Course: Technologies for Renewable Energy Sources

Module-3: Hydrogen Energy

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Introduction

- Hydrogen as an energy carrier can play an important role as an alternative to conventional fuels, provided its technical problems of production, storage and transportation can be resolved satisfactorily and the cost could be brought down to acceptable limits.
- One of the most attractive features of hydrogen as an energy carrier is that it can be produced from water which is abundantly available in nature.
- Hydrogen has the highest energy content per unit of mass of any chemical fuel and can be substituted for hydrocarbons in a broad range of applications, often with the increased combustion efficiency.
- Its burning process is non-polluting and it can be used in the fuel cells to produce both electricity and useful heat.

- Use of hydrogen as an energy source involves five basic issues:
  (1) Production (2) Storage and transportation (3) Safety and Management
  (4) Utilization (5) Economy.
- The hydrogen can be used as a fuel directly, or it might be used as a raw material to produce methanol, ammonia, or hydrocarbons by using either carbon dioxide or nitrogen from the atmosphere.
- The combination of hydrogen with oxygen (e.g., from air) results in the liberation of energy, with water as the sole material product; thus,

$$H_2 + \frac{1}{2}O_2 \longrightarrow H_2O + \text{energy}$$

- The reaction can be carried out and the energy made available in several different ways, so that hydrogen is a versatile fuel material.

The possible areas of use for hydrogen in the near future are as follows:

- Direct addition of hydrogen to the existing natural gas distribution network.
- Production of electrolytic hydrogen, for full load exploitation of nuclear power stations.
- Use of hydrogen in the processing of heavy oil.
- Use of hydrogen for the manufacture of synthetic liquid or gaseous fuels.
- Direct use of hydrogen as a motor vehicle fuel in urban transport, particularly where air pollution problems are already critical.
- Reduction of iron oxides by means of hydrogen in the steel industry.
- Direct use of hydrogen as an aircraft fuel in air transport.

Hydrogen Production

Introduction

- Commercial production of hydrogen today is carried out by the steam reformation or partial oxidation of hydrocarbons (natural gas or crude oil) depending on supplies and economics.
- Clearly, with gas and oil in diminishing supply, these sources for hydrogen will become less attractive as a basis for an energy delivery system.
- Small quantities of hydrogen are commercially produced today by the electrolysis of water usually in situations where electric power is cheap, or where reliable unattended operations is required.
- Electrolysis is the only presently available technology by which hydrogen can be made from non-fossil energy (nuclear, solar, geothermal, or wind), and it is this aspect that makes electrolysis so important in the context of a hydrogen energy system.

- Electrolysis suffers from a disadvantage as an energy conversion system because its raw energy requirement must be supplied as a high quality energy form: electricity.
- Considerable research work is under way to develop a thermal cycle that would utilize heat to achieve the chemical splitting of water to its elements without the need for inter mediate electricity generation, and without the need to use the extremity high temperature of 2500°C or more, (which would be required to dissociate water directly). This so called ***thermochemical hydrogen production.***

Hydrogen Production Technologies

1. Thermo chemical production
2. Electrolytic Production
3. Photolytic production

Electrolytic Production of Hydrogen

The methods of producing hydrogen may be classified according to the immediate source of addition of energy to decompose, thus electrical energy (in electrolysis), heat energy (in thermo-chemical methods), fossil fuels, and solar energy.

- The process of splitting water into hydrogen and oxygen by means of a direct electric current is known as ***electrolysis.***
- This is the simplest method of hydrogen production.
- In principle, an electrolysis cell consists of two electrodes, commonly flat metal or carbon plates, immersed in an aqueous conducting solution called the ***electrolyte***.

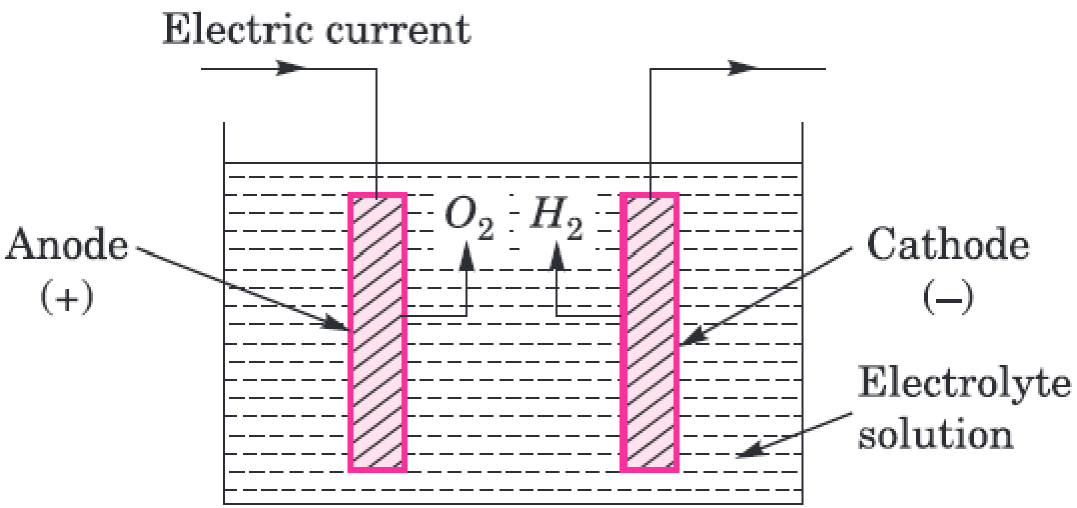
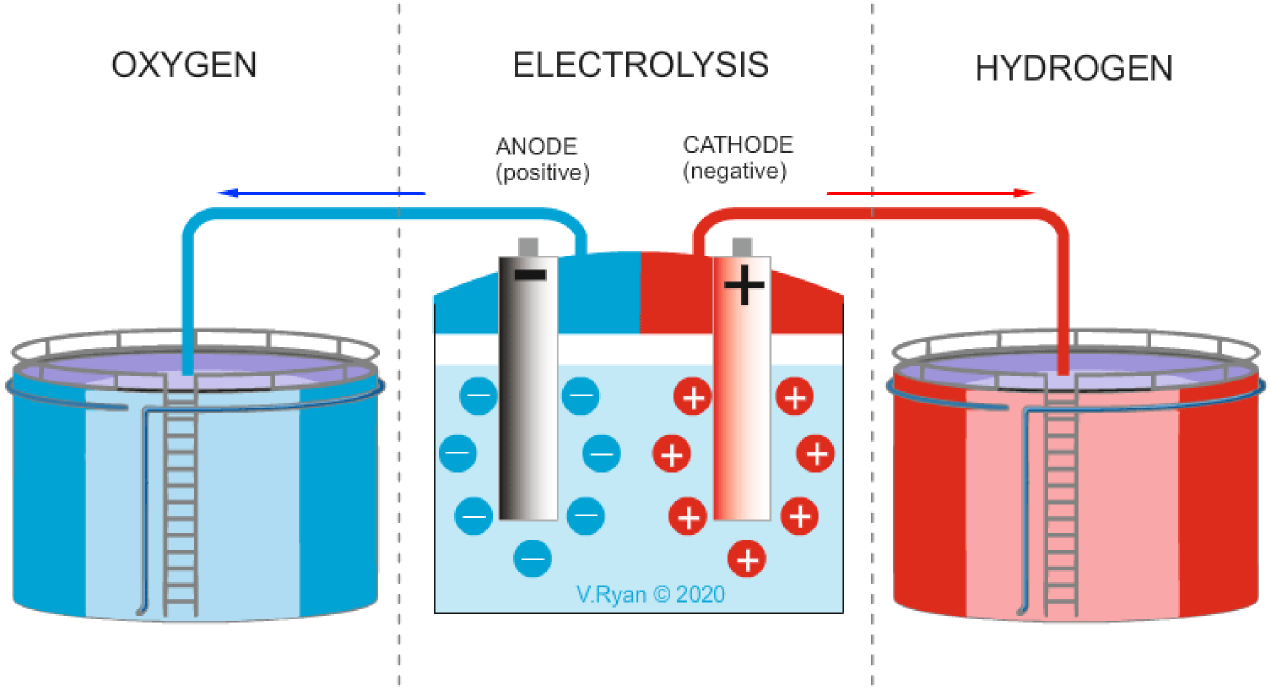


Fig.3.1: Simple Electrolytic Cell

- A source of direct current voltage is connected to the electrodes so that an electric current flows through the electrolyte from the positive electrode (or anode) to the negative electrode (or cathode).
- As a result, the water in the electrolyte solution is decomposed into hydrogen gas (H_2) which is released at the cathode, and oxygen gas (O_2); released at the anode.
- Although only the water is split, an electrolyte (e.g., KOH solution) is required because water itself is a very poor conductor of electricity.
- Ideally, a voltage of 1.23 volts should be sufficient for the electrolysis of water at normal temperature and pressure.
- For various reasons, especially the slowness of the electrode processes that lead to the liberation of hydrogen and oxygen gases, higher voltages are required to decompose water.

*KOH: Potassium hydroxide

- The decomposition voltage increases with the current density (i.e., the current per unit (area of electrode).
- Since the rate of hydrogen production is proportional to the current strength, a high operating current density is necessary for economic reasons.
- Hence, in practices the decomposition voltage (per cell) is usually around 2 volts.



Thermo-chemical Methods

- The overall efficiency for the conversion of primary energy from fossil and nuclear fuels into hydrogen by electrolysis is dependent, in the first place on the net efficiency of generating electricity.
- This efficiency may be upto about 38% for modern fossil fuel plants and 32% for nuclear installations.
- Assuming that electrolyzer efficiency can be increased to 80%, the overall efficiency for hydrogen production would be only 25% to 30%.
- A higher conversion efficiency might be possible if the heat produced by the primary fuel could be used directly to decompose water, without the intermediary of electrical energy.
- Such direct decomposition into hydrogen and oxygen is possible, but it requires a temperature of atleast 2500°C.

- Because of the temperature limitations and conversion process equipment, direct single step water decomposition can not be achieved.
- However a sequential chemical reaction series can be devised in which hydrogen and oxygen are produced, water is consumed and all other chemical intermediates are recycled.
- The operation is called a thermochemical cycle, it is so called because energy is supplied as heat at one or more of the chemical stages.
- In the reaction series, water is taken up at one stage, and hydrogen and oxygen are produced separately in different stages.

Westinghouse Electrochemical Thermal Sulphur Cycle

- This is a two-step process, where in hydrogen and Sulphur acid are produced electrolytically by the reaction of sulphurous acid and water.
- SO_2 is recovered by reducing SO_3, obtained from sulphuric acid at high temperature, oxides of sulphur serve as recycling intermediates within the process.
- The use of sulfur compounds results in several process advantages.
- The process in the most general form consists of two chemical reactions: one for producing oxygen and the other for producing hydrogen.
- The production of oxygen occurs via thermal reduction of sulphur trioxide obtained from sulphuric acid.

$$H_2SO_4 \longrightarrow H_2O + \frac{1}{2}O_2 + SO_2 \qquad \ldots(i)$$

- The equilibrium for reaction (equ. 1) lies to the right at temperatures above 1000 K*.
- Catalysts are available for accelerating the rate of sulphur trioxide reduction to sulphur dioxide and oxygen.
- The process is completed by using sulphur dioxide from thermal reduction step to depolarize the anode of a water electrolyzer.

The overall reaction occurring electro chemically is:

$$2H_2O + SO_2 \longrightarrow H_2 + H_2SO_4 \qquad \ldots(ii)$$

***1000K − 273.15 = 726.85°C**

Basic Process Description

The process is shown in Fig. 2. Hydrogen is generated electrolytically in an electrolysis cell which anodically oxidises sulphurous acid to sulphuric acid

- While simultaneously generating hydrogen at cathode.
- Sulphuric acid formed in the electrolyzer is sent to a tank from where it is fed to two vaporizers in series.
- The first of these is a recuperative heat exchanger heated by the effluent from the high temperature sulphur trioxide reduction reactor.
- The second is heated by helium from an ultra high temperature reactor.

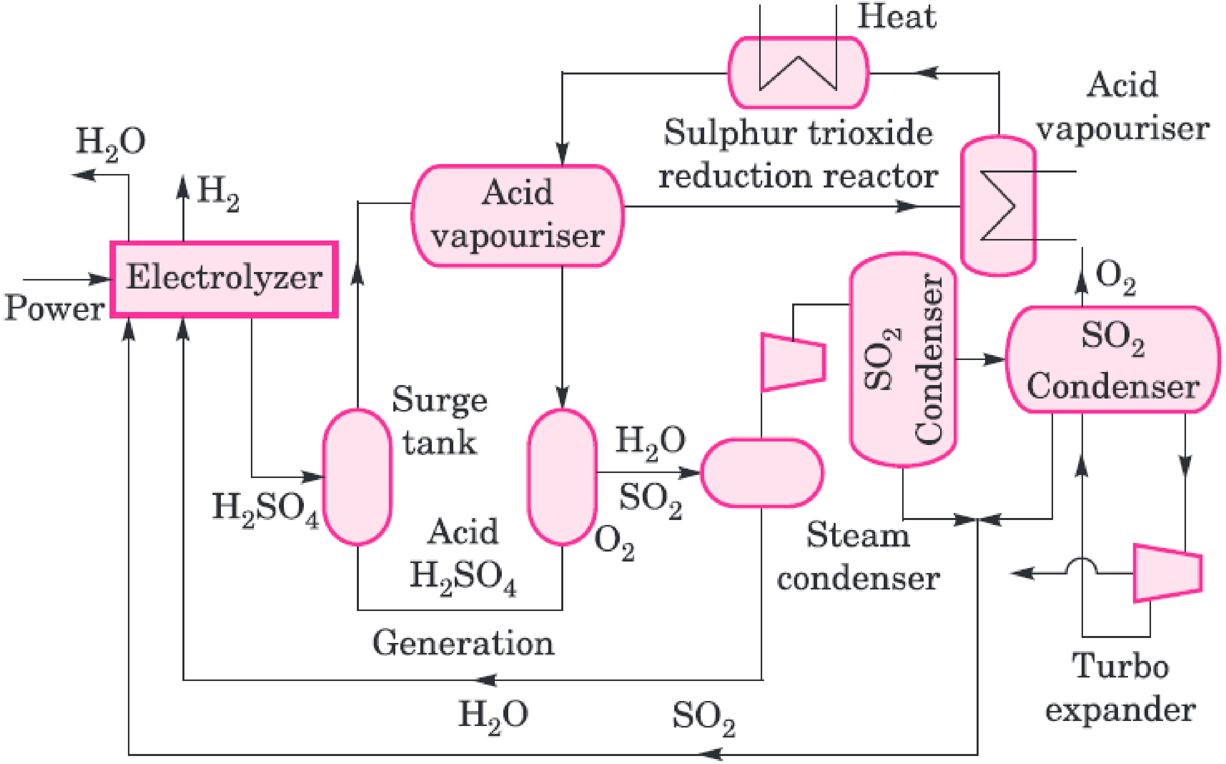


Fig.3.2: Westinghouse sulphur cycle flowsheet schematic.

- The sulphur trioxide steam mixture from the second vaporizer flows to the helium heated reduction reactor where sulphur dioxide and oxygen are formed.
- These gases are subsequently cooled against the incoming acid and unreacted sulphur trioxide is recovered on sulphuric acid in knockout system.
- Steam is first condensed, following with the SO_2/O_2 mixture is compressed and sulphur dioxide recovered.
- Bulk sulphur dioxide removal is accomplished by condensation against cooling water.
- Final removal is achieved by condensation against low temperature oxygen.
- This refrigeration and some auxiliary power production is generated by expansion of the oxygen stream prior to its venting.
- Hence in this process sulphur dioxide in sulphuric acid solution is oxidized electrochemically to sulphuric acid, hydrogen being formed at cathode.

Hydrogen Storage

- In an energy system there is a need to be able to store energy somewhere between the production point and the utilization point.
- The need for storage is due to the almost inevitable mismatch between the optimum production rate of energy and the fluctuations in demand for energy by the users.
- In the electric energy system storage, presents considerable difficulty because electricity itself is not readily storable.
- In contrast to the electrical energy system, both the gas energy and the oil energy systems are endowed with the capability store very large quantities of energy.
- In the oil industry, liquid fuels are stored in above and below ground tanks at the refinery, at the distribution centres and even at the consumers premises.
- In the gas industry, storage is provided to a small extent in the pipeline themselves and to a large extent in the underground systems which can be either depleted gas or oil fields or so called aquifer systems.

- The location of energy storage systems is very important. If a large storage system can be installed very close to customer, the load factor on the transmission systems is automatically raised, and therefore the transmission cost becomes lower.
- One of the advantages often claimed for a hydrogen energy systems is that hydrogen is storable.
- However, it must be realized that storage of hydrogen is not an easy problem compared with storage of liquid fuels such as gasoline or oil.
- It is only when it is compared with electricity that storage of energy as hydrogen seems relatively easy.
- It is when hydrogen is considered as a replacement fuel in applications currently met by natural gas and oil, that bulk energy storage becomes very important.

There are five principle methods that have been considered for hydrogen storage, these are:

(1) Compressed gas storage.

(2) Liquid storage (cryogenic storage in vacuum insulated or super insulated storage tank).

(3) Line pack system (allowing the pressure in the transmission or distribution system to vary).

(4) Underground storage (in depleted oil and gas fields or in aquifer systems).

(5) Storage as metal hydrides.

- Hydrogen can best be stored in different ways, depending on the various field of applications.
- Storage can be effected in a gaseous or liquid state, or in the structure of solids.
- According to the field of application, it is necessary to distinguish between storage on a large scale and on a small scale.

Compressed Gas Storage;

- Hydrogen is conveniently stored for many applications in high pressure cylinders.
- This method of storage is rather expensive and very bulky because very large quantities of steel are needed to contain quite small amounts of hydrogen.
- In the conventional industrial hydrogen system, compressed gas is used to supply relatively small amounts of hydrogen, but when hydrogen is considered as a fuel, it is soon realized that tank storage of hydrogen is not really a practical proposition.

Liquid Storage;

- On a small scale or moderate scale, hydrogen is frequently stored under high pressure in strong steel cylinders, this type of storage would be too costly for a large scale applications.
- A more practical approach is to store the hydrogen as liquid at a low temperature, (i.e., cryogenic storage).

- For example, the liquid hydrogen fuel used as rocket propellant in the space program is stored in large tanks.
- Very large facilities for hydrogen liquification have been designed and built, and large storage tanks have also been constructed.
- One major difference exists between handling liquid natural gas and liquid hydrogen the storage temperature.
- Thus, a liquid hydrogen plant normally requires some kind of primary refrigeration, such as a liquid nitrogen plant, to precool hydrogen.
- The net result is that about 25 to 30% of the heating value of hydrogen is required to liquefy hydrogen.

Line Packing;

- The use of line pack storage in the natural gas industry provides a relatively small capacity storage system, but one with a very fast response time that can take care of minute by minute or hour by hour variations in demand.
- A hydrogen transmission and distribution system running on hydrogen would have a similar capability although the capacity would be reduced by a factor of about 3 because of the reduced heating value of hydrogen, compared with natural gas.

Underground Storage;

- The cheapest way to store large amounts of hydrogen for subsequent distribution would probably be in underground facilities similar to those used for natural gas; these facilities would include depleted oil and gas reservoirs and aquifers.

Metal Hydrides (Storage in chemically bound form);

- Considerable interest has been shown recently in the possibility of storage of hydrogen in the form of metal hydride.
- A number of metals and alloys form solid compounds, called metal hydrides, by direct reaction with hydrogen gas.
- When the hydride is heated, the hydrogen is released and the original metal (or alloy) is recovered for further use.
- Thus, metal hydrides provide a possible means for hydrogen storage.
- An important property of metal hydrides is that the pressure of the gas released by heating a particular hydride depends mainly on the temperature and not the composition.
- At a fixed temperature, the gas pressure remains essentially constant until the hydrogen content almost exhausted.

Utilization of Hydrogen Gas

1. For residential uses
2. For industrial uses
3. For as an alternative transport fuel
4. For as an alternative fuel for aircraft
5. For electric power generation (utilities).

(i) Residential uses

- Electricity for lighting and for operating domestic appliances (e.g., refrigerators) could be generated by means of fuel cells, with hydrogen gas at one electrode and air at the other.
- Hydrogen can be used in domestic cooking.
- The burners of domestic appliances (e.g., stoves) would have to be modified if hydrogen were to replace natural gas.

(ii) Industrial Uses:

- There are many potential uses for hydrogen in industry, either as a fuel or a chemical reducing (i.e. oxygen removal) agent if the economics were favorable.
- For example, in several industrial processes natural gas has been the most satisfactory source of heat in a hydrogen energy economy, hydrogen could replace natural gas in these operations.
- Hydrogen gas could also be used with advantage, instead of coal or coal-derived gases, to reduce oxide ores (e.g. iron ore) to the metal (iron).

(iii) Road vehicles:

- The use of hydrogen fuel in internal combustion engines for automobiles, buses, trucks, and farm machinery has attracted interest as a means of conserving petroleum products and of reducing atmospheric pollution.
- Because of the fuel is a gas, the conventional carburetor of a spark-ignition engine, in which liquid gasoline is vapourized in air, must be modified for use with hydrogen.

(iv) Air Craft Applications

- The earliest application of liquid hydrogen fuel is expected to be in a jet air craft; this possibility was demonstrated in a subsonic air craft in 1957.
- The main advantage is the much lower overall weight of the fuel and storage tank than for ordinary jet fuel.

(v) Electric Power Generation

- It is unlikely that hydrogen would serve as a major fuel for electric power generation by a utility.
- However, its substitution for natural gas in peak shaving turbines is possible.
- Hydrogen could also be used as a means for storing and distributing electrical energy.

ADVANTAGE AND DISADVANTAGE OF HYDROGEN ENERGY

Advantage:

- Uncoupling of primary energy source and utilization
- Hydrogen is a gas hence can be stored easily compared to electricity
- Hydrogen can be obtained from any primary source
- Efficient when used as fuel cells
- Very good safety records for specific application

Disadvantage:

- Very less efficiency
- Low energy density
- Need for high pressure and low temperature storage
- Safety problems
- High cost

PROBLEM ASSOCIATED WITH HYDROGEN ENERGY

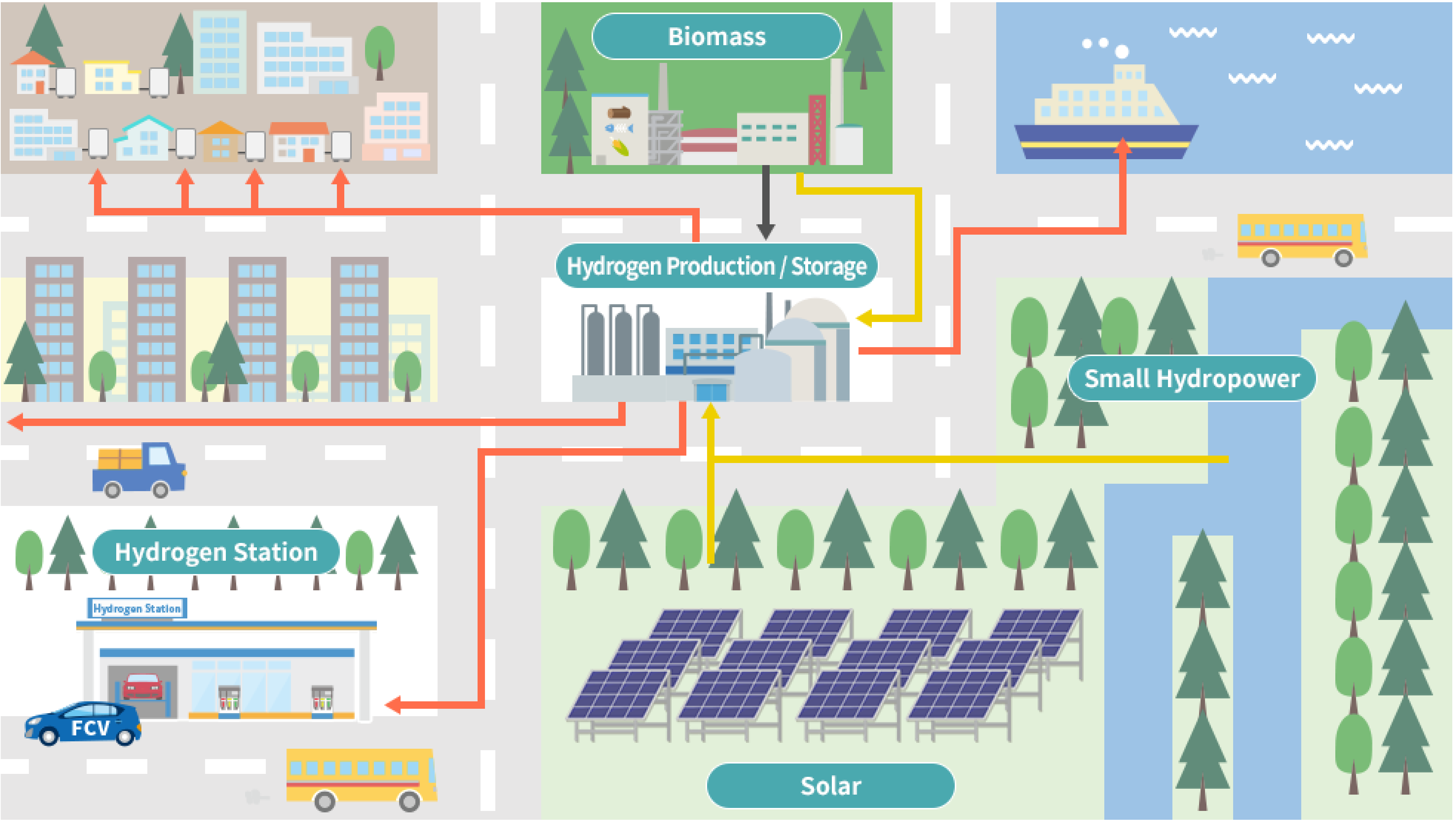
Hydrogen Storage: it is a major issue. Because container used must withstand high pressure when hydrogen is stored.

High Reactivity of Hydrogen: it is extremely reactive it is combustible and flammable. The filled container may explode.

Cost and methods of hydrogen fuel production: the cost of production is very high and newer and cleaner technology need to be found.

Consumer Demand: gas filling station to be changed to hydrogen filling, it should be free available to consumers and meet their demand.

Cost of Changing Infrastructure: to accommodate hydrogen equipment and appliances.


Biomass
Hydrogen Production / Storage
Small Hydropower
Hydrogen Station
Hydrogen Station
FCV
Solar

Wind Energy

Basic Principles of Wind Energy Conversion

- The circulation of air in the atmosphere is caused by the nonuniform heating of the earth's surface by the sun.
- The air immediately above a warm area expands, it is forced upwards by cool, denser air which flows in from surrounding areas causing a wind.
- The nature of the terrain, the degree of cloud cover and the angle of the sun in the sky are all factors that influence this process.
- In general, during the day the air above the land mass tends to heat up more rapidly than the air over water.
- In coastal regions this manifests itself in a strong onshore wind.
- At night the process is reversed because the air cools down more rapidly over the land and the breeze, therefore, blows off shore.

- Despite the wind's intermittent nature, wind patterns at any particular site remain remarkably constant year by year.
- Average wind speeds are greater in hilly and coastal areas than they are well inland.
- The winds also tend to blow more consistently and with greater strength over the surface of the water where there is a less surface drag.
- Wind speeds increase with height. They have traditionally been measured at a standard height of ten metres where they are found to be 20-25% greater than close to the surface.
- At a height of 60 m they may be 30-60% higher because of the reduction in the drag effect of the earth's surface.

The Power in the Wind

Wind possesses energy by virtue of its motion. Any device capable of slowing down the mass of moving air, like a sail or propeller, can extract part of the energy and convert it into useful work.

Three factors determine the output from a wind energy converter:

(i) The wind speed

(ii) The cross-section of wind swept by the rotor and

(iii) The overall conversion efficiency of the rotor, transmission system, and generator or pump.

- The power in the wind can be computed by using the concept of kinetics.
- The windmill works on the principle of converting the kinetic energy of the wind to mechanical energy.
- We know that power is equal to energy per unit time.
- The energy available is the kinetic energy of the wind.
- The kinetic energy of any particle is equal to one-half its mass times the square of its velocity, or $\frac{1}{2}mV^2$.
- The amount of air passing in unit time, through an area A, with velocity V, is A.V, and its mass m is equal to its volume multiplied by its density Þ of air, or

$$m = \rho AV \qquad \text{..... (i)}$$

(m is the mass of air transversing the area A swept by the rotating blades of a wind mill type generator). Substituting this value of the mass in the expression for the kinetic energy, we obtain, kinetic energy = $\frac{1}{2}$ ÞAV.V^2 watts

$$= \frac{1}{2} \rho A V^3 \text{ watts} \qquad \text{..... } (ii)$$

- Equation (2) tells us that the maximum wind available the actual amount will be somewhat less because all the available energy is not extractable and is proportional to the cube of the wind speed.
- It is thus evident that small increase in wind speed can have a marked effect on the power in the wind.
- Equation (2) also tell us that the power available is proportional to air density (1.225 kg/m3 at sea level).
- It may vary 10-15 % during the year because of pressure and temperature change.
- Equation also tells us that the wind power is proportional to the intercept area.
- Thus an aeroturbine with a large swept area has higher power than a smaller area machine; but there are added implications.

Since the area is normally circular of diameter D in horizontal axis aeroturbines,

then $A = \frac{\pi}{4} D^2$, (sq. m.)

which when put in equation (2) gives,

$$\text{Available wind power } P_a = \frac{1}{2} \rho \frac{\pi}{4} D^2 V^3 \text{ watts}$$

$$= \frac{1}{8} \rho \pi D^2 V^3 \qquad \text{..... (iii)}$$

- The equation tells us that the maximum power available from the wind varies according to the square of the diameter of the intercept area (or square of the rotor diameter), normally taken to be swept area of the aero turbine.
- Thus doubling the diameter of the rotor will result in a four-fold increase in the available wind power.
- Equation (3) gives us insight into why the designer of an aero turbine for wind electric use would place such great emphasis on the turbine diameter.

- The combined effects of wind speed and rotor diameter variations are shown in. Fig.3.3. Wind machines intended for generating substantial amounts of power should have large rotors and be located in areas of high wind speeds.
- Where low or moderate powers are adequate, these requirements can be relaxed.
- The physical conditions in a wind turbine are such that only a fraction, of the available wind power can be converted into useful power.

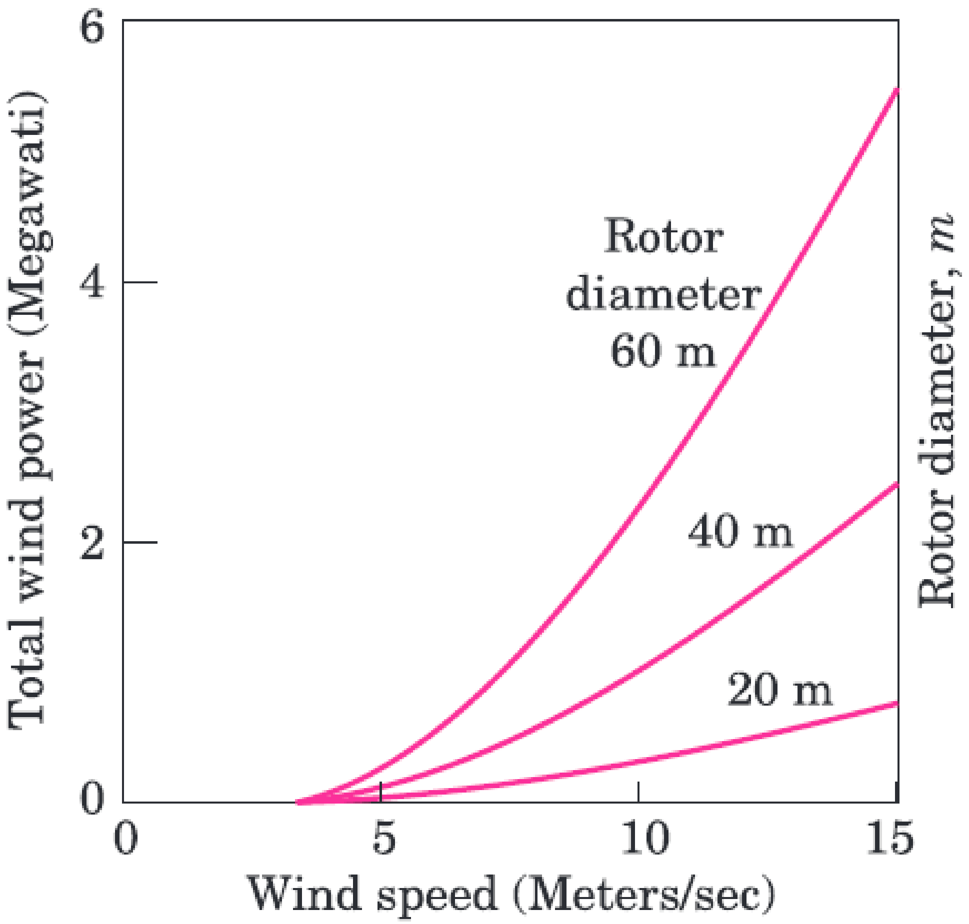


Fig.3.3 : Dependence of wind-rotor power on wind speed and rotor diameter.

Site Selection Considerations

- The power available in the wind increases rapidly with the speed, hence wind energy conversion machines should be located preferable in areas where the winds are strong and persistent.
- Technical, economic, environmental, social, and other factors are examined before a decision is made to erect a generating plant on a specific site.

Some of the main considerations are discussed below.

High annual average wind speed.

- A fundamental requirements to the successful use of WECS, obviously, is an adequate supply of wind.
- The wind velocity is the critical parameter. The power in the wind P, through a given cross-sectional area for a uniform wind velocity V is

$$P_w = KV^3 \qquad \text{..... (iv)}$$

where, K is a constant.

- It is evident, because of the cubic dependence on wind velocity that small increases in V markedly affect the power in the wind, e.g., doubling V, increases P, by a factor of 8.
- It is obviously desirable to select a site for WECS with high wind velocity.
- Thus a high average wind velocity is the principal fundamental parameter of concern in initially appraising a WECS site.

Strategy for siting is generally recognized to consists of:

(i) Survey of historical wind data.
(ii) Contour maps of terrain and wind are consulted.
(iii) Potential sites are visited.
(iv) Best sites are instrumented for approximately one year.
(v) Choose optimal site.

Availability of anemometry data.

- It is another important siting factor. The principal object is to measure the wind speed which basically determines the WECS output power.
- The anemometry data should be available over some time period at the precise spot where any proposed WECS is to be built and that this should be accomplished before a siting decision is made.

Wind structure at the proposed site.

- The ideal case for the WECS would be a site such that the V curve was flat, i.e., a smooth steady wind that blows all the time; but a typical site is always less than ideal.
- Wind specially near the ground is turbulent and gusty, and changes rapidly in direction and in velocity.
- This departure from homogeneous flow is collectively referred to as "the structure of the wind.

Altitude of the proposed site.

- It affects the air density and thus the power in the wind and hence the useful WECS electric power output.
- Also, as is well known, the winds tend to have higher velocities at higher altitudes.

Terrain and its aerodynamic.

- One should know about terrain of the site to be chosen.
- If the WECS is to be placed near the top but not on the top of a not too blunt hill facing the prevailing wind, then it may be possible to obtain a 'speed up' of the wind velocity over what it would otherwise be.

Local Ecology.

- If the surface is bare rock it may mean lower hub heights hence lower structure cost.
- If trees or grass or vegetation are present, all of which tend to destructure the wind, then higher hub heights will be needed resulting in larger system costs than the bare ground case.

Distance to Roads or Railways.

- This is another factor the system engineer must consider for heavy machinery, structures, materials, blades and other apparatus will have to be moved into any chosen WECS site.

Nearness of site to local centre / users.

- This obvious criterion minimizes transmission line length and hence losses and costs.

Nature of ground.

- Ground condition should be such that the foundations for a WECS are secured.
- Ground surface should be stable. Erosion problem should not be there, as it could possibly later wash out the foundations of a WECS, destroying the whole system.

Favourable land cost.

- Land cost should be favourable as this along with other siting costs, enters into the total WECS system cost.

Other conditions such as icing problem, salt spray or blowing dust should not present at the site, as they may affect aeroturbine blades, or environmental is generally adverse to machinery and electrical apparatus.

Offshore Wind

Onshore Wind

Basic Components of a WECS (Wind Energy Conversion System)

The main components of a WECS are shown in Fig. (6.12), in block diagram form. Summary of the system operation is as follows:

Aeroturbines convert energy in moving air to rotary mechanical energy. In general, they require pitch control and yaw control (*only in the case of horizontal or wind axis machines)* for proper operation. A mechanical interface consisting of a step up gear and a suitable coupling transmits the rotary mechanical energy to an electrical generator. The output of this generator is connected to the load or power grid as the application warrants.

Yaw control. For localities with the prevailing wind in one direction, the design of a turbine can be greatly simplified. The rotor can be in a fixed orientation

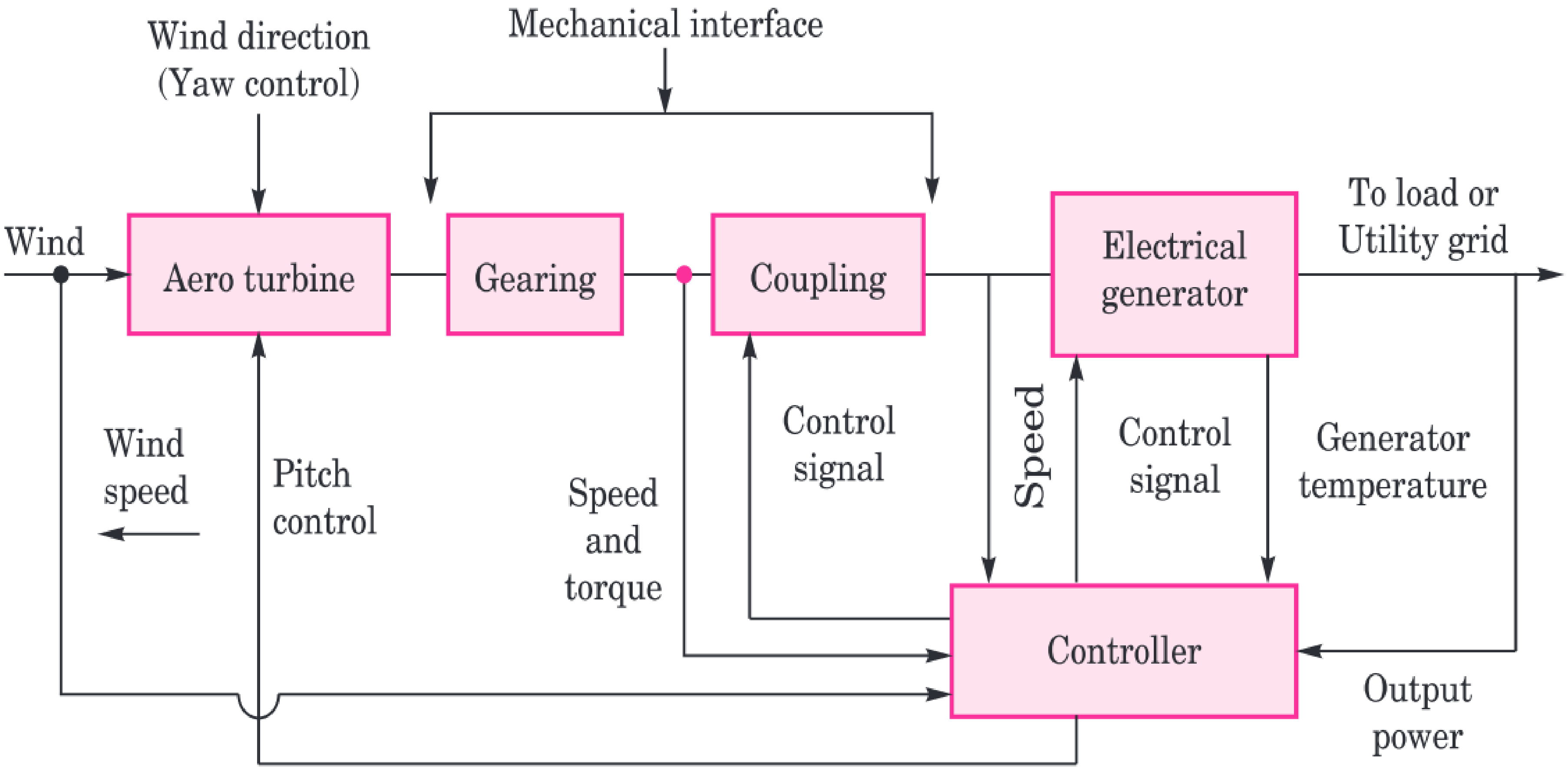


Fig. 6.12. Basic components of a wind electric system.

The purpose of the controller is to sense wind speed, wind direction, shafts speeds and torques at one or more points, output power and generator temperature as necessary and appropriate control signals for matching the electrical output to the wind energy input and protect the system from extreme conditions brought upon by strong winds electrical faults, and the like.

Classification of WEC Systems

1. First, there are two broad classifications:

(*i*) *Horizontal Axis Machines.* The axis of rotation is horizontal and the aeroturbine plane is vertical facing the wind.

(*ii*) *Vertical Axis Machines.* The axis of rotation is vertical. The sails or blades may also be vertical, as on the ancient Persian windmills, or nearly so, as on the modern Darrievs rotor machine.

2. Then, they be classified *according to size* as determined by their useful electrical power output.

3. As per the type of *output power,* wind aerogenerators are classified as:

(*i*) *DC output*

(*a*) DC generator

(*b*) Alternator rectifier

(*ii*) *AC output*

4. As per the *rotational speed* of the aeroturbines

5. Wind turbines are also classified as per how the *utilization of output is*

   (*i*) Battery storage.

   (*ii*) Direct connection

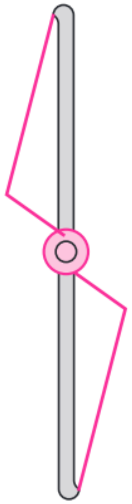
Advantages of Wind Energy Conversion Systems:

1. Renewable and Clean
2. Abundant Resource
3. Energy Independence
4. Cost-Effective
5. Job Creation and Economic Growth

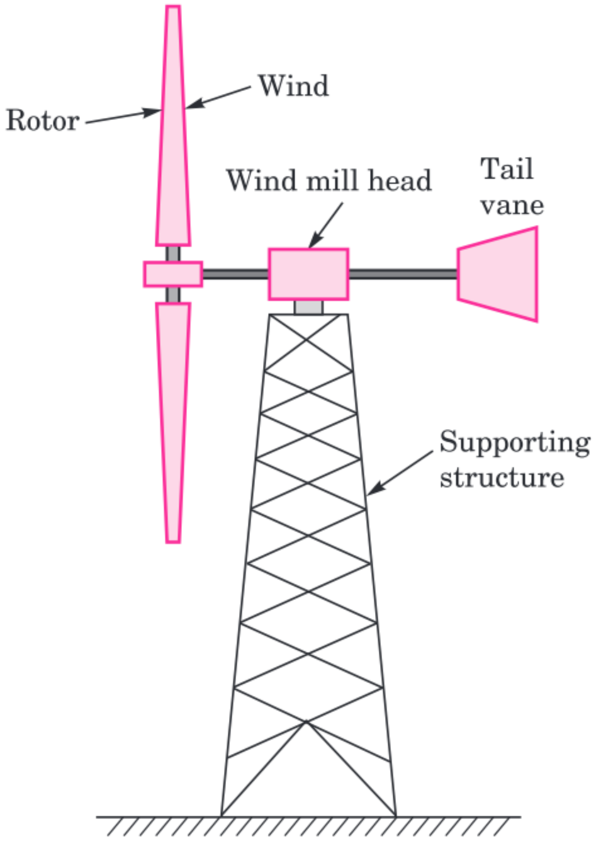
Disadvantages of Wind Energy Conversion Systems:

1. Intermittent and Unpredictable
2. Land and Visual Impact
3. Noise and Wildlife Concerns
4. Initial Capital Investment
5. Grid Integration and Transmission

Horizontal Axis Machine

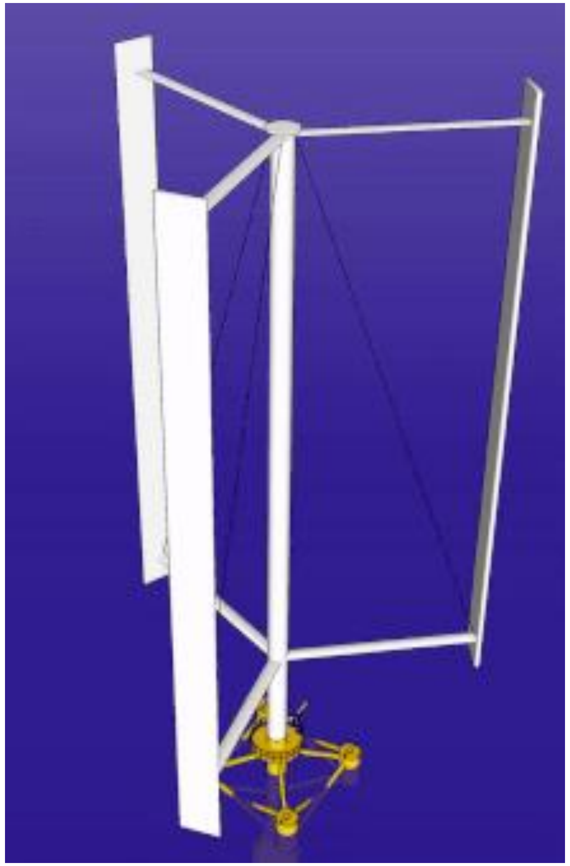


a) Two blade prufile



(*b*) Schematic of a horizontal axis type wind mills

Vertical Axis Machine



Geothermal Energy

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.
- 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. 3.4 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 that 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.

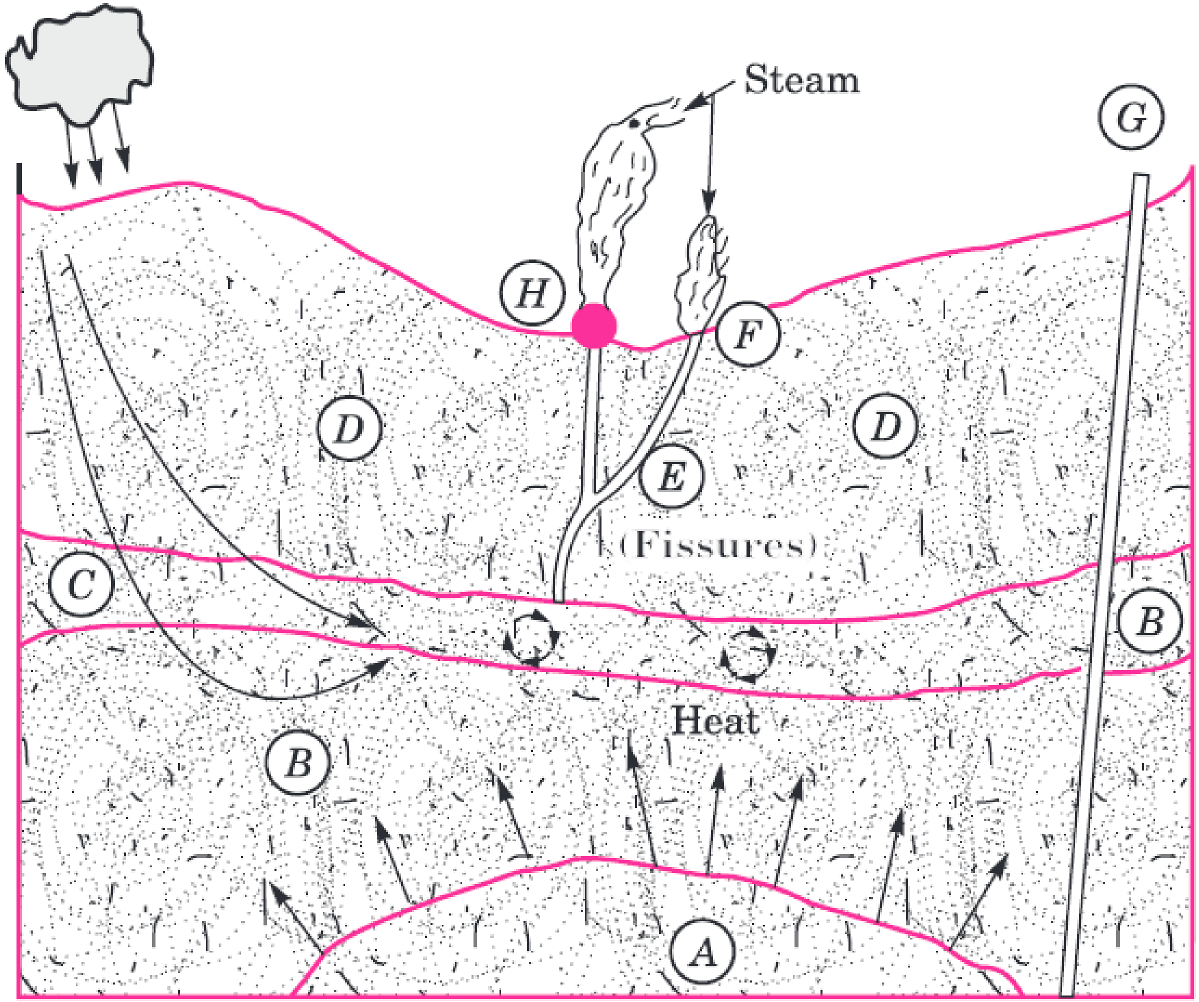


Fig. 3.4 shows a typical geothermal field

- 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.

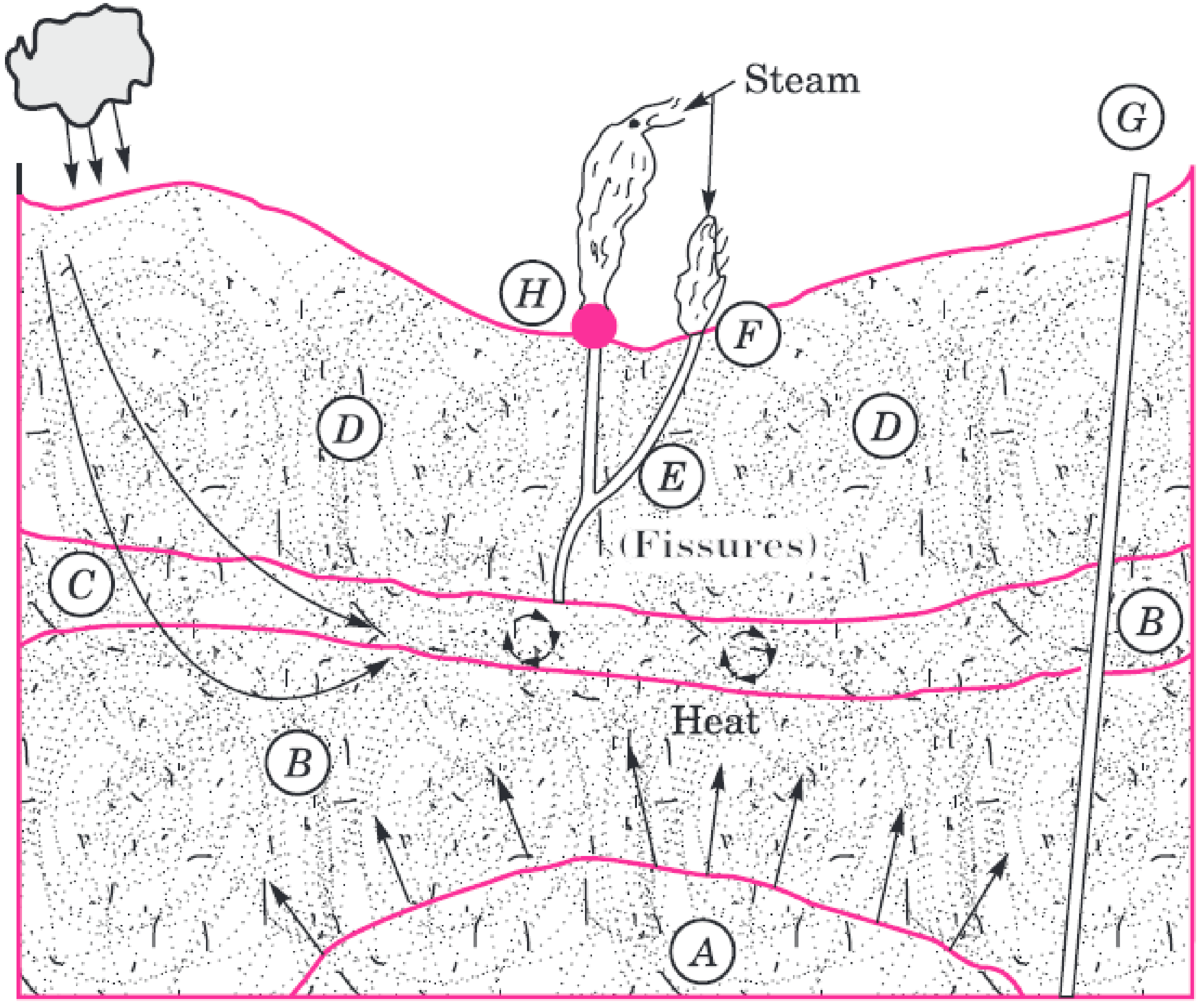


Fig. 3.4 shows a typical geothermal field

Main advantages of geothermal energy are:

- It is a reliable and cheap source of energy.
- It is available 24 hours per day.
- Its availability is independent of weather.
- It has inherent storage feature so no extra storage facility required.
- Geothermal plants require little land area.
- Feasibility of modular approach represents lot of opportunities for development of relatively quick, cost-effective geothermal projects.

Major disadvantages are:

- It is site specific there are not many places where you can build a geothermal power station.
- Generally, energy is available as low grade heat.
- Continuous extraction of heated ground water may leads to subsidence (setting or slumping) of land.

- Geothermal fluid also brings with it the dissolved gases and solute (as high as 25 kg/m3) which leads to air and land pollution.
- Drilling operation leads to noise pollution.
- The available thermal energy cannot be distributed easily over long distances (longer than ~30 km).
- Corrosive and abrasive geothermal fluid reduces the life of the plant.

Types of Geothermal Resources

There are four types of geothermal resources:

(i) Hydrothermal, (ii) Geo-pressured, (iii) Hot Dry Rock (HDR) and (iv) Magma.

- At present the technology for economic recovery of energy is available for hydrothermal resource only.
- Thus this is the only commercially used resource at present.
- Other resources are going through development phase and have not become commercial so far.
- For practical purposes, hydrothermal resources are further subdivided into (i) vapour dominated (dry steam fields), (ii) liquid dominated (wet steam fields) and (iii) hot water resource.
- Vapour dominated fields deliver steam with little or no water and liquid dominated fields produce mixture of steam and hot water or hot water only.

Vapour Dominated (Dry Steam) System

Dry steam fields occur when the pressure is not much above the atmospheric pressure and the temperature is high. Water boils underground and generates steam.

- The layout of vapour-dominated system is shown in Fig 3.5.
- The steam is extracted from the well (1) where it is nearly saturated.
- The extracted steam is then cleaned in centrifugal separator to remove solid matter.
- While passing through the well, as well as centrifugal separator the pressure drops, which causes it to slightly super heat.

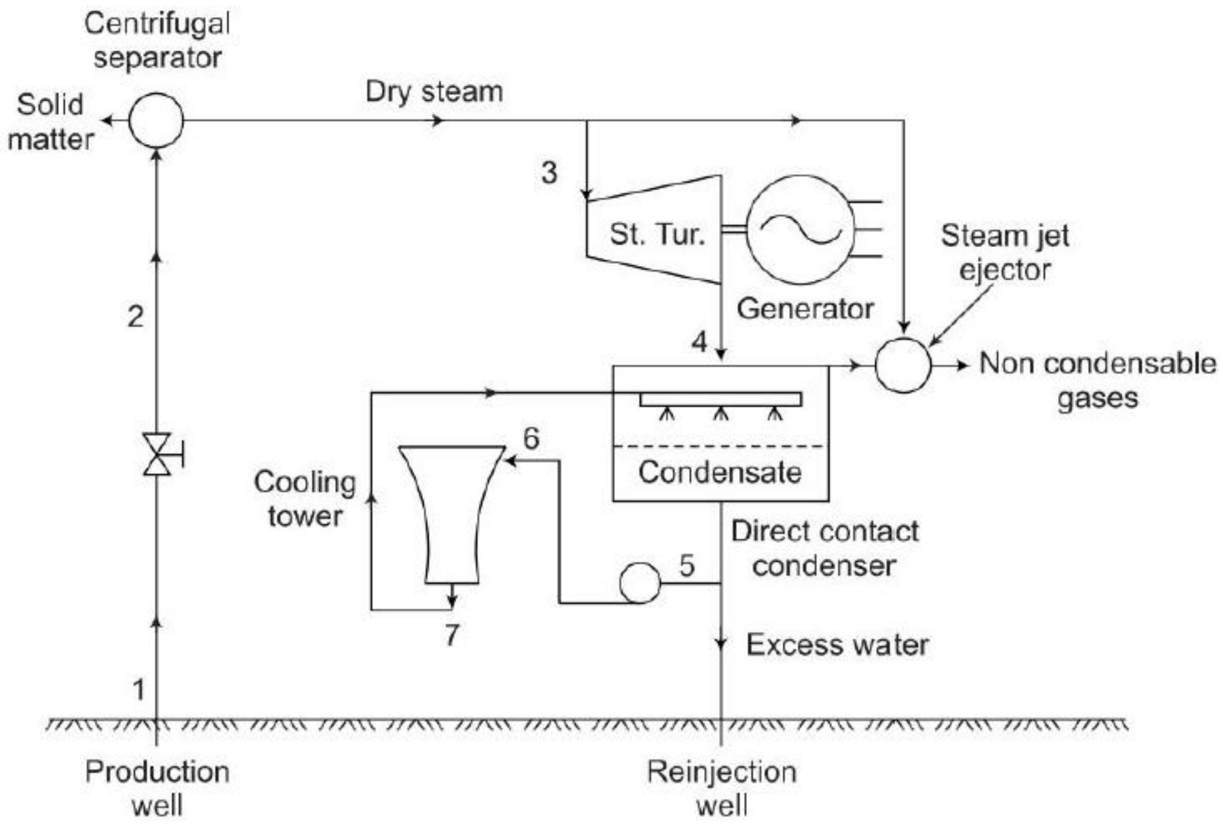


Fig. 3.5 Layout of vapour-dominated system

- The steam is then supplied to a turbine (3) at temperature of about 165 °C and pressure of about 7.8 atm. (the temperature and pressure in the reservoir are higher) and allowed to expand (4).
- The exhaust steam of turbine is condensed in direct contact condenser, in which the steam is condensed by direct contact with cooling water.
- The resulting warm water (5) is circulated and cooled in cooling tower and returned to the condenser (7).

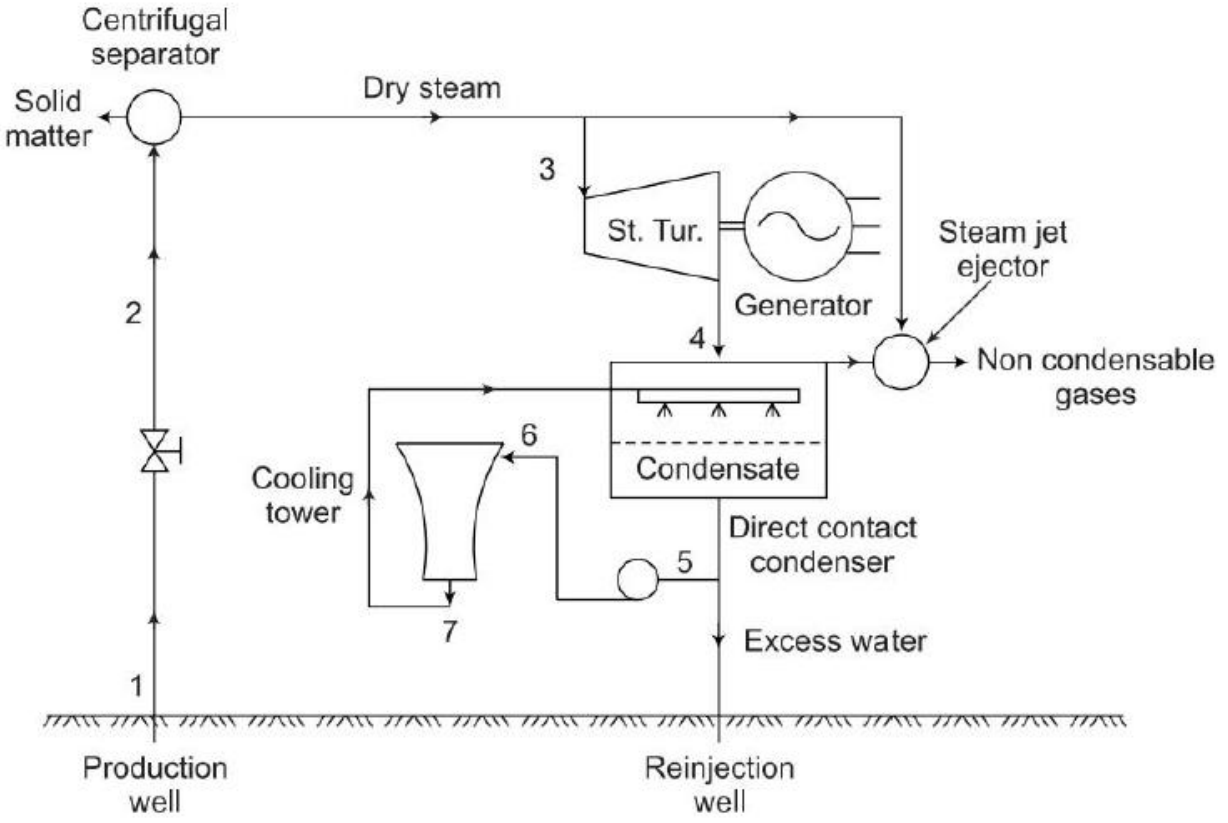


Fig. 3.5 Layout of vapour-dominated system

- The condensation of steam continuously increases the volume of cooling water. Excess water is reinjected at some distance deep into the ground for disposal.
- The non-condensable gases are removed from the condenser by steam jet ejection.

Flash Geothermal Power Plants

- The term flash steam refers to the process where high-pressure hot water is flashed (vaporized) into steam inside a flash tank by lowering the pressure.
- This steam is then used to drive around turbines.
- At high pressure below earth's surface, the water exists as compressed liquid.
- Pipeline is installed to tap into the resource.

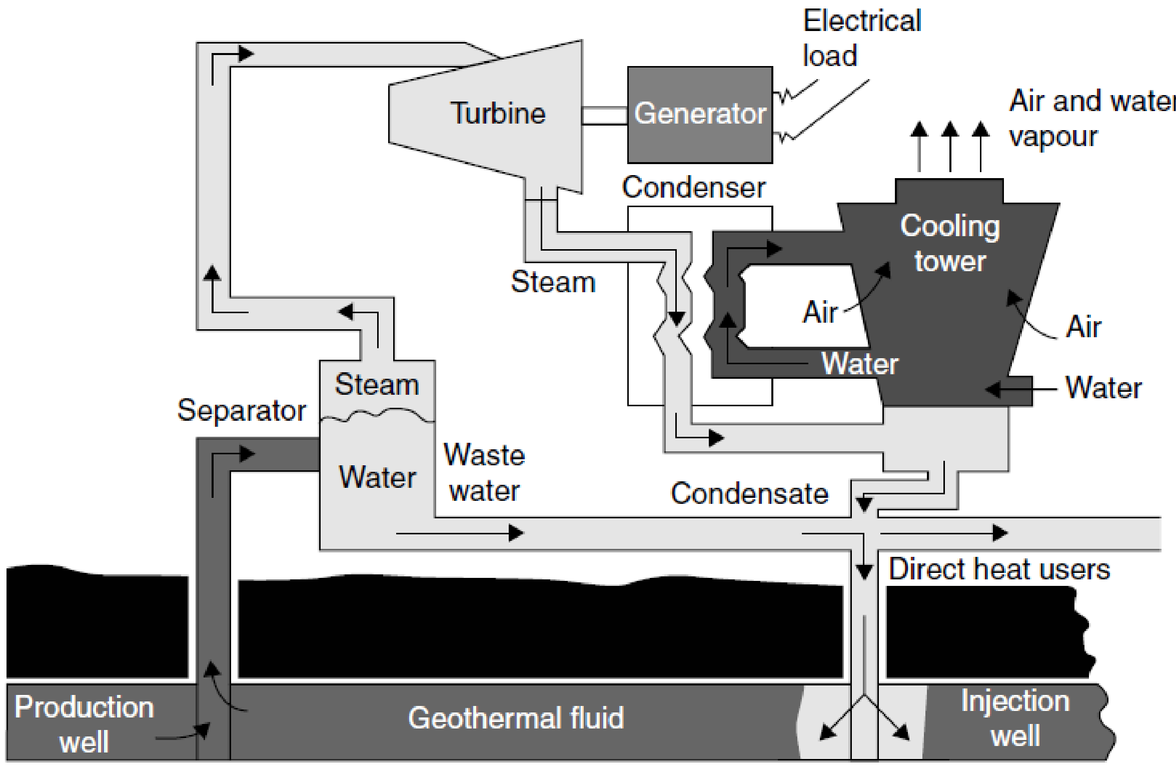


Fig. 3.6 Single-flash geothermal steam-electric power plant

- When the compressed liquid water reaches the surface at atmospheric pressure then, a portion of it immediately flashes to steam.
- The steam portion is redirected into a steam turbine, where power is produced.

- The exhaust is then piped to a condenser where it is returned to liquid. This hot liquid water can then be used for further heating applications prior to the reinjection into the rock.
- Flash steam plants are the most common type of geothermal power generation plants in operation today.
- Fluid at temperatures greater than 182°C is pumped under high pressure into a tank at the surface held at a much low pressure, causing some of the fluid to rapidly vaporize, or ‘flash.’
- The vapour then drives a turbine, which drives a generator. If any liquid remains in the tank, it can be flashed again in the second tank to extract more energy.

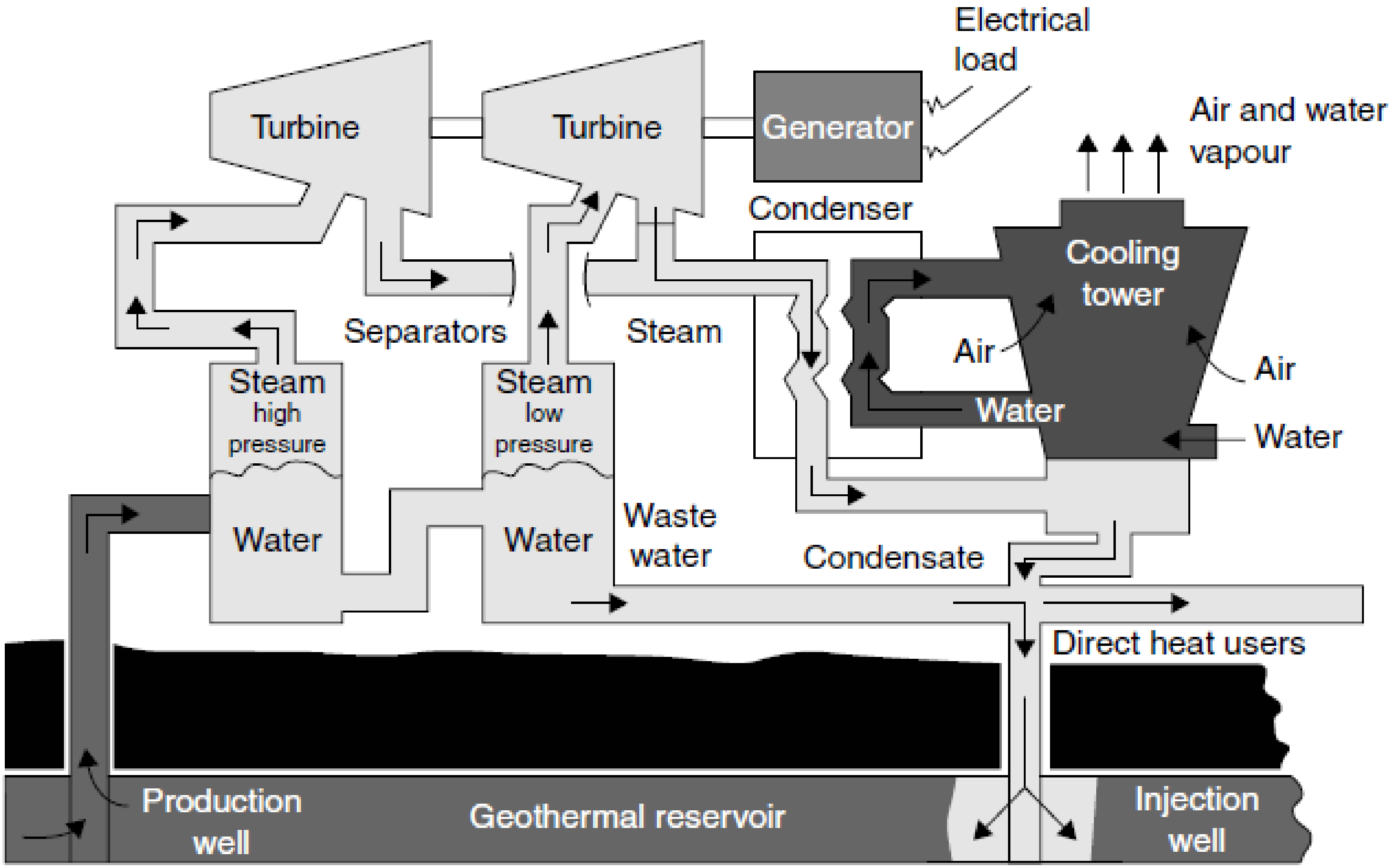
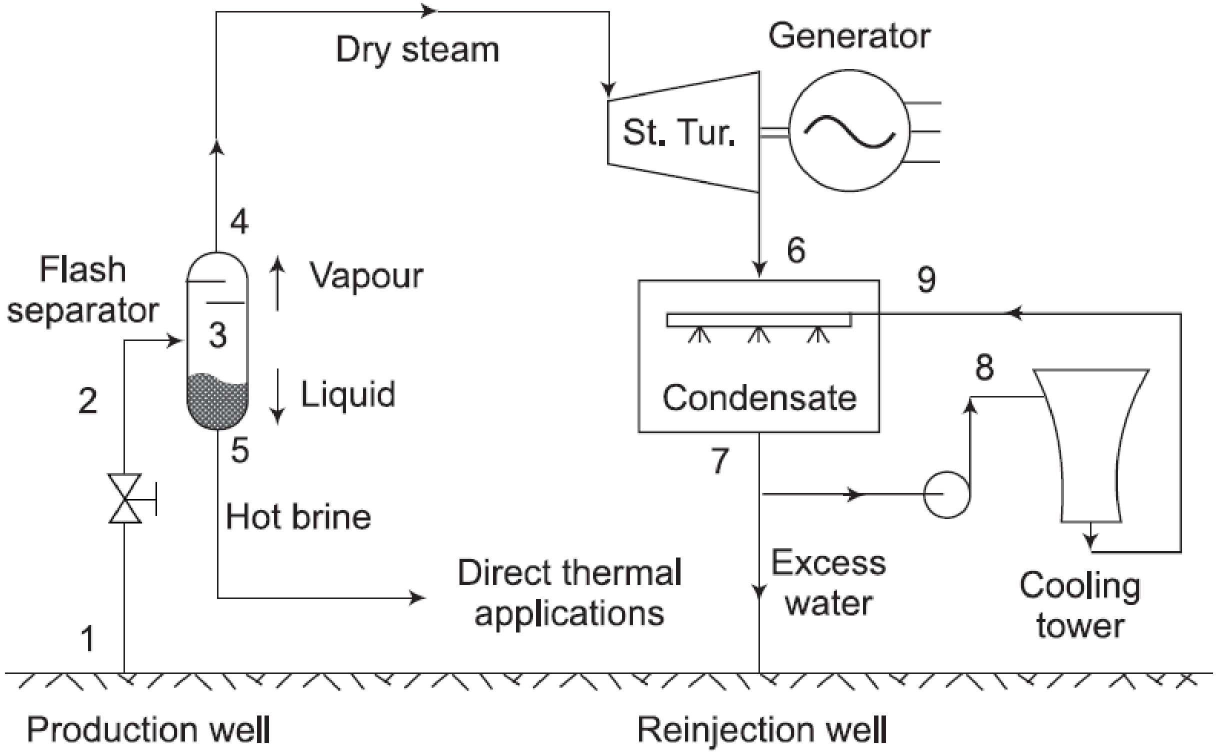
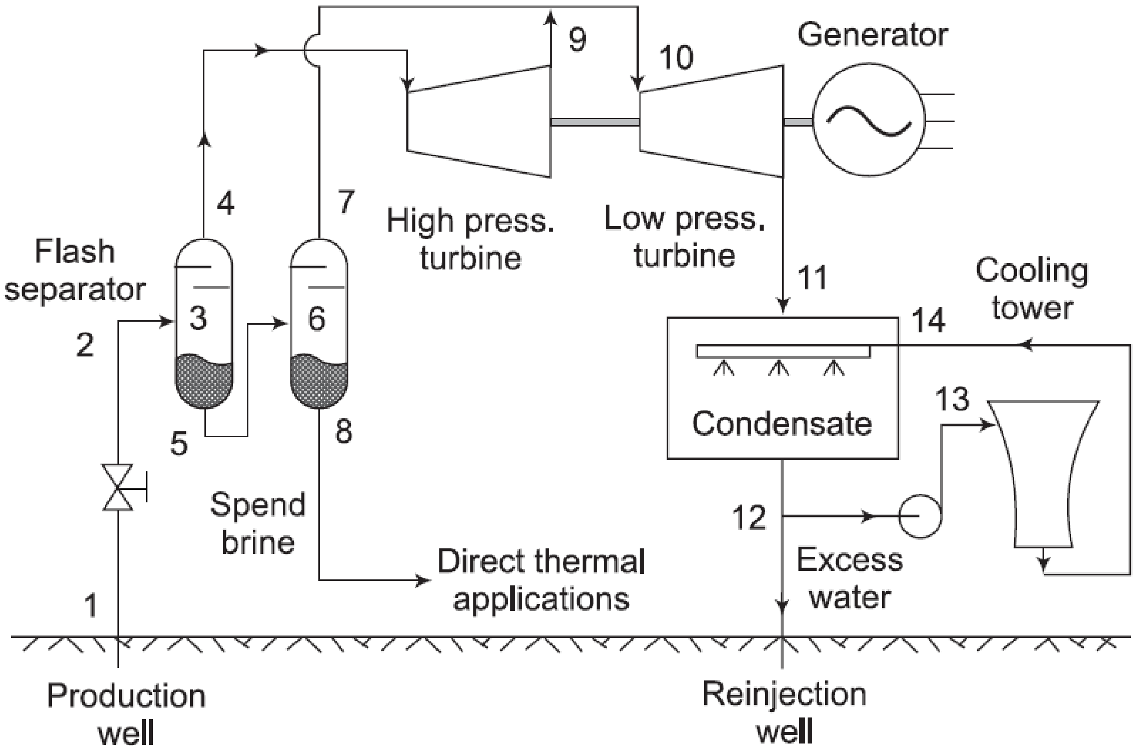


Fig. 3.7 Double-flash geothermal steam-electric power plant



Single-flash geothermal steam-electric power plant



Double-flash geothermal steam-electric power plant

Binary Cycle-based Geothermal Plants

- A binary-fluid system is employed, where the heat of geothermal fluid is used to vapourize a volatile organic fluid, such as isobutene (B.P. 10 °C), under pressure in a primary heat exchanger.
- The geothermal fluid is reinjected after extraction of heat.
- This vapourized fluid serves as working fluid in a Rankine cycle plant.

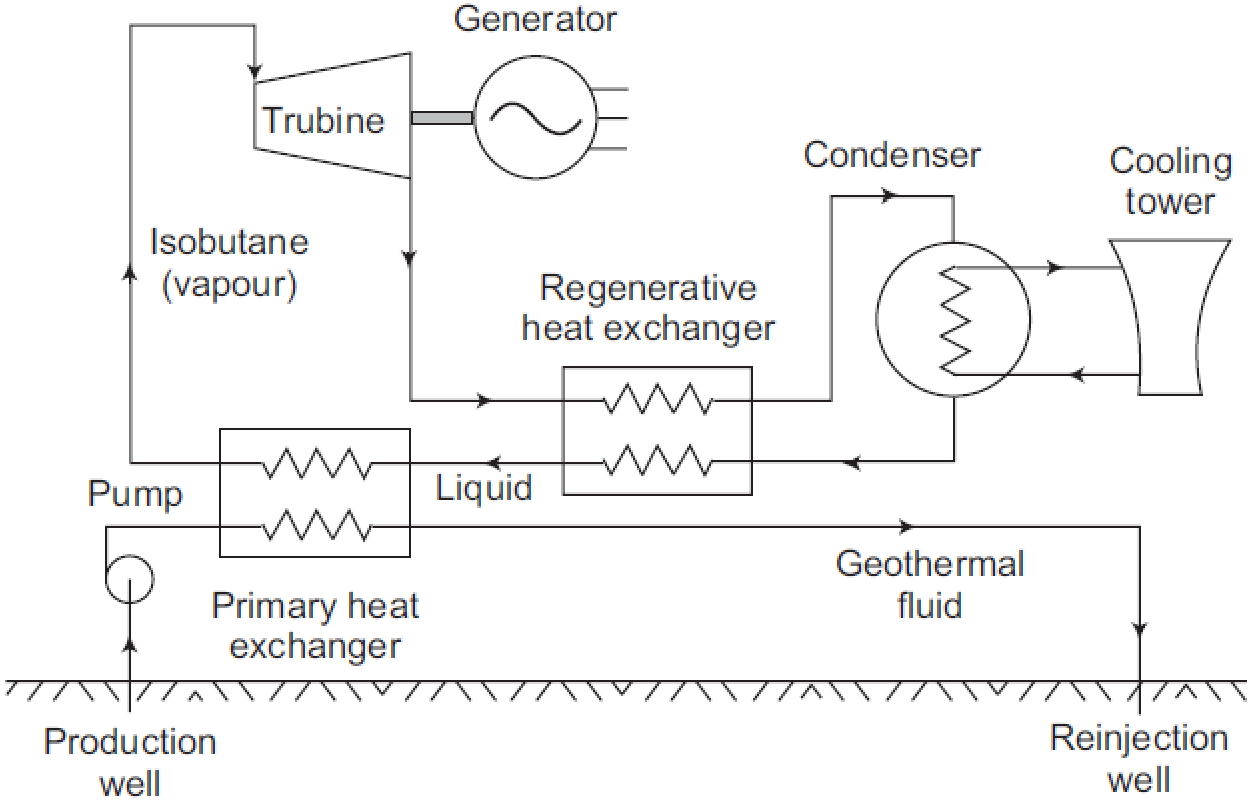


Fig. 3.8 Binary fluid hydrothermal system

- The exhaust vapour from the turbine is cooled in the regenerative heat exchanger and then condensed in a condenser.
- The condensed liquid isobutene is returned to primary heat exchanger by way of the regenerative heat exchanger.
- The layout of the system is shown in Fig 3.8. Binary plants have no emissions.
- The thermal efficiency of such a plant is typically about 10–13 percent.
- These plants do not produce any steam condensate and have to rely on external source of cooling water or air-cooling.

Solid Wastes and Agricultural Refuse

Solid waste is the unwanted or useless solid materials generated from human activities in residential, industrial or commercial areas.

It may be categorized in three ways, According to its:

- Origin (domestic, industrial, commercial, construction or institutional)
- Contents (organic material, glass, metal, plastic paper etc.)
- Hazard potential (toxic, non-toxin, flammable, radioactive, infectious etc.).

SOURCES AND TYPES OF WASTES

The following are some of the wastes:

Residential wastes:

- These are single family or multifamily dwellings.
- They constitute kitchen wastes, paper and cardboards, clothes and leather materials, plastics and rubber materials, glass, wood and metal crockery and furniture, electrical and electronics appliances and gadgets, etc.

Municipal services wastes:

- They include general wastes collected from street sweeping, park, recreational places, sludge, landscaping, and tree trimming.

Industrial and commercial wastes:

- They are housekeeping and food wastes, packaging and demolition material wastes, scraps, hazardous wastes, wood, cardboard paper, plastics, etc.

Building construction and demolition:

- They constitute various types of wastes such as wood, concrete, steel, and dust.

Agriculture:

- It consists of dairy and agriculture farm crop wastes, hazardous pesticides, etc.

Effect of Solid Waste on Environment

Litter Surroundings

Due to improper waste disposal systems, particularly by municipal waste management teams, wastes heap up and become a menace.

Impact on Human Health

Improper waste disposal can affect the health of the population living nearby the polluted area or landfills.

Disease-causing Pests

Dumping of waste materials forces biodegradable materials to rot and decompose under improper, unhygienic and uncontrolled conditions.

Environmental Problems

Solid wastes from industries are a source of toxic metals, hazardous wastes, and chemicals. When released to the environment, the solid wastes can cause biological and physicochemical problems to the environment that may affect or alter the productivity of the soils in that particular area.

Soil and Groundwater Pollution

Toxic materials and chemicals may seep into the soil and pollute the groundwater.

Emission of Toxic Gases

When hazardous wastes like pesticides, batteries containing lead, mercury or zinc, cleaning solvents, radioactive materials, e-waste and plastics mixed up with paper and other non-toxic scraps are burned they produce Toxic Gases

Impact on Land and Aquatic Animals

Our carelessness with our waste and garbage also affects animals, and they suffer the effects of pollution caused by improperly disposed of wastes and rubbish.