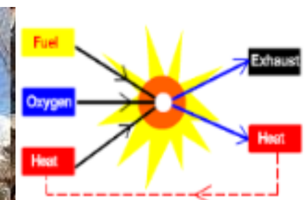
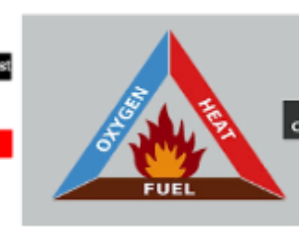
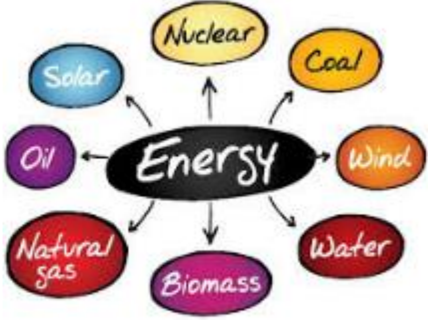
Energy sources

Module 5

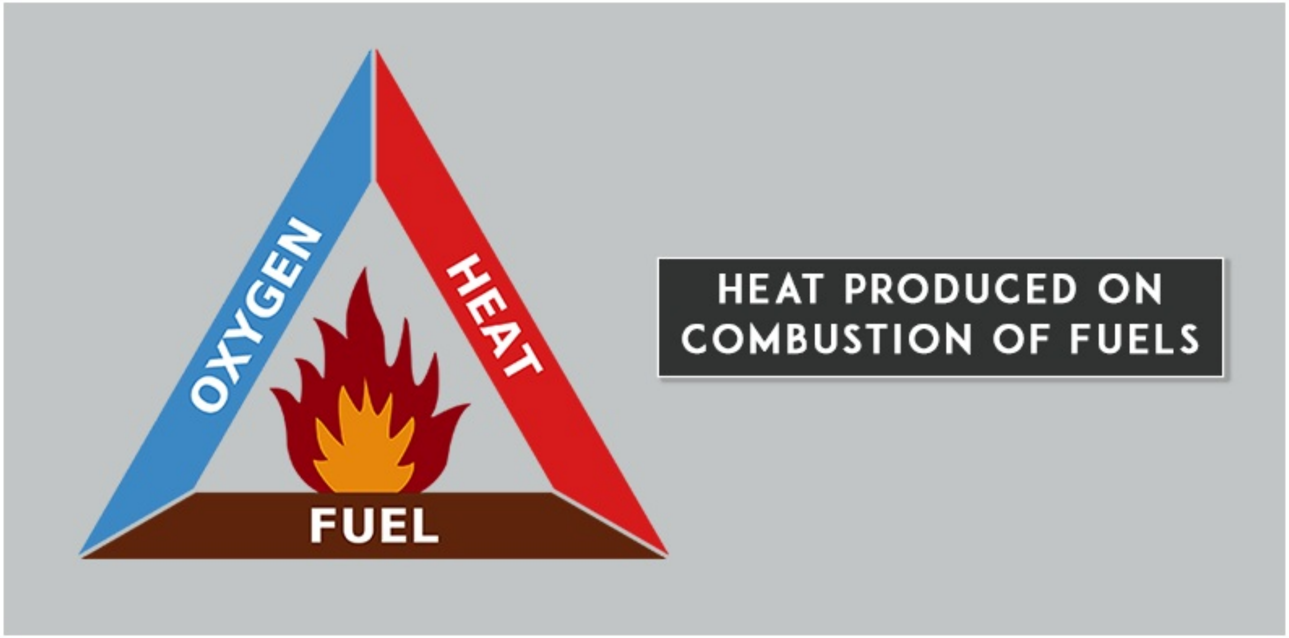




Fuels and Combustion



"For many years to come, the greatest portion of the world's power will come from the combustion of fuels"



Fuels

- Combustible substance (may be solid, liquid or gas) having carbon as major constituent gives energy while burning.

  Energy: Heat or Light

- Reacts with oxygen leading to the formation of the product with the evolution of heat at a rapid rate.

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

- The energy liberated as heat can be used economically for domestic and industrial purpose. Example wood, charcoal, kerosene, petrol, natural gas etc.

Classification of Fuel

Fuels can be classified:

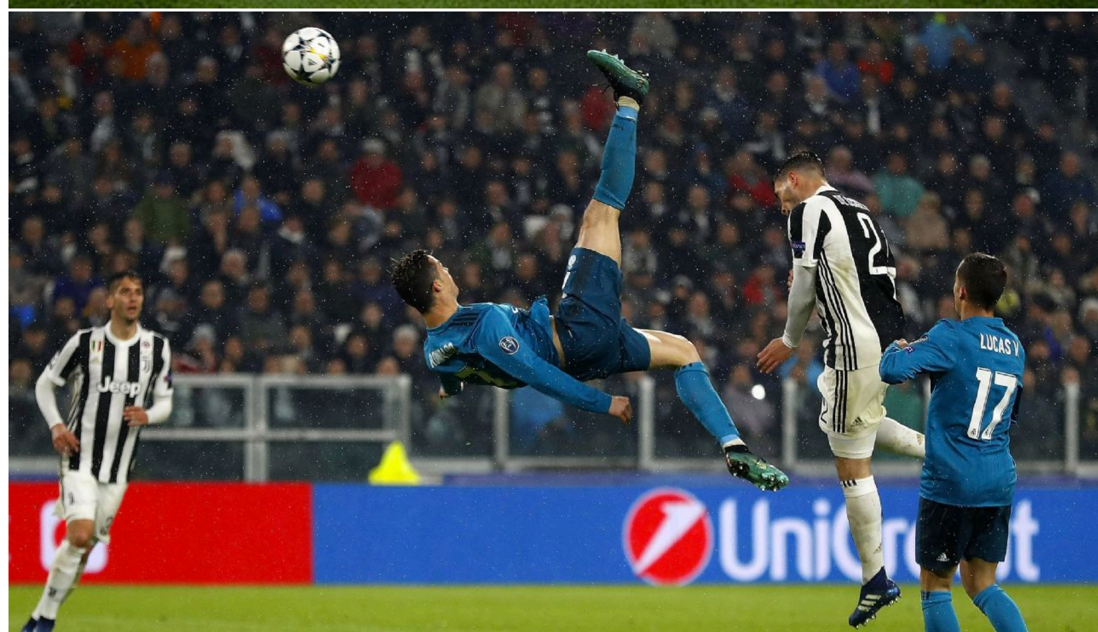
a) On the basis of their occurrence

b) On the basis of physical state of aggregation

On the basis of occurrence

Primary

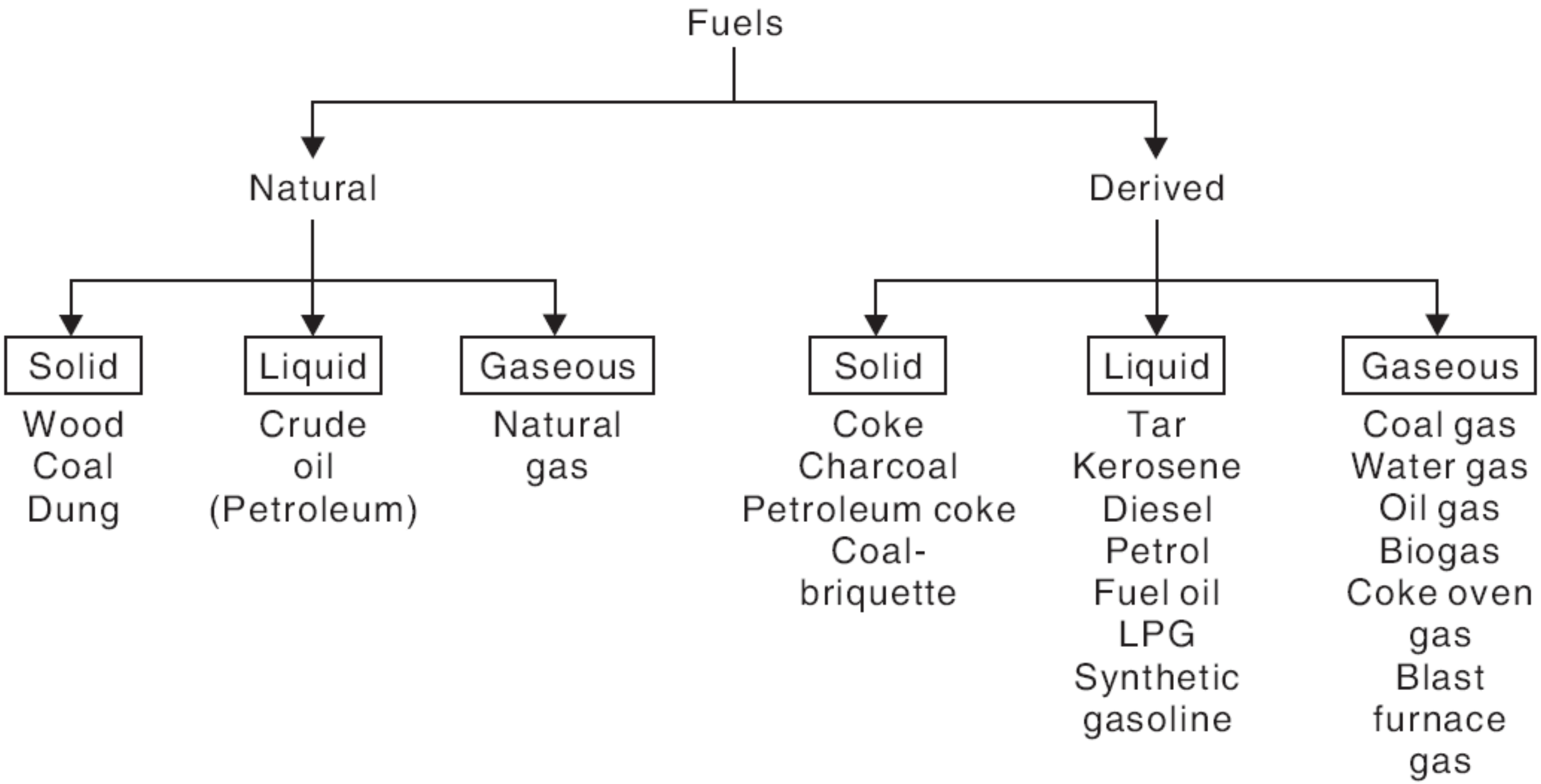
Fuels which are found in nature. For e.g.- Wood, Coal, Petrol, Natural Gas.



Secondary

Fuels obtained after prcoessing of natural fuels.For e.g.- Coke, Charcoal, Kerosene oil, Coal gas, Petrol

On the basis of physical state



Units of heat

- **Calorie:** It is defined as the total amount of heat required to raise the temperature of 1 gm of water through 1^{o} C.

  1 cal = 4.184 Joules

- **British Thermal Unit (B.T.U.):** It is defined as the total amount of heat required to raise the temperature of 1 pound of water through 1^{o} F.

- **Centigrade Heat Unit (C.H.U.)**: It is defined as the total amount of heat required to raise the temperature of 1 pound of water through 1^{o} C.

  1 Kcal = 3.968 B.T.U. = 2.2 C.H.U

Calorific value of fuels

- Total quantity of heat liberated when a unit mass of fuel is burnt completely is known as ***Calorific Value***.

Calorific values of **solid and liquid fuels** are usually expressed in *calories per gram (Cals/g) or Kilocalories per kilogram (Kcals/Kg)* or *British Thermal Units per pound (B. Th. U./lb.)*;
whereas the calorific values of **gases are expressed** as *Kilocalories per cubic metre (K cals/m^3) or British thermal units per cubic foot (B. Th. U./ft^3) or Centigrade Thermal Units per pound (C.H.U./lb) or C.H.U./ft^3.*

These units can be interconverted as follows:

1 cal/g = 1 Kcal/Kg = 1.8 B. Th. U./lb.
1 K cal/m^3 = 0.1077 B. Th. U./ ft^3
1 B. Th. U./ft^3 = 9.3 Kcals/m^3

GCV/HCV– Gross / Higher calorific value

- "Amount of heat produced, when unit mass/volume of the fuel is burnt completely and the products of combustion have been cooled to room temperature".

- If the product of combustion are condensed to the room temperature, the latent heat of condensation of steam also gets included in the measured heat, which is then called Gross Calorific Value or Higher Calorific Value.

- Hydrogen is present in all most all the fuels & when the calorific value of the fuel is determined experimentally, hydrogen is converted into steam.

LCV/NCV– Low / Net calorific value

- It is the net heat produced when unit mass or volume of fuel has been burnt completely and the products of combustion are allowed to escape.

- In actual use of any fuel, the water vapour and moisture etc. escape as such along with hot combustion gases. Since they are not condensed. Hence a lesser amount of heat is available.

- LCV = HCV – Latent heat of water vapour formed

LCV/NCV– Low / Net calorific value

$$\begin{array}{cccc} H_2 & + O & \rightarrow & H_2O \\ 2g & 16g & & 18g \end{array}$$

(1 part by mass of hydrogen produces 9 part by mass of water)

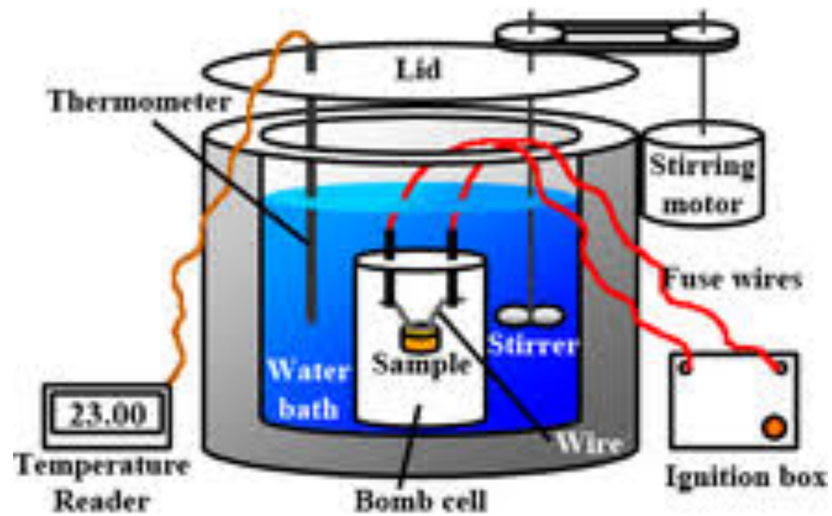
LCV = HCV – 9 x Percentage of Hydrogen x Latent Heat of steam

LCV = HCV – 0.09 * %H * 587

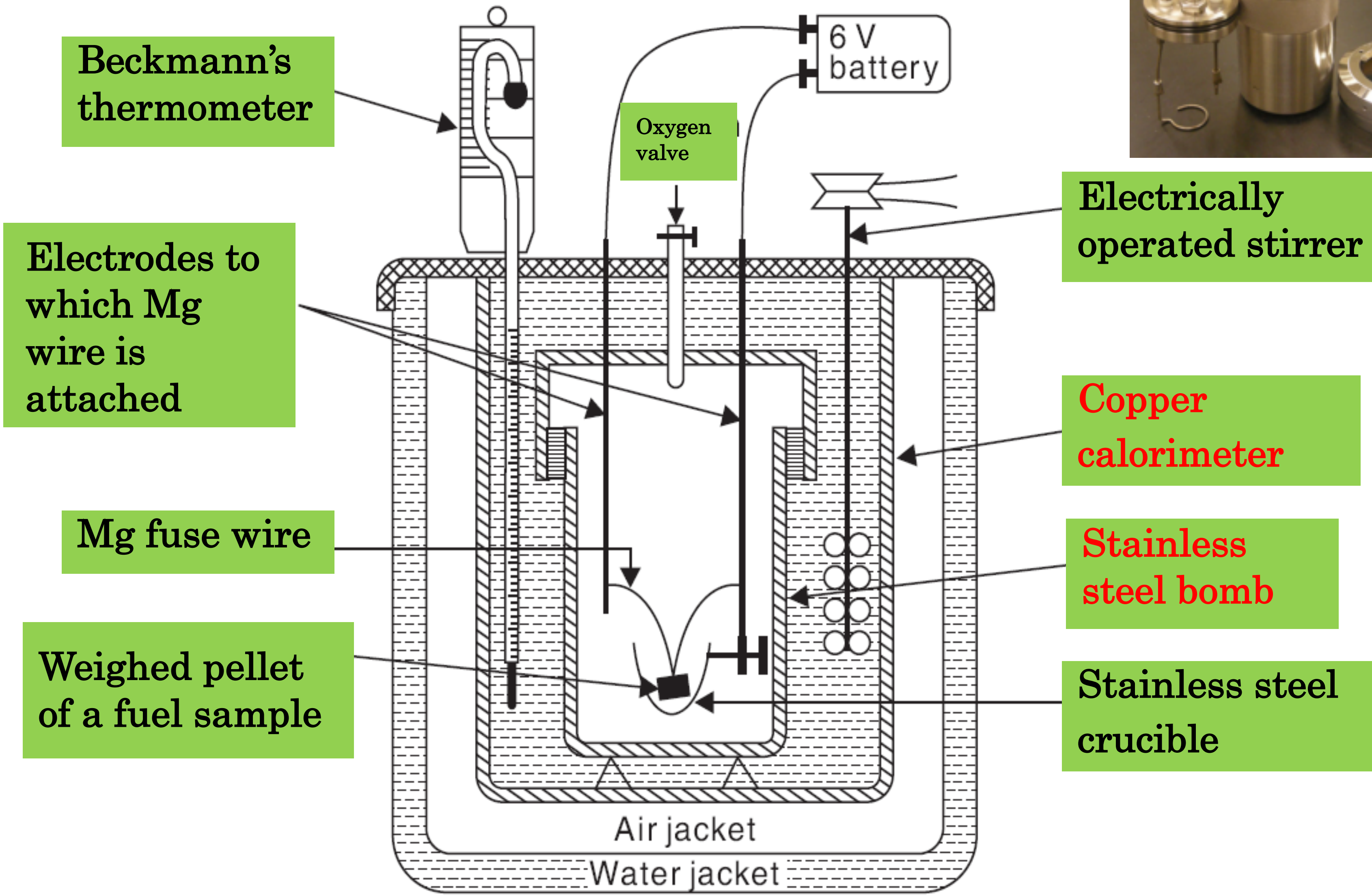
Latent Heat of steam= 587 cal/g.

Determination of Calorific Value by Bomb Calorimeter

A known mass of the fuel is burnt and the quantity of heat produced is absorbed by water & measured, then the quantity of heat produced by burning unit mass of fuel is calculated.



Bomb Calorimeter



Construction

Steel Bomb

- Stainless steel bomb in which the combustion of fuel takes place
- Two holes for 2 electrodes and one oxygen inlet valve.
- small ring is attached where a Nickel/steel crucible is kept
- fuse wire of Magnesium is connected to both the electrode.
- A cotton thread is tied at one end of the fuse wire while other end remain in contact with fuel in the stainless crucible.
- Can withstand a pressure upto 50 atm
- Lined with platinum to resist acid corrosion

Copper calorimeter

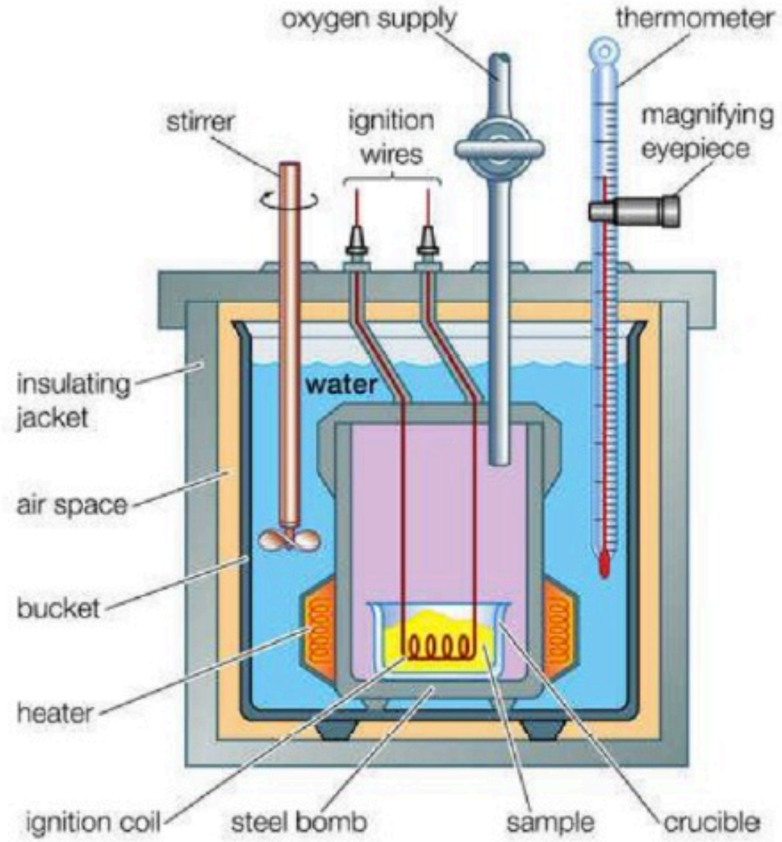
- The bomb is kept in a copper calorimeter having known quantity of water.

- The copper calorimeter is provided with an electrical stirrer and a Beckmann's thermometer.

- The copper calorimeter is surrounded by air-jacket and water-jacket to prevent loss of heat due to radiation.

Working

- Known amount of fuel is taken.
- Bomb is filled with Oxygen at 25 atm. Pressure.
- Kept inside the calorimeter having known amount of water.
- Start the stirring and Initial temperature of water is noted **(t_1° C).**
- Then electrodes are connected to 6 V battery.
- Sample burns and heat liberated which is transferred to water.
- Stirring is continued and maximum temperature attained is noted **(t_2° C)**



Calculation

m = mass of fuel pellet

w_1 = mass of water in the calorimeter

w_2 = water equivalent of calorimeter and others

w_1+w_2= total weight

t_1 = initial temperature of calorimeter

t_2 = final temperature of calorimeter

t_2-t_1 = Increase in temperature

Heat lost by 'm' mass of fuel = heat gained by system

$$= (w_1+w_2) * \text{Sp. Heat X } (t_2-t_1)$$

$$= (w_1+w_2) * 1 * (t_2-t_1)$$

HCV or GCV = $(w_1+w_2) * (t_2-t_1) / m$ cal or kcal

LCV of Fuel (L) = HCV – 0.09 * %H * 587 (cal or kcal)

Corrections

- ***Fuse wire corrections:*** Heat liberated & measured includes heat given by the ignition of fuse wire due to short circuit. Hence it should be deducted.

- ***Acid corrections:*** Fuel containing S and N are oxidised under high pressure. Formation of acid (H_2SO_4, HNO_3) is exothermic reaction so, measured heat also includes the heat given out during acid formation. Hence it should be deducted.

- ***Cotton Thread corrections:*** Cotton thread is used for the ignition of fuel, so its burning also generates heat & it should be deducted.

- ***Cooling corrections:*** Time taken to cool the water in calorimeter from maximum temperature to room temperature is noted. From the rate of cooling (dT/minute) and actual time taken for cooling (t min.) the cooling correction of (dT*t) is added to the rise in temperature.

$$\textbf{HCV /GCV} = \{(w_1+w_2) *(t_2-t_1 + CC) - FC - AC - CtC\} /m$$

Problem

Calculate the GCV and NCV of a fuel from the following data:

- Mass of fuel burnt= 750 mg
- Water equivalent = 350 g
- Mass of water taken =1.15 kg
- Initial temperature= 16 ^{0}C
- Final temperature = 19.02 ^{0}C
- Percentage of hydrogen in fuel = 2.8

ANS: HCV : 6040 cal/g

LCV: 5892 cal/g

Problem

A Coal sample contains C= 92%; H= 5% and ash = 3%. When this coal sample was tested in the laboratory for its cv in a bomb calorimeter, the following data were obtained.

Mass of coal burnt= 0.95 g
Water equivalent = 700 g
Mass of water taken = 2 kg
Initial temperature= 16 ^{0}C
Final temperature = 18.48 ^{0}C
Acid correction = 60 cal
Fuse wire correction = 10 cal
Cooling correction = 0.02 ^{0}C

Calculate the GCV and NCV

Ans: GCV= 7031.57 cal/g
NCV= 6767.43 cal/g

Boy's gas calorimeter

- The calorific value of gaseous or volatile liquid fuels is measured by Boy's Calorimeter.

- **The Boys gas calorimeter is a simple and effective means of measuring the calorific values of gaseous fuels.**

- The principle is to **burn the gas at a constant rate** in a vessel & the entire amount of heat produced is **absorbed by water which is also flowing at constant rate**.

- From the volume of gas burnt, the volume of water collected and mean rise in temperature of water, the calorific value of gaseous fuel can be calculated.

Construction

A burner situated in chimney which is the centre of the annual vessel.

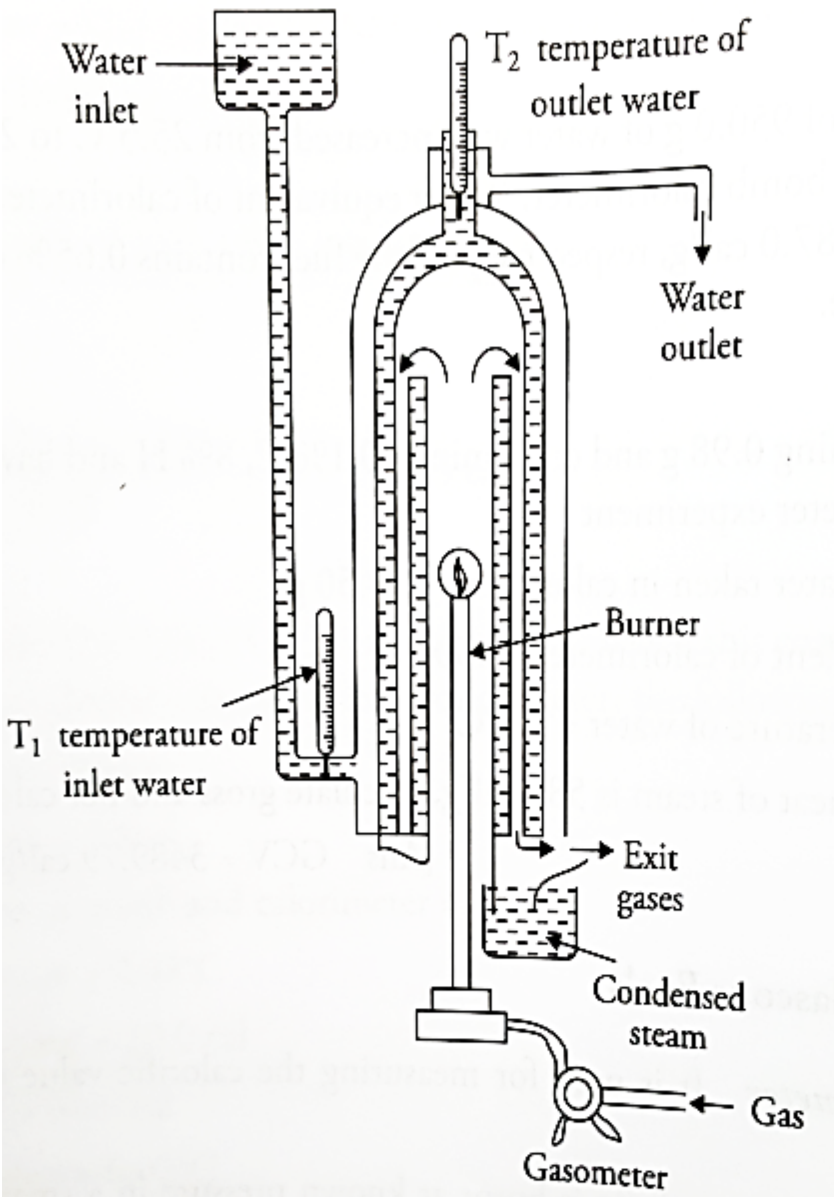
A tank where the water condensate from the product

The product of combustion moves upwards to the chimney and deflected downward by water cooled head.

A gasometer measures volume of gas burning per unit time.

Water: The water flows from outer coil to the inner coil and the temperature of inlet and outlet water are measured with different thermometers.

Outer Jacket: Prevents heat loss by radiation.



Calculation

- Volume of gas burn = V m^3
- Mass of the water = W kg
- Temperature of inlet water = t_1
- Temperature of outlet water = t_2
- Specific heat of water S = 1 Kcal
- **Heat absorbed by circulating water = $W(t_2-t_1)\times S$**

  $= W(t_2-t_1)$

- **HCV = $W(t_2-t_1)$ / V Kcal/m^3**

If 'm' kg of steam condensed from V m^3 of the fuel
Then, mass of condensation per 1 m^3 of the fuel == m/v kg
So, Latent heat of steam= 587* m/V Kcal

LCV = HCV - (587* m / V)

During the determination of calorific value of a gaseous fuel by Boy's calorimeter, the following results were recorded:

Vol. of the gaseous fuel burnt at NTP = 0.093 m^3
Wt. of water used for cooling the combustion products = 30.5 kg
Wt. of steam condensed = 0.031 kg
Temp. of inlet water = 26.1 ˚C
Temp. of outlet water = 36.5 ˚C

Determine the GCV & NCV of the gaseous fuel per cubic meter at NTP, provided that the heat liberated in condensation of water vapour and cooling the condensate is 587 Kcal/kg

SOLUTION:

GCV = $[w(t_2\text{-}t_1)]$ / V = [30.5 (36.5-26.1)]/0.093 = 3410 Kcal/m^3

Net Calorific Value = [G.C.V. - {(m x 587)/V}] = 3410 – {(0.031 x 587)/0.093}
= 3214.3 Kcal/m^3

Problem

Following data were obtained in a Boy's calorimeter

- Volume of gas burn = 0.1 m^3
- Mass of the water = 25 kg
- Temperature of inlet water = 20 ^{0}C
- Temperature of outlet water = 33^{0}C
- Weight of steam condensed = 0.025 kg

Calculate GCV and LCV

ANS:

GCV= 3250 kcal/m3

LCV= 3103 kcal/m3

Problem

The following data were obtained in the Boy's gas calorimeter experiments

Specific heat of the water = 4.186 J/gram. K

Volume of gas used = 0.5 m^3 at NTP

Weight of water heated = 20 kg

Temp. of inlet water = 22° C

Temp. of outlet water = 35° C

Weight of steam condensed = 0.021 kg

Calculate the gross and net calorific value per m^3 at NTP. The heat liberated in condensing water is 587 Kcal/Kg

Theoretical Calorific Value: Dulong's Formula

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:

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 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

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

Dulong's Formula

Depending upon the chemical composition of fuel, calorific value can be estimated using Dulong's formula

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

Where, C, H, O and S are the percentages of carbon, hydrogen, oxygen & sulphur in the fuel respectively. Here, Oxygen is assumed to be present in combination with hydrogen as water, and

$$LCV = \left[HCV - \frac{9}{100} H \; x \; 587\right] = [HCV - (0.09H \; x \; 587)] kcal/kg$$

Coal

- Coal is a fossil fuel found under the earth crust commonly known as coal beds or coal seams. It is formed from the dead plants and animals by a process called coalification.

- All coals are of vegetable origin and are the remains of prehistoric forests.

- Dead plants and animals are first converted into peat which in turn is converted into lignite, after that bituminous coal and then anthracite.

Coal

- The factors of time, depth of beds, disturbance of beds and the intrusion of mineral matter resulting from such disturbances have produced the variation in the degree of evolution from vegetable fiber to hard coal.

- Coal is classified on the basis of % of carbon which is known as "Rank of Coal".

S.No.	Coal	% Carbon	Rank
1	Peat	57	Low
2	Lignite	67	
3	Bituminous Coal	83	
4	Anthracite	93	High

Coal Composition

- Some of the C in coal combines with H and together with other gaseous substances form volatile matter of the coal.

- The uncombined carbon in coal is known as fixed carbon.

- The ash varies in different coals from 3 to 30 per cent and the moisture from 0.75 to 45 per cent of the total weight of the coal, depending upon the grade and the locality in which it is mined.

- A large percentage of ash is undesirable as it not only reduces the calorific value of the fuel, but chokes up the air passages in the furnace and through the fuel bed, thus preventing the rapid combustion necessary to high efficiency.

- Moisture in coal may be more detrimental than ash in reducing the temperature of a furnace, as it is non-combustible, absorbs heat both in being evaporated and superheated to the temperature of the furnace gases.

- In some instances, however, a certain amount of moisture in a bituminous coal produces a mechanical action that assists in the combustion and makes it possible to develop higher capacities than with dry coal.

Analysis of Coal

The analysis of coal done to determine the coal's energy value. Coal's heating value is a important factor for deciding the usage of coal.

Analysis of coal done by two methods:

a) **Proximate Analysis**

b) **Ultimate Analysis (Elemental Analysis)**

Proximate Analysis of Coal

Proximate analysis gives information about

- Moisture Content
- Volatile Content
- Ash Content
- Fixed Carbon Content

Moisture Content:

- Moisture Content quenches the fire and it evaporates during the burning of coal & takes the liberated heat in the form of latent heat evaporation & reduces the effective calorific value.

- High percentage lesser will be the calorific value of coal; moisture in coal consumes more heat in the form of latent heat of evaporation. Hence more heat is to be supplied to the coal.

Procedure:

- The weight of empty crucible is taken and 1 gm of coal sample is taken in it (W_1 gm).
- The crucible is kept in a oven at 105-110° C for a period of 60 min. The crucible is then withdrawn from the oven & kept in a desiccator for cooling. After cooling weight of the crucible is again taken (W_2 gm).

% Moisture Content = $(W_1-W_2)*100$ / Weight of coal sample

Volatile Content:

- The volatile matter may be combustible gases (like H_2, CO, CH_4 & other lower hydrocarbons) and non-combustible gases (like CO_2 & N_2).

- The presence of volatile matter is undesirable since they don't add to the heating value. Coal with high volatile content burns with long flame, high smoke & has low calorific value.

Procedure:

- After the analysis of moisture content, the crucible with residual coal sample is covered with a lid and it is heated at 950 +/- 20° C for 7 minutes in a muffle furnace. The crucible is taken out & air cooled inside the desiccator and weighed (W3 gm).

% Volatile Content = $(W_2\text{-}W_3)$*100 / Weight of coal sample

Ash Content:

- Ash is a non-combustible & useless which is left behind when all the combustible substance is burnt off & reduces the calorific value.

High percentage of ash content is undesirable because,

- It reduces the calorific value of coal,
- Ash causes hindrance to heat flow as well as produces clinkers, which blocks the air supply through the fuel,
- It increases the transporting, handling, and storage costs. It involves additional cost in ash disposal.

Procedure:

- After the analysis of volatile matter, the crucible with residual coal sample is heated without lid at 700 +/- 50^{o} C for 1 hour in a muffle furnace. The loss in weight of the sample is found out and the % of ash content is calculated as,

% Ash Content = Weight of Ash formed *100 / Weight of coal sample

Fixed Carbon Content:

- After the determination of moisture, volatile content and ash content the remaining matter is Fixed Carbon.

- Higher % of Fixed carbon, greater is the calorific value.

- The percentage of fixed carbon helps in designing the furnace and the shape of the fire-box.

% Fixed Carbon = 100 - %(moisture + volatile + ash)

Problem

- A sample of coal was analyzed as following:

Exactly 2.5 g was weighed into silica crucible. After heating for an hour at 110 ^{0}C, the residue weighed 2.415 gm. The crucible was then covered and strongly heated for 7 to 10 minutes at 950 ^{0}C. The residue weighed 1.528 g. The crucible was then heated without cover until a constant weight was obtained. The last residue was found to weigh 0.245 g.

Calculate the % of moisture, volatile matter, ash and fixed carbon in the coal sample.

ANS:

Moisture = 3.4 %; Volatile = 36.7%; Ash= 9.8%; Carbon= 50.1%

Ultimate Analysis

Elemental Analysis of Coal

It involves the determination of percentage of:

- Carbon and hydrogen contents: % of C is the basis for the classification of coal, higher the %C, better the quality of coal. % of H is associated with the volatile matter and affects the usability of coal, lower the %H, better the quality of coal.

- Nitrogen content: Nitrogen is an inert and non-combustible gas & hence is presence is undesirable. Thus a good quality of coal should have very less/no Nitrogen content.

- Sulphur content: Presence of sulphur is undesirable in coal as on oxidation it produces harmful and corrosive SO_2 and SO_3.

- Oxygen content: High Oxygen content coals have high moisture & low calorific value. Thus a good quality coal should have low % of oxygen.

Determination of Carbon & Hydrogen

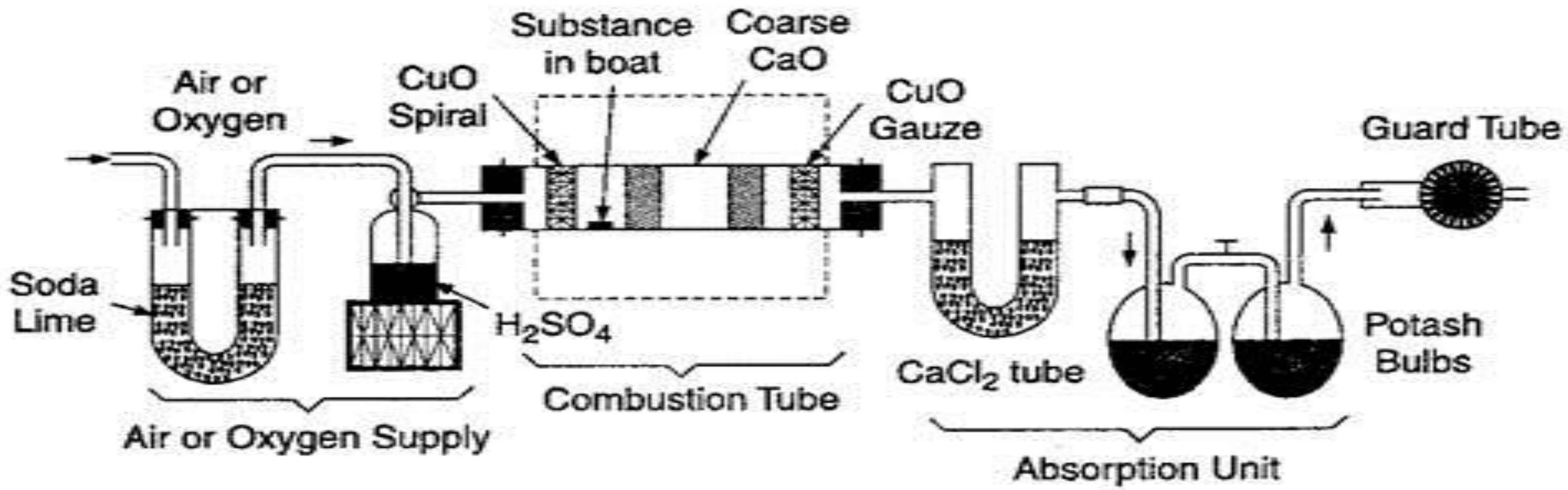
A known quantity of coal (about 1-2 gm) is burnt in the current of dry oxygen when carbon and hydrogen in coal are oxidised to CO_2 & H_2O respectively.

$$C + O_2 \rightarrow CO_2$$
$$H_2 + ½\ O_2 \rightarrow H_2O$$

A gaseous product of combustion are passed through $CaCl_2$ tube and potash bulbs.

The $CaCl_2$ tube contains weighted amount of anhydrous $CaCl_2$ absorbs water.
$CaCl_2 + 7\ H_2O \rightarrow CaCl_2.7.H_2O$

The Potash tube contains weighted amount of KOH absorbs CO_2.
$2KOH + CO_2 \rightarrow K_2CO_3 + H_2O$



Determination of Carbon & Hydrogen

$$\% \text{ C} = \frac{\text{Increase in weight of KOH} * 12 * 100}{\text{Weight of Coal sample taken} * 44}$$

$$\% \text{ H} = \frac{\text{Increase in weight of } CaCl_2 * 2 * 100}{\text{Weight of Coal sample taken} * 18}$$

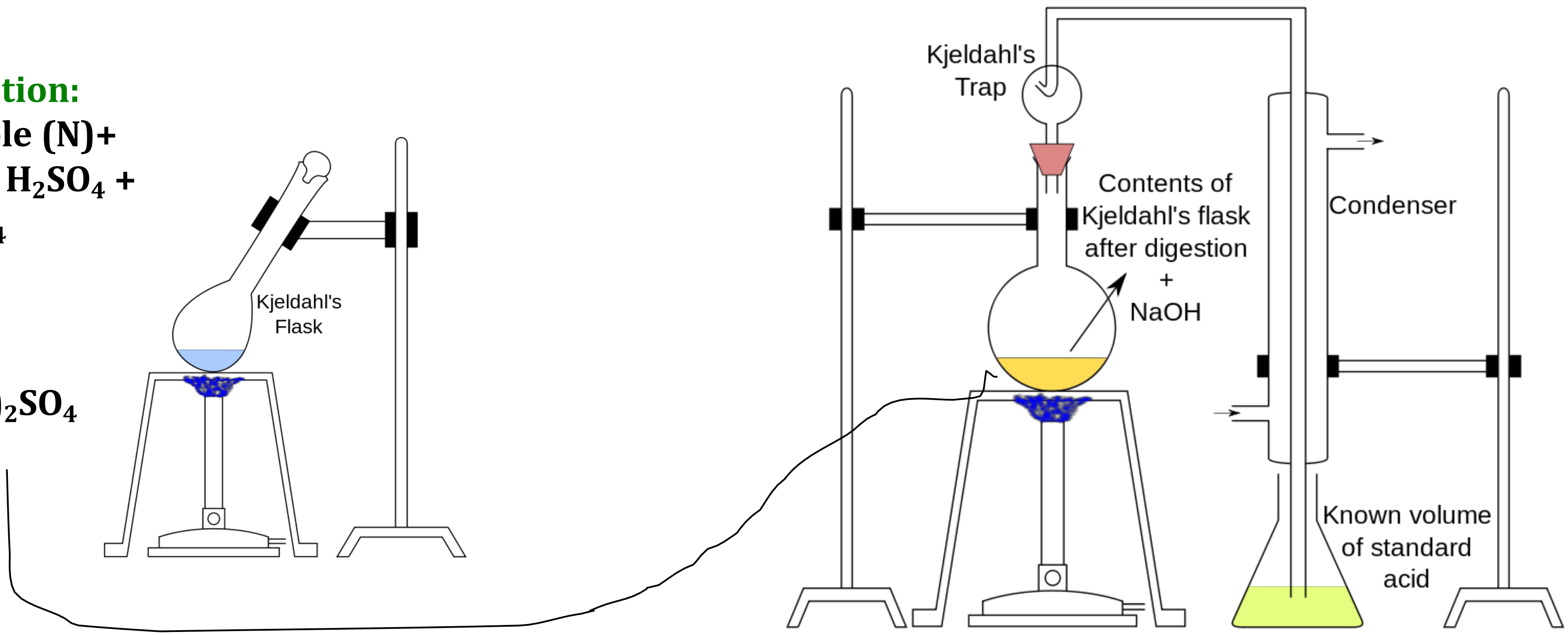
Determination of Nitrogen

Nitrogen in coal is determined by Kjeldhal’s method

- 1 gm of accurately weighed powdered coal is heated with conc. H_2SO_4 along with K_2SO_4 (Catalyst) in a long necked flask (Kjeldahl’s flask).
- Nitrogen in the coal is converted into ammonium sulphate.
- It is heated with 50% NaOH and it produce NH_3
- The liberated NH_3 is distilled over and absorbed in a known volume of std 0.1N HCl
- $NH_3 + HCl \rightarrow NH_4Cl$
- The volume of unused acid is determined by back titration with std. NaOH (0.1N)

Digestion:
Sample (N)+
Conc. H_2SO_4 +
K_2SO_4

$(NH_4)_2SO_4$



Determination of Nitrogen

$$\%\ \mathrm{N} = \frac{14 * \text{Normality of HCl} * \text{Volume of HCl } \textit{used}}{\text{Weight of Coal sample taken} * 1000}$$

Determination of Sulphur

A known amount of coal (W_1 gm) is burnt completely in bomb calorimeter in the current of oxygen, by which sulphur is oxidised to sulphates.

The ash from the bomb calorimeter is extracted with dil. HCl. The acid extracted is treated with $BaCl_2$ to precipitate sulphate as $BaSO_4$.

The $BaSO_4$ is filtered, washed, dried and heated to constant weight.

$$S + O_2 \rightarrow SO_4^{2-} \rightarrow BaSO_4$$

$$\% \, S = \frac{\text{weight of BaSO4 ppt formed} * 32 * 100}{\text{Weight of Coal sample taken} * 233}$$

Determination of Oxygen

- Oxygen is present in combined form with hydrogen in coal and thus hydrogen available for combustion is lesser than the actual one.

- High Oxygen content coals have high moisture & low calorific value. Thus a good quality coal should have low % of oxygen.

$$\% \text{ Oxygen} = 100 - \% \,(C + H + N + S + \text{Ash})$$

Dulong's Formula

Depending upon the chemical composition of fuel, calorific value can be estimated using Dulong's formula

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

Where, C, H, O and S are the percentages of carbon, hydrogen, oxygen & sulphur in the fuel respectively. Here, Oxygen is assumed to be present in combination with hydrogen as water, and

$$LCV = \left[HCV - \frac{9}{100} H\, x\, 587\right] = [HCV - (0.09H\, x\, 587)] kcal/kg$$

Problem

A coal has following composition by weight: C= 90%; O= 3%; S= 0.5%; N= 0.5% and Ash= 2.5%. NCV of coal = 8490.5 Kcal/gm. Calculate the % of H and HCV.

Problem

Calculate the GCV and NCV of coal having following composition:

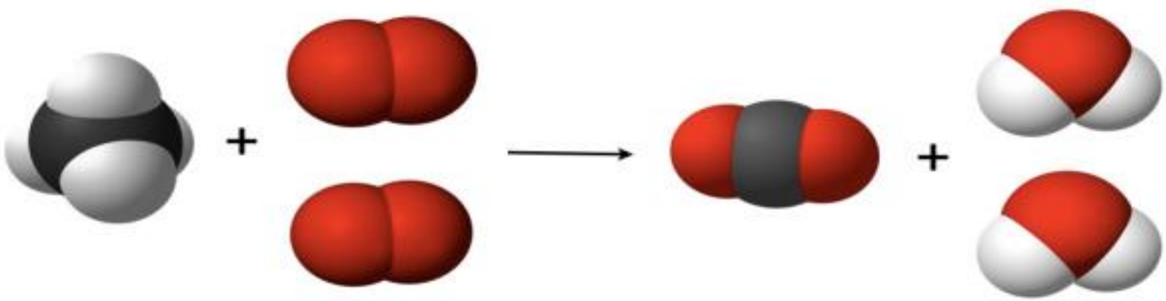
Carbon= 85%; Hydrogen= 8%; Sulphur= 1%; Nitrogen= 2% and Ash= 4%

$$\mathrm{HCV} = \frac{1}{100}\left[8080\ \mathrm{C} + 34500\left(\mathrm{H} - \frac{0}{8}\right) + 2240\ \mathrm{S}\right]\mathrm{kcal/kg}$$

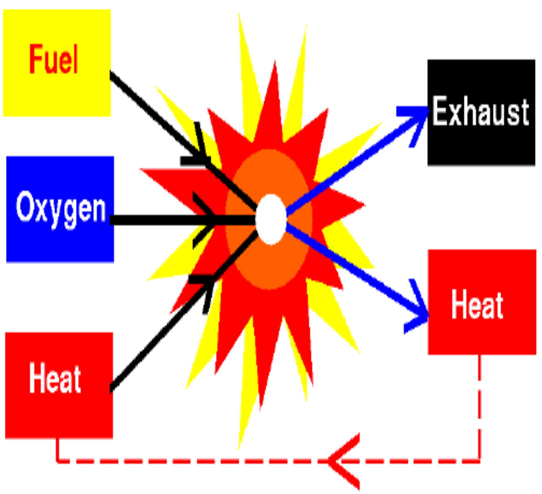
Ans: GCV : 9650 Kcal/Kg

LCV: 9227 kcal/kg

Combustion



$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$



Combustion

Combustion (burning) is a chemical process in which fuel reacts with an oxidant to give out heat. The release of heat can produce light in the form of flame.

- Rapid Combustion: Combustion in which a substance burns rapidly and produces heat & light with the help of external heat.
  Burning of LPG

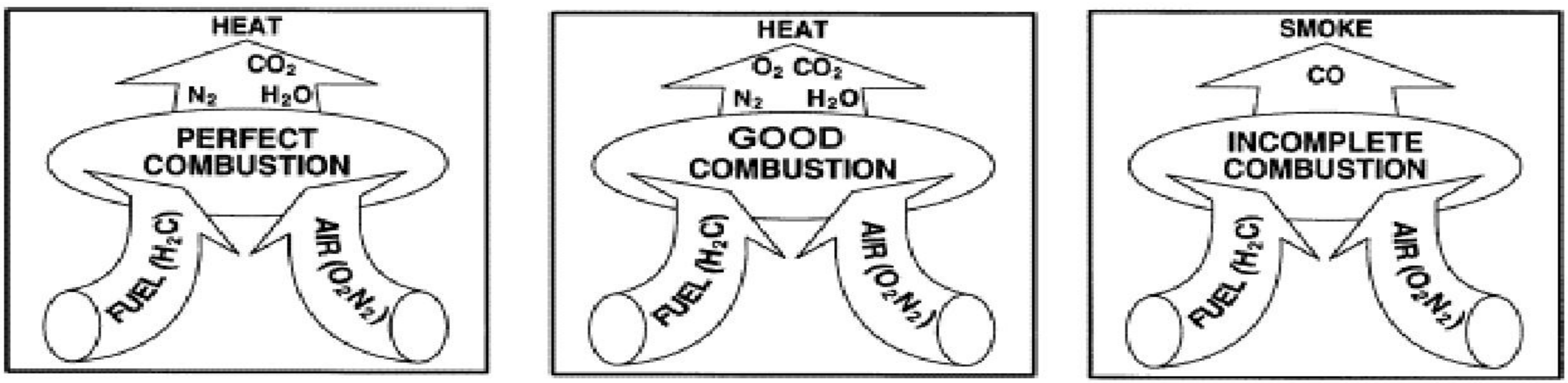
- Spontaneous Combustion: Combustion in which a substance burns spontaneously and produces heat & light without the help of external heat.
  Phosphorous burns spontaneously at RT.

- Explosion: Combustion in which a substance burns suddenly and produces heat, light and sound with the help of heat/pressure.
  Explosion of Crackers on applying heat/pressure.

Objective of Combustion:

The objective of good combustion is to release all of the heat in the fuel. This can be done by controlling the "three T's" of combustion i.e.

(1) Temperature high enough to ignite and maintain ignition of the fuel
(2) Turbulence or intimate mixing of the fuel and oxygen,
(3) Time sufficient for complete combustion.



Too much, or too little fuel with the available combustion air may result in unburned fuel and carbon monoxide generation.

Basic Stoichiometry

A very specific amount of oxygen is required for perfect combustion & some additional/excess air is required to ensure the complete combustion.

In general a fuel may contain Carbon, Hydrogen, Oxygen, Nitrogen & Sulphur. During combustion these elements combine with oxygen.

If the % of Carbon, Hydrogen, Oxygen, Nitrogen & Sulphur is known the quantity of oxygen/air required for combustion can be calculated.

Basic Stoichiometry

Oxygen required for combustion of Carbon

C	+	O_2	$\rightarrow$	CO_2
12Kg		32 Kg		44 Kg

12 kg Carbon Requires = 32 kg of oxygen

x Kg of Carbon requires = $\frac{32\,x}{12} = 2.67\,x$ Kg of Oxygen

Oxygen required for combustion of Hydrogen

H_2	+	$1/2O_2$	$\rightarrow$	H_2O
2Kg		16 Kg		18 Kg

2 kg Hydrogen Requires = 16 kg of oxygen

y Kg of Hydrogen requires = $\frac{16\,y}{2} = 8\,y$ Kg of Oxygen

Oxygen required for combustion of Sulphur

S	+	O_2	$\rightarrow$	SO_2
32Kg		32 Kg		64 Kg

32 kg Sulphur Requires = 32 kg of oxygen

z Kg of Hydrogen requires = $\frac{32\,z}{32} = 1\,z$ Kg of Oxygen

Basic Stoichiometry

Quantity of oxygen required for combustion of 1 Kg of Fuel

$$= (2.67 * C + 8 * H + S)\ Kg$$

If oxygen is already present in the fuel then this should be reduced.

Quantity of O_2 required = (O_2 required - O_2 present in the fuel)

Minimum Quantity of O_2 or Theoretical amount of O_2 required for complete combustion

$$= (2.67 * C + 8 * H + S - O)\ Kg$$

Air Required

By weight

Air contains 23% by weight.

$$\textit{Hence Air required} = \frac{100}{23} * (2.67 * C + 8 * H + S - O) \text{ Kg}$$

$$\textit{1 Kg of } O_2 \textit{ is supplied by } \frac{100}{23} * 1 = 4.35 \text{ Kg of air}$$

By Volume

Air contains 21% by volume.

$$\textit{Hence Air required} = \frac{100}{21} * (2.67 * C + 8 * H + S - O) \text{ m}^3$$

Non combustible substances like Nitrogen, Ash, CO_2 etc. don't require any oxygen for combustion.

Problem

- Calculate the mass of air needed for complete combustion of 5kg of coal contain C=80% and H= 15%. Find out HCV and LCV.

5 Kg coal contains C= 5*80/100 = 4kg
H= 5* 15/100= 0.75 Kg
O= 5*5/100= 0.25 Kg

Mass of the Air $= \frac{100}{23}[2.67X4 + 8X\ 0.75 - 0.25] = 71.43$ kg

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

$$= \frac{1}{100}\left[8080X\ 80 + 34500\ \left(15 - \frac{5}{8}\right)\right] = 11423 \text{ kcal/kg}$$

LCV = GCV - 0.09 x H x 587
= 11423 - 0.09 x 15 x 587 = 10630 kcal/gm

Problem

A sample of coal was found to have the following % composition C = 75%, H = 5.2%, O = 12.1%, N = 3.2%, & ash = 4.5%. (1) Calculate the minimum amount of air necessary for complete combustion of 1 kg of coal. (2) Also calculate the HCV & LCV of the coal sample.

Composition (%)	Composition in 1 kg of coal	Combustion Reaction	Weight of O_2 needed for combustion of 1 kg of coal
C = 75%	0.75	$C + O_2 \rightarrow CO_2$	32*0.75/12 = 2 kg
H = 5.2%	0.052	$H_2 + ½ O_2 \rightarrow H_2O$	16*0.052/2 = 0.416 kg
O = 12.1%	0.121	No Reaction	-
N = 3.2%	0.032	No Reaction	-
ASH = 4.5%	0.045	No Reaction	-
		Total O_2 needed	2.416

Net O_2 required = Total O_2 needed – O_2 present = 2.416 – 0.121 = 2.295 kg

O_2 Required = 2.67* 0.75+ 8*0.052-0.121= 2.295

weight of air = 100 * Net O_2 / 23 = 100 * 2.295/23 = 9.9782 kg

GCV = 1/100 [8080 %C + 34500 (%H- %O/8) + 2240% S] = 7332.1875 kcal/kg

LCV = GCV – 0.09 * H * 587 = 7057.47 kcal/kg

A gas used in an I.C. engine had the following composition by volume, H_2 = 45%, CH_4 = 36%, CO = 15%, N_2 = 4%. Find the volume of air required for combustion of $1m^3$ of the gas.

Composition (%)	Composition in 1 m^3 of fuel	Combustion Reaction	Weight of O_2 needed for combustion of 1 kg of coal
H_2 = 45%	0.45	$H_2 + ½ O_2 \rightarrow H_2O$	½ * 0.45 = 0.22 m^3
CH_4 = 36%%	0.36	$CH_4 + 2 O_2 \rightarrow CO_2 + 2H_2O$	2 * 0.36 = 0.7 m^3
CO = 15%	0.15	$CO + ½ O_2 \rightarrow CO_2$	½ * 0.15 = 0.07 m^3
N_2 = 4%	0.04	No Reaction	-
		Total O_2 needed	1.02 m^3

Net O_2 required = 1.02 m^3

Hence Air required = $\frac{100}{21} * 1.02\ m^3$

Alternative Fuel

- Alternative fuel defines as a product that is substantially non-petroleum which yields energy security and environmental benefits.