Topic 6-Energy Science

Syllabus: Fuel and its classification, Characteristics of good fuel, Properties of solid, liquid and gaseous fuels. Calorific value, Gross and net calorific value, its units, and determination by bomb and Boys calorimeter, Numerical problems on calorific value. Fuel cell, its types and applications

6.1. Fuel:

It is a carbonaceous substance which on combustion produces large amount of heat which is used economically for betterment of mankind.

Carbonaceous substances are rich in carbon content (80 to90% carbon) and when these are subjected for combustion they produce large amount of heat because reaction, $C + O_2 \rightarrow CO_2\uparrow$ is highly exothermic.

6.2Classification:

Fuels are classified on the basis of their Occurrence & physical state of aggregation. Many fuels are naturally available and are called Natural or Primary fuels. (Coal, Wood, Crude oil etc.). Some fuels are synthesized in laboratory or obtained by processing of natural/ primary fuels called artificial or secondary fuels. (Petrol, Diesel, CNG, LPG etc.).

On the basis of Physical state of existence both primary and secondary fuels are sub classified as solid fuels, liquid fuels and gaseous fuels.

Fuels or Chemical fules

- Primary or Natural(Which found in nature)
  They further classified on state of aggregation
  - Solid: e.g. Wood, Coal, Dung, Peat, Lignite
  - Liquid: Cruid oil
  - Gaseous: Natural gas
- Secondary or Artificial (which are prepared from primary fuels)
  They further classified on state of aggregation
  - Solid: e.g. Coke, Charcoal, Petroleum coke, Coke, Briquette, Coal
  - Liquid: Petrol, Kerosene, Diesel, Tar, Gasolien, L. P. G.
  - Gaseous: Coal gas, Water gas, Oil gas, Bio gas, Blast furnace gas, Coke oven gas

6.3Characteristics of a good fuel:

1. The good fuel must possess high calorific value – Calorific value is heat content of fuel which depends on carbon content in fuel. Higher the carbon content greater is the calorific value which assure large amount of heat by combusting lesser amount of fuel.
2. A good fuel must possess moderate ignition temperature. Ignition temperature is minimum temperature at which fuel catches fire and start to combust. If it is low fuel is not safe for storage and if it is high, it is difficult to ignite it easily.
3. Good fuel should be dry and should have less moisture content. Dry fuel assures continuous combustion and production of less smoke while high moisture content affects its calorific value due to slow velocity of combustion and non-continuous burning.
4. A good fuel must possess moderate velocity of combustion – If velocity of combustion is slow less amount of heat will be produced in unit time and required temperature is not attained. If velocity of combustion is high large amount of heat will be produced in short interval of time causing wastage of heat.

5. It must undergo clean and smokeless burning.

6 The products of combustion must be nontoxic/hazardous. If the products of combustion are toxic, then it leads to cause several kind of health hazards to public on exposure.

7. The good fuel can be stored safely.

8. It should burn spontaneously to avoid disturbance in supply of heat during its use.

9. Its handling and transportation should be easy.

10. It should be readily available and cheaper.

6.4Comparison of Solid , Liquid and Gaseous Fuels

Sr. No.	Parameter /Property	Solid Fuel	Liquid Fuel	Gaseous Fuel
1	Physical State of existence	Solid	Liquid	Gaseous
2	Calorific value	Low	High	Highest
3	Ignition Temperature	High	Low	Lowest
4	Thermal Efficiency	Low	High	Highest
5	Control On combustion	Cannot controlled	Controlled	Controlled
6	Products of Combustion	Ash and smoke	Smoke	Clean burning
7	Storage and Transport	Easy to transport and store	Careful storage and Transport	Critical transport and storage.
8	Limitation	Cannot be used in IC engines	No Limitation	No limitation
9	Labour cost	High	Low	Least
10	Cost	Cheaper	Costly	Costliest
11	Examples	Wood, Coke, Coal	Petrol, Diesel	LNG,CNG,LPG

6.5 Calorific Value – Calorific value is most important property of any kind of fuel. It is defined as" It is total amount of heat liberated on complete combustion of a unit mass or volume of a fuel."

Units of calorific value: Calorific value is heat content of fuel and is measured in terms of following units:

(i) Calorie: It is the amount of heat required to raise the temperature of 1gm of water by 1°C

1 calorie = 4.184 Joules

(ii) Kilo Calorie: It is amount of heat required to raise temperature of 1 Kg water by 1°C

1Kcal = 1000 cal

(iii) British Thermal Unit: (B. T. U.) It is amount of heat required to raise the temperature of 1 pound of water through 1°F.

1 B.T.U. = 252 Cal = 0.252 Kcal

(IV) Centigrade Heat Unit (C.H.U): It is amount of heat required to raise the temperature of 1 pound of water through 1°C.

1K Cal = 3.968 B.T.U. = 2.2 C.H.U.

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Types of Calorific Values

High/Gross Calorific Value: Most of fuels contain some extent of hydrogen and this hydrogen converts to water (Steam) when calorific value is experimentally determined. When products of combustion are cooled to room temperature the latent heat of condensation is added to calorific value. This is called as High or Gross calorific value (HCV / GCV)

Definition: **GCV/HCV** –'The total amount of heat produced by complete burning of unit mass of fuel and the products of combustion are allowed to cool down to the room temperature'.

As the products of combustion are cooled down to room temperature, the steam gets condensed into water and latent heat is evolved which is added to heat release by fuel.

Low/Net Calorific Value: During actual utilisation of fuel the products of combustion are allowed to escape, hence less amount of heat is available and is referred as Low or Net calorific value(LCV/NCV)

Definition: **LCV/NCV**- **'**The total amount of heat produced by complete burning of unit mass of fuel and the products of combustion are allowed to escape.'

The water vapour do not condense and escape with hot combustion gases. Hence, lesser amount than gross calorific value is available. It is also known as lower calorific value (LCV).

Relation between GCV & LCV:

LCV=HCV-Latent heat of water vapours formed

Since 1 part by weight of hydrogen gives nine parts by weight of water i.e.

$$H_2 + ½ O_2 \rightarrow H_2O$$

= HCV –[Mass of Hydrogen X 9 X latent heat of steam]

$$\boxed{L.C.V. = HCV – [0.09 \times \%H_2 \times \text{Latent heat of Steam}]}$$

Latent heat of steam is 587 Kcal/Kg or 1.060 BThU/lb at room temperature

6.6 Determination of Calorific value –

1. Theoretical Determination – Dulong's formula

The calorific value of a fuel can be calculated theoretically, if the percentages of constituent elements are known. If oxygen is also present, it combines with hydrogen to form H_2O. Thus the hydrogen in the combined form is not available for combustion and is called fixed hydrogen.

Amount of hydrogen available for combustion = Total mass of hydrogen-hydrogen combined with oxygen.

$$H_2 + 1/2\ O_2 \rightarrow H_2O$$

1g 8g 9g

Fixed Hydrogen depends on Mass of oxygen in the fuel

Therefore, mass of hydrogen available for combustion = Total mass of hydrogen-1/8 mass of oxygen in fuel

H available = (amount OR %H - % O/8)

HCV = 1/100[8080 x %C + 34500 (% H - % O/8) + 2240 x %S] Kcal/Kg

2) By Oxygen Bomb Calorimeter:

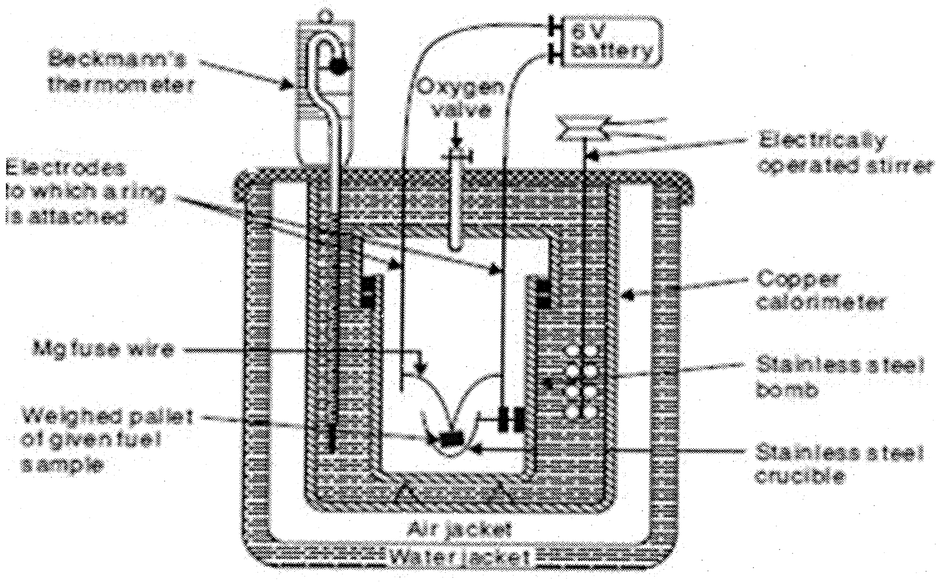
Principle –It works on the basis that heat evolved by fuel on combustion is equal to heat absorbed by water in calorimeter.

The schematic diagram of Bomb calorimeter is as shown in figure below.

Construction –

It consists of following components –

a) **Oxygen Bomb** – It is main component of Bomb calorimeter. It is made up of stainless steel. It is thick walled narrow cylinder with screwed lid. The inner walls are coated with anti-corrosive layer (Gold or Platinum). The lid is fitted with two electrodes. Top ends of electrodes are connected to power supply while lower ends are connected to fuse wire. (Nichrome wire). One of electrode is fitted with crucible holder at bottom. The centre of lid is having oxygen valve for filling oxygen in bomb. The sample is kept in crucible which is properly kept in crucible holder taking care that fuse wire just touch fuel.



b) **Copper calorimeter** – It is second main component. The oxygen bomb is placed at centre of copper calorimeter on studs provided. The calorimeter is filled with known mass of water which absorbs heat released from fuel. It is equipped with electrically operated stirrer.

c) **Beckman thermometer** – Used to measure rise in temperature of water on combustion of fuel. Immersed in water present in calorimeter.

d) **Air and water jacket** – The calorimeter with oxygen bomb is kept in air jacket followed by water jacket to avoid loss of heat.

e) **Insulating Lid** – The whole assembly as above is covered with insulating lid (Ebonite)

Working –A calorific value is determined as under using Bomb Calorimeter.

1About 0.6 to 1.0 gram of solid /liquid fuel is accurately weighed and placed in crucible, which is then kept properly into crucible holder.

2The lower ends of electrodes are connected by fuse wire such that wire just touches fuel. Then the lid is tightly fitted on bomb and pure dry oxygen gas is filled in bomb (About 30 atm pressure). The Bomb is then placed in calorimeter on studs.

3A known mass of water is then added in calorimeter and adjusted Beckman thermometer is inserted in it. This setup is placed in insulating environment of air jacket followed by water jacket.

4The setup is then closed by insulating lid. Top ends of electrodes are connected to power supply. The electrical stirrer is switched on and finally fire button on power supply is pressed.

5Now we have to wait till maximum constant temperature is observed in Beckman thermometer and finally rise in temperature is recorded.

Calculations – We have following data

W- Mass of water taken in calorimeter

w – Water equivalent of calorimeter

T1 - Initial Temperature

T2 – Final Temperature, $\Delta T = (T2 - T1)$

X – Mass of fuel taken in crucible.

$$\textbf{HCV / GCV} = \frac{(w + W)(\Delta T)}{X} \quad \text{Cal / gram or Kcal/Kg}$$

Corrections – Following are some corrections in order to get accurate calorific value.

Acid Correction (Ac) – If fuel consist sulphur or nitrogen at high temperature and pressure inside bomb they lead to form sulphuric or nitric acid and reaction is exothermic so heat is added. Knowing % of S or N in fuel appropriate correction is made called acid correction which is subtracted.

Fuse wire Correction (Fc) – It is heat added due to burning of fuse wire and need to be subtracted. Amount depends on type of fuse wire and its length taken.

Cooling Correction (Cc) - After combustion of fuel some time is required to attain maximum temperature, at same time water in calorimeter gets cooled with respect to time. So appropriate correction is essential called cooling correction. It is generally say A °C /min. This is added to ΔT.

By considering corrections

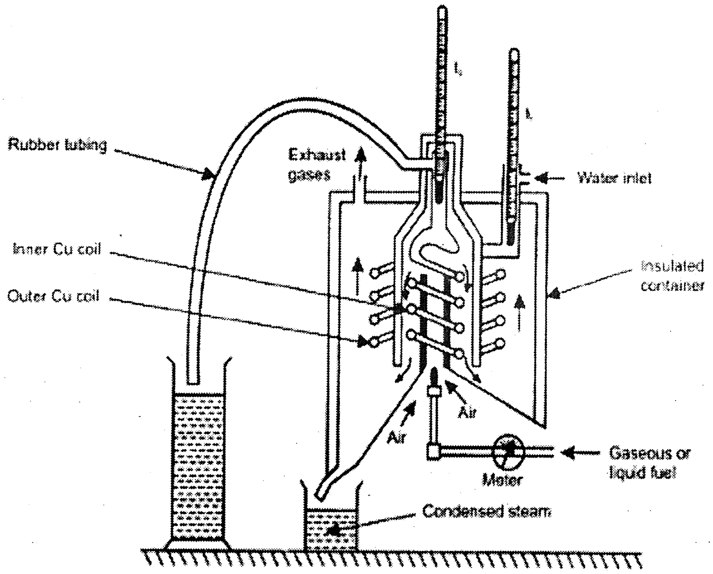
$$\textbf{HCV / GCV} = \frac{(w + W)(\Delta T + Cc) - (Ac + Fc)}{X} \quad \text{Cal / gram or Kcal/Kg}$$

$$LCV/NCV = HCV/GCV - [0.09 \times \%H_2 \times \text{Latent heat of Steam}]$$

3. **By Boy's Gas Calorimeter** – It is used to determine calorific value of gaseous and liquid fuels.

Principle- It is based on fact that heat evolved from fuel is equal to heat absorbed by water passed through calorimeter.

The schematic diagram of Boy's gas calorimeter is as shown in figure.



Construction- It consists of combustion chamber called chimney. It's a hollow metallic cylinder. The water is circulated around this combustion chamber via inner and outer coils (Tubing). The temperatures of water at inlet and outlet are recorded with separate thermometers. The gaseous fuel at regulated flow rate is burned in combustion chamber through a burner and volume of gas burned is recorded with gas flow meter. The assembly is covered with insulated cover. The water coming out through outlet is collected in separate container.

Working –

1. The equipment is first warmed up to get steady condition in all respect by burning fuel for about 5 minutes.
2. On getting steady conditions the inlet temperature is recorded.
3. The fuel is then burned at regulated flow rate till steady maximum temperature is recorded at outlet.
4. The burner and fuel valve is then shut. Volume of fuel passed during this is recorded along with outlet temperature. Flow of water is terminated.
5. Mass of water collected from outlet is measured. 6 Calorimeter is cooled and mass of steam condensed is measured.

Calculations-

If 1 W= Mass of water collected through outlet within time t

2 V = Volume of fuel burned within time t

3 T1 = Temperature at inlet of water

4 T2 = Temperature at outlet of water (Maximum), T2 -- T1 = ΔT

Then GCV/HCV = $\frac{W \times \Delta T}{V}$ Kcal /m^3

NCV/LCV = GCV – $\frac{m \times 587}{V}$ Kcal /m^3, where m = mass of steam condensed.

$$\boxed{NCV/LCV = GCV - \frac{m \times 587}{V}}$$

6.7 Fuel Cells –

A fuel cell is an electrochemical cell that converts the chemical energy of a fuel (often hydrogen) and an oxidizing agent (often oxygen) into electricity through a pair of redox reactions.

A fuel cell is like a battery; it generates electricity from an electrochemical reaction. Both batteries and fuel cells convert chemical energy into electrical energy and also, as a by-product of this process, into heat. However, a battery holds a closed store of energy within it and once this is depleted the battery must be discarded, or recharged by using an external supply of electricity to drive the electrochemical reaction in the reverse direction.

A fuel cell, on the other hand, uses an external supply of chemical energy and can run indefinitely, as long as it is supplied with a source of hydrogen and a source of oxygen (usually air). The source of hydrogen is generally referred to as the fuel and this gives the fuel cell its name, although there is no combustion involved. Oxidation of the hydrogen instead takes place electrochemically in a very efficient way.

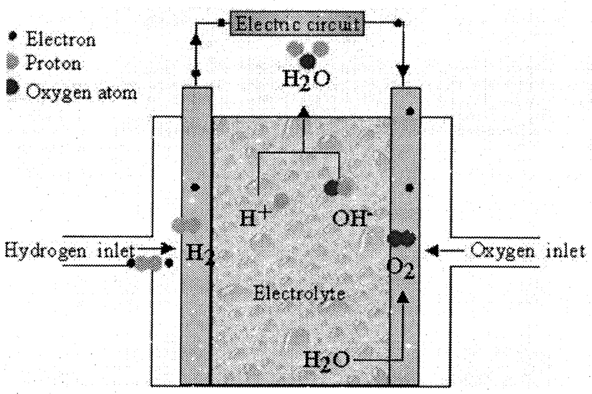
During oxidation, hydrogen atoms react with oxygen atoms to form water; in the process electrons are released and flow through an external circuit as an electric current.

Fuel cells can vary from tiny devices producing only a few watts of electricity, right up to large power plants producing megawatts.

All fuel cells are based around a central design using two electrodes separated by a solid or liquid electrolyte that carries electrically charged particles between them. A catalyst is often used to speed up the reactions at the electrodes.

Fuel cell types are generally classified according to the nature of the electrolyte they use. Each type requires particular materials and fuels and is suitable for different applications.

A schematic of the basic fuel cell (H2-O2) components is shown below



Working of Fuel Cell:

The reaction between hydrogen and oxygen can be used to generate electricity via a fuel cell. Such a cell was used in the Apollo space programme and it served two different purposes – It was used as a fuel source as well as a source of drinking water (the water vapour produced from the cell, when condensed, was fit for human consumption).

The working of this fuel cell involved the passing of hydrogen and oxygen into a concentrated solution of sodium hydroxide via carbon electrodes. The cell reaction can be written as follows:

Cathode Reaction: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

Anode Reaction: $2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$

Net Cell Reaction: $2H_2 + O_2 \rightarrow 2H_2O$

However, the reaction rate of this electrochemical reaction is quite low. This issue is overcome with the help of a catalyst such as platinum or palladium. In order to increase the effective surface area, the catalyst is finely divided before being incorporated into the electrodes. A block diagram of this fuel cell is provided above

Types of Fuel Cells

Despite working in a similar manner. there exist many varieties of fuel cells. Some of these types of fuel cells are discussed in this subsection.

The Polymer Electrolyte Membrane (PEM) Fuel Cell

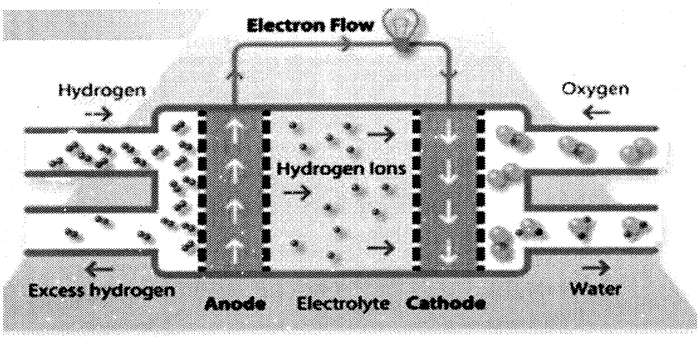
These cells are also known as proton exchange membrane fuel cells (or PEMFCs).

The temperature range that these cells operate in is between 50ºC to 100º C

The electrolyte used in PEMFCs is a polymer which has the ability to conduct protons.

A typical PEM fuel cell consists of bipolar plates, a catalyst, electrodes, and the polymer membrane.

Despite having eco-friendly applications in transportation, PEMFCs can also be used for the stationary and portable generation of power.



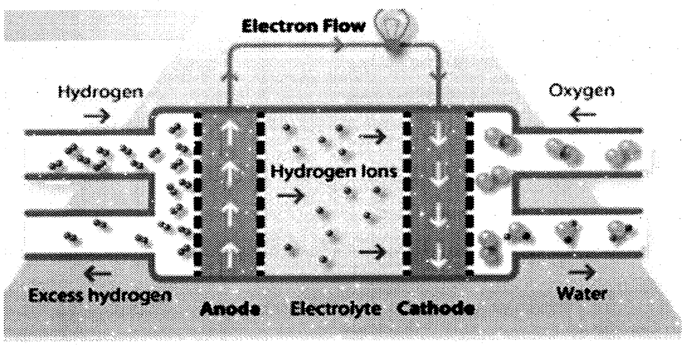
Phosphoric Acid Fuel Cell

These fuel cells involve the use of phosphoric acid as an electrolyte in order to channel the H^+

The working temperatures of these cells lie in the range of 150ºC – 200º C

Electrons are forced to travel to the cathode via an external circuit because of the non-conductive nature of phosphoric acid.

Due to the acidic nature of the electrolyte, the components of these cells tend to corrode or oxidize over time.

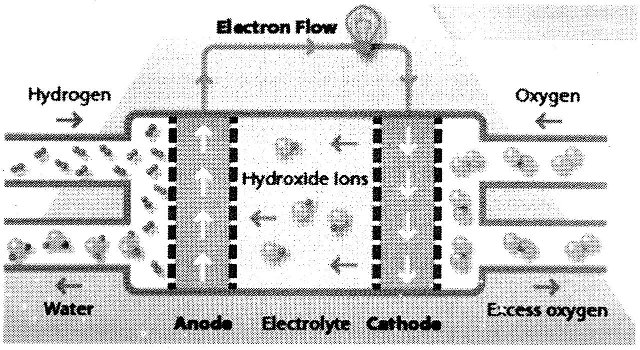


Alkaline Fuel Cell

This was the fuel cell which was used as the primary source of electricity in the Apollo space program.

In these cells, an aqueous alkaline solution is used to saturate a porous matrix, which is in turn used to separate the electrodes.

The operating temperatures of these cells are quite low (approximately 90°C).
These cells are highly efficient. They also produce heat and water along with electricity.



Solid Oxide Fuel Cell

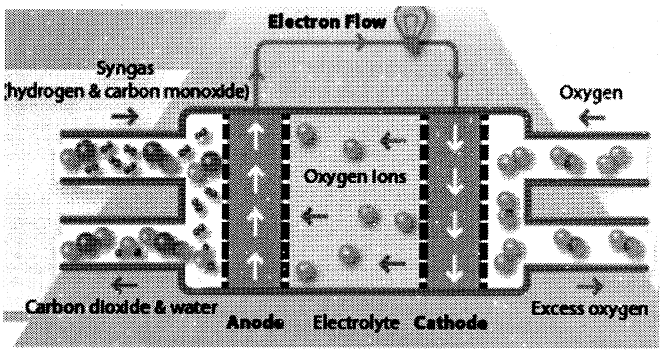
These cells involve the use of a solid oxide or a ceramic electrolyte (such as yttria-stabilized zirconia).

These fuel cells are highly efficient and have a relatively low cost (theoretical efficiency can even approach 85%).

The operating temperatures of these cells are very high (lower limit of 600°C, standard operating temperatures lie between 800 and 1000°C).

Solid oxide fuel cells are limited to stationary applications due to their high operating temperatures.

Syn Gas
$H_2 + CO$



Molten Carbonate Fuel Cell

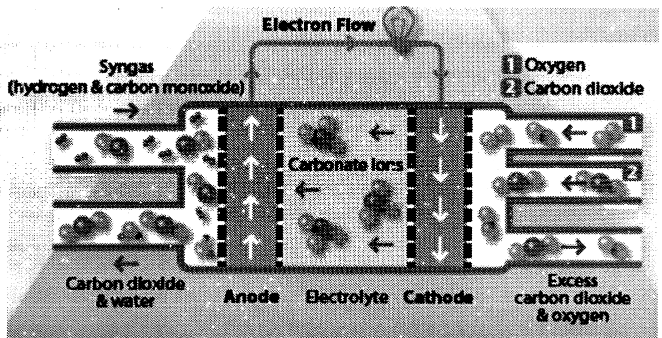
The electrolyte used in these cells is lithium potassium carbonate salt. This salt becomes liquid at high temperatures, enabling the movement of carbonate ions.

Similar to SOFCs, these fuel cells also have a relatively high operating temperature of 650°C

The anode and the cathode of this cell are vulnerable to corrosion due to the high operating temperature and the presence of the carbonate electrolyte.

These cells can be powered by carbon-based fuels such as natural gas and biogas.

natural gas & biogas can also be used.



☆☆☆ Applications of fuel cell

Fuel cell technology has a wide range of applications. Currently, heavy research is being conducted in order to manufacture a cost-efficient automobile which is powered by a fuel cell. A few applications of this technology are listed below.

- Fuel cell electric vehicles, or FCEVs, use clean fuels and are therefore more eco-friendly than internal combustion engine-based vehicles.
- They have been used to power many space expeditions including the Appolo space program.
- Generally, the by products produced from these cells are heat and water.
- The portability of some fuel cells is extremely useful in some military applications.
- These electrochemical cells can also be used to power several electronic devices.
- Fuel cells are also used as primary or backup sources of electricity in many remote areas.

Questions –

Answer the following

1. Define fuel and discuss how fuels are classified.
2. Give characteristics for good fuel.
3. Compare/ Differentiate between Solid-Liquid, Solid-Gas, Liquid-Gaseous, Solid-Liquid and Gaseous fuels.
4. What is Calorific value of fuel? Explain terms High and Low Calorific value.
5. Discuss different units used to measure calorific value.
6. With neat diagram discuss determination of Calorific value by Bomb/Boy's calorimeter.
7. What are fuel cells? With diagram explain working of H2-O2 fuel cell.
8. What are different types of fuel cells? With diagram describe any two.

Define terms

Calorific value, Net Calorific value, Gross Calorific value, Fuel cell.

Give reason

1. Calorific value of fuel should be high.
2. Fuels may bear moderate ignition temperature.
3. Fuel must burnt with moderate velocity of combustion.
4. There is very high risk while storing gaseous fuels.
5. Solid fuels don't burn cleanly.
6. Handling or labour cost for liquid and gaseous fuels is less than solid fuel.
7. Acid correction is amount of heat subtracted from calorific value determined by Bomb calorimeter.
8. Carbonaceous substances are generally used as fuels.
9. Bomb calorimeter is not suitable to determine Calorific value of gaseous fuel.
10. Fuel cell is emerging clean source of energy.

Numerical

1. A sample of coal containing 6% hydrogen was tested in Bomb Calorimeter for its calorific value, following data were recorded. Weight of coal burnt= 0.92gm, Acid correction = 50 Cal. Rise in temperature = 2.42 0C, Water equivalent of bomb & calorimeter

= 550 gm, Weight of water taken in copper calorimeter = 2200 gm. and Latent heat of condensation of steam = 587 cal/gm. Calculate Gross & Net CV

2. Following data were recorded from Bomb Calorimeter calorimeter experiment.
   Weight of Coal burnt = 0.92 gm , Weight of water taken = 2100 gm , Water Equivalent of apparatus = 400 gm , Rise in Temperature = 2.12 o C , Fuse wire correction = 10.0 Cal , Acid Correction = 40.0 Cal. If % of Hydrogen is 5 & Latent Heat of condensation of steam is 587 Cal/gm. Calculate HCV & LCV of fuel.

3. The Ultimate analysis of coal shows following result
   Carbon = 86%, Hydrogen = 5%, Oxygen = 2%, Sulphur = 1%, Nitrogen = 2%, ash = 4%. If latent heat of steam is 587 Cal/gm Calculate Lower/Net Calorific value of above coal using Dulong's formula.
4. The following data was obtained in Boy's gas calorimeter experiment
   Volume of gas used = 0.101 m^3 at STP
   Weight of water heated = 26 Kg
   Temperature of in late water = 22 ^{0}C
   Temperature of out late water = 35^{0}C
   Weight of steam condensed = 0.026 Kg
   Calculate Higher & Lower calorific value in if heat liberated in condensing water vapour and cooling the condensate as 587 Kcal/ kg.

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