Module 5

Geothermal Energy Conversion: *Principle of working, types of geothermal station with schematic diagram, geothermal plants in the world, problems associated with geothermal conversion, scope of geothermal energy.*

Energy from Bio Mass: *Photosynthesis, photosynthetic oxygen production, energy plantation, bio gas production from organic wastes by anaerobic fermentation, description of bio-gas plants, transportation of bio-gas, problems involved with bio-gas production, application of bio-gas, application of bio-gas in engines, advantages.*

Hydrogen Energy: *Properties of Hydrogen with respected to its utilization as a renewable form of energy, sources of hydrogen, production of hydrogen, electrolysis of water, thermal decomposition of water, thermos-chemical production bio-chemical production.*

Contents

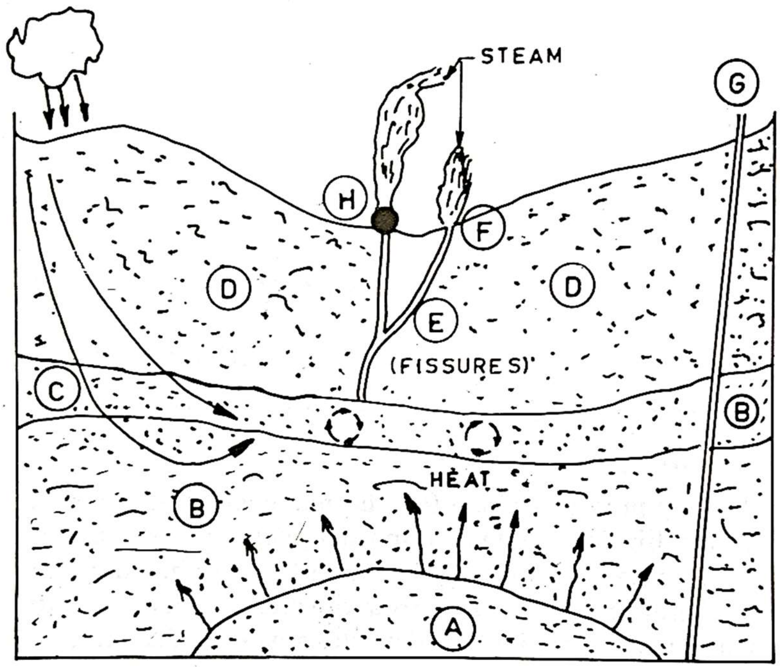
1 Geothermal Energy Conversion

1.1 Introduction

Energy present as heat (i.e., thermal energy) in the earth's crust; the more readily accessible heat in the upper most (10 km) or so, of the crust constitutes a potentially useful and almost inexhaustible source of energy. This heat is apparent from the increase in temperature of the

earth with increasing depth below the surface. Although higher and lower temperatures occur, the average temperature at a depth of 10 km is about 200°C.

U.S. Geological survey defines geothermal source as "all of the heat stored in the earth's crust above 15°C to a depth of 10 km." It occurs when the immense heat energy in the core of earth rises closer to the surface of the earth due to cracks or faults as accounted by the "Plate Techonics Theory", in the crust and heats the surrounded rock. These hot spots can be liquid dominated, vapour dominated, petro-thermal or geo-pressure system, depending upon several geological and hydrological factors. These in turn are tapped artificially to use the vast stored heat energy, for power generation and several other uses, depending upon the temperature of occurrence and other parameters.



Hot molten (or partially molten) rock, called "Magma" is commonly present at depths greater than 24 to 40 km. In some places, however, anomalous geologic conditions cause the magma to be pushed up toward the surface, in an active volcano, the magma actually reaches the surface, where heat of the magma is being conducted upward through an overlying rock layer.

Fig. shows a typical geothermal field. The hot magma (molten mass) near the surface (A) solidifies into igneous rock (B). Igneous is Latin word, igneous meaning "'of fire" specially formed by volcanic action or great heat. (Igneous rock found at the surface is called volcanic action rock). The heat of the magma is conducted upward to this igneous rock. Ground water finds its way down to this rock through fissures in it, will be heated by the heat of the rock or by mixing with hot gases and steam emanating from the magma. The heated water will then rise convectively upward and into a porous and permeable reservoir (C) above the igneous rock. The reservoir is capped by a layer of impermeable solid rock (D) that traps the hot water in the reservoir. The solid rock, however, has fissures (E) that act as vents of the giant underground boiler. The vents show up at the surface as geysers fumarols (F) (steam is continuously vented through fissures in the ground, these vents are called fumarols) or hot spring (G). A well (H) taps steam from the fissures for use in a geothermal power plant. It can be seen that geothermal steam is of two kinds that originating from the magma itself, called magmetic steam, and that from ground water heated by the magma called meteoritic steam. The latter is the largest source of geothermal steam. Not all geothermal sources produce steam as described above. Some are lower in temperature so that there is only hot water. Some receive no ground water at all and contain only hot rock. Geothermal sources are therefore of three basic kinds : (1) hydrothermal (2) geopressured and (3) petrothermal.

The total amount of energy in the outer 10 km of the earth's crust exceeds greatly that obtainable by the combustion of coal, oil and natural gas. At present, however, only the relatively small proportion of the geothermal energy in wet reservoirs (a geothermal reservoir is defined as a region where there is a concentration of extractable heat), may be regarded as economically useful. Nevertheless, this amount is large enough to make a significant contribution to the energy resources. With advances in technology, a portion of the much larger dry geothermal energy resources may also become available.

1.2 Geothermal Sources

Five general categories (or kinds) of geothermal resources have been identified:

(1) Hydrothermal convective systems.
  a. Vapour-dominated or dry steam fields.
  b. Liquid-dominated system or wet steam fields, and
  c. Hot-water fields.

(2) Geo-pressure resources.

(3) Petro-thermal or Hot dry rocks (HDR).

(4) Magma resources.
(5) Volcanoes.

The hydrothermal convective systems are best resources for geothermal energy exploitation at present. Hot dry rock is also being considered.

Hydrothermal Systems: Hydrothermal systems are those in which water is heated by contact with the hot-rock, as explained earlier.

Vapor-dominated Systems: In these systems the water is vaporized into steam that reaches the surface in a relatively dry condition at about 200°C and rarely above 7 kg/cm^3 (8 bar). This steam is the most suitable for use in turbo electric power plants, with the least cost. It does, however, suffer problems similar to those encountered by all geothermal systems, namely, the presence of corrosive gases and erosive material and environmental problems. These type of systems are very less in numbers; they are only five known sites in the world. The Geysers plant in the United States, the largest in the world today, and Larderello in Italy, are both vapor-dominated systems.

Liquid-dominated Systems: In these systems the hot water circulating and trapped underground is at a temperature range of 175 to 315°C. When tapped by wells drilled in the right places and to the right depths, the water flows naturally to the surface or is pumped upto it. The drop in pressure, usually to 7 kg/cm^2 (8 bar) or less, causes it to partially flash to a two-phase mixture of low quality i.e. liquid-dominated. It contains relatively large concentration of dissolved solids ranging between 3000 to 25,000 ppm and sometimes higher. Power production is adversely effected by these solids because they precipitate and cause scaling in pipes and heat exchanger surfaces, thus reducing flow and heat transfer. Liquid dominated systems, however, are much more plentiful than vapour-dominated systems, and, next to them. require the least extension of technology.

Geopressured Systems. These resources occur in large, deep sedimentary basins. The reservoirs contain moderately high temperature water (or brine) under very high pressure. They are of special interest because substantial amounts of methane CH4 (natural gas) are dissolved in the pressurized water (or brine) and are released when the pressure is reduced. Geopressured water is tapped in much deeper underground aquifers (it is a water-bearing stratum of permeable rock, gravel or sand), at depths between about 2400 to 9000 m. This water is thought to be at the relatively low temperature of about 160°C and is under very high pressure, from the overlying formation above, of about 1050 kg/cm^2 (more than 1000 bar). It has a relatively high salinity of 4 to 10 per cent and is often referred to as brine. The geopressured resources are quite large: they could be used for the generation of electric power and the recovery of natural gas if suitable technology could be developed and if individual reservoir productivity and longevity prove to be adequate.

Hot Dry Rocks. (or Petrothermal Systems). These are very hot solid rocks occurring at moderate depths but to which water does not have access, either because of the absence of ground-water or the low permeability of the rock (or both). In order to utilize this resource, means must be found for breaking up impermeable rock at depth, introducing cold water, and recovering the resulting hot water (or steam) for use at the surface. The known temperatures of HDR vary between ~ 150 to 290°C. This energy, called petrothermal energy, represents by far the largest resource of geothermal energy of any type, as it accounts for large per cent of the geothermal resource. Much of the HDR occurs at moderate depths, but it is largely impermeable as stated above in order to extract thermal energy out of it, water will have to be pumped into it and back out to the surface. It is necessary for the heat transport mechanism that a way be found to render the impermeable rock into a permeable structure with a large heat-transfer surface. A large surface is particularly necessary because of the low thermal conductivity of the rock. Rendering the rock permeable is to be done by fracturing it. Fracturing methods that have been considered involve drilling wells into the rock and then fracturing by (1) high-pressure water or (2) nuclear explosives. Efforts in this direction are in progress.

Magma Resources. These consist of partially or completely molten rock, with temperatures in excess of 650°C, which may be encountered at moderate depths, especially in recently active volcanic regions. These resources have a large geothermal energy content, but they are restricted to a relatively few locations. Furthermore, the very high temperatures will make extraction of the energy a difficult technological problem. The geothermal resources outlined above and means used or proposed for their development are described more fully in the following sections.

1.3 Hydrothermal (Convective) Resources

These are wet reservoirs at moderate depths containing steam and/or hot water under pressure at temperatures upto about 350°C. These systems are further subdivided, depending upon whether steam or hot water is the dominant product. Hydrothermal resources represent only a small fraction of the potential geothermal resources, but they are the only ones that have been utilized commercially so far. If the temperature is high enough, the water or steam can be used to generate electricity, otherwise the geothermal energy is best supplied to process and space heating.

Hydrothermal resources arise when water has access to high temperature rocks, this accounts for the description as "hydrothermal' The heat is transported from the hot rocks by circulating movement (i.e. by convection of the water in a porous medium). The general geological structure of a hydrothermal convective region is shown in simplified form in Fig. The molten rock (magma), raised by internal earth forces is overpaid by an impervious rock formation, through which heat is conducted upward. Above this is a permeable layer into which water has penetrated, often from a considerable distance. The permeability could result from fractures or intergranular pores. The heat taken up by the water from the rocks below, is transferred by a convection to a layer of impervious rocks above, (In convection, the heated water rises, because of its lower density, and then descends when it is cooled by transferring heat to the colder rocks above).

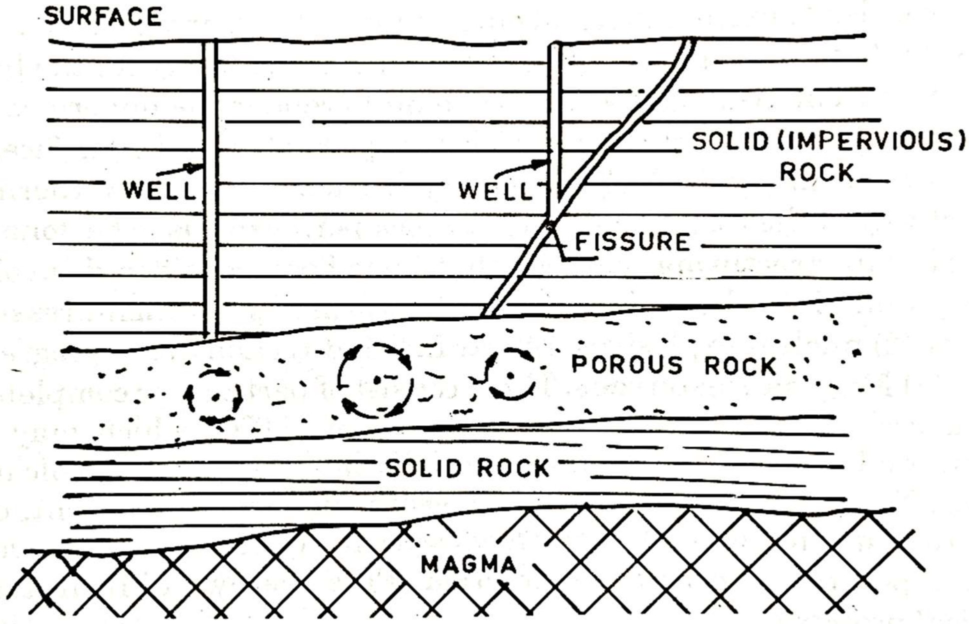
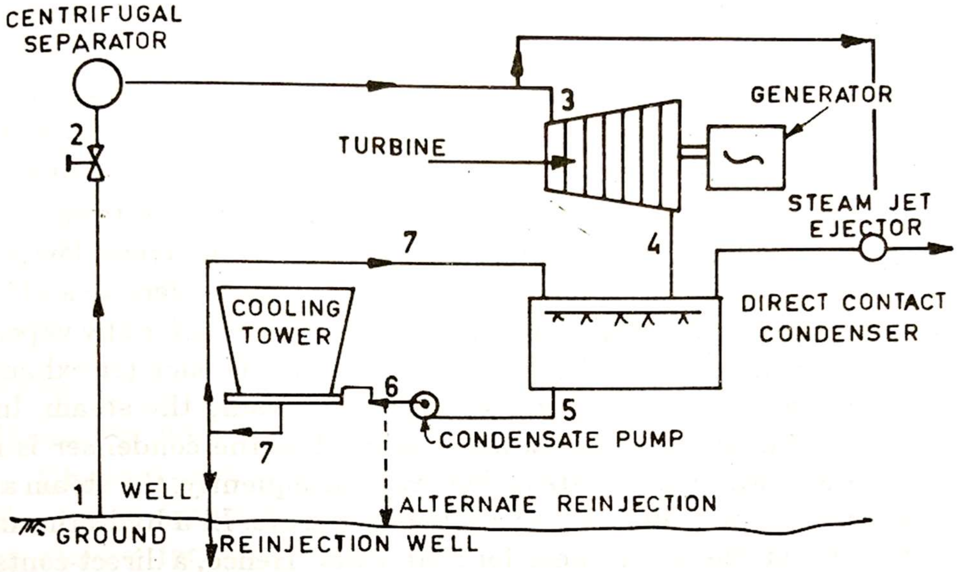


Fig. Hydrothermal conventive region.

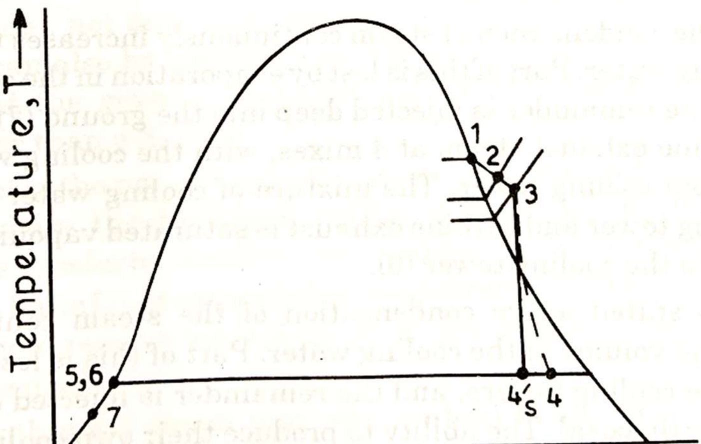
Hot water or steam often escapes through fissures in the rock, thus forming hot springs, geysers fumaroles, etc. In order to utilize the hydrothermal energy, wells are drilled either to intercept a fissure or, more commonly, into the formation containing the water (i.e. the hydrothermal reservoir). Most hydrothermal wells range in depth from about 600 to 2100 m, although there are some shallower and deeper production wells. As already mentioned for practical purposes hydrothermal resources are further subdivided into vapor-dominated (Dry steam) and liquid-dominated (wet steam) types. In vapour dominated systems, the wells deliver steam, with little or no liquid water, usually at temperatures of about 150°C to 250°C but occasionally higher. Liquid dominated systems, on the other hand produce a mixture of steam and hot water.

1.3.1 Vapour Dominated Systems



(*a*)

Scheme of a vapour-dominated power plant.



(*b*)

Fig. Vapour dominated system on T.S. diagram.

As indicated previously these are the most attractive geothermal resources because they are the most easily developed. They have the lowest cost and least number of serious problems. However, they constitute only a few per cent of hydrothermal resources and a much smaller proportion of the accessible geothermal energy resources. Fig. below show a schematic and T.S. diagram of a vapour-dominated power system. Dry steam from the wells is collected, filtered to remove abrasive particles and passed through turbines, which drive electric generators in the usual manner. The essential difference between this system and a conventional steam turbine-generator system, using fossil or unclear fuel, is that geothermal steam is supplied at a much lower temperature and pressure. The dry steam from the well (1) at perhaps 200°C is used. It is nearly saturated at the bottom of the well and may have a shut-off pressure up to about 35 kg/cm^2 is (= 35 bar). Pressure drops through the well causes it to slightly superheat at the wellhead (2). The pressure there rarely exceeds 7 kg/cm^2 (~ 7 bar). It then goes through a centrifugal separation and then enters the turbine after additional pressure drop. Processes between well and wellhead, and centrifugal separator and turbine are essentially throttling processes with constant enthalpy. The steam after expansion in the turbine (3) enters the condenser at 4.

Because turbine flow is not returned to the cycle but reinjected back into the earth, a direct-contact condenser of barometric or low level type may be used. Direct contact condensers are more effective and less expensive than surface type condensers. As with steam (or any vapour) turbines in general, the efficiency is improved if the back (or exhaust) pressure is maintained at a low level by condensing the steam. In a conventional plant, the pure water produced in the condenser is required as feed water for the steam boilers; consequently, the steam and impure condenser cooling water are kept separate. In a hydrothermal plant, however, there is no need for feed water. Hence, a direct-contact system is used at the Geysers in which the turbine exhaust steam is condensed by direct contact with cooling water. The resulting warm water is circulated through a mechanical-draft cooling tower and returned to the condenser. The condensation of steam continuously increases the volume of the cooling water. Part of this is lost by evaporation in the cooling towers (6), and the remainder is injected deep into the ground (7) for disposal. The turbine exhaust steam at 4 mixes, with the cooling water (7) that comes from the cooling tower. The mixture of cooling water coming from the cooling tower and turbine exhaust is saturated vapour at (5) that is pumped to the cooling tower (6).

1.3.2 Liquid-Dominated Systems (Wet steam fields)

In the liquid dominated reservoir, the water temperature js above the normal boiling point (100°C). However because the water in the reservoir is under pressure, it does not boil but remains in the liquid state. When the water comes to the surface the pressure is reduced; rapid boiling then occurs and the liquid water "flashes" into a mixture of hot water and steam. The steam can be separated and used to generate electric power in the usual manner. The remaining hot water can be utilized to generate electric power or to provide space and process heat, or it may be distilled to yield purified water. The water comes with various degrees of salinity, ranging from 3000 to 280,000 ppm of dissolved solids, and at various temperatures There are, therefore, various systems for converting liquid-dominated system into useful work that depend upon these variables. For liquid. dominated (high temperature) systems two methods which will be covered are:

(a) the flashed-steam system, suitable for water in the higher temperature range, and

(b) the binary-cycle system, suitable for water at moderate temperatures.

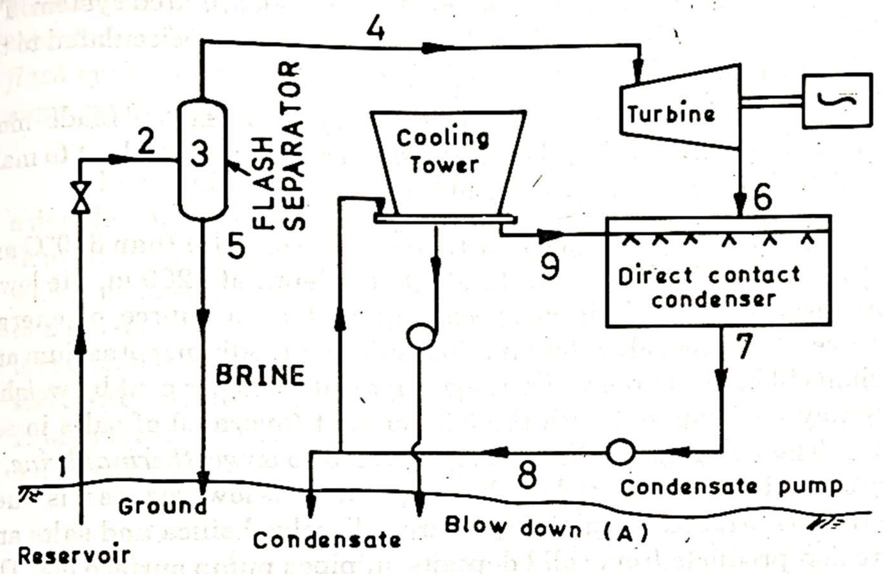
(c) A third method, called the total flow system,

Liquid-dominated (high temperature) system: steam from liquid-dominated, high temperature reservoirs is being used in several countries to generate electric power. The most extensive development has been in the volcanic Wairakei field in Newzealand. The water in the hydrothermal reservoir is at the temperature of about 230°C and pressure of 40 atm (4 MP). The liquid originates mainly from depths of 600 to 1400 m and is flashed into a mixture of steam and water at the surface.

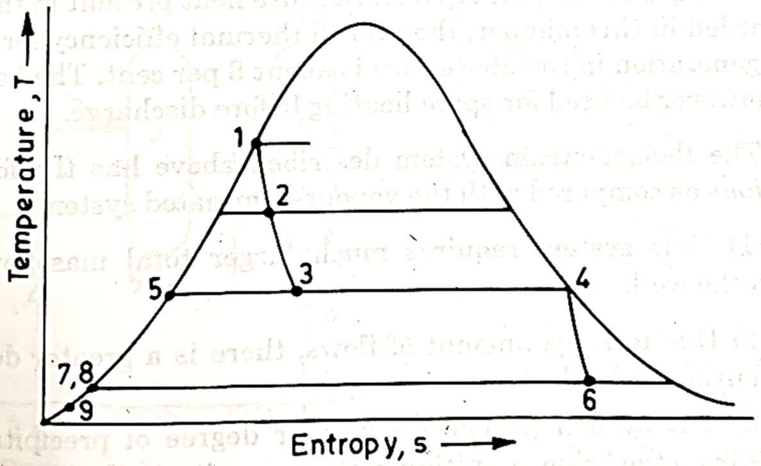
After passage through a cyclone separator, to remove the water, the steam is supplied to the turbine connected to electric generators. The maximum initial steam temperature is about 175°C and the gauge pressure is 3.5 atm (0.35 MP.). The exhaust steam is condensed by direct contact with cold water from the nearby Waikaro river; the warm condenser cooling water is then discharged to the river. This simple procedure, which does not require, cooling towers, is possible only because of the ample flow-of river water.

1.3.2.1 The Flashed-Steam System.

This is illustrated by the flow and T-S diagram of Fig. Water from the underground reservoir at 1 reaches the well head at 2 at a lower pressure. Process 1-2 is essentially a constant enthalpy throttling process that results in a two-phase mixture of low quality at 2. This is throttled further in a flash separator resulting in a still low but slightly higher quality at 3. This mixture is now separated into dry saturated steam at 4 and saturated brine at 5. The latter is reinjected into the ground. The dry steam, a small friction of the total well discharge (because of low quality at 3), and usually at pressures below 7 kg/cm^2 gauge (0.7 MP), is expanded in a turbine to 6 and mixed with cooling water in a direct-contact condenser with the mixture at 7 going to a cooling tower in the same fashion as the vapor-dominated system. The balance of the condensate after the cooling water is recirculated to the condenser is reinjected in to the ground. The power generation from such system can be made more economical by associating chemical industry with power plant to make use of the brine and the gaseous effluent.



(a) Schematic of a liquid dominated single-flash steam system.



(b) T-S diagram of a liquid dominated single flash steam system.

Fig. 8.5.3.

1.3.2.2 Liquid-Dominated Systems: Binary Cycle.

In order to isolate the turbine from corrosive or erosive materials and/or to accommodate higher concentration of non-condensable gases, the binary cycle concept is now receiving considerable attention as an alternate power cycle concept. This is basically a Rankine cycle with an organic working fluid. A heat exchanger system is used to transfer a fraction of the brine enthalpy to vaporize the secondary working fluid. Expansion through a turbine to a lower pressure, fixed by the heat rejection temperature, provides the means for power generation. About 50 per cent of hydrothermal water is in the moderate temperature range of ~ 153 to

205°C. This water which is available in lower temperature ranges is unsuitable for power production. It is however suitable for direct utilization for domestic and industrial process heating. If this water is used in a flashed-steam system, it would have to be throttled down to such a low pressures that results in excessively large specific volume flows as well as even poor cycle efficiencies. Instead this water is used as a heat source for a closed cycle that uses another working fluid that has suitable pressure-temperature volume characteristics. As stated above the binary fluid (or two fluid) system, is being investigated to overcome these limitations of flashed steam system. In the binary system an organic fluid with a low boiling point, such as isobutane (2 methal propane) C_4H_{10} (normal boiling point at one atm. pressure = 10°C) and Freon-12 (normal boiling point - 29.8°C) are usually recommended. Ammonia and propane may also be used. The working fluid would operate at higher pressures, corresponding to the source water and heat-sink temperatures. Flow diagram of a binary-cycle system is shown schematically in Fig. below.

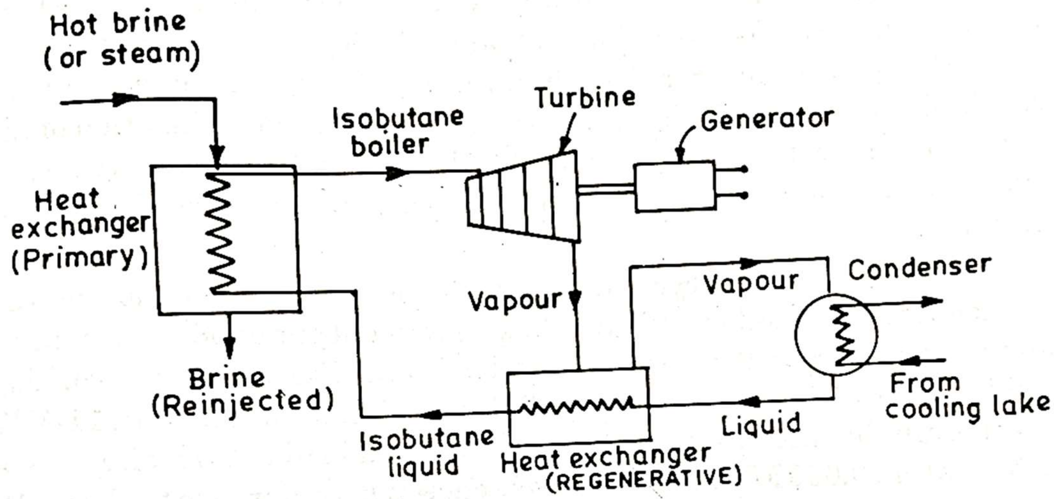


Fig. Binary-fluid geothermal power system.

Hot water or brine from the under-ground reservoir, either as unflashed liquid o as steam producing by flashing is circulated through a primary heat exchanger. In the heat exchanger the hot brine transfer its heat to the organic fluid thus converting it to a superheated vapour that is used in a standard closed Rankine cycle. The vapour drives the turbine-generator. The exhaust vapour from the turbine is cooled in the regenerative heat exchanger and then condensed, using either and air-cooled condenser or a water-cooled condenser and cooling tower. The condensed liquid organic fluid is returned to the primary heat exchanger by way of the regenerative heat exchanger. The hot geothermal fluid and the organic fluid, constitute the two fluids of the binary-fluid system. The condenser is cooled by water from a natural source, if available, or a cooling tower circulation system. The blow down from the tower may be reinjected to the ground with the cooled brine. Make-up of the cooling tower must be provided, however. In the binary cycle there are no problems of corrosion or scaling in the working cycle components, such as the turbine and condenser. Such problems are confined only to the well casing and the heat exchanger. The heat exchanger is a shell-and-tube type so that no contact between brine and working fluid takes place.

1.3.3 Hot Dry Rock Resources or Petrothermal Systems

Petrothermal systems are those that are composed of hot dry rock (HDR) but no underground water. They represent by far the largest geothermal resource available. The rock, occurring at moderate depths, has very low permeability and needs to be fractured to increase its heat transfer surface. The thermal energy of the HDR is extracted by pumping water (or other fluid) through a well that has been drilled to the lower part of the fractured rock. The water moves through the fractures, picking up heat. It is then travels up a second well that has been drilled to the upper part of the rock and finally back to the surface. There, it is used in a power plant to produce electricity. These types are not associated with hydrothermal activity. Such resources, with rock temperatures exceeding about 200°C at depths upto 5 km, are estimated to be significant and worthy of development as a source of energy. Hot dry rocks exist because they are impermeable to water or because water does not have access to them. Quite often both conditions occur; that is to say, the rocks are impermeable, and there is little or no surface water in the vicinity. In principle, the recovery of heat from such hot dry rocks involves breaking up or cracking the rock to make it permeable and then introducing water from the surface. The water is heated up by the rock and is returned to the surface where the heat is utilized as stated above.

There are two methods to tap this geothermal energy one possible method is to detonate a high explosive at the bottom of a well drilled into the rock. This may be a nuclear explosive. Water would be injected into this well, circulated through the cavities so formed to extract heat from the rock. The water or water-steam mixture is withdrawn through another well.

Another method is to use hydraulic fracturing to produce the heat transfer surface and permeability required to extract energy at a high rate from hot dry rock. Hydraulic fracturing, which is performed by pumping water at high pressure into the rock formation, is commonly used in oil and gas fields to improve the flow. The crack produced in this manner is roughly in the from of a large, thin vertical disk, resembling a pancake, possibly a few hundred meters in diameter but less than a centimeter thick. Heat can then be extracted from the hot rock by circulating water through the crack. The hot water or water steam mixture is utilized for generation of electricity with a binary liquid system using Freon (R-114) as the turbine working fluid. A feature of this scheme is that, as the reservoir heat is depleted with time, temperature differences within the rock result in stresses that cause the original fractures to propagate, thereby unlocking more HDR surface to the water and resulting in a pancake-shaped fracture zone.

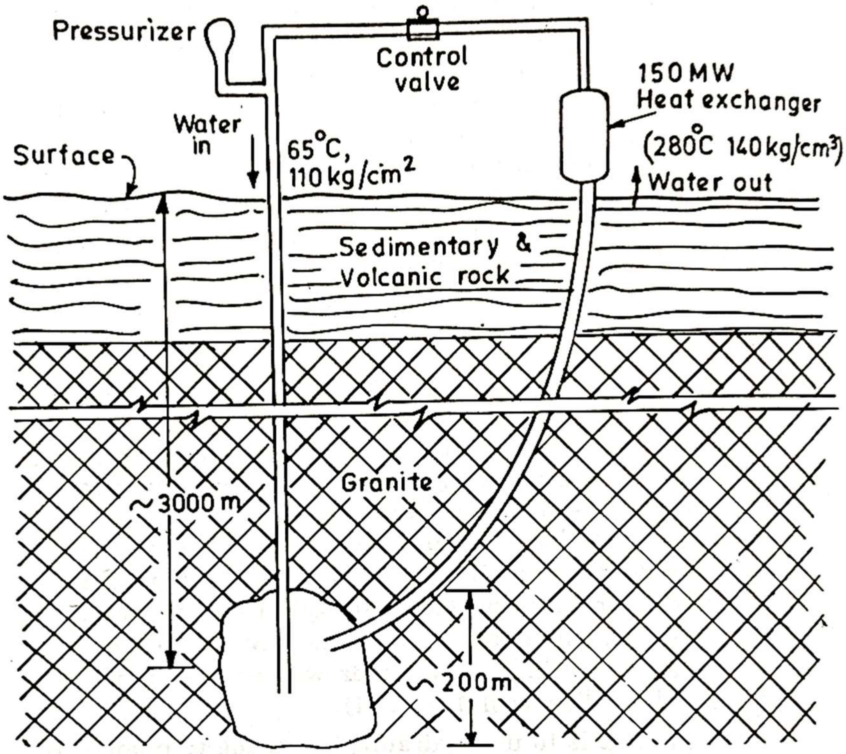


Fig. Heat Extraction from Hot dry Rocks.

It is believed that HDR systems offer more flexibility in operation and design than other geothermal systems. For example, the designer can have a choice of water flow rates and temperatures by drilling to various depths, and the operator can change pumping pressure and hence flow rates to suit load conditions.

One of the uncertainties associated with the hydraulic fracturing and heat extraction procedure is the useful life time of the cracked region. This can be determined only be continued testing. However computer modeling suggests that, as heat is extracted, the cracking should be increase with time and make more hot rock accessible to water. The effective life time of the fractured system should thus be extended. There are problems which are faced by developers include leakage of water (or other fluid) underground and the necessity of make up for it from resources above ground, the effect of the water or fluid on rock composition; material carryover with the fluid, and cost. It should be noted that two wells are to be drilled instead of the one for the hydrothermal energy and that these wells are drilled deeper and in much harder rock. This is expected to make petrothermal exploitation very costly, unless the underground rock being developed is very hot. Many more studies on the mechanical, thermo-dynamic; and economic aspects of petrothermal systems are necessary before commercial exploitation becomes feasible.

1.4 Geothermal plants in the world

Many countries have developed the technology for power generation from geothermal source. Italy, USA and Newzealand have received greater attention towards the power generation by geothermal fields. In 1980, about 1872 MW of power was generated in the world from geothermal source and units under construction were of 1650MW capacity. The total power production was estimated around 4850 MW. The geothermal energy was first used for space heating, cooking and medicinal purposes. In 1897, the first mechanical con version device was installed at Larderallo, Italy and it was driving a small steam engine. In 1904, at Larderello, a first attempt was made to generate electricity by using geothermal resource. By 1944 the plant at Larderello was producing 127MW and reached 360 MW capacity in 1981. In 1922, the first attempt was made to trap geothermal energy in USA and a 1IMW capacity plant began operation in 1960. In 1980, the total capacity reached about 1500 MW. Other electric generating units are in New Zealand, Japan, Mexico, Phillipines, Soviet Union and Iceland. In Indonesia, a 300 MW Kamojang Geothermal power station was installed recently.

India has around 340 known thermal areas of hot or warm springs. So far, 113 spring area are discovered. Among them, 46 are high temperature type (above 150°C), which could generate 1838 MW for 30 years, 59 are intermediate temperature type (90 - 150°C), which uses binary vapour cycle for power generation and remaining are low temperature (below 90°C) types. In Puga Valley, Jammu and Kashmir, a 20M W capacity plant is in operation. In Parvati Valley and Manikaran, Himachal Predesh, plants are extracting energy from Geothermal fields for power generation. The places where hot springs occurs in India are

1. Cambay Graben Province
2. N. W. Himalayan Geothermal Province
3. Damodar Valley Graben Province
4. Narbada Tapti Graben Province
5. West Coast Geothermal Province
6. Andaman Nicobar Geothermal Province

1.4.1 Advantages and disadvantages of geothermal energy

Advantages:

1. Geothermal energy is cheaper and versatile in its use
2. In comparison with conventional systems, it produces greater amount of net energy.
3. In comparison with conventional energy sources, these are less polluting, have highest annual load factor of 85 to 90%.
4. The Geothermal source is amenable for multiple uses from a single resource.
5. It is renewable, in exhaustible, economical and has highest energy density.

Disadvantages:

1. Low overall power generation efficiency i.e., about 15%.
2. Every tapping is done by drilling operation which is noisy
3. For exploitation of Geothermal energy, large area is neaded.
4. There is surface subsidence or settlement due to extraction of large amount of steam or water from hydrothermal reservoir.

1.5 Applications of Geothermal energy

1. For electric power generation
2. Industrial process heating
3. Space heating of buildings

1.6 Problems associated with Geothermal conversion

There are many problems associated with the use of geothermal energy. The temperature is not sufficiently high to provide fluids to run turbines. The presence of dissolved gases and salts, particulate matter in the steam and hot water causes serious operating problems. Geothermal power plants create a number of environmental problems. It produces salty effluent with sodium and potassium compounds. It also consists of Lithium, fluorine, boron and arsenic compounds. The discharge of such effluents to existing water results in severe pollution problems. The presence of these constituents in the effluents are very harmful to the plants and animals life in concentrations as low as two parts per million. So, to prevent degradation of water quality, suitable water treatment plants to be installed. The non-condensable gases in the steam may contain 4 to 5 percent of hydrogen sulfide which has an unpleasant odor and is harmful to plant and animal life. The extraction of large amount of steam or water from hydrothermal reservoir causes surface subsidence or settlement. The power plants also discharge much of the heat present in the turbine exhaust to the atmosphere which causes environmental problems. The control of noise generated by the release of steam during well venting, during release of over pressures and during general plant operations is a problem associated with the geothermal fields.

1.7 Scope of Geothermal energy

There is a vast scope to use geothermal energy for various applications like space heating, cooking and medicinal purposes and for industrial process heating. It's varied application and versatility make the source suitable for many purposes. This source of energy for electric generation has proved most economical. Geothermal energy can be tapped from any point on the earth simply by drilling deep enough holes. It is cheaper, less pollutant and has highest load factor. The geothermal source is renewable, inexhaustible and posses highest energy density. It is estimated that the thermal value of the geothermal field in the world is equivalent to 5×10^{10} barrels of oil per year. This is almost equivalent to the present world yearly consumption. In comparison with the size of the source, the energy available for exploitation and extraction is less. There is an ample scope to utilize geothermal power in India, but still development in geothermal field is in its initial stage. About 340 known thermal areas are present in India. Each of them may be hot or warm spring. There are about 113 spring area, where geothermal power is available.

2 Energy from Biomass

Biomass is a scientific term for living matter, but the word biomass is also used to denote products derived from living organisms - wood from trees, harvested grasses, plant parts and residues such as twigs, stems and leaves, as well as aquatic plants and animal wastes. All the Earth's biomass exists in a thin surface layer called the biosphere. This represents only a tiny fraction of the total mass of the Earth, but in human terms it is an enormous store of energy - as fuel and as food. More importantly, it is a store which is being replenished continually. The source which supplies the energy is of course the Sun, and although only a tiny fraction of the solar energy reaching the Earth each year is converted into biomass, it is nevertheless equivalent to over five times total world energy consumption. The plants which are grown on land (terrestrial) and aquatic (grown in water) and their derivatives, results in the formation of organic matter called "Biomass". The forest crops, animal manure etc all comes under Biomass. As plant lite renews and adds to itself every year. Biomass is a type of renewable source of energy. It is considered as indirect form of solar energy. It is the way of harnessing solar energy by photosynthesis. We can write

Solar energy $\rightarrow$ photosynthesis $\rightarrow$ Biomass $\rightarrow$ energy

Biomass energy or "bio-energy" includes any solid, liquid or gaseous fuel, or any electric power or useful chemical product derived from organic matter; whether directly from plants or indirectly from plant-derived industrial, commercial, or urban wastes, or agricultural and forestry residues. Thus bio-energy can be derived from a wide range of raw materials and produced in a variety of ways. Because of the wide range of potential feed stocks and the variety of technologies to produce them and process them, bio-energy is usually considered as a series of many different feedstock/ technology combinations. If biomass is cultivated and harvested in a way that allows re growth without depleting nutrient and water resources, it is a renewable resource that can be used to generate energy on demand, with little net additional contributions to global "Green house gas" emissions

The Biomass resources are grouped into:

1. In the form of solid mass (wood and agricultural waste) which could burn to release energy directly
2. In non traditional form (liquid fuels) in which ethanol (ethyl alcohol) and methanol (methyl alcohol) are used as fuels to run the engines.
3. In the form of gaseous fuel called biogas.

The energy density of biomass in liquid and gaseous form is high. The anaerobic decomposition of the organic matter results in the formation of biogas or methane. This gas is produced from cow dung and other wastes. The methane gas is also produced by aquatic biomass. If the mixture contains 7 to 9% solid matter, the gas generation rate will be higher. The mixture of biogas and diesel oil is used to run diesel engine to reduce diesel consumption. Traditional bio energy is in the form of fuel wood, char coal and residues. The dry biomass like wood and straw could be burnt to release energy by direct combustion. The wet biomass contains moisture content like sewage sludge and vegetable matter and is to be dried and burnt. The moisture content of the biomass decreases value of the biomass as fuel. Usually, the wet organic matter or biomass is converted in to premium fuels by digestion or fermentation.

The biomass fuels are available in the form of solid, liquid and gaseous fuels:

1) Solids: The solid biomass fuels are available in the form of wood, straw, municipal refuse etc. Wood has low ash and Sulphur content and is used for domestic heating and in timber and furniture industries. Straw burning stoves are used for crop drying, space and water heating and other similar applications. The energy content of the municipal refuse is very low and can be used to generate heat and power.
2) Liquids: The liquid biofuels considered for power generation are alcohols, vegetable oil, hydro carbons from Euphorbia plants etc. Mainly methanol and ethanol are used as fuels in I C engines to replace petrol and diesel. The octane rate is high, but calorific value is less. The vegetable oils used as bio fuels are sun flower and rape seed oil peanuts oil, palm oil, Soya and corn oil etc.., These vegetable oils may be directly burnt to release energy or may be blended with other fuels like diesel and releases energy.
3) Gases: The biogas is a mixture of methane and carbon dioxide and is generated from cow dung and agricultural wastes. The percentage of methane ranges from 50 to 70 % The carbon dioxide may be removed from biogas to increase the fuel quality. biogas can be used for water heating, space heating and cooking purposes.

The Biomass gasifies were used as fuel for transport vehicles during 1920 - 1930s in war and Rudolf diesel used Peanut oil as fuel in car engines in 1893.

Estimates of how much of the Earth's land-based production is used by the human population worldwide range from a low figure of about 5% to a high of over 30% (this includes food, animal fodder, timber and other products, as well as bioenergy). Biomass energy use worldwide been independently estimated at about 55 hex joules per year, or about 2% of annual biomass production on land.

Worldwide, biomass is the fourth largest energy resource after coal, oil, and natural gas estimated at about 14% of global primary energy (and much higher in many developing countries). In the U.S., biomass today provides about 3-4% of primary energy (depending on the method of calculation). Biomass is used for heating (such as wood stoves in homes and for process heat in bio processing industries), cooking (especially in many parts of the developing world), transportation (fuels such as ethanol) and, increasingly, for electric power production. Installed capacity of biomass power generation worldwide is about 35,000 MW with about 7,000 MW in the United States derived from forest-product-industry and agricultural residues (plus an additional 2,500 MW of municipal solid waste-fired capacity, which is often not counted as part of biomass power, and 500 MW of landfill gas-fired and other capacity). Much of this 7,000 MW capacity is presently found in the pulp and paper industry, in combined heat and power (cogeneration) systems.

2.1 Photosynthesis

It is the biological con version of sun's radiant energy in to sugars and starches which are rich energy compounds. The green pigment chlorophyll of the plant absorbs sun's energy and it is stored in the form of chemical bond energy. It is possible to harvest and burn the plants with high photosynthesis efficiency to generate steam which could be used to generate electricity as in thermal power plants. It is the best way of harnessing solar energy and is a renewable resource. In plants, solar energy con version is only about 1% and overall efficiency of con version of sunlight to electricity is 0.3%. Hence in comparison with photovoltaic cells, which have 10% efficiency, this concept is less attractive.

2.1.1 Photosynthetic oxygen production

Photosynthesis is a complex process in which water and CO, molecules are broken down in sun light and releases carbohydrate and pure oxygen.

$CO_2 + H_2O$ + sun light + chlorophyll --› $(H_2CO)_6 + O_2$ + chlorophyll

$6CO_2 + 12\ H_20$ --> $C_6H_{12}\ O_6 + 6H_2O + 6O_2$

The absorbed light is in the ultraviolet and infrared range. The chlorophyll absorbs visible light and passes its energy on to the water molecules and releases a hydrogen atom. The hydrogen atom thus produced reacts with CO_2 molecule to produce H_2CO and O_2 At high temperature

H_2CO breaks to release energy.

$H_2CO + O_2$ --> CO_2+ H_2O + 112 Kcal / mol of energy.

By growing algae in plastic tubes or ponds, we can produce large amount of carbohydrates. The heat could be generated by burning algae and then could be used to generate electricity by conventional methods.

Thus, photosynthesis is a reduction and oxidation process which produces carbohydrates such as sugar in the green leaf. The O_2 is liberated from H_2O molecule. Mainly the photosynthesis consists of two steps:

1) Due to action of chlorophyll and sunlight, water molecule breaks in to H, and O, This phase is called light reaction in which solar energy is converted in to potential chemical energy. The O, escapes and H, gets converted into some unknown compound.

2) This phase of reaction is called dark reaction which forms CO, and starch or sugar from unknown compound of H, and does not require sunlight.

2.2 Energy Plantation

It is a means of extracting maximum solar energy by growing plants. The plants are grown, especially for their fuel value and acts as solar collectors. They are economical, free from pollution and require no maintenance. Energy farms are the best alternatives for present fuel crisis and to replace fossil and nuclear energy sources. In plant farm, the natural photosynthesis process stores ten times more energy annually than consumed by the world. In India, the total forest area is around 25%. Jojaba, Acacia, Tortilla, Albizzia, Lebbak, Prasois, Juliflora are some of the tree species which have been identified for energy farm in our country. Indian Institute of Science, Bangalore running a program to grow monoculture plantations of fast growing species and monitor the biomass productivity. They also studied the economics of monoculture plantations and developed an alternative forestry strategy to meet various village needs.

Energy farm is a locally available energy source with highest versatility among renewable energies. No other energy source can open such new opportunities for agricultural and forest development. A number of projects have been taken up to full fill the needs of fuel and power generation. A number of projects, worth about 5M W capacity, have been taken under DNES (Development of Non-conventional Energy Sources) at various places in the country. Gasifiers and sterling engines are used for generation of energy from various types of biomasses.

2.3 Biogas generation

The decomposition of animal, plant and human wastes generates biogas and is a mixture of methane (50 to 70%), carbon dioxide (30 to 40%), hydrogen, hydrogen sulphide and nitrogen. The biogas is a clean, slow burning gas with its calorific value ranging from 21000kJ/kg to 23028 kJ/kg (38131kJ/m^3). Biogas is mainly used for cooking applications. The materials used for biogas generation retains its fertilizer properties and return to the soil. The biogas is generated from cow dung, piggery waste, poultry droppings, algae, crop residues, garbage kitchen wastes etc. The cellulosic organic material of animal or plant origin forms raw material with high potential for biogas generation. There are three methods by which biogas could be generated. They are digestion, pyrolysis or hydro gasification.

Digestion is a biological process which occurs in a chamber called digester. The process occurs in the presence of anaerobic organisms at atmospheric pressure and temperatures of 35 - 70°C and in the absence of oxygen.

2.3.1 Anaerobic digestion

It is the method of generating biogas through fermentation or bio digestion of different types of wastes by a number of anaerobic and facultative organisms. Facultative organisms are bacteria which grow with or without oxygen. Bacteria are classified in to two groups, aerobic which grow in presence of oxygen and anaerobic - does not require oxygen to grow (The biodegradation or decomposition of the organic matter by fermentation process through anaerobic digestion, results in the formation of biogas.

The anaerobic digestion produces sugar, alcohols, pesticides and amino acids by breaking organic matter. This results in the formation of methane by another type of bacteria. The phases of anaerobic digestion are:

1. Enzymatic hydrolysis: In this phase, the fats, starches and proteins present in the cellulose biomass are converted in to simple compounds.
2. Acid formation: In this phase, the complex organic compounds converted in to simple organic acids. The acids and volatile solids are formed by hydrol and fermentation from microorganism of facultative and anaerobic group and together called acid formers. This stage may last about two weeks and this phase results in the formation of large amount of carbon dioxide.
3. Methane formation: In this phase, the acids produced from previous phase converted

in to methane (CH_4) and CO_2 by anaerobic bacteria which are also known as methane fermenters. For digestion process to be efficient, these acid formers and methane fermenters must be in a state of dynamic equilibrium. The variation in pH value, will affect the methane formers as they are sensitive to pH variations. For fermentation and biogas generation, a pH value of 6.5 to 8 is suitable.

The anaerobic digestion is represented by the general equation

$C_xH_yO_2 + [x-y/4-2/2]H_20 \dashrightarrow [x/2-y/8+z/4]CO_2 + [x/2+y/8-z/4]CH_4$

For cellulose,

$(C_6H_{10}\,O_5)n + nH_2O \rightarrow 3nCO_2 + 3nCH_4$

It is also to be noted that, the digestion at high temperature is faster than that at lower temperature. For every 5°C raise in temperature, the gas yield rate increases twice. The temperature ranges that influence the bacteria are

Psicrophilic, about 20°C
Mesophilic, about35°C
Thermophilic, about 55°C

In tropical countries, the digesters are operating in psichrophilic range. The digesters are heated in cold climates by using a part of biogas output and temperature ranges up to 35°C. Some digesters work at 55°C, to digest material.

Advantages of Anaerobic digestion

1) The anaerobic digestion produces biogas which has a calorific value. Hence this gas could be successfully used to produce steam or hot water.
2) A smaller quantity of excess sludge is produced during anaerobic digestion of organic matter.
3) The running cost is very less when compared to equivalent aerobic system
4) The odor is less
5) The use of biogas in industries reduces the consumption of coal and also reduces air pollution.
6) The nutrient requirement is less due to low production of bacterial solids.

2.4 Classification of biogas plants

Biogas plants are classified in to

1) continuous and batch types
2) The dome and drum types
3) Different variation in the drum type

2.4.1 Continuous and batch type

a) Continuous plant: In this type, the raw material is fed in to a single digester and the process is carried out without interruption. The process may be completed in a single stage or two stages

i) Single stage process: The raw material is fed to a single chamber in which organic matter is converted to biogas. The sludge is removed from the chamber continuously.

ii) Two stage process: This type consists of two chambers. The acid formation is carried out in one chamber and bio-methanation is carried out in a separate chamber. The biogas is generated in the second chamber.

In the continuous plant, the size of the digester is small and takes lesser time for digestion process. The biogas generation is continuous and encounters lesser problems compared to batch type.

b) The batch plant: In this type, after digestion process, the digester is emptied. The urea lime etc., are fed in to a number of digesters which produces gas for 40to 50 days. As these digesters are charged and emptied one by one in a synchronous manner, the gas will be continuously supplied through a common gas holder. The system uses a number of digesters and gas generation is intermittent. It is expensive and encounters more problems.

2.4.2 The dome and the drum types:

Mainly two types of biogas plants are used

1. The floating gas holder plant
2. Fixed dome digester

In India, the first type is known as KVIC plant and the later type is called Chinese plant. A vertical or horizontal digester may be used. In both the designs, cylindrical, rectangular and spherical shapes are used. In floating gas holder plant, the gas holder is free from digester whereas in fixed type, the gas holder and digester are combined.

2.4.3 Different variations in the drum type:

The floating design is either provided with water seal or without water seal. The plant works as anaerobic digester with water seal and this design reduces corrosion of the gas holder drum. The materials of gas holder and digester are also varied. Usually bricks and stones are used. In latest designs of gas holder, fiber glass reinforced plastic is used.

2.5 Types of Biogas plant

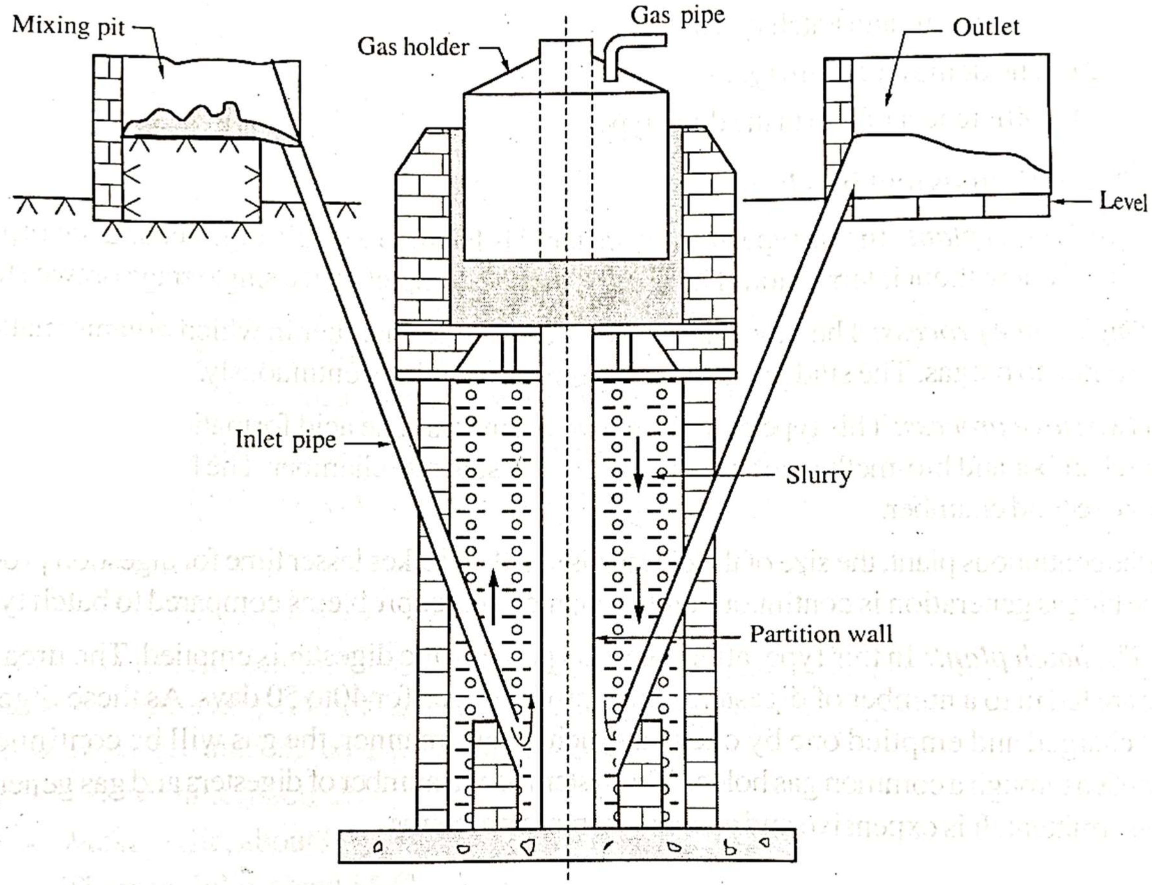


Fig. Circular digester with floating gas holder (KVIC digester)

As discussed earlier, the biogas plants are classified into 1) floating gas holder plant and 2) fixed dome digester plant. In India, biogas plants are again classified into K VIC (Khadi Village Industries commission) model and Janata model.

The KVIC model biogas plant shown in figure uses floating gas holder design. A masonry well contains raw material slurry. The digestion occurs in this well and the gas formed will be collected and taken out from the top. As the drum floats, this design is called floating gas holder type.

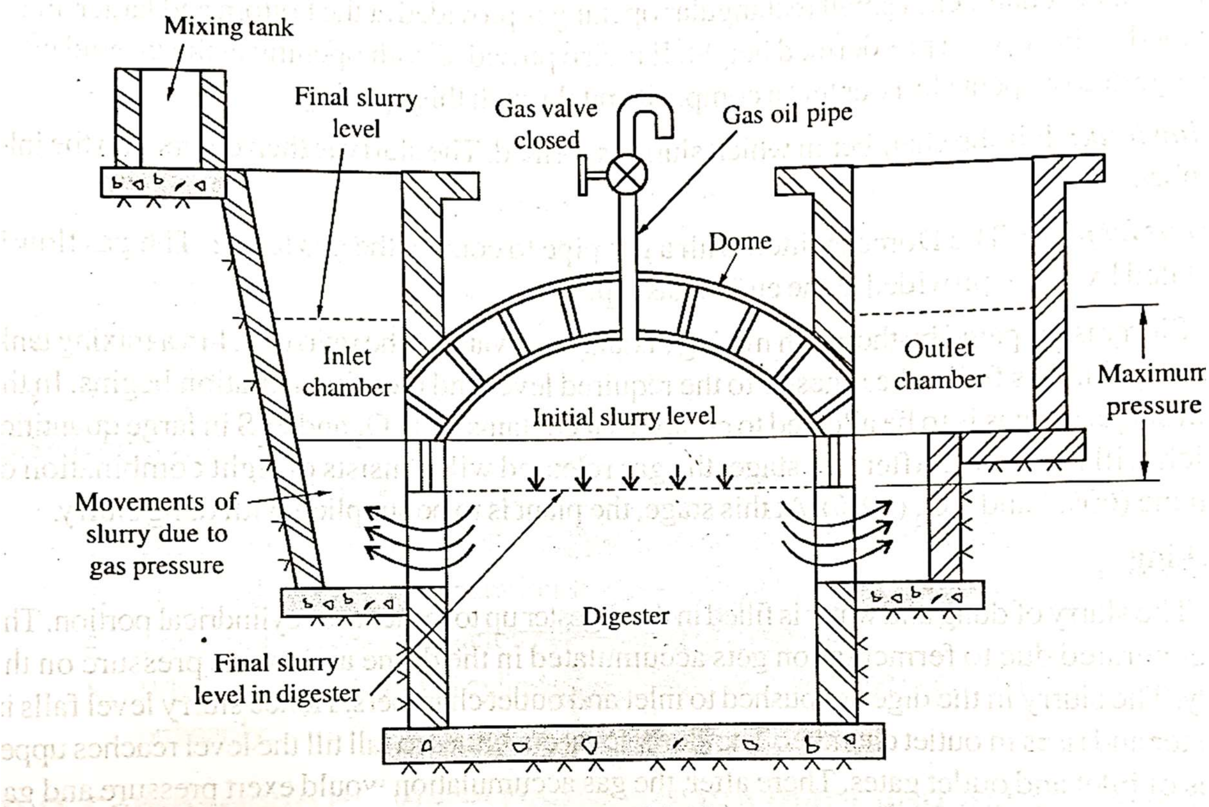


Fig. **Janata model gobar gas plant**

The fixed dome digester plant is also known as Janata Model or Chinese plant and is similar to KVIC plant except that the masonry fixed'dome replaces floating steel drum. The basic components of this model are.

Foundation: The foundation is made of cement, concrete and brick ballast. The plant should provide stable foundation to the digester walls and should bear full load of slurry filled in the digester. In order to avoid water leakage, the foundation is made water proof.

Digester: The digester is a cylindrical chamber made of bricks, sand and cement constructed under the ground where fermentation of dung takes place. The slurry flows in and out of digester through rectangular openings provided as shown in figure.

Dome: The roof the digester is shaped hemispherical and is called Dome and it is of fixed type. The gas collected in the dome space exerts pressure on the slurry in the digester.

Inlet chamber: It is made of bricks, cement and sand and is provided with an opening at ground level. A sloppy wall at the outlet ensures easy movement of the cattle dung to the digester.

Outlet chamber: The digested slurry moves out of the digester at a pre-determined height through outlet chamber. A small rectangular opening is provided at the bottom and larger area is provided at the top to a pre-defined height. It is also provided with opening at the ground level. The digested or spent slurry enters a composite pit through this opening.

Mixing tank: It is the chamber in which slurry is formed. The slurry is then enters into the inlet chamber.

Gas out let pipe: The Dome is fitted with a gas pipe to con vey the gas to use. The gas flow is regulated by valve provided at the end of gas pipe.

Slurry is prepared by thorough mixing of dung and water in the ratio of 1:1 in a mixing tank. Then the slurry is fed to the digester to the required level and then fermentation begins. In the initial stage, the gas is to be allowed to escape as it contains CO,, O, and H,S in large quantities (which will not burn). After this stage, the gas released will consists of right combination of methane (60%) and CO, (40%). At this stage, the plant is to be supplied with dung slurry.

Working

The slurry of dung and water is filled in the digester up to the level of cylindrical portion. The gas generated due to fermentation gets accumulated in the dome and exerts pressure on the slurry. The slurry in the digester pushed to inlet and outlet chambers. Hence slurry level falls in digester and rises in outlet chamber. The slurry level continues to fall till the level reaches upper edges of inlet and outlet gates. Thereafter, the gas accumulation would exert pressure and gas escapes to atmosphere through gates. The bubbling and froth formation of the slurry in inlet and outlet chambers indicates escape of gas to atmosphere. By knowing increase in slurry volume in these chambers, the quantity of usable gas can be calculated. When gas is supplied for usage, the slurry level in the digester increases and that of in inlet and outlet chamber decreases. During the process, an equivalent amount of digested slurry is discharged from outlet chamber and the fresh slurry enters and settle down in the digester.

2.6 Problems involved with Biogas production

1. Handling of effluent slurry is a major problem and sufficient open space is to be provided to dry the slurry. It also requires human animal labor to carry effluent to the field.
2. The methanogenic bacteria involved in gas generation are very sensitive to temperature and affects the gas generation rate.
3. Due to lack of knowledge about Biogas generation, some persons add urea fertilizer which results in toxicity of ammonia nitrogen and decreases gas production.

4. When cattle dung and water is not properly mixed, volatile fatty acids will be accumulated and results in failure of digester.
5. It is necessary to maintain an optimum range of PH and volatile fatty acids, otherwise digester will not work properly.
6. There is chance of leakage of gas from gas holder in case of Janata Model

2.7 Advantages and disadvantages of Biomass

Advantages

1. The initial investment is low and costlier equipment are not used.
2. The use of Biomass as fuel reduces environmental hazards.
3. The technology is best suited for rural areas of developing countries like India.
4. The byproducts can be fully recycled.
5. Less polluting, suitable for domestic purposes.
6. Easily transportable to consumers

Disadvantages

1. The plant uses larger land area.
2. The efficiency of biological energy con version is very less (0.1%).
3. In centralized power generation system, the cost of energy production is higher.
4. Collection and transportation of biomass is expensive.
5. When compared to LPG cylinders, it is difficult to store the gas, as it cannot be liquified ordinarily.

2.8 Factors affecting biogas generation

1. **PH or hydrogen ion concentration:** In the digester, a suitable PH range is to be maintained to provide constant supply of the gas. In a PH range of 6.5 to 7.5, microorganisms will be very active and bio-digestion will be very efficient. The addition of some material to the digester causes variations in the PH value and results in the imbalance of bacteria population. For sewage solids, the ideal PH is from 7 to 7.5.
2. **Temperature:** The temperature ranges from 35°C to 38°C results in better methane formation. The gas generation starts decreasing at 20°C and ceases completely at 10°C.

3. **Total solid content of feed material:** In order to get total solid content of 8 to 10%, the cow dung is to be mixed in the range of 1:1 by weight. Around 80-82% of moisture is present in raw cow dung and remaining 18-20% is called total solids. The adjustment made in total solid content increases the bio-digestion rate.
4. **Loading rate:** The amount of raw material supplied to the fermentation tank (digester) per day per unit volume is known as loading rate. For municipal sewage treatment plants, the loading rate ranges from 0.5 to 1.6 kg/m/day. The optimum range of loading rate ranges from 1.2 to 5.3 kg/m°/day. High loading rate, results in the formation of acids and thus fermentation stops.
5. **Seeding:** Seeding is nothing but the increase in number of methane formers by artificial means. It uses digested sludge which is rich in methane formers. But higher seeding is also not desirable as gas production decreases beyond certain limits due to reduction of total solid contents of the cow dung.
6. **Uniform feeding**: In order to provide good fermentation in the digester, a control over quality and quantity of raw material supplied to the digester is essential. Therefore, all the time uniform feeding of digester is necessary.
7. **Carbon nitrogen ratio of the input material:** For an optimal digestion rate, a carbon nitrogen ratio of 30: 1 is necessary. High carbon in raw material slows down the digester. High nitrogen content of the raw material may stop the fermentation process. The ammonia formed due to nitrogen and hydrogen may kill methane producers.
8. **Diameter to depth ratio:** It was investigated that the maximum gas production rate occurs with diameter to depth ratio of 0.66 to 1.0. But the effect of temperature at different depths also plays important role is deciding this ratio.
9. **Nutrients:** In digester, the bacteria always require C, H_2, O_2, P and S. Out of these nutrients, the supply of N_2 and P are always short. In order to compensate this, extra raw material which is rich in phosphorus and N, must be added to increase the gas generation rate.
10. **Mixing or stirring or agitation of content of digester:** In digester, a proper mixing of slurry is required to improve the fermentation process. Slight mixing results in good fermentation and the digestion may be retarded due to violent agitation.
11. Retention period or feeding rate: The temperature and feed stocks influence the retention period of the material for biogas generation. Usually, the retention period is kept from 30 to 45 days.

12. Pressure: The fermentation process is also influenced by the pressure acting on the slurry surface. Lower pressure gives better fermentation process.
13. Acid accumulation inside the digester: When fresh raw material is supplied in excess, the PH value decreases due to the formation of acids. The addition of neem cake produces methane from these acids.

2.9 Thermo chemical conversion of biomass

In bio chemical energy conversion, the action of bacteria results in the formation of biogas. In thermo chemical conversion of biomass, its temperature is raised and processes like pyrolysis, combustion and gasification occurs depending on amount of oxygen supplied. The example for combustion is burning of biomass in open fire and stoves. In this case, oxygen is supplied in excess of theoretically required. When less O_2 is supplied, pyrolysis and gasification occur. The conversion of wood and incineration of solid waste is an example of pyrolysis. A gas mixture consisting of carbon monoxide and hydrogen [producer gas] is generated at some temperature and O_2 supply. The formation of gaseous mixture of carbon monoxide and hydrogen is called thermal gasification.

The conversion of solid fuel in to producer gas by undergoing a series of thermo chemical processes like drying, pyrolysis, oxidation and reduction is known as thermal gasification. Carbon monoxide, hydrogen and oxygen are the main constituents when air is used as gasification agent.

A typical gas composition is as follows,

Carbon monoxide	18-22%
Hydrogen	13-19%
Methane	1-5%
Hydrocarbons (heavier)	0.2-0.4%
Carbon dioxide	9-12%
Nitrogen	45-55%
Water vapour	4%

The dual fuel engines and diesel engines uses this gas as working fluid with some design changes.

2.10 Classification of Biomass gasifiers

A chamber through which oxygen or air required for combustion is passed, known as gasifier. The gasifier converts solid fuel into producer gas by undergoing a series of thermos chemical processes. Gasifiers are classified into

1. According to direction of gas flow: down draught, up draught and cross draught generator.

2. According to generation capacity: small size up to 10 kW, medium size for outputs from 10k W to 50k W, large size from 50 to 300 kW and very large above 300 kW output.

3. According to type of bed: fixed bed and fluidized bed.

2.10.1 Fixed bed gasifiers

There are three main designs of fixed bed type:

1. Up draught type: In this type, air entry is below combustion zone and producer gas escapes from top of gasifier. It is suitable for char-coal, in stationary engines.
2. Down draught gasifier: In this type, air entry is at combustion zone and gas escapes through bottom of gasifier. These are suitable for wood and agricultural wastes.
3. Cross draught gasifiers: The gasifier contains charcoal which acts as insulator and dust filter. The gas flows around the gasifier in the annular space.

2.10.2 Fluidized bed gasifier:

The use of this type allows gasification of any biomass. It burns any combustible material with high efficiency and less pollution. The inert particles burn in suspension, fluidized by air current flowing upward.

2.11 Gasification process

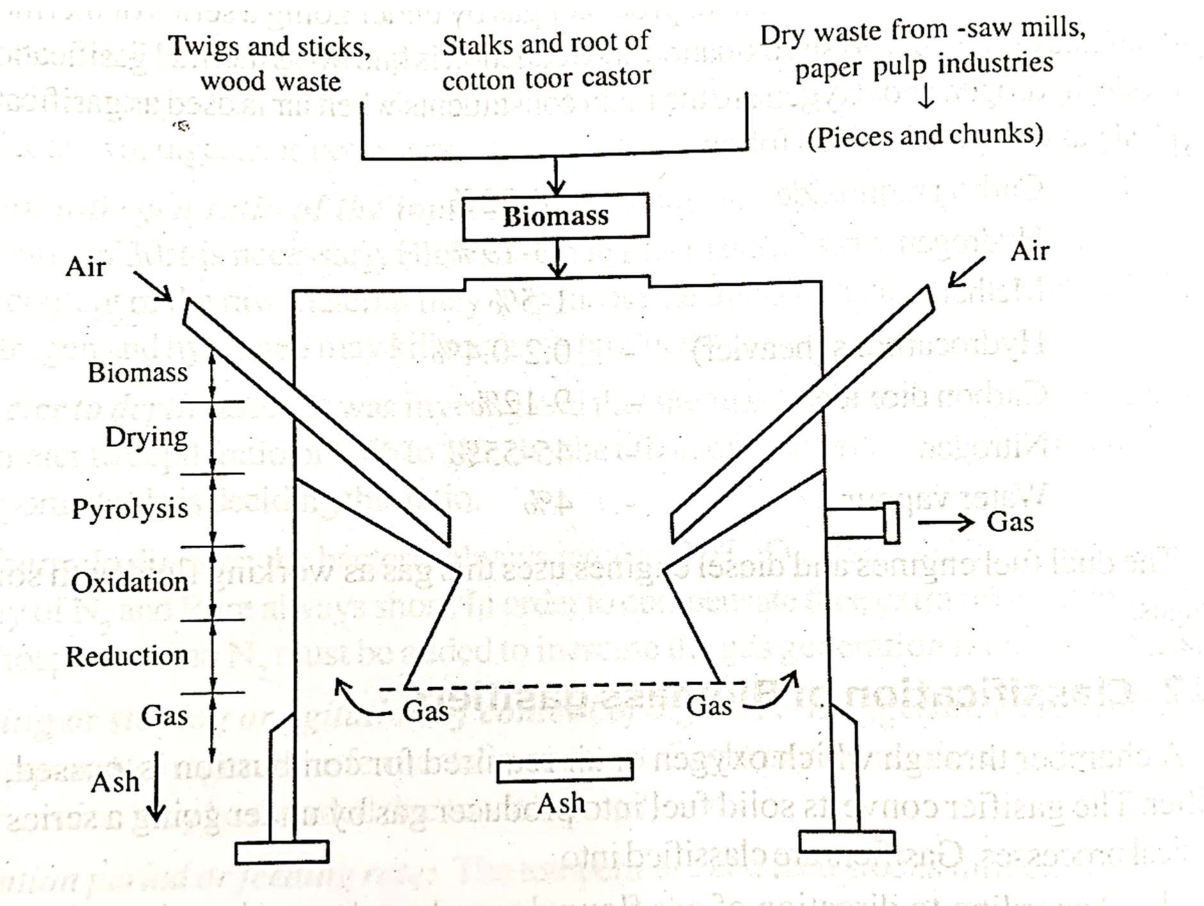


Fig. Schematic diagram of a gasifier

The figure shows schematic diagram of a gasifier with four zones i.e., drying, pyrolysis, oxidation and reduction. The solid biomass under goes partial combustion in a vertical flow packed bed reactor and results in formation of producer gas. There are three zones namely oxidation, reduction and distillation zones in which reactions occurs. In the oxidation zone, O, reacts with carbon of fuel and releases H, and carbon dioxide. In reduction zone, CO, of oxidation zone is reduced to CO.

$CO + H_20 \text{ ----> } CO_2 + H$

In the distillation zone, the condensable and non-condensable gases are formed by preheating and carbonizing the raw fuel.

The main reactions involved are,

$C + 0_2 + 3.79\ N_2 \text{ ----> } 3.79\ N_2 + CO_2$

$C + CO_2 + 3.79\ N_2 \text{ -------> } 3.79\ N_2 + 2\ CO$

$2C + O_2 + 3.79\ N_2 \text{ ----› } 3.79\ N_2 + 2\ CO$

$C + H_2O \text{------>} CO + H_2$

$C + 2H_2O \text{------›} CO_2 + 2\ H_2$

$CO + H_2O \text{ ------› } CO_2 + H_2$

3 Hydrogen as energy carrier

Hydrogen is the simplest element. An atom of hydrogen consists of only one proton and one electron. It is also the most plentiful element in the universe. Despite its simplicity and abundance, hydrogen doesn't occur naturally as a gas on the Earth it is always combined with other elements. Water, for example, is a combination of hydrogen and oxygen (H_2O).

Hydrogen holds the potential to provide clean, reliable and affordable energy supply that can enhance economy, environment and security. It is flexible and can be used by all sectors of economy. It is non-toxic and recyclable. Due to these qualities, it is considered to be an ideal energy carrier in the foreseeable future. An energy carrier moves and delivers energy in a usable form to consumers.

Hydrogen can be produced by using a variety of energy sources, such as solar, nuclear and fossil fuels and can be converted to useful energy forms efficiently and without detrimental environmental effects. When burned as fuel or converted to electricity it joins with oxygen to produce energy with water as the only emission. When air is used for combustion instead of oxygen, some NO_x is also produced, which can be reduced by lowering the combustion temperature. Despite all these benefits, realization of hydrogen economy faces multiple challenges. Unlike gasoline and natural gas, hydrogen has no existing, large scale supporting infrastructure. Building of such an infrastructure will require major investment. Although hydrogen production, storage and delivery techniques are currently in commercial use by the chemical and refining industries, existing hydrogen storage and conversion technologies are too costly for widespread use in energy applications.

The individual segments of hydrogen energy system; production, delivery, storage conversion and end use applications are closely interrelated and interdependent as shown in Fig. below. Design and application of a hydrogen economy must carefully consider each of these segments as well as the whole system.

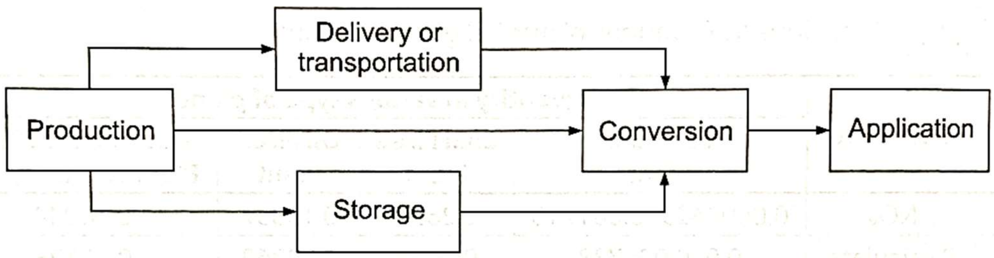


Figure Hydrogen energy system

Hydrogen can be produced in centralized facilities and distributed to an energy conversion site via pipeline or stored and shipped via rail or road. It can also be produced at decentralized locations onsite where it will be stored and/or fed directly into conversion device for stationary, mobile or portable applications.

3.1 Properties of Hydrogen

Hydrogen is an odorless and colorless gas. It has the simplest and lightest atom with one proton and one electron and molecular weight of 2.016. Important properties are listed and compared with natural gas and gasoline in Table below.

S.N.	Properties	Gasoline	Natural gas	Hydrogen
1.	Density (kg/m^3)	730	0.78	0.0837
2.	Boiling point, (°C)	38 to 204	−156	−253 (20.3 K)
3.	Lower heating value, (MJ/kg) (MJ/m^3)	44.5 32	48 37.3	125 10.4 (gas), 8520 (liquid)
4.	Higher heating value, (MJ/kg) (MJ/m^3)	50.8 36.6	55 42.6	141.90 11.89 (gas), 10046 (liquid)
5.	Flammable limit, % in air	1.4–7.6	5–16	4–75
6.	Flame speed, (m/s)	0.4	0.41	3.45
7.	Flame temperature, (°C)	2197	1875	2045
8.	Flame luminosity	High	Medium	Low

3.2 Production

Although hydrogen is the third most abundant element on the earth, it does not exist in free state, except for small quantities in the upper atmosphere. It is, therefore, not a primary energy source. However, large amounts of combined hydrogen are present in compounds such as water, fossil fuels and biomass. It can therefore, be produced through two routes:

(a) Fossil fuels, such as natural gas, coal, methanol, gasoline etc., and biomass are decomposed by thermo-chemical (steam reforming or partial oxidation) methods to obtain hydrogen. The CO produced in the process is eliminated by water gas shift reaction. This route of hydrogen production causes CO_2 emission. The energy content of the produced hydrogen is less than the energy content of the original fuel, some of it being lost as excessive heat during production.

(b) Hydrogen can also be produced by splitting water into hydrogen and oxygen by using energy from nuclear or renewable sources such as solar, wind, geothermal, etc., through electrical or thermal means (i.e. electrolysis and thermolysis respectively). Water splitting is also possible through bio-photolysis process using solar radiation.

Splitting of water is thus possible at the expense of renewable energy to produce secondary fuel H_2. On use, H_2 and O_2 recombine to produce water again and energy is released. This route is therefore a clean and sustainable route of energy supply.

3.2.1 Thermo-chemical Methods

Steam reforming of methane is the most energy efficient, commercialized technology currently available and most cost effective when applied to large, constant loads. The method accounts for 95 per cent of the hydrogen production in USA. The steam reforming method has been described in the previous section on fuel cell.

3.2.2 Electrolysis of Water

Electrolysis is the simplest method of hydrogen production. Currently, this method is not as efficient or cost effective as thermo-chemical method using fossil fuels or biomass. But it would allow for more distributed hydrogen generation and open the possibilities for use of electricity generated from renewable and nuclear resources for hydrogen production.

An electrolysis cell essentially consists of two electrodes, commonly flat metal or carbon plates, immersed in an aqueous conducting solution called electrolyte, as shown in Fig. below. A direct current decomposes water into H_2 and O_2, which are released at cathode (-ve electrode) and anode (+ve electrode) respectively. As water itself is poor conductor of electricity, an electrolyte, commonly aqueous KOH is used.

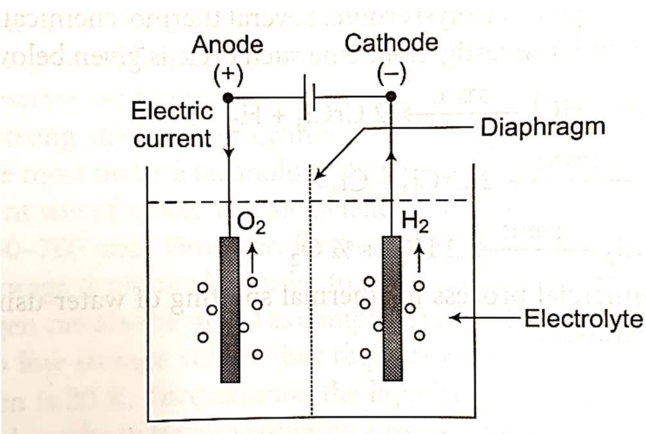


Figure Electrolytic cell

Ideally, a decomposition voltage of 1.23 V per cell should be sufficient at normal temperature and pressure; however, due to various reasons a voltage of about 2 V per cell is applied in practice. The energy required is 3.9-4.6 kWh per m^3 of hydrogen produced. About 60-70 per cent of this energy is actually utilized in electrolysis. Therefore, the efficiency of electrolysis process is about 60-70 per cent, which can be improved up to 80 per cent by using catalyst such as porous platinum or nickel. A diaphragm (usually woven asbestos) prevents electronic contact between the electrodes and passage of gas or gas bubbles. Electrolysis method is most suitable when primary energy is available as electrical energy, e.g. solar photovoltaic energy. It is also suitable where cheap electricity is available from other sources such as wind, geothermal, etc.

3.2.3 Thermolysis of Water

When primary energy is available in the form of heat (e.g. solar thermal), it is more logical to produce hydrogen by splitting water directly from heat energy using thermolysis. This would be more efficient than conversion of heat, first to electricity (using heat engine - generator) and then producing hydrogen through electrolysis. The efficiency of thermal plant is usually in range 32-38 per cent and that of electrolysis is 80 per cent. The overall efficiency through thermal-electrical-hydrogen route would thus be only 25-30 per cent.

Direct thermal decomposition of water is possible but it requires a temperature of at least 2500°C; because of temperature limitations of conversion process equipment, direct single-step water decomposition cannot be achieved. However, sequential chemical reactions at substantially lower temperature can be devised to split water into H_2 and O_2. In the reaction series, water is taken up at one stage and H_2 and O_2 are produced in different stages. The energy is supplied as heat at one or more stages and partly released at some stage in the cycle. Apart from decomposition of water, all other materials are recovered when the cycle is completed. Therefore, the method is known as thermo-chemical cycle. The efficiency of conversion from heat energy to hydrogen is better than its conversion through electrolysis route only when the upper temperature of thermo-chemical cycle is above 700 °C. For the upper temperature of 950 °C the efficiency of conversion is about 50 per cent. This is a marked improvement over what is possible through electrolysis route. Several thermo-chemical cycles have been proposed and are under investigation. One such cycle is given below:

$$2\,CrCl_2 + 2\,HCl \xrightarrow{325\,°C} 2\,CrCl_3 + H_2$$

$$2\,CrCl_3 \xrightarrow{875\,°C} 2\,CrCl_2 + Cl_2$$

$$H_2O + Cl_2 \xrightarrow{850\,°C} 2\,HCl + \tfrac{1}{2}\,O_2$$

At present, no commercial process for thermal splitting of water using thermo- chemical cycle is in operation.

3.2.4 Biophotolysis

In this method the ability of the plants (especially algae) to split water during photosynthesis process is utilized. An artificial system is devised, which could produce hydrogen and oxygen from water in sunlight using isolated photosynthetic membrane and other catalysts. Since this process is essentially a decomposition of water using photons in the presence of biological catalysts, the reaction is called photolysis of water.

There are three distinct functional components coupled together in the system as shown in Fig. below: (i) photosynthetic membrane, which absorbs light, split water to generate oxygen, electrons and protons, (in) an electron mediator, which is reducible by photo-synthetically generated electrons and (in) a proton activator that will accept electrons from the reduced mediator and catalyze the reaction: $2\ H^{+} + 2\ e^{-} \rightarrow H_2$

A system with chloroplast (small bodies containing the chlorophyll in green plants) as a photosynthetic membrane to split hydrogen and oxygen, ferredoxin as e^{-} mediator and hydrogenase (an enzyme) or finely dispersed platinum as proton activator, has been successfully tested. The method is being extensively studied further.

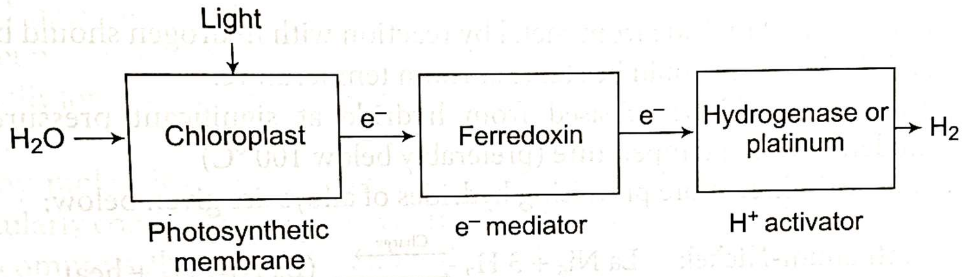


Figure Functional components of biophotolysis

3.3 Applications of Hydrogen

Hydrogen can be used in combustion based power generation, such as gas turbine using hydrogen alone or mixed with natural gas. Such applications are proposed for stationary power generation including backup power units, stand-alone power plants, distributed generation for buildings and cogeneration. Alternatively, hydrogen may be obtained from steam reforming of natural gas and then used in fuel cell to generate electricity.

Portable applications for fuel cell based generation include consumer electronics, business machinery and recreational devices. These portable power applications range from 25 W for portable electronics to 10 kW system for critical commercial and medical functions and on site power generation for individual homes and office buildings.

Hydrogen is also being proposed for commercial vehicles (bus, trucks, cars, trains, etc.). Technologies are being developed to use hydrogen in both fuel cells and IC engines including methanol system.