...accomplished is not quite clear, but it is to be associated with the fact that two ions ($K^+$ and $Cl^-$) in KCl or ($NH_4^+$ and $NO_3^-$) in $NH_4NO_3$ possess nearly equal speeds and these operate to yield junction potentials between two solutions of the cell and salt bridge. These potentials are opposite in sign and hence cancel each other. It is still more questionable whether there such bridge can reduce the junction potentials to a point where they are negligible, Neverthelees, effective or not, the fact remains that salt bridges have come in to existence.

The second method involves the addition of indifferent electrolytes, at the same concentration to both sides of the cell. If the added substance has a concentration greater than that of any other electrolyte, then the added salt carries almost the whole of the current across the junction between the two solutions. As the concentration of added salt is same on both sides of the boundary then the liquid junction potential will be negligible. This method is not used these days because the indifferent electrolyte added has a marked effect on the activity of the substance in solution.

## 10.14. FUEL CELLS

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

or

Fuel cells are the electrochemical devices which convert the energy of fuel oxidation reactions into electrical energy.

Theoretically the effectiveness of transforming chemical energy into electrical energy through heat is very slow. For this reason, at the end of $19^{th}$ century, scientists attempted to create devices for the direct conversion of chemical energy into electrical energy without the intervention of thermal devices such as generators turbines etc. This required the development of galvanic cells in which the reactions of oxidation of the fuel and reduction of the oxygen proceed electrochemically. The first fuel cell was constructed in 1839 by the British physicist and lawyer Sir William Robert Grove; it had platinum electrodes with hydrogen bubbled over one electrode and oxygen over the other. For many years little was done to develop fuel cells for commercial purposes, but since the 1960s there has been a considerable revival of interest in this problem, particularly in view of present energy shortages. Recent advances in technology and electrochemistry have made the scientists successful to introduce the fuel cell which are more efficient, than thermal source of electrical energy. Fuel cells have been used as sources of auxiliary power in space craft, and major research efforts are under-way to develop their use in automobiles in order to minimize air pollution and noise Fuel cells employ the same electrochemical principles as conventional cells. Their distinguishing feature is that the reacting substances are continuously fed into the system, so, that fuel cells, unlike conventional cells, do not have to be discarded when the chemical are consumed. In fuel cells an attempt is made to make the fullest possible use of the free energy of reactions, such as combustion of fuels, to produce electrical energy. Processes are chosen which occur as nearly reversible as possible in order to obtain the maximum useful proportion of free energy change. The mode of operation of fuel cells is fundamentally different from that of batteries. While batteries store electrical energy fuel cells convert energy obtainable from chemical powers directly into electrical energy.

**Kinds of Fuel Cells**

Depending on the kind of fuel used, we have the following types of fuel cells:

(i) Hydrogen-oxygen fuel cell.

(ii) Hydrocarbon-oxygen fuel cell

(iii) Carbon monoxide-oxygen fuel cell

(iv) Methyl alcohol-oxygen fuel cell

(v) Solid coal-oxygen fuel cell

**Hydrogen-Oxygen Fuel Cell**

This fuel cell consists of two electrodes made of porous graphite. Platinum is coated on the surface of the electrodes. The electrodes are placed in aqueous solution of NaOH or KOH. Hydrogen and oxygen are bubbled into the cell under a pressure of about 50 atm. When the electrodes are connected, a flow of electric current takes place.

The electrode reactions are:

**Anode reaction:**

$$H_2 \longrightarrow 2H^+ + 2e^-$$

$$2H^+ + 2OH^- \longrightarrow 2H_2O$$

The net half-cell reaction is

$$H_2 + 2OH^- \longrightarrow 2H_2O + 2e^-$$

Cathode reaction:

$$\frac{1}{2}O_2 + H_2O + 2e^- \longrightarrow 2OH^-$$

Now, the overall cell reaction is

$$2H_2(g) + O_2(g) \longrightarrow 2H_2O(l)$$

The emf of the cell is found to be 1.23 volts. The cell reaction is the same as combustion of $H_2$ in air or oxygen. The energy of the fuel oxidation has not been liberated as heat but it has being directly converted into electrical energy. Fig. 10.9 gives a schematic diagram of such cell.

For an efficient cell all processes must occur rapidly. Reactant must be able to reach the electrodes easily so that porous electrodes with large internal surface area, saturated with electrolyte, are used. Such cells are used in space crafts. The electrolyte used in these cells is an ion-exchange material and not a solution of NaOH or KOH. This ion-exchange material is used in the form of a membrane. This membrane allows easy flow of protons ($H^+$) which react with $O_2$ and electrons to form $H_2O$.

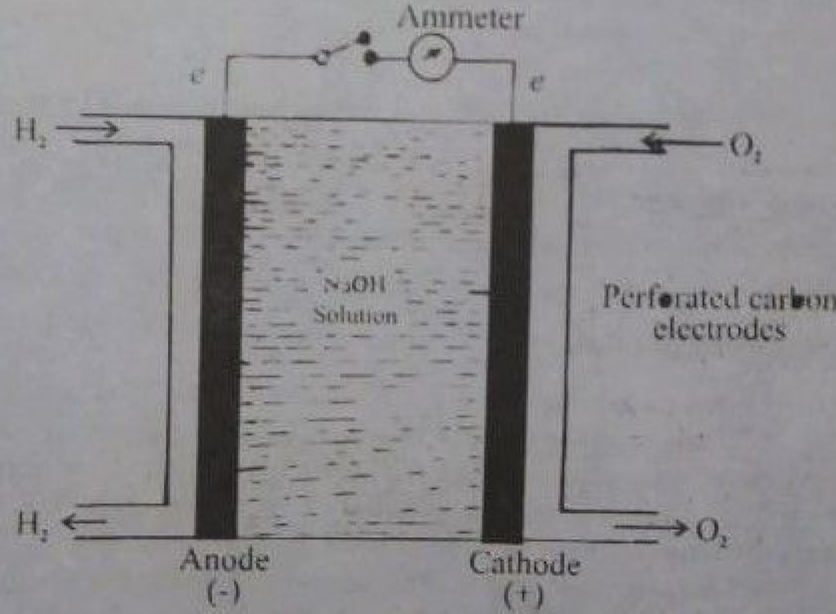


Fig. 10.9 Hydrogen-Oxygen Fuel Cell.

**Efficiency of Fuel Cells**

The ability of a cell to convert chemical energy of a fuel-oxidation reaction into electrical energy is expressed in terms of efficiency of the cell (ε). It is defined as

$$\varepsilon = \frac{\Delta F}{\Delta H} \times 100 \qquad (10.42)$$

Where $\Delta H$ = Maximum available heat, when oxidation of fuel

Occurs at constant temperature and pressure.

$\Delta F$ = The part of this energy i.e., part of $\Delta H$, convertible into electrical energy

The efficiency of different fuel cells is given as under:-

1. $H_2 - O_2$ fuel cell: $\Delta F^{\circ} = -273.2$ kJ mole$^{-1}$

$\Delta H^{\circ} = -258.9$ kJ mole$^{-1}$

$$\epsilon = \frac{\Delta F}{\Delta H} = \frac{-273.2 \times 100}{-258.9} = 83\%$$

2. Carbon $O_2$ fuel cell: $\epsilon = \frac{\Delta F}{\Delta H} = \frac{-137.3 \times 100}{-110.0} = 124\%$

3. $CH_4$-$O_2$ fuel cell: $\epsilon = \frac{\Delta F}{\Delta H} = \frac{-818.0 \text{ kJ mole}^{-1} \times 100}{-890.4 \text{ kJ mole}^{-1}}$

$= 92\%$

4. $CH_3OH$-$O_2$ fuel cell: $\epsilon = \frac{\Delta F}{\Delta H} = \frac{-706.9 \text{ kJ mole}^{-1} \times 100}{-764.0 \text{ kJ mole}^{-1}} = 93\%$

**Superiority of Fuel Cells**

1. The fuel cells possess very high efficiency. By using certain kinds of fuel in such cells 75-90 percent conversion of chemical energy of the fuel into electrical energy has been made possible. In heat engines the efficiency does not exceed 40 percent.
2. The individual cells can be stacked and connected in series to generate higher voltage.
3. They are also very light.
4. The fuel cells do not create pollution problems.
5. These cells play an important role in manned space flights.

**Practical Success of Fuel Cells**

Owing to various technological and operational difficulties (such as increased requirements of the purity of the fuel, the insufficient period of services, etc.), however the economical advantages of the fuel cells even with their higher efficiency are still not clear. For this reason, the possibility of using them for production of electrical energy, instead of heat power plants, requires further study. If these problems could be solved, the fuel cell technology would bring revolution in the area of energy production. There is no doubt, however that for more limited purposes fuel cells will find broad applications in the nearest future (e.g., they have been successfully employed in the manned space flights.)