HYDROGEN ENERGY

INTRODUCTION

Hydrogen energy (“*energy carrier*“ *like electricity*) *is an alternative energy of future which can also be stored in addition to other qualities of electrical energy*. But it is *highly inflammable* and special handling precautions are needed during its production, transportation, storage and utilisation.

- Hydrogen energy has a *tremendous potential* because it can be produced from *water* which is available in a*bundance in nature*. It can be produced from water by using *solar energy*. *All plants and hydrocarbons* (*fossil fuels*) *are sources of hydrogen*.

- Hydrogen has the *highest energy content per unit mass*. Its specific energy content is almost *three times that of hydrocarbon fuels*. Therefore, it can be directly used as aircraft fuel for air transport. It has been used as a fuel for space crafts. A H_2-O_2 fuel cell *liberates energy and also water as sole material product* for the use of space craft passengers.

- The simplest way to obtain hydrogen from water is its "*electrolysis*" using electricity. The latter can be generated from renewable energy sources like solar energy, wind energy and geothermal energy.

- The *main issues* associated with the *use of hydrogen at energy* source are: Production; (*ii*) *Storage and transportation*; (*iii*) *Utilisation;* (*iv*) *Safety* and *Management*, and (*v*) *Economy.*

Sources of hydrogen: Hydrogen is found only in compound form with other elements. H2 combines with O2 to form water. Hydrogen combines with carbon to form different compounds such as coal, petroleum, methane gas etc.

10.2. PROPERTIES OF HYDROGEN

The *properties* of hydrogen are:

1. The burning process of hydrogen is *pollution free*.

2. The standard heating value of *hydrogen gas* is 12.1 MJ/m_3 compared with 38.3 MJ/m^3 for natural gas.

3. The heating value of *liquid hydrogen* is 120 MJ/kg or 8400 MJ/m^3 as compared to 44 MJ/kg or 32000 MJ/m^3 of aviation petrol.

4. Hydrogen is a *light gas* at *room temperature and pressure*. Its density is 1/4 th of that air and 1/9 th that natural gas.

5. Hydrogen can be *liquefied at –253°C at atmospheric pressure*. The liquid hydrogen has a *specific gravity of 0.07* which is 1 /10 th that of gasoline.

6. Mixture of hydrogen and air are *combustible over wide range of composition*. The flammability limits are from 4 to 74% by volume of hydrogen in air at ordinary temperatures.

7. The flame speed of hydrogen when burning in air is *much greater* than for natural gas.

8. The ignition energy to initiate combustion is *less* for hydrogen than for natural gas.

10.3 ADVANTAGES OF HYDROGEN AS FUEL

Following are the *advantages* of hydrogen as fuel:

1. *Very* high energy content.

2. Burning is *non-polluting*.

3. Hydrogen produced from biomass and supplied to the consumers in the transport sector *costs only 50%* compared to hydrogen produced electrolytically.

4. For fuel-cell operated bus, hydrogen produced from biomass can *compete well* with gasoline-operated vehicles.

5. It is a *superior fuel for turbojet aircraft* due to *greater economy*, *lower noise level* and *little pollution*.

6. Hydrogen as a velicular fuel can reduce dependence on fossil fuel which is increasing in cost every year.

7. Hydrogen can easily be transported and distributed through pipelines.

8. Hydrogen being a high density fuel, its low transport cost compensates for its high product cost to make it an *economically viable fuel*.

9. Hydrogen can be used for generating electricity for domestic appliances, in domestic cooking as a fuel, in automobiles etc.

10.4. APPLICATIONS OF HYDROGEN (ENERGY)

Following are the *applications* of hydrogen energy:

1. It can be used for H_2–O_2 *fuel cell* for production of electrical energy.

2. Hydrogen is used as fuel in *aircrafts and rockets in liquid form.*

3. *Used in cooking, water heaters* and *air-conditioning.*

4. Can also be used in *furnaces*.

5. Can also be used in *generators.*

6. Widely used in petroleum refining.

7. Widely used in manufacture of vanaspati, fertilizers and alcohols.

10.5. PRODUCTION OF HYDROGEN

The *most commonly used methods of production of hydrogen* are enumerated and described as follows:

1. Electrolysis of water.
2. Steam reformation.
3. Coal gasification.
4. Methane gas reformation.
5. Biological production of hydrogen.
6. Photo-electrolysis

The methods of producing hydrogen may be *classified* according to the *immediate source of addition of energy to decompose* as follows:

1. *Electrical energy* .... Electrolysis
2. *Fossil fuels* ..... Steam reformation; Coal gasification
3. *Heat energy* ..... Thermo-chemical methods
4. *Solar energy*:

(*i*) Bio-photolysis. (*ii*) Photo-electrolysis.

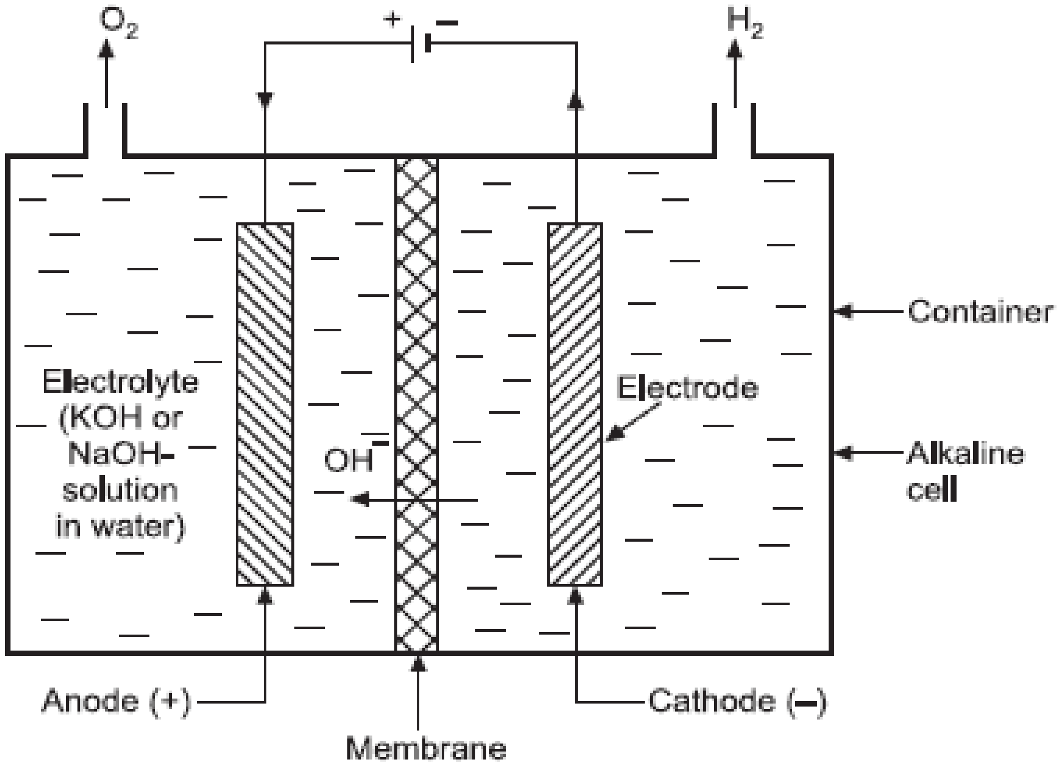
Electrolysis of Water

It is the process in which hydrogen splits from water by means of direct electrical current, by using two electrodes and electrolyte.

The reaction of electrolysis is as follows:

$$2H_2O \xrightarrow{\text{Direct current}} \underbrace{2H_2}_{\text{At cathode}} + \underbrace{O_2}_{\text{At anode}} + \text{Heat energy released}$$

Fig. 10.1 shows the *principle of operation of an alkaline water electrolysis cell.*



The reactions at cathode and anode are given below:

Cathode: $4H_2O + 4e^- \longrightarrow 2H_2\uparrow + 4OH^-$

Anode: $4OH^- \longrightarrow O_2\uparrow + 2H_2O + 4e^-$

Overall reaction: $\underbrace{2H_2O}_{\text{Electrolyte}} + \text{Energy} \longrightarrow \underbrace{2H_2}_{\text{At cathode}} + \underbrace{O_2}_{\text{At anode}}$

The energy required to produce hydrogen is 3.5 kWh/m^3.

The *available electrolysis* processes are:

1. Alkaline electrolysis,
2. Membrane electrolysis, and
3. High temperature steam electrolysis.

10.5.2. Steam Reformation (Fossil Fuels)

In this process, steam is passed over hot sponge iron sheets at a suitable temperature where hot iron and steam react to produce *ferric oxide* (Fe_2O_3), hydrogen (H_2), carbon dioxide (CO_2) and carbon monoxide (CO) in small quantities. The gases are passed through a *scrubber* where dilute NaOH absorbs CO_2 and CO.

Reaction: $3H_2O + 2Fe \rightarrow Fe_2O_3 + 3H_2$

10.5.3. Coal Gasification

In the gasification of coal, there is *complete conversion of the organic part of the coal into gas*, so that ash alone remains. This is done by reacting the coal with a gasifying agent *e.g.* steam above 700°C.

In this process, the carbon in coal reacts with steam to form CO and H_2. This low energy gas mixture is submitted to water gas shift reaction with *steam*. The CO is then converted into CO_2 with the formation of *additional* H_2 *gas*.

The *reactions* for coal gasification are:

$$C + H_2O \rightarrow CO + H_2$$

$$CO + H_2O + H_2 \rightarrow 2H_2 + CO_2$$

10.5.4. Methane Gas Reformation

In this process, *methane mixed with steam is passed over a nickel oxide catalyst at elevated temperature*. The *reforming reaction* being *endothermic*, it is usually carried out in fire tube reformed in a fire to be reformer where the catalyst is loaded in the tubes.

The reaction for methane gas reforming:

$$CH_4 + H_2O \rightarrow CO + 3H_2 + \text{Heat energy } \textit{released}.$$

After steam reforming, the gas products contain considerable amount of CO which may further undergo reaction with *additional steam*, and it *increases the* H_2 production.

The reaction of CO with steam:

$$CO + H_2O \rightarrow CO_2 + H_2 + \text{Heat energy } \textit{absorbed}.$$

The above reaction is known as water gas shift reaction which is *exothermic*.

10.5.5 THERMO-CHEMICAL METHOD

The thermo-chemical method *involves thermal chemical reactions between primary energy, water and specific chemicals to produce hydrogen at temperatures range from 700°C to 1000°C.*

General thermo-chemical *reactions*:

$$ZO_x + H_2O \rightarrow ZO_{x+1} + H_2$$

$$ZO_{x+1} + \text{Heat} \rightarrow ZO_x + \frac{1}{2}O_2$$

where Z represents a *metallic ion or a complex radical.*

10.5.6. Solar Energy Methods

These methods are described below:

10.5.6.1. Bio-photolysis (Biological production)

In this process, Hydrogen is produced with the help of photosynthetic micro-organisms. Blue green algae as well as other anaerobic bacteria are capable of splitting water into hydrogen and oxygen by light driven process and such a process is called *bio-photolysis.*

10.5.6.2. Photo-electrolysis.

In this process, the *decomposition of water into hydrogen and oxygen takes place with the help of electric current which is generated by exposing electrode to sunlight.*

In this process at least one of the electrodes is usually *semiconductor; a catalyst may be included to facilitate the electrode process.*

10.6. HYDROGEN STORAGE

The need for storage arises due to the almost inevitable mismatch between the optimum production rate of energy and fluctuations in demand for energy by users.

The following *three* methods are used for *storage of hydrogen*:

1. Compressed gas storage.
2. Liquid storage.
3. Solid state storage.

10.6.1. Compressed Gas Storage

Hydrogen can be stored in compressed gaseous state in *underground reservoirs* similar to natural gas or can be stored in *high pressure cylinders*.

This method of storage is costly as large quantity of steel is required to store a small amount of hydrogen. The gaseous storage of hydrogen, for industrial use is *economically not viable as a fuel*.

10.6.2. Liquid Storage

Liquid hydrogen fuel is used as a *rocket propellent* in space vehicles as it has the *highest energy density* which is almost *three times the conventional fuels.*

It boils at –253°C (*i.e.,* 20 K) and therefore must be maintained at or below this temperature in storage unless pressure build up can be tolerated. It is necessary to use insulated cylinder to *avoid air condensation* over its surface.

The main *problems associated with the storage of hydrogen are:*

1. Flammabily danger from the fact that liquefied atmospheric gases, rich in oxygen, would concentrate in the vicinity of hydrogen tank.
2. Considerable amount of energy (25-30% of the heating value of hydrogen) is required to convert hydrogen gas into the liquid phase.

Thus, a liquid hydrogen plant requires some kind of primary refrigeration, such as a *liquid nitrogen plant, to precool hydrogen.*

10.6.3. Solid State Storage

A number of metals and alloys form solid compounds, called metal *"hydrides"*, by *direct reaction with hydrogen gas.*

In a solid storage, the hydrogen is stored in the form of metallic hydrides. The **metal hydride system** is *based on the principle that a few metals absorb hydrogen in an 'exthermonic reaction' when treated with gas and the absorbed gas is released when the metal hydride is heated.*

The *Chemical reactions* given below:

$$H_2 + \text{Metal} \xrightarrow{\text{Charge}} \textit{Metal hydride} + \text{Heat}$$

$$\text{Metal hydride} + \textit{heat} \xrightarrow{\text{Discharge}} \text{Metal} + \mathbf{H_2}$$

For hydrogen storage, the metal hydride should have the following *properties*:

1. *Large amount of hydrogen per unit volume per unit mass.*
2. Fairly *inexpensive.*
3. Release of gas at a significant pressure from the hybrid at a moderately high temperature, preferably below 100°C.
4. Easy formation of hybride (by reaction of metal with H_2 gas) should be stable at room temperature.

10.7. GAS HYDRATES

Gas hydrates have been identified by ONGC (Oil Natural Gas Commission) as one of the non-conventional energy sources, to be studied for exploration to ensure energy security for the country. These are naturally occurring *ice like compounds* of *methane and are water formed under low temperature and pressure conditions*. These ice formations consist of water molecules that trapped gas molecules in a *cage-like structure*, found at varying depths in areas of low temperature.

The gas hydrates are *important* due to following *reasons*.

1. Total energy contained in hydrogen is estimated to be *double the amount of the total fossil fuels*.
2. Contain a *great volume of methane*, which is a source of cleaner fuel.
3. One volume of gas hydrates produces 164 volume of gas at standard temperature and pressure.
4. Methane made by drilling around these gas hydrates, can be *captured*, *stored* and *fed into pipelines* for further use.

   Methane can be used to extract hydrogen and use it to power fuel cells.

HYDROGEN TRANSPORTATION

Hydrogen can be transported by the following three methods.

1. By Pipelines
2. By insulated tanks.
3. By metal hydride transportation

10.8.1. By Pipelines

Long distance gas transmission lines of lengths greater than about 90 km must be supplied with pipeline compressors at fairly regular intervals. These compressors must handle a *considerably greater volume* of the gas—somewhere between 3 to 4 times the number of m^3 to the same energy capacity. This would require a considerably higher horse power to drive a hydrogen compressor (in comparison then that needed to drive a natural gas compressor for the same energy throughout).

Therefore, the cost of hydrogen transportation by pipelines must include the cost of piping, compressors and power consumption by compressors.

10.8.2. By Insulated Tanks

Hydrogen in bulk can be transported in well insulated cryogenic tanks having liquid hydrogen either by trucks or rails. The transportation cost, however, is very high.

10.8.3. By Metal Hydrides

Hydrogen can also be transported as a solid metal hydride. The main drawback is the heavy weight of hydride relative to its hydrogen yield. The transportation cost is very high.

10.9. SAFETY PRECAUTIONS

Hydrogen is *highly inflammable* and *explosive* and can lead to fire and serious accidents. The production, storage and distribution of hydrogen require special precautions, as given below:

1. The system should be designed to withstand the explosion pressures.
2. The system should be designed to withstand pressure surges.
3. Proper explosion relief system must be provided.
4. Flame traps, flame suppressors, explosion-relief devices and rapid closing devices must be used.
5. The design, manufacture and storage methods/system should follow Petroleum Act.