- Early man depended mainly on muscular energy and later began to use wind and flowing water as sources of energy. He learned the art of making and controlling a fire. Fire became his source of light at night. He used fire for warmth and realized that cooked food tastes better than raw food. As civilization advanced, man started using fire in making weapons, pottery etc. Today, with the progress in science and technology, fuels have become indispensable to man.
- E.g. Coal, Coke, Bituminous coal, Anthracite coal, Petrol, Diesel, Kerosene, alcohol etc
- Followings are not fuels
- Paper, resin, furniture etc
- **Definition:** It is combustible substance, Containing carbon as main constituent, which on proper burning gives large amount of heat, which can be used economically for domestic & industrial purposes
- **Significance of fuels**
- Fuels are substances that are burnt for the production of heat or light energy. Example: Coal, Wood, Kerosene, L.P.G.

Importance of fuels

Application		Example
Domestic	Cooking	LPG, Wood, Coal, Kerosene
	Lighting	Vegetable oil, paraffinwax, kerosene
Transport	Light motor vehicles	Petrol
	Heavy motor vehicles	Diesel
	Ships	Fuel oil
	Aviation	Refined kerosene
Generation electricity		Coal, Natural gas
Propulsion of rockets		Methyl hydrazine Thiokol

What happen during combustion?

- Combustion is process of oxidation
- In that process ground state ingredients/element present in substance react with oxygen to form their corresponding oxides with lower energy
- Hence react reaction is exothermic & Heat, Light & some time sound is evolved
- $C + O_2 \rightarrow CO_2$ + Heat

Combustion is oxidation of a fuel that results in the release of heat, light and some times sound energy. In simple words it means burning.

1. $C + O_2 \rightarrow CO_2 + \Delta$
2. $2H_2 + O_2 \rightarrow 2H_2O + \Delta$
3. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \Delta$
4. $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$

Classification of fuel: They are classified on the basis of their Occurrence & State of aggregation

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

Classification of fuel on state of aggregation

Fuels or Chemical fules

- **Solid** e.g. Wood, Coal, Dung, Peat, Lignite, Coke, Charcoal, Petroleum coke, Coke, Briquette, Coal
- **Liquid** Cruid oil, Petrol, Kerosene, Diesel, Tar, Gasolien, L. P. G.
- **Gaseous** Natural gas, Coal gas, Water gas, Oil gas, Bio gas, Blast furnace gas, Coke oven gas

Terms in Fuel

- **Calorific value:** It is defined as the total quantity of heat liberated when a unit mass of a fuel is burnt completely.
- Units of heat:
- The quantity of heat can be measured in the following units:
- **(i) Calorie:** It is defined as the amount of heat required to raise the temperature of 1gm of water by 1^oC
  1 calorie = 4.184 Joules
- **(ii) Kilo Calorie:** 1 k cal = 1000 cal
- **(iii) British thermal unit:** (B. T. U.) It is defined as the amount of heat required to raise the temperature of 1 pound of water through 1^oF.
- 1 B.T.U. = 252 Cal = 0.252 k cal
- **(IV) Centigrade heat unit (C.H.U):** It is defined as the amount of heat required to raise the temperature of 1 pound of water through 1^oC.
- 1k cal = 3.968 B.T.U. = 2.2 C.H.U.

Types of Calorific Values

- **Gross and net calorific Value i.e GCV & NCV**
- **Gross Calorific Value:** It is the total amount of heat generated when a unit quantity of fuel is completely burnt in oxygen and the products of combustion are cooled 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. Thus in the determination of gross calorific value, the latent heat also gets included in the measured heat. Therefore, gross calorific value is also called the higher calorific value.
- The calorific value which is determined by Bomb calorimeter gives the higher calorific value (HCV)
- **Net Calorific Value:** It is defined as the net heat produced when a unit quantity of fuel is completely burnt 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).
- 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
- latent heat of steam is 587 Kcal/Kg or 1060 BThU/lb at room temperature.

Characteristics of good fuel

- 1. Fuel with **High CV** is good one, because temperature attained thereby depends upon its calorific value.(If heat content is less then less CV, means fuel is not economical)
- 2. Fuel with **Moderate Ignition temperature** is good one, (it is minimum preheating temp at which fuel stats burning smoothly & contineously) Low Ignition temp fuels dangerous to store, handle & there is chance of fire hazards. While high Ignition temperature fuels difficult to ignite.
- 3. Fuel with **Low or free from moisture content** is good one, because it reduces heating value & involves in a loss of money.
- 4. Fuel with **Low non combustible matter** is good one, because it remain in the form of ash or clinker after combustion & 1% of it reduces heating value by 1.5%
- 5. Fuel with **Moderate velocity of combustion** is good one, because in low velocity of combustion most of the heat lost by radiation & in high velocity of combustion most of the heat is lost due to radiation. While in moderate required temp is attended & heat is completely utlised
- 6. Fuel on combustion should **not produce harmful gases** is good one
- 7. Fuel which **is easy to available, low cost, easy to store, easy to handle, easy to transport** is good one.
- 8.Must undergo clean burning: Smokeless, ash less, Soot less

Fuel & its CV table

Fuel	Calorific value (kJ / g)
Hydrogen	150
Methane	55
Butane (LPG)	50
Natural gas	40-50
Biogas	35-40
Petrol	50
Kerosene	48
Diesel	45
Alcohol	30
Charcoal	33
Wood	17
Dung cake	6-8

Hydrogen as a fuel

- Hydrogen has the highest calorific value among all the fuels. It is 150 kJ/g. But it is not used as a domestic or industrial fuel commonly. This is because of the following drawbacks :
- **Drawbacks of hydrogen as a fuel**
- Highly combustible - explodes on combustion.
- Low ignition temperature - unsafe.
- Extremely light - difficult to store and transport.
- Not present in free state in nature.
- Needs to be manufactured from water - is expensive.
- **Advantages of hydrogen as a fuel**
- High calorific value.
- Non polluting - produces only water on combustion.
- The raw material for its manufacture is water which is present in abundance on Earth.
-

Comparison bet S,L,G fuels

Comparative property	Solid	Liquid	Gas
1. Physical state	Solid	Liquid	Gas
2. Calorific Value	Low	High	Highest
3. Relative cost	Cheaper	Costly	More costly
4. Space for storage	Large	50% less than solid	Depends on pressure
5. Specific gravity	Highest	Medium-Low	Lowest
6. Product of combustion	Ash, Smoke	Smoke	Ash less, Smoke less
7. Ignition Temp.	High	Low	Lowest
8. Mode of supply (pipe)	Cannot	Can be	Can be
9. Thermal efficiency	Low	High	Highest
10. Care in storage & Transportation	Less Care	Care is necessary	Great care is necessary
11. Control on combustion	Can't control	Can be control	Can be control
12. Fuel in IC engine	Can't use	Can be used	Can be used
13. e.g.	Wood, Coal	Petrol, Diesel	Bio gas, Producer gas

Air Fuel Ratio: Excess,Low Least

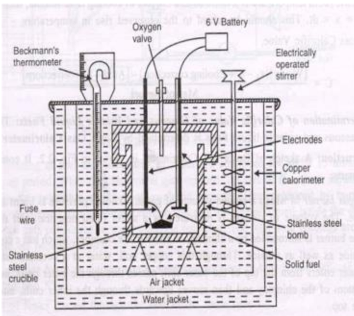
Fire Hazard: Less chance, High risk, Highest risk

Determination Of CV

1. **Determination of calorific value of solid and non volatile liquid fuels:** It is determined by bomb calorimeter.

- **Principle:** A known amount of the fuel is burnt in excess of oxygen and heat liberated is transferred to a known amount of water. The calorific value of the fuel is then determined by applying the principle of calorimetery

i.e. Heat gained = Heat lost



- **Construction:** It consists of central strong stainless steel cylinder; with lead this lead having
- 1. Pair of screw: with the help of screw we make whole assembly air tight.
- 2. Pair of electrode: It helps to carry out process of combustion.
- 3. Non return oxygen valve: It supplies required oxygen for process of combustion
- Out of two electrodes, one having small ring at the bottom, on which Nickel or Stainless steel crucible is suspended.
- Sample with known weight is taken in crucible for process of combustion.
- This bomb is kept in copper calorimeter, containing known weight of water.
- The heat absorbed by water during combustion is uniformly distributed with the help of electrically rotating stirrer & it is recorded by Beckmann's thermometer.
- This copper calorimeter is surrounded by air & water jacket, which prevent loss of heat due to radiation & prevent absorption of heat from outside respectively.
- **Working:** Take known quantity of fuel in crucible.
- Stretch Mg-fused wire across two electrodes in such a way that, it touches fuel sample under test.
- The lid of the bomb is screwed. The bomb is then filled with oxygen of 25 atm.
- This bomb is kept in copper calorimeter containing known weight of water.
- Note down initial temperature of water.
- Connect electrodes to terminals of the battery & carry out combustion.
- Note down maximum temperature attended by water.
- **Calculations**
- Let weight of the fuel sample taken = x g
- Weight of water in the calorimeter = W g
- Water equivalent of the Calorimeter, stirrer, bomb, thermometer = w g
- Initial temperature of water = $t_1{}^oC$
- Final temperature of water = $t_2{}^oC$
- Higher or gross calorific value = HCV cal/g
- Heat gained by water = W x Dt x specific heat of water
- = W (t_2-t_1) x 1 cal
- Heat gained by Calorimeter = w (t_2-t_1) cal

- Heat liberated by the fuel = x HCV cal
- Heat liberated by the fuel = Heat gained by water and calorimeter
- x HCV = (W+w) (t_2-t_1) cal
- HCV=(W+W)(t_2-t_1)/X cal/g
- **Net Calorific value:**
- Let percentage of hydrogen in the fuel = H
- Weight of water produced from 1 gm of the fuel = 9H/100 gm
- Heat liberated during condensation of steam
- = 0.09H $\times$ 587 cal
- Net (Lower calorific value) = GCV-Latent heat of water formed
- = HCV-0.09H $\times$ 587 cal/gm
- **Corrections:** For accurate results the following corrections are also incorporated:

(a) **Fuse wire correction:** As Mg wire is used for ignition, the heat generated by burning of Mg wire is also included in the gross calorific value. Hence this amount of heat has to be subtracted from the total value.

(b) **Acid Correction:** During combustion, sulphur and nitrogen present in the fuel are oxidized to their corresponding acids under high pressure and temperature.

- $S + O_2 \rightarrow SO_2$
- $2SO_2 + O_2 + 2H_2O \rightarrow 2H_2SO_4 \quad \Delta H = -144000Cal$
- $2N_2 + 5O_2 + 2H_2O \rightarrow 2HNO_3 \quad \Delta H = -57160Cal$
- The corrections must be made for the heat liberated in the bomb by the formation of H_2SO_4 and HNO_3. The amount of H_2SO_4 and HNO_3 is analyzed by washings of the calorimeter.
- For each ml of 0.1 N H_2SO_4 formed, 3.6 calories should be subtracted.
- For each ml of 0.01 HNO_3 formed, 1.43 calories must be subtracted.
- **(C) Cooling correction:** As the temperature rises above the room temperature, the loss of heat does
- occur due to radiation, and the highest temperature recorded will be slightly less than that obtained. A temperature correction is therefore necessary to get the correct rise in temperature.
- If the time taken for the water in the calorimeter to cool down from the maximum temperature attained, to the room temperature is x minutes and the rate of cooling is dt/min, then the cooling correction = x $\times$ dt. This should be added to the observed rise in temperature.
- Therefore, Gross calorific value
- HCV=(W+w)$(t_2-t_1$+Cooling correction)-[Acid+ fuse corrections] / Mass of the fuel.
- **HCV = (W + w) (t2 – t1) S/ X in Joule or KJ**

Net Calorific value (LCV)

$$= [HCV - \frac{9H}{100} \times 587] kcal / kg$$

$$= [HCV - 0.09H \times 587] kcal / kg$$

- **Numerical problem:** A sample of coal containing 91% C, 5% H & 3% ash. When this coal was tested in laboratory for it's calorific value in bomb calorimeter, the following data were obtained.
- Weight of coal burnt = 0.95 gm, Wt of water taken = 700 gm, Water equivalence of apparatus = 2000gm, Rise in temperature = 2,48 ^{0}C, Cooling correction = 0.02^{0}C, Acid correction = 60 cal, Fused wire correction = 10 cal. Calculate Net & Gross CV assuming latent heat of condensation of steam as 580 cal/ gm

- Given: x =Weight of coal burnt = 0.95 gm, W = Wt of water taken = 700 gm, w = Water equivalence of apparatus = 2000gm,

- t2- t1 = Rise in temperature = 2,48 ^{0}C, Cc = Cooling correction = 0.02^{0}C, Ac = Acid correction = 60 cal, Fc = Fused wire correction = 10 cal. &Latent heat of condensation of steam as 580 cal/ gm

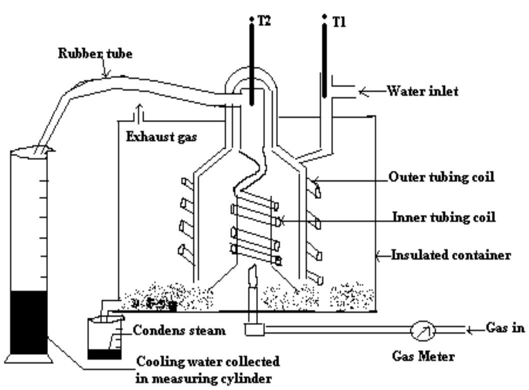
- HCV= (W + w) (t2 – t1+ Cooling correction) – (Acid correction + Fused wire correction)/ X in Cal/g or Kcal/kg
- = (700 + 2000) (2.48 + 0.02) – (60 + 10) / 0.95
- = 7031.6 Cal/ g
- LCV= HCV – (0.09*H*580) in Cal/g or Kcal/kg
- = 7031.6 – (0.09 * 5 * 580)
- = 6770.6 Cal/g or Kcal/kg
- HCV= 7031.6 Cal/ g or Kcal/kg = 7031.6 * 4.18 = 29392 J or KJ
- LCV= 6770.6 Cal/g or Kcal/kg = 6770.6 * 4.18 = 28301.108 or KJ

Determination of CV

1. **Determination of calorific value of volatile liquid and gaseous fuels:** It is determined by boy's calorimeter.

- **Principle:** A known volume of the fuel is burnt in in time "t". Heat liberated is transferred to a known Volume of water in time "t". The calorific value of the fuel is then determined by applying the principle of calorimetery

- i.e. Heat gained = Heat lost



Boy's Calorimeter

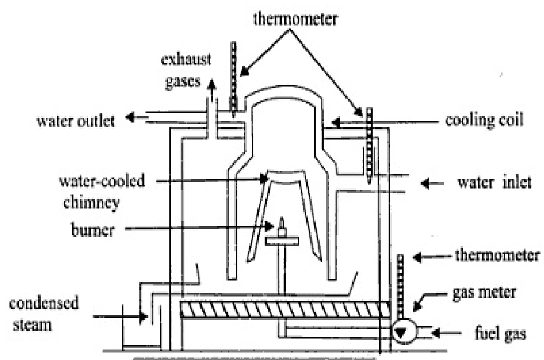


Fig. 11.2 Boy's calorimeter

- **Construction:**
- The apparatus consists of a suitable gas burner in which a known volume of gas at a known pressure can be burnt at a uniform rate of 3 to 4 liter per minute.
- Combustion taking place in combustion chamber, which has copper tubing coiled inside & out side the chamber.
- Water at constant rate is passed through the coil.
- Water enters from top of the outer coil, moves to the bottom of combustion chamber &then goes up through the inner coil to the exit at top. The thermometer T1 &T2 gives the temperature of incoming & outgoing water respectively.
- During the process of down & up movement through coil, the flowing water takes away practically whole of the heat of burner & any steam formed during combustion condensed gets as water, which can be collected. The whole assembly is enclosed in an insulating container.
- **Working:**

- Circulation of water & burning of gaseous fuel are continued at constant rate for about 15 minutes for initial worm up.
- The rate of fuel burning & water circulation is controlled so that the exit water leaves the apparatus nearly at atmospheric pressure.
- When steady conditions are established then readings are taken simultaneously of
- i) the volume of gas burnt at given temperature & pressure in certain time ‘t’
- ii) The quantity of water passing through the coil, during the same time ‘t’
- iii) The steady rise in temperature (T2 –T1) &
- iv) mass of water condensed during same time ‘t’
- **Calculation:** V = Volume of gas burnt at STP in certain time ‘t’,
- W = Mass of water in gram used in time ‘t’,
- T1 = Temp. of inlet water, T2 = Temp. of outgoing water,
- m = Mass of steam condensed when V volume of gas burnt in time ‘t’ L = HCV & S = Specific heat of water (4.18 KJ/Kg)
- Heat liberated during process of combustion = **L V**
- Heat absorbed by circulating water during process of combustion = **W (T2 - T1)**
- But Heat liberated during process of combustion = Heat absorbed by circulating water during process of combustion
- **L V = W (T2 - T1)**
- **Therefore L = [W (T2 – T1) / V] in Kcal / m^3**
- **HCV= L = [W (T2 – T1) / V] * S in KJ**
- **Mass of water condensed from 1m^3 of gas = m / V**
- **Therefore Latent heat of steam per m^3 of gas = m X 587 / V**
- **Therefore LCV =[L – (m X 587 / V)] in Kcal/ m^3**
- **LCV =[L – (m X 587 / V)]* S in KJ**
- **Numerical problem:** Following data were obtained in Boy’s gas calorimeter.
- Volume of gas used = 0.1 m^3 at STP, Weight of water used = 25 Kg, Temperature of inlet water = 20^0C, Temperature of outgoing water = 33^0C, weight of steam condensed = 0.025 Kg. Calculate HCV & LCV. Take the heat liberated in condensing water vapor & cooling the condensate as 580 Kcal/ Kg.
- Given: **V**= Volume of gas used = 0.1 m^3 at STP,**W** =Weight of water used = 25 Kg, **T1** = Temperature of inlet water = 20^0C, **T2** = Temperature of outgoing water = 33^0C, **m** = weight of steam condensed = 0.025 Kg. Take latent heat of condensation 580 Kcal/ Kg.
-
- **HCV= L = [W (T2 – T1) / V] in Kcal / m^3**
- **= 25 (33- 20)/0.1 = 3250 Kcal / m^3**
- **= 3250 X 4.18 = 13585 KJ**
- **LCV =[L – (m X 580 / V)] in Kcal/ m^3**
- **= [3250 – (0.025 X 580 / 0.1)] = 3105 Kcal / m^3**

  = 3105 X 4.18 = 12978.9 KJ

Theoretical calculation of Calorific value of a Fuel: The calorific value of a fuel can be calculated if the percentages of the 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 = 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-O/8

HCV = $$= \frac{1}{100}[8080C + 34{,}500(H - \frac{O}{8}) + 2{,}240S]kcal/kg$$

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

Example 1. *A coal has the following composition by weight $C = 90\%$, $O = 3\%$, $S = 0.5\%$, $N = 0.5\%$ and ash = 2.5%. Net calorific value of the fuel was found to be 8490.5 kcal/kg. Calculate the percentage of H and GCV.*

Sol.
$$\text{HCV} = \text{net calorific value} + (0.09\text{ H} + 587)\text{ kcal/kg}$$
$$= (8490.5 + 0.09\text{ H} + 587)\text{ kcal/kg} \qquad [\because \quad \text{H} = \%\text{ of hydrogen}]$$
$$= (8490.5 + 52.8\text{ H})\text{ kcal/kg}.$$
$$\text{HCV} = \frac{1}{100}\left[8080 \times 90 + 34500\left(\text{H} - \frac{3}{8}\right) + 2240 \times 0.5\right]\text{ kcal/kg}.$$
$$= 7754.8 + 345\text{ H} = \text{kcal/kg}.$$
$$= 7754.8 + 345\text{ H} = 8490.5 + 52.8\text{ H}.$$
$$\therefore \quad 7754.8 + 345\text{ H} = 8490.5 + 52.8\text{ H}.$$
$$\text{or} \quad 292.2\text{ H} = 1335\%$$
$$\therefore \quad \text{H} = 4.575\%$$
$$\therefore \quad \text{HCV} = (8490.5 + 52.8 \times 4.575) = 8731.8\text{ kcal/kg}.$$

3.8 What are Fuel Cells? Explain the Classification of Fuel cells based on temperature

Fuel cells are the galvanic cells in which chemical energy of fuel is directly converted into electrical energy.

Classification of Fuel cells

These are classified into three types as follows.

1] Low temp fuel cells: Which operates at the temp range about 75₀ C and contains water base electrolytes.

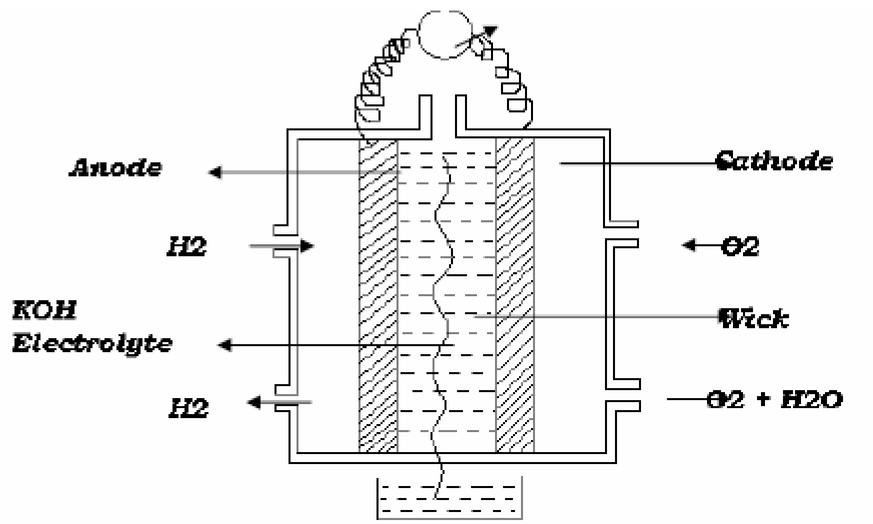
2] Moderate temp fuel cells: Which operates at the temp range about 600₀ C and contains salt electrolyte.

3) High temp fuel cells: Which operates at the temp range about 1000₀ C and contains ceramics as electrolyte.

Difference between battery and fuel cell

Battery	Fuel cell
1. A battery stores the chemical reactants, usually metal compounds once used up you must recharge or throw away the battery	1.A fuel cell creates electricity through reactants stored externally

Explain the construction and working of $H_2 – O_2$ fuel cell.



H2-O2 Fuel cell

Hydrogen - oxygen fuel cells consisting of two porous graphite electrodes, which is impregnated with an electro catalyst such as finely, divided Pt – Co - Ru or Pt-Ni-Ru. Concentrated KOH is used as an electrolyte. A wick is placed to maintain water balance. Hydrogen gas and oxygen gas are continuously supplied to the anode and cathode respectively. The hydrogen undergoes combustion generating electric current. The cell delivers an emf of 1.23v. The cell reactions are as follows.

At anode : $H_2(g) + 2OH^-(aq) \longrightarrow 2H_2O + 2e^-$

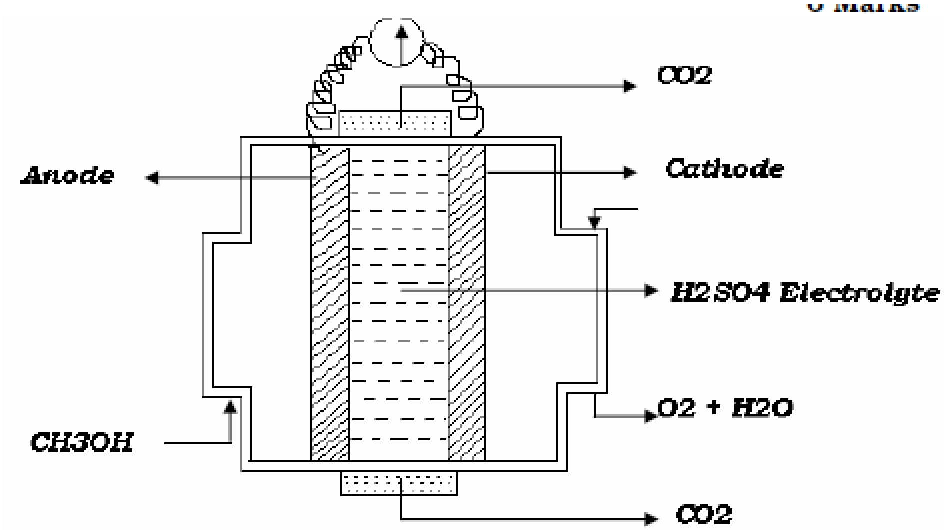
At cathode : $½ O_2(g) + H_2O + 2e^- \longrightarrow 2OH^-$

NCR : $H_2(g) + ½ O_2(g) \longrightarrow H_2O(l)$

Uses: The H_2-O_2 cells are used in Space vehicles, military and mobile power systems

Explain the construction and working of Methanol – Oxygen fuel cell.

6 Marks



CH3OH - O2 Fuel cell

It consists of two electrodes made up of platinum in between the electrodes H_2SO_4 is placed as a electrolyte. Methanol and H_2SO_4 is supplied at the anode and pure oxygen gas is supplied at the cathode. The ethanol is oxidized to CO_2 & H_2O with the liberation of electrical energy. The cell delivers an emf of 1.20v. The cell reactions are as
follows.

$$\text{At anode} \quad : CH_3OH + H_2O \longrightarrow CO_2 + 6H^+ + 6e^-$$

$$\text{At cathode} \quad : \tfrac{3}{2}\, O_2 + 6H^+ + 6e^- \longrightarrow 3H_2O$$

$$\text{NCR} \quad : CH_3OH + \tfrac{3}{2}\, O_2 \longrightarrow CO_2 + 2H_2O$$

Uses:
1) Used in Military applications.
2) Used for large scale power production stations
Explain the Classification of fuel cells based on the electrolyte
Fuel cells are classified into the following types based on the type of electrolyte used.
1) Alkaline fuel cells.
2) Phosphoric acid fuel cell.
3) Molten carbonate fuel cell.
4) Solid oxide fuel cell.
5) Solid polymer electrolyte fuel cell.
1) Alkaline fuel cells: These fuel cells containing alkali such as KOH or NaOH as electrolyte. Hydrogen is used as fuel and oxygen gas is used as an oxidant. The cell operates at a temp of 80^0C.
Uses: These are used in emergency lights and portable power generations, space applications, military applications etc.,
2) Phosphoric acid fuel cells: These fuels cells consisting of 98% phosphoric acid, 2% water as electrolyte, O_2 is used as oxidant. Hydrogen LPG, NPG etc are used as fuels. These operate at a temp 190 to 200 ^oC . Platinum alloys such as platinum- cobalt- chromium, are used as electro catalyst.
Uses: These cells are used to provide light and heat in large buildings.
3) Molten carbonate fuel cells: These fuel cells consisting of molten carbonates such as lithium carbonate 26.2% and potassium carbonate (K_2CO_3) 23% and lithium. Aluminum carbonate as electrolyte. The anode is made up of nickel and cathode made up of nickel oxide. Operating temperature is 650^0C.
Uses: These are used in chemical industries such as aluminium Cloroalkali industries.
4) Solid oxide fuel cells: These contains ZrO_2, Y_2O_3 are solid electrolytes. Cathode is made up of porous strontium doped with $LaMnO_3$ or In_2O_3 and SnO_2. Anode is made up of cobalt, nickel, or ZrO2. Operating temperature is 1000 ^0C.
Uses: These cells are used in KW power plants, water heating etc,

5) Solid Polymer Electrolyte: These contain ion exchange membrane as solid electrolyte for ionic conduction “nafion–R” membranes which are chemically and electrochemically stable at 200^0C are used .Operating temperature of the cell is 80^0C. The electrodes are made up of platinum and noble metals are used as electro catalysts.

Uses: Used in the manned Gemini terrestrial orbital missions.

Advantages of fuel cell:

1. It has high efficiency because it converts energy isothermally (Chemical into electricity). In heat engine subjected to Carnot cycle.
2. No moving parts in fuel cell, involving silent operation (no sound pollution) and high operation reliability.
3. Easy to maintain fuel cell.
4. Clean operation i.e. No polluting exhaust.
5. Completion fuel consumption i.e. fuel efficient.
6. No consumption of electrode. Cell capacity decided by fuel tank size.
7. Fuel cell have modular construction, which is simple and easy to maintain and repair.

Disadvantages of fuel cells

1. Requires a constant fuel supply.
2. They are expensive.
3. Some types of fuel cell use expensive electrolytes and catalysts.
4. They generate direct current (DC) Many appliances works on AC.
5. Effectiveness of some fuel cells are affected by impurities in the hydrogen fuel.
6. Use of fuel cell in transport is limited by lack of facilities for hydrogen storage and distribution.