* for changes in demand like oxidizing or reducing atmosphere, length of flame, temperature, etc. (6) They burn *without any soot* (or smoke) and are ashless, so there is no labour involved in ash handling, etc. (7) They are *clean* in use. (8) They do *not* require any special burners. (9) They can be produced by using even the *poorest* quantity of coal, etc. (10) They burn without heat loss, due to convection currents. (11) They burn in slight excess of air supply. (12) They are free from solid and liquid impurities. Hence, they do not affect the quality of metal produced, when used as a metallurgical fuel. (13) Complete combustion without pollution is possible, due to uniform mixing of air and fuel. (14) They have *high calorific values*. (15) They can also be used as *internal combustion engine fuels*.

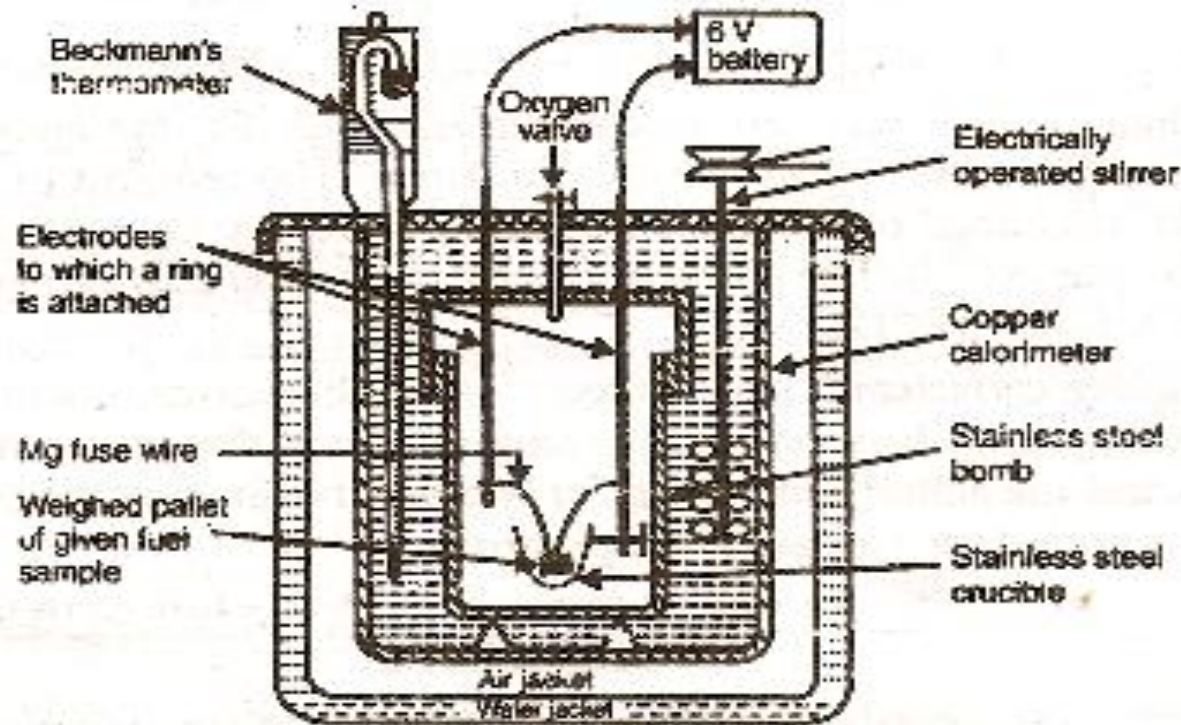
Disadvantages : (1) Very *large storage tanks* are needed for them. (2) They are *highly inflammable*, so chances of fire hazards are high in their use. (3) They are *more costly* as compared to solid and liquid fuels.

BOMB CALORIMETER

This apparatus is used to find the *calorific value of solid and liquid fuels*.

Construction : A simple sketch of bomb calorimeter is shown in Fig. 1. It consists of a strong cylindrical stainless steel *bomb* in which the combustion of fuel is made to take place. The bomb has a *lid*, which can be screwed to the body of bomb so as to make a perfect gas-tight seal. The lid is provided with two stainless steel *electrodes* and an *oxygen inlet valve*. To one of the electrodes, a small *ring* is attached. In this ring, a nickel or stainless steel *crucible* can be supported. The bomb is placed in a copper *calorimeter*, which is surrounded by an *air-jacket* and *water-jacket* to prevent heat losses due to radiation. The calorimeter is provided with an electrically operated *stirrer* and *Beckmann's thermometer*, which can read accurately temperature difference upto 1/100th of a degree.

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 the 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.



Bomb calorimeter.

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.

\therefore Heat liberated by burning of fuel = $x L$

and heat absorbed by water and apparatus, etc.

$$= (W + w) (t_2 - t_1)$$

But heat liberated by the fuel = Heat absorbed by water, apparatus, etc.

$$\therefore x L = (W + w) (t_2 - t_1)$$

$$\text{or HCV of fuel (L)} = \frac{(W + w) (t_2 - t_1)}{x} \text{ cal/g (or kcal/kg)} \quad \dots(2)$$

Note : The water equivalent of the calorimeter is determined by burning a fuel of known calorific value and using the above equation. The fuels used for this purpose are benzoic acid (HCV = 6,325 kcal/kg) and naphthalene (HCV = 9,688 kcal/kg).

If H = percentage of hydrogen in fuel, then :

$$\frac{9H}{100} \text{ g} = \text{Mass of H}_2\text{O from 1 g of fuel} = 0.09 H \text{ g}$$

\therefore Heat taken by water in forming steam

$$= 0.09 H \times 587 \text{ cal} \quad (\because \text{Latent heat of steam} = 587 \text{ cal/g})$$

$$\begin{aligned} \therefore \text{LCV} &= \text{HCV} - \text{Latent heat of water formed} \\ &= (L - 0.09 H \times 587) \text{ cal/g (or kcal/kg)} \end{aligned} \quad \dots(3)$$

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

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

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



Formation 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 washings 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.

(iii) *Cooling correction* : Time taken to cool the water in calorimeter from maximum temperature to room temperature is noted. From the rate of cooling (dt°/minute) and the actual time taken for cooling (t minutes), the cooling correction of $dt \times t$ is added to the rise in temperature.

$$\therefore L = \frac{(W + w) (t_2 - t_1 + \text{cooling correction}) - [\text{Acid} + \text{fuse corrections}]}{\text{Mass of fuel (x)}} \quad \dots(4)$$

THEORETICAL CALCULATION OF CALORIFIC VALUE OF A FUEL

The calorific value of fuel can be *approximately* computed by noting the amounts of the constituents of the fuel. The higher calorific value of some of the chief combustible constituents of fuel are tabulated below :

Table 1. Calorific values of fuel constituents.

Constituent	Hydrogen	Carbon	Sulphur
HCV (kcal/kg)	34,500	8,080	2,240

The oxygen, if present in the fuel, is assumed to be present in *combined form with hydrogen, i.e.,* in the form of *fixed hydrogen* [H_2O]. So, the amount of hydrogen available for combustion

= Total mass of hydrogen in fuel – Fixed hydrogen

= Total mass of hydrogen in fuel – (1/8) Mass of oxygen in the fuel

(\because 8 parts of oxygen combine with one part of hydrogen to form H_2O)

Dulong's formula for calorific value from the chemical composition of fuel is :

$$\text{HCV} = \frac{1}{100} \left[8,080 C + 34,500 \left(H - \frac{O}{8} \right) + 2,240 S \right] \text{ kcal/kg} \quad \dots(7)$$

where C , H , O , and S are the percentages of carbon, hydrogen, oxygen and sulphur in the fuel respectively. In this formula, oxygen is assumed to be present in combination with hydrogen as water, and

$$\text{LCV} = \left[\text{HCV} - \frac{9}{100} H \times 587 \right] \text{kcal/kg} = [\text{HCV} - 0.09 H \times 587] \text{kcal/kg}$$

This is based on the fact that 1 part of H by mass gives 9 parts of H_2O , and latent heat of steam is 587 kcal/kg.

COAL

Coal is a highly carbonaceous matter that has been formed as a result of alteration of vegetable matter (e.g., plants) under certain favourable conditions. It is chiefly composed of C, H, N, and O, besides non-combustible inorganic matter.

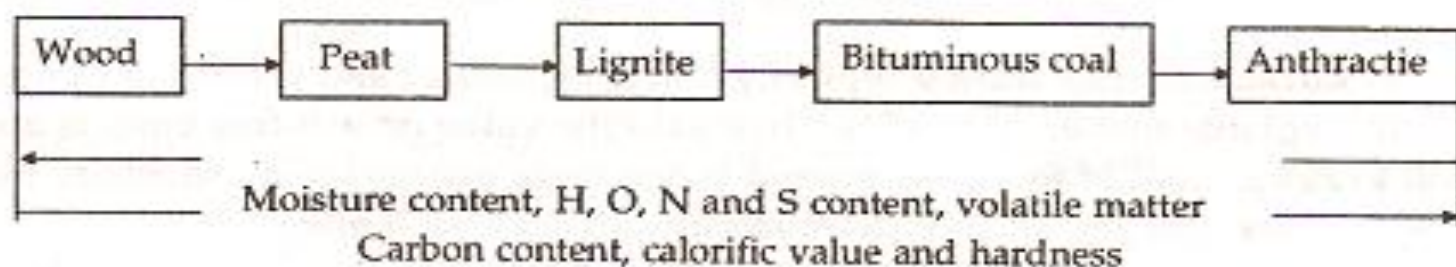
Origin of coal : Geologists have put forward *two* theories of coal formation :

(1) *In situ theory* : According to it, coal formation took place *at the place of vegetation itself*. The great purity of many coal seams can be better explained by this theory.

(2) *Drift (or transportation) theory* : According to it, the trees, etc. were uprooted and *transported* by rivers to big lakes and other deep depressions, which got filled and blocked. These huge piles of wood then got buried underground. Under high temperature, excessive pressure, absence of oxygen, presence of bacteria, and time, the cellulosic material of wood underwent gradual decomposition with the simultaneous liberation of gases (such as CO_2 and methane). Great thickness of coal seams appear more reasonable on the basis of this theory.

CLASSIFICATION OF COAL BY RANK

Various types of coal commonly recognized on the basis of *rank* or *degree of alternation or coalification* from the parent material, wood, are :

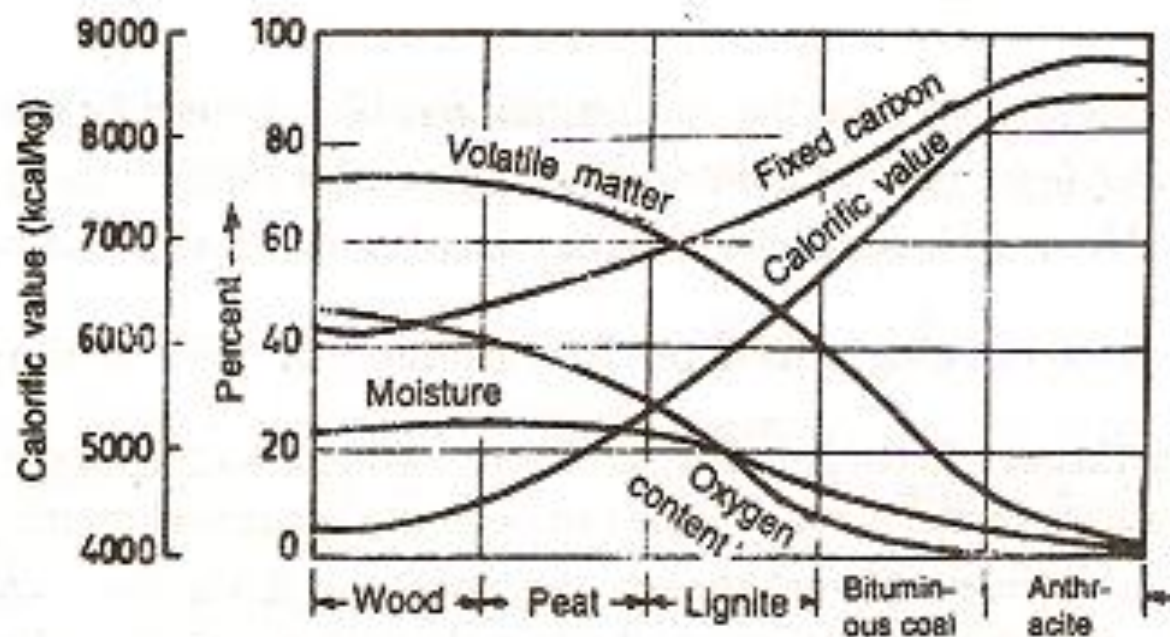


This progressive transformation of wood to anthracite results in : (i) *decrease in the moisture content* ; (ii) *decrease in hydrogen, oxygen, nitrogen and sulphur contents, with a corresponding rise in carbon content* ; (iii) *decrease in volatile matter content* ; (iv) *increase in the calorific value* ; (v) *increase in hardness*.

1. **Peat** is brown fibrous jelly-like mass. It is regarded as the *first stage* in the coalification of wood. Peat is mostly dug by manual labour. It is uneconomical fuel, since it may contain as much as 80–90% water, but on air-drying (after 1 to 2 months drying), it burns freely. The average composition of air-dried peat is : C = 57% ; H = 6% ; O = 35% ; ash content = 2.5 to 6%. Its calorific value is about 5,400 kcal/kg (on air-dry basis). In India, peat deposits occur in Nilgiri hills (South India).

2. **Lignites (brown coals)** are soft, brown coloured variety of *lowest rank coals*, which consist of vegetable matter decomposed more than that in peat. Lignite is compact in texture, containing 20 to 60% moisture and on air-drying, it breaks up into small pieces. Air-dried lignite contains : C = 60 to 70% ; O = 20%. Lignite burns with long smoky flame. The calorific value is about 6,500–7,100 kcal/kg (on air-dry basis).

In India, lignite deposits occurs in Assam, Kashmir, Rajasthan (at Palana) and Madras (at Neyveli). Lignites are usually dried, powdered and pressed into small briquettes and then burnt as *household fuel* and *for steam raising* (boiler, fuel). Its most important use is in the manufacture of *producer gas*.



Transformation of wood to anthracite.

3. **Bituminous coals (common coals)** are *pitch-black to dark-grey* coals, which usually soil hands. They show a *laminated structure* of alternate very bright and dull layers. The common bituminous coals are *sub-classified* on the basis of carbon content :

(a) *Sub-bituminous coals* are black in colour and more homogeneous and smooth in appearance. Their moisture and volatile contents are high ; and on exposure in air, these crumble into small pieces. They are non-caking coals. Their calorific value is about 7,000 kcal/kg. Carbon content varies from 75 to 83% and oxygen content from 10 to 20%.

(b) *Bituminous coals* show a typically *banded appearance* and C content ranges from 78 to 90% and volatile matter 20 to 45%. Their calorific value on ash-free basis is about 8,000 to 8,500 kcal/kg. Coal of this class is used in the large quantities in industries for making *metallurgical coke, coal gas, and for steam raising and domestic heating.*

(c) *Semi-bituminous coals* include varieties of bituminous coals that are rich in carbon (90–95%) and have low volatile matter. These are used for *coke manufacture.* Their calorific value is about 8,500 to 8,600 kcal/kg.

In India, bituminous coals reserves are located at Bihar, Bengal, Madhya Pradesh and Orissa.

4. Anthracite is a class of highest rank coal, containing highest percentage of carbon (92-98%) and has lowest volatile matter and moisture contents. They are hardest of all kinds of coals, quite dense and lustrous in appearance. Their volatile matter is less than 8%, therefore, they ignite with difficulty, burn without any smoke and give intense local heating. They possess no caking power. Their calorific value is about 8,650 to 8,700 kcal/kg and ash content is very small (about 3%).

They are used for *steam raising, house hold purposes, in metallurgical processes,* where no smoke and high local heat is desired. In India, anthracite is found in Kashmir and in eastern Himalayas.

Changes in the average composition from wood to anthracite.
(Dry ash-free-basis)

Fuel	Moisture of air-dried sample at 40°C (%)	C (%)	H (%)	N (%)	O (%)	Calorific value (kcal/kg)
Wood	25	50.0	6.0	0.5	43.5	4,000–4,500
Peat	25	57.0	5.7	2.0	35.3	4,125–5,400
Lignite	20	67.0	5.0	1.5	26.5	6,500–7,100
Sub-bituminous coal	11	77.0	5.0	1.8	16.2	7,000–7,500
Bituminous coal	4	83.0	5.0	2.0	10.0	8,000–8,500
Semi-bituminous coal	1	90.0	4.5	1.5	4.0	8,350–8,500
Anthracite	1.5	93.3	3.0	0.7	3.0	8,650–8,700

ANALYSIS OF COAL

In order to assess the quality of coal, the following two type of analysis are made :

(A) *Proximate analysis* involves in the following determinations :

(1) **Moisture** : About 1 g of finely powdered air-dried coal sample is weighed in a crucible. The crucible is placed inside an electric hot air-oven, maintained at 105° – 110°C. The crucible is allowed to remain in oven for 1 hour and then taken out (with the help of a pair of tongs), cooled in a desiccator and weighed. Loss in weight is reported as moisture (on percentage-basis).

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

(2) **Volatile matter** : The dried sample of coal left in the crucible in (1) is then covered with a lid and placed in an electric furnace (muffle furnace), maintained at $925^{\circ} \pm 20^{\circ}\text{C}$. The crucible is taken out of the oven after 7 *minutes* of heating. The crucible is cooled first in air, then inside a desiccator and weighed again. Loss in weight is reported as volatile matter on percentage-basis. Percentage of volatile matter

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

(3) **Ash** : The residual coal in the crucible in (2) is then heated without lid in a muffle furnace at $700 \pm 50^{\circ}\text{C}$ for *1/2 hour*. The crucible is then taken out, cooled first in air, then in desiccator and weighed. Heating, cooling and weighing is repeated, till a *constant weight* is obtained. The residue is reported as ash on percentage-basis. Thus, percentage of ash

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

(4) **Fixed carbon** : Percentage of fixed carbon

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

Importance of proximate analysis : Proximate analysis provides following valuable informations in assessing the *quality of coal* :

(1) **Moisture** in coal evaporates during the burning of coal and it takes some of the liberated heat in the form of latent heat of evaporation. Therefore, moisture lowers the effective calorific value of coal. Moreover, it quenches the fire in the furnace. Hence, lesser the moisture content, better the quality of coal as a fuel. However, presence of moisture, upto 10%, produces a more uniform fuel-bed and less of "fly-ash".

(2) **Volatile matter** : A high volatile matter content means that a high proportion of fuel will *distill over* as gas or vapour, a large proportion of which *escapes unburnt*. So, higher volatile content in coal is undesirable. A high volatile matter containing coal burns with a long flame, high smoke and has low calorific value. Hence, lesser the volatile matter, better the rank of the coal.

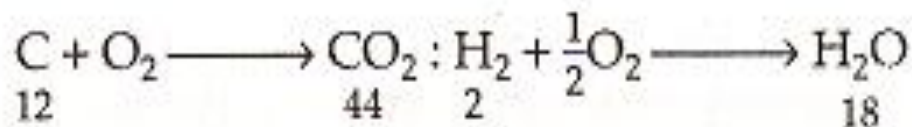
A high volatile matter content means that high-proportion of fuel will be distilled and burned as a gas or vapour. The volatile matter present in the coal may be as high as 50%. The volatile matter present in the coal may be combustible gases (such as methane, hydrogen, carbon monoxide and other hydrocarbons) or non-combustible gases (like CO₂ and N₂). The presence of non-combustible gases is always undesirable, as they do not add to heat value, but increases the volume of the furnace required. Moreover, *the volatile matter affects the furnace volume and arrangement of heating space*. Thus, a furnace with small combustion volume or of short flame travel is not suitable for burning high volatile coals at high rates of combustion, since a large proportion of volatile matter will escape unburnt. On the other hand, burning of low volatile coals necessarily requires forced draught and the intensity of draught increases with the decrease in volatile matter percentage. Volatile matter content is of special significance in coal gas manufacture and in carbonization plants, particularly when by-product recovery is the main object. *Thus, high-volatile matter containing coals (usually of low rank) do not cake well; whereas medium-volatile matter content coals (containing 26–30% volatile matter) are capable of yielding hard and strong coke on carbonization. On the other hand, low-volatile matter containing coals do not cake at all and consequently, they are totally unsuitable for coke making.*

(3) **Ash** is a useless, non-combustible matter, which reduces the calorific value of coal. Moreover, ash causes the hindrance to the flow of air and heat, thereby lowering the temperature. Also, it often causes trouble during firing by forming *clinkers* (i.e., fused ash lumps), which block the interspaces of the grate, on which coal is being burnt. This in-turn causes obstruction to air supply, thereby the burning of coal becomes irregular. Hence, lower the ash content, better the quality of coal. The presence of ash (similar to moisture) also increases transporting, handling and storage costs. It also involves additional cost in ash disposal. The presence of ash also causes early wear of furnace walls, burning of apparatus and feeding mechanism.

(4) **Fixed carbon** : Higher the percentage of fixed carbon, greater is its calorific and better the quality coal. Greater the percentage of fixed carbon, smaller is the percentage of volatile matter. This also represents the quantity of carbon (in coal) that can be burnt by a primary current of air drawn through the hot bed of a fuel. Hence, high percentage of fixed carbon is desirable. The percentage of fixed carbon helps in designing the furnace and the shape of the fire-box, because it is the fixed carbon that burns in the solid state.

(B) Ultimate 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 of known weights. The increase in weights of these are then determined.



$$\therefore \text{Percentage of C} = \frac{\text{Increase in weight of KOH tube} \times 12 \times 100}{\text{Weight of coal sample taken} \times 44}$$

and

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

(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 becomes 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 :

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

(3) **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 this 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.

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

Importance of ultimate analysis : (1) **Carbon and hydrogen** : Greater the percentage of carbon and hydrogen, better is the coal in quality and calorific value. However, hydrogen is mostly associated with the volatile matter and hence, it affects the use to which the coal is put.

Note : Also higher percentage of carbon in coal reduces the size of combustion chamber required. The amount of carbon, the major combustible constituent of coal, depends on the type of coal and its percentage increases with rank from lignites to anthracites. Thus, percentage of carbon forms the basis of classification of coal.

(2) **Nitrogen** has no calorific value and hence, its presence in coal is undesirable. Thus, a good quality coal should have very little nitrogen content.

(3) **Sulphur**, although contributes to the heating value of coal, yet on combustion produces acids (SO_2 and SO_3), which have harmful effects of corroding the equipments and also cause atmospheric pollution. Sulphur is, usually, present to the extent of 0.5 to 3.0% and derived from ores like iron pyrites, gypsum, etc., mines along-with the coal.