FUELS

A fuel is combustible substance which on proper burning in air liberates huge amount of heat, that can be used economically for domestic and industrial purposes. Fuels generally contain carbon as the main constituents. e.g. coke, coal, charcoal, petroleum, diesel, kerosene oil etc. During combustion carbon, hydrogen etc. present in fuel react with O_2 to form products like CO_2, H_2O etc and release heat.

$$\underset{\text{high energy content}}{\text{Fuel}} + O_2 \longrightarrow \underset{\text{low energy content}}{\text{Products}} + \text{heat}$$

Classification of fuels:- Fuels are classified ~~are~~ on the basis of :- (i) Occurence (ii) Physical state or state of aggregation

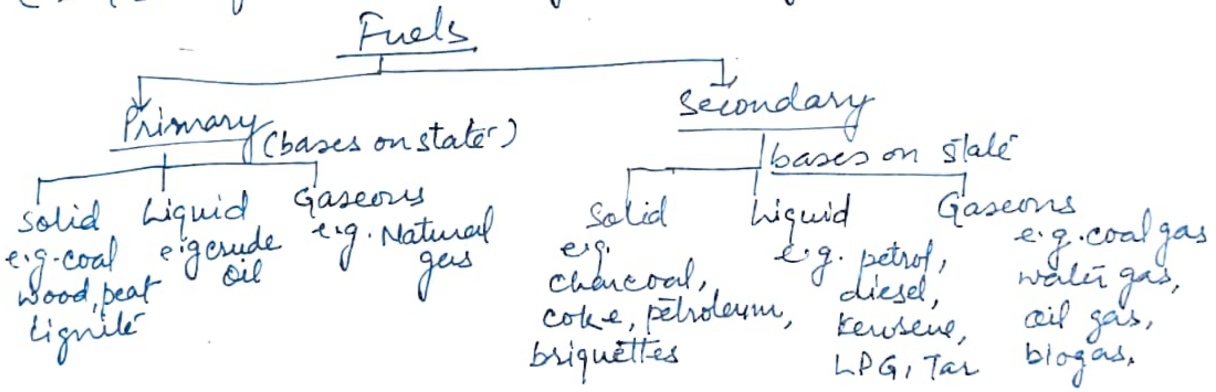
(i) <u>On the basis of occurence</u>:- Fuels are of two types (a) Natural fuels & (b) Artificial fuels.

(a) <u>Natural fuels</u>:- Fuels which occur in nature are known as natural fuels. They are also known as <u>primary fuels</u>. e.g. wood, peat, coal, petroleum, natural gas, crude oil.

(b) <u>Artificial fuels</u>:- Fuels ~~are~~ which are derived ~~f~~ artificially from natural fuel are known as artificial fuel. They are also known as secondary fuels. e.g. charcoal, coke, kerosene oil, diesel.

(ii) <u>On the basis of physical state</u>:- fuels are of three types:-

(a) Solid fuels → wood, coal, coke, charcoal, lignite etc.
(b) Liquid fuels → Crude oil, petrol, diesel, ~~oil~~ kerosene oil etc.
(c) Gaseous fuels → Natural gas, LPG, coal gas, bio gas, CNG



Comparision b/w Solid, Liquid & Gaseous fuels

S.No.	Properties	Solid fuels	Liquid fuels	Gaseous fuels
1.	Price	cheap and easily available (low cost)	costlier than solid fuel, but cheaper in the countries of origin (higher cost)	costly except natural gas. (highest cost)
2.	Transport & storage	Transportation ~~as~~ & storage is easy. chance of spontaneous explosion is rare.	They can easily be transported through pipes and must be stored in closed containers carefully.	They are stored in leak proof tanks and can be transported/ distributed through pipelines.
3.	combustion	slow	Quick	Very fast
4.	Fire hazards	Less risk	Greater risk	Even greater than liquid fuels.
5.	Smoke & ash	Always produced & reduces calorific value	Ash is not produced but smoke is produced.	Neither ash nor smoke is produced.
6.	calorific value	Least	Higher	Highest
7.	Thermal efficiency	Least	Higher	Highest

CALORIFIC VALUE

The total amount of heat evolved when unit mass or unit volume of a fuel is burnt completely in excess supply of Oxygen is known as calorific value. For a good fuel calorific value should be high.

$$C + O_2 \longrightarrow CO_2 + 394\ KJ/mole$$

$$12g \quad 32g \qquad 44g$$

$\because$ 12 g C produces = 394 KJ of energy

$\therefore$ 1 g . . . . . $\frac{394}{12} = 32.83$ KJ

Therefore calorific value of carbon is 32.83 KJ

UNITS OF HEAT

(1) Calorie :- The amount of heat required to raise the temp. of 1g water through 1°C (14.5 – 15.5 °C).

(2) Kilo calorie :- The amount of heat required to raise the temp. of 1 kg of water through 1°C (14.5–15.5°C).

(3) British Thermal unit :- (B.Th.U.) – The amount of heat required to raise the temp. of 1 pound water through 1°F (60-61°F).

4. Centigrade Heat Unit :- (CHU):-
The amount of heat required to raise the temp. of one pound of water through 1°C.

Relation b/w different units -

$\boxed{1\text{ Kcal} = 1000\text{ cal.} = 3.968\text{ B.Th.U.} = 2.2\text{ CHU.}}$

Units of calorific value -

for solid & liquid fuels :- cal/gm, Kcal/kg, B.Th.U/pound

for gaseous fuels :- Kcal/m^3, B.Th.U./ft^3.

GROSS CALORIC VALUE & NET CALORIFIC VALUES

Depending upon the fact ~~th~~ whether the products of combustion are allowed to cool down at room temp. or they are allowed to escape, there are two types of calorific values :-

(i) Higher calorific value (HCV) or Gross calorific value (GCV):-
The amount of heat evolved when unit mass or unit volume of a fuel is burnt completely in excess supply of Oxygen and the products of combustion are allowed to cool at room temperature ~~are~~ is known as higher calorific value or Gross cal. value.

(ii) Lower calorific value (LCV) or Net calorific value (NCV):-
The amount of heat evolved when unit mass or unit volume of a fuel is burnt completely in excess supply of oxygen and the products of combustion are allowed to escape is known as Lower calorific value or Net calorific value.

Lower cal. value (LCV) = Higher cal. value (HCV) − Latent heat of water vapour (steam) formed during burning

(Latent heat of steam (water vapour) = 587 cal/g)

We know :- $H_2 + \frac{1}{2}O_2 \longrightarrow H_2O(v)$ (water vapour)

2g — 18g

1 part — 9 part by wt.

LCV = HCV − Mass of H present per unit mass of fuel × 9 × Latent heat of steam

If % of H present in fuel is H% ;-

$LCV = HCV - \frac{H}{100} \times 9 \times 587$ cal/g or kcal/kg

or $\boxed{LCV = HCV - 0.09 \times H \times 587 \text{ cal/g or kcal/kg}}$

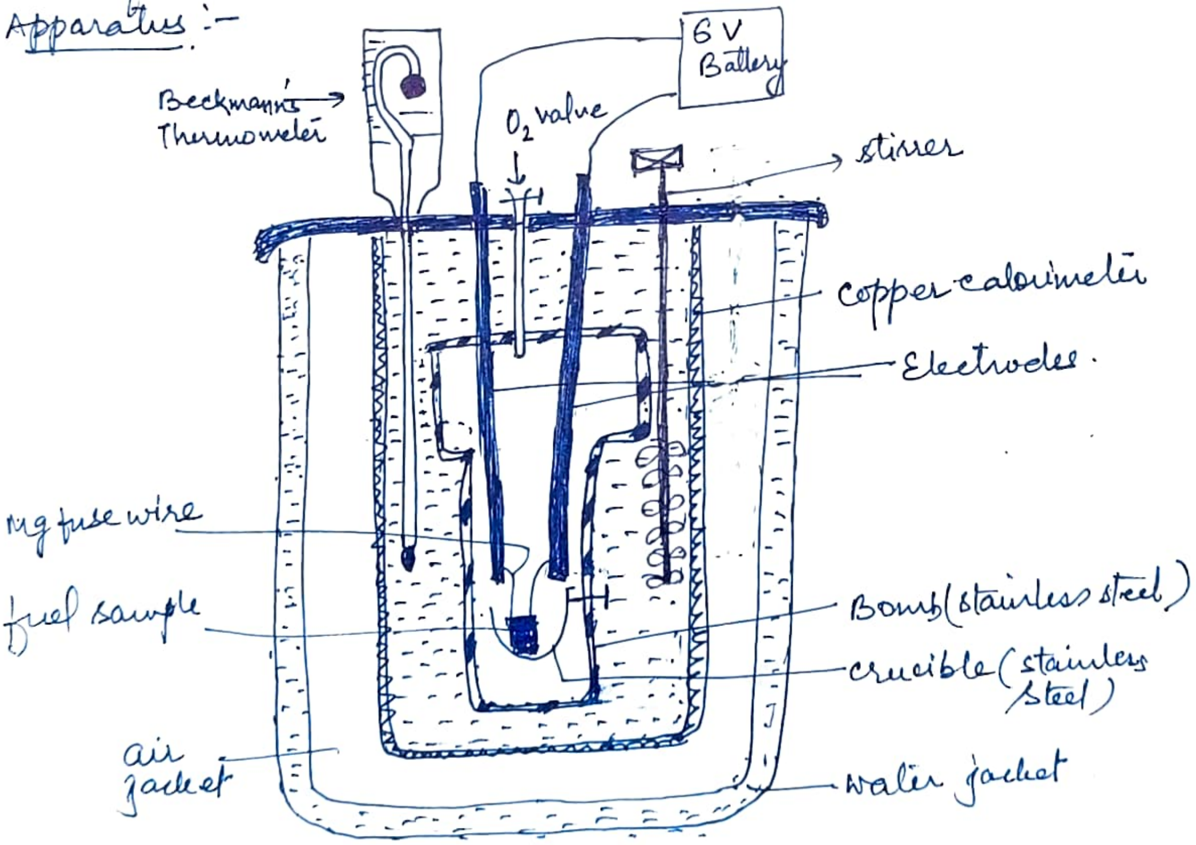
Difference b/w GCV & NCV

GCV	NCV
1- Definition	1- Definition
2- Latent heat of condensation of steam included	2- Not included
3- Also known as HCV	3- Also known as LCV.
4 - Higher value than NCV	4- Lower value than GCV.

Determination of calorific value of fuels by BOMB CALORIMETER

Bomb calorimeter is used to determine the calorific value of solid fuel & Non-volatile liquid fuel.

Apparatus :-



Principle of Bomb calorimeter :-

A known wt of the fuel is burnt in excess supply of O_2 and the heat liberated is ~~transformed~~ transferred to a known amount of water. The calorific value of the fuel is then determined by applying the principle of calorimetery. i.e.

$$\boxed{\text{Heat gained} = \text{Heat lost}}$$

Apparatus :

Bomb calorimeter consists of a cylindrical stainless steel vessel, called bomb and is capable of withstanding high pressure. It is having a lid which is screwed firmly on the bomb. The lid contains two stainless steel electrodes and an oxygen inlet valve. A small ring is attached to one of the electrodes which is provided with stainless steel crucible.

The bomb is placed in a copper calorimeter containing a known wt of water. It is provided with electrically operated stirrer with thermometer. This calorimeter, in-turn, is surrounded by an air-jacket and then water jacket to prevent heat loss-es due to radiation.

Procedure :- A known wt of fuel is placed in the crucible. The crucible is placed over a ring and a fine Mg-wire touching the fuel is stretched across the electrodes. The lid is tightly screwed and bomb is filled with O_2 upto 25 atm. pressure. Initial temp. is recorded. Electrodes are then connected to 6 V battery & circuit is completed, the current is switched on, the fuel burns with the evolution of heat which increases the temp of surrounding water. This max. temp. is recorded.

Calculation :- Mass of fuel = m gm

Mass of water = W gm

water equivalent of calorimeter, bomb, thermometer, stirrer etc. (apparatus) = w gm

Initial temp = t_1

final temp = t_2

Higher Cal. value = HCV

w gm = water eq. of apparatus in gm

= wt of apparatus × specific heat of water

or w = w' × S

sp. heat of water = 1 cal/gm/°C

Heat liberated by m gm fuel = m × HCV cal

Heat absorbed by water = $W \times S \times (t_2 - t_1)$

Heat absorbed by apparatus = $w' \times S \times (t_2 - t_1)$

Hence, total heat absorbed $= W \times 1 \times (t_2 - t_1) + w' \times 1 \times (t_2 - t_1)$

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

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

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

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

$$\boxed{HCV = \frac{(W+w)(t_2-t_1)}{m}} \text{ cal/g or Kcal/kg}$$

If H be the percentage of hydrogen in the fuel,

$$\boxed{LCV = HCV - 0.09 \times H \times 587} \text{ cal/g or Kcal/kg}$$

CORRECTIONS: In order to get more accurate results, following corrections are needed:

(i) Fuse wire correction (C_F): The measured heat includes the heat given out by the ignition of fuse wire used.

(ii) Cotton thread correction (C_{CT}): It is made by the weight of dry cotton thread used for firing which is added into acid correction and fuse wire correction.

(iii) Acid correction (C_A): Under high pressure and temp. of ignition N & S present in fuel are oxidised to ~~ac~~ their respective acids ~~which are exotherming~~ through exothermic reactions. This heat is added to C_F and C_{CT}.

(iv) Cooling correction (C_c): The rate and time taken for cooling of water in calorimeter from max. temp. attained to the room temp. is noted. If the rate of cooling is degree/minute and the actual time taken for cooling is x, then cooling correction $= x \times dt$ must be added to the rise in temp (t_2-t_1).

Therefore,

$$\boxed{HCV = \frac{(W+w)(t_2-t_1+C_c)-(C_A+C_F+C_{CT})}{m}} \text{ cal/g or Kcal/kg}$$

CHARACTERISTICS OF A GOOD FUEL

→ A good fuel must have high calorific value. It decides the amount of heat liberated by a fuel.

→ The minimum temp. at which a fuel catches fire is known as ignition temp. A good fuel must have ~~a~~ moderate ignition temp. A high ignition temp. causes difficulty in catching fire and low causes fire hazards.

→ A high combustion rate makes the control of fuel combustion difficult and at low rate of combustion, the required temp is not attained. Hence, for continuous and smooth supply of heat, the fuel must have moderate rate of combustion.

→ Low moisture content in fuel is desired as it reduces the calorific value of fuel.

→ Low ash content is desired in fuel as it also reduces the calorific value and also causes hindrance in proper supply of Oxygen/air ~~to~~ resulting in inefficient burning of fuel.

→ A good fuel must be cheap and readily available in bulk.

→ It should be from from substances like H_2S, CO, SO_2 etc. and should be free from smoke.

→ It should have low storage cost and easily transportable.

~~RANK OF C.~~

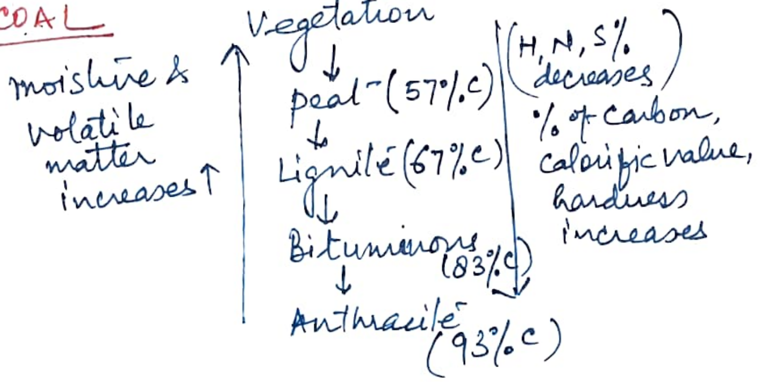
COAL (Fossil fuel or primary fuel)

Coal is a high carbonaceous matter that has been formed from fossilised remains of plants under suitable conditions.

It is mainly composed of C, H, N, O and non-combustible inorganic matter. It consists of layers of fused aromatic nuclei stacked one over another.

The action of high temp., pressure, anaerobic condition, presence of bacteria and crores of years converted cellulosic material of wood into coal. This process involved evolution of CO_2 & CH_4, loss of water, increase in hardness and transition from vegetation to anthracite.

RANKS OF COAL



Analysis of coal

The quality of coal is ascertained by the analysis of coal. It is ascertained by any of two types :-
(i) Proximate Analysis (ii) Ultimate analysis

PROXIMATE ANALYSIS

It is the simplest type of analysis of coal which includes the determination of moisture, ~~vo~~ volatile matter, ash and fixed carbon. This analysis is an assay rather than true analysis. However, this analysis gives valuable information for accessing the application of a fuel for a particular domestic and industrial purposes.

(A) **Determination of Moisture content** :- Coal contains two types of moisture:

(a) Free or surface moisture - This is lost by air drying.
(b) Internal moisture - Moisture retained by air dried coal is internal moisture.

A known wt of air dried coal sample is heated at 105 -110°C for 1 hr in silica crucible, cooled & then weighed. Loss in wt is used to determine The inherent moisture

$$\boxed{\% \text{ of moisture} = \frac{\text{wt of moisture}}{\text{wt of coal sample}} \times 100}$$

Significance - Moisture reduces the cal. value of coal. It also increases the transportation cost and some amount of heat is wasted for its evaporation from coal during combustion.

(B) **Determination of Volatile matter** :- After removing the moisture, the coal sample is heated at 925°C ± 20°C in a muffle furnace for 7 minutes. The crucible is cooled & then weighed. The loss in wt is recorded.

$$\boxed{\% \text{ of volatile matter} = \frac{\text{Loss in wt due to volatile matter}}{\text{wt of coal sample}} \times 100}$$

Significance - A high volatile matter reduces the cal. value of fuel. Such coal burns with long flame and high smoke. It gets converted into gas and tar during heating.

(C) **Determination of Ash content**:- The non-combustible matter left after burning of coal is ash. The coal is heated gradually upto 700°C and then heated strongly at 750°C for half an hr. The crucible then cooled and weighed.

$$\boxed{\% \text{ of ash content} = \frac{\text{wt of ash content}}{\text{wt. of coal sample}} \times 100}$$

Significance:- Ash reduces the cal. value of coal. It causes hindrance in air supply and hence production & distribution of heat is adversely affected.

(D) **Determination of fixed carbon**:- Fixed carbon in coal can be determined as:-

$$\boxed{\% \text{ of fixed carbon} = 100 - \% \text{ of } (\text{Moisture} + \text{Ash} + \text{Volatile matter})}$$

Significance:- cal. value depends upon the fixed carbon present in fuel. The higher % of fixed carbon, the greater is the cal value and better is the quality of coal.

Ultimate Analysis

Ultimate analysis includes the exact estimation of elements like C, H, N, S & O present in fuel.

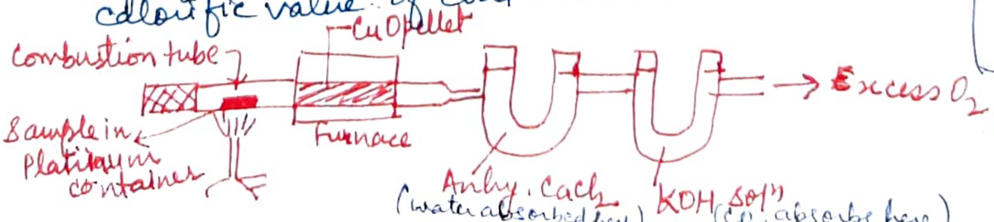
A) **Determination of C & H**:- Known wt of coal is burnt in excess of oxygen in a combustion apparatus. The products of combustion CO_2 & H_2O from C & H are absorbed in KOH & calcium chloride tubes of known weights respectively. The increase in wts of these tubes are then determined:

$$\underset{12g}{C} + O_2 \longrightarrow \underset{44g}{CO_2} \quad ; \quad \underset{2g}{H_2} + \frac{1}{2}O_2 \longrightarrow \underset{18g}{H_2O}$$

$$\boxed{\% \text{ of carbon} = \frac{\text{Increase in wt of tube}}{\text{wt of coal sample}} \times \frac{12}{44} \times 100}$$

$$\boxed{\% \text{ of Hydrogen} = \frac{\text{Increase in wt of } CaCl_2}{\text{wt of coal sample}} \times \frac{2}{18} \times 100}$$

Significance:- The greater the % of the C & H, higher is the calorific value of coal i.e. better is the coal.



CuO → converts/oxidizes C & CO to CO_2 & H to H_2O

$2KOH + CO_2 \rightarrow K_2CO_3 + H_2O$

$CaCl_2 + 7H_2O \rightarrow CaCl_2 \cdot 7H_2O$

(B) Determination of Nitrogen :- ~~E~~ Estimation of nitrogen in coal sample is carried out by Kjeldahl's method. 1 g. coal is heated with conc H_2SO_4 & K_2SO_4 (catalyst) in Kjeldahal's flask. The liberated NH_3 is absorbed in std solution of H_2SO_4. The unused acid is then determined by back titration with std NaOH.

$$N_2 + H_2SO_4 \rightarrow (NH_4)_2SO_4 \xrightarrow[\text{excess}]{NaOH} Na_2SO_4 + NH_3\uparrow + H_2O$$

$$2NH_3 + \underset{(std)}{H_2SO_4} \xrightarrow[\text{neutralisation}]{} (NH_4)_2SO_4$$

$$\boxed{\%\ \text{of N} = \frac{\text{Vol. of acid used (with } NH_3) \times \text{Normality of acid}}{\text{wt of coal sample}} \times 1.4}$$

$$\boxed{\text{or } \%\ \text{of N} = \frac{1.4 \times N \times V}{m}}$$

Significance :- Nitrogen is an inert and non-combustible material. It has no calorific value. It's presence is undesirable.

(C) Determination of sulphur :- A known wt of coal sample is burnt completely in Bomb calorimeter in a current of O_2 where S ~~conto~~ converts to sulphates. The % of S is then determined by the washings of bomb calorimeter. The washings are treated with $BaCl_2$ solution which makes $BaSO_4$ ppt. It is ($BaSO_4$ ppt) now filtered, washed & ~~wei~~ heated to constant weight.

$$\underset{32\ g}{S} \xrightarrow{O_2} SO_4^{--}$$

$$SO_4^{--} + BaCl_2 \rightarrow \underset{233}{BaSO_4} \times 2Cl^-$$

$$\boxed{\%\ \text{of S} = \frac{\text{wt of } BaSO_4}{\text{wt of coal sample}} \times \frac{32}{233} \times 100}$$

Significance :- Sulphur has its calorific value and hence, it contributes to the calorific value of the fuel. However, the combustion products of sulphur i.e. SO_2, SO_3 etc. cause air pollution and corrosion of equipments.

(D) Determination of Ash :- Ash is determined by proximate analysis.

(E) Determination of Oxygen :-

$$\%\ \text{of O} = 100 - \%\ \text{of } [C + H + N + S + Ash]$$

Significance :- A good quality of coal should contain low % of oxygen as it lower the cal. value of coal.