Rashtreeya Sikshana Samithi Trust

RV Institute of Technology and Management®

(Affiliated to VTU, Belagavi)

JP Nagar, Bengaluru - 560076

Department of Mechanical Engineering

Course Name: Elements of Mechanical Engineering

Course Code: 21ME15/25

I/II Semester

2021 Scheme

MODULE – 1

Introduction to Mechanical Engineering (Overview only):

Role of Mechanical Engineering in Industries and Society- Emerging Trends and Technologies in different sectors such as Energy, Manufacturing, Automotive, Aerospace, and Marine sectors and contribute to the GDP.

Steam Formation and Application:

Formation of steam and thermodynamic properties of steam (Simple Problems using Steam Tables), Applications of steam in industries namely, Sugar industry, Dairy industry, Paper industry, Food processing industry for Heating/Sterilization, Propulsion/Drive, Motive, Atomization, Cleaning, Moisturization, Humidification

Energy Sources and Power Plants:

Review of energy sources; Construction and working of Hydel power plant, Thermal power plant, and Nuclear power plant, solar power plant, Tidal power plant, Wind power plant.

Introduction to basics of Hydraulic turbines and pumps:

Principle and Operation of Hydraulic turbines, namely, Pelton Wheel, Francis Turbine and Kaplan Turbine. Introduction to working of Centrifugal Pump

Contents

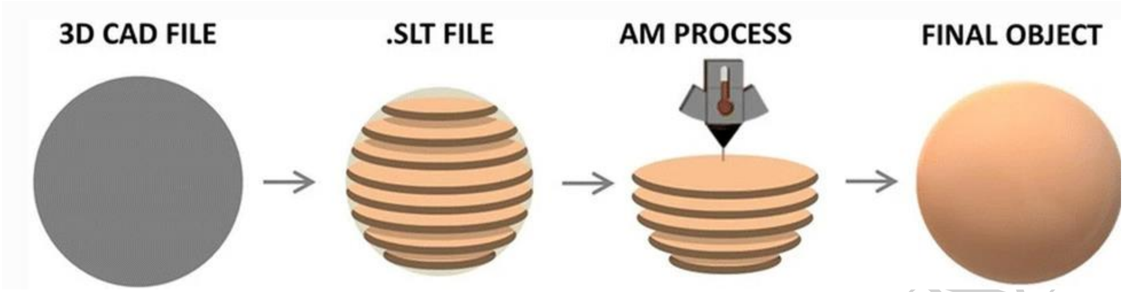
1.1 Emerging Trends in Mechanical Engineering (An Overview)

Mechanical engineering is one of the broadest engineering disciplines. Mechanical engineers design, develop, build, and test. They deal with anything that moves, from components to machines to the human body.

Traditionally, mechanical engineers have to deal with many concepts such as kinematics, mechanics, thermodynamics, structural analysis, robotics, and fluid mechanics. These concepts are applied while designing the most advanced manufacturing units, different motor vehicles, aircraft, and aerospace parts. The list below discusses the emerging technologies in various sector for mechanical engineers:

1. **3D Printing (Additive Manufacturing (AM)):** AM or additive layer manufacturing (ALM) is the industrial production name for 3D printing, it is the opposite of subtractive manufacturing, in which an object is created by cutting away at a solid block of material until the final product is complete. Technically, AM can refer to any process where a product is created by building something up, such as molding, but it typically refers to 3-D printing. Figure 1.1(a) discuss the different steps involved in AM. To create an object using additive manufacturing, someone must first create a design. This is typically done using computer aided design, or CAD, software, or by taking a scan of the object someone wants to print. Software then translates the design into a layer by layer framework for the additive manufacturing machine to follow. This is sent to the 3-D printer, which begins creating the object immediately. AM uses any number of materials, from polymers, metals, and ceramics to foams, gels, and even biomaterials (As long as you find a way to locally join two parts, you can 3-D print it). Figure 1.1(b) shows the AM application in different sectors.

(a)



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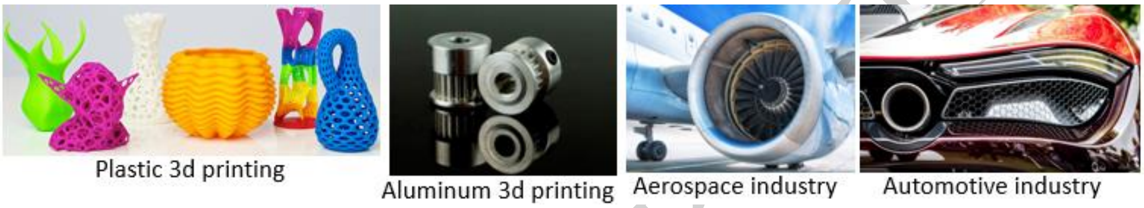


Fig. 1.1 (a) Different steps for additive manufacturing process, (b) Application of additive manufacturing in various domains.

2. **Internet of Things:** In this system, there is no need of human intervention. Each and every system is under the control of devices connected around it. It is a system of mechanical and digital machines which are provided with UID's in order to transfer the data over a wide variety of networks. It actually involves machine learning with real time analytics. Examples include thermostats, security systems (Fig. 1.2(a)), cars, alarm clocks, electronic appliances, lights in commercial and household environments, vending machines, speaker systems and more.

3. **Industry 4.0:** Industry 4.0 (Fig. 1.2(b)) is one of the emerging trends for mechanical engineers which focuses on data exchange and automation in manufacturing technologies and processes which include the Internet of Things (IoT), artificial intelligence, Cloud computing, Industrial Internet of Things (IIOT). Industry 4.0" factories have the machines which have sensors and other parts with wireless connectivity which can visualise the entire production line and make the decisions on its own.

(a)

(b)

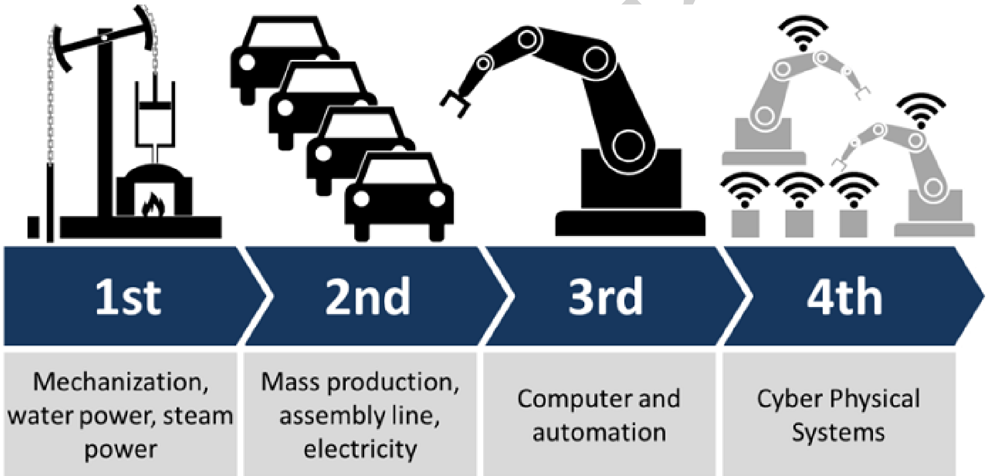
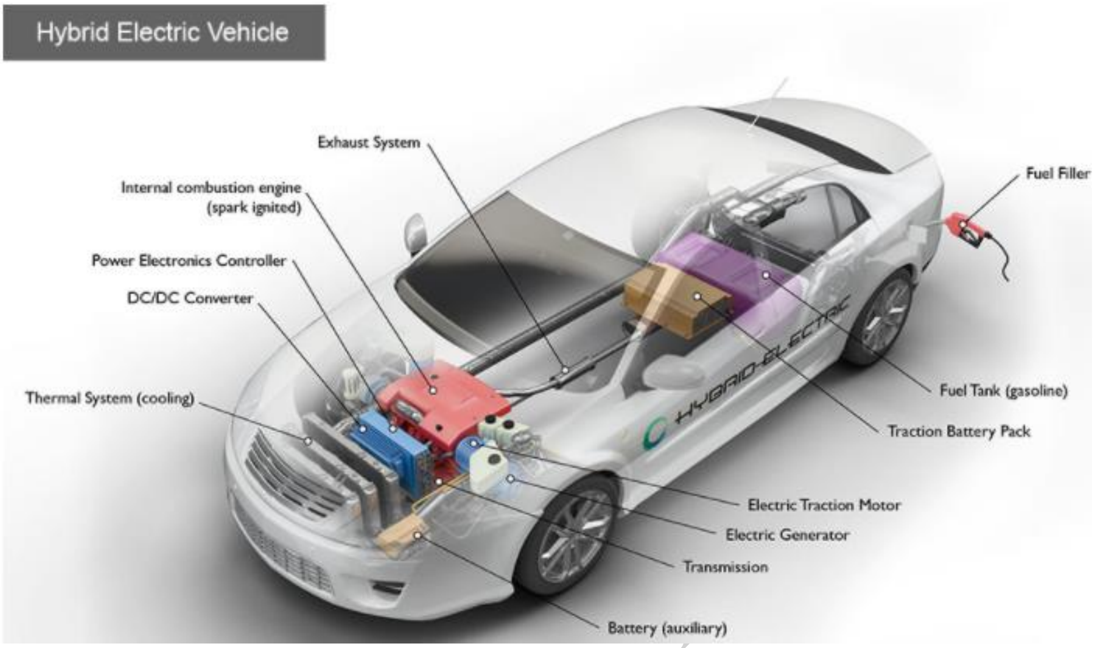


Fig. 1.2 (a) IOT: The Ring video doorbell, mounted next to the front door of a house, (b) Illustration of Industry 4.0, showing the four "industrial revolutions" with a brief English description.

4. **Automotive Sector:** Example hybrid electric cars (Fig. 1.3(a)). Hybrid electric vehicles are powered by an internal combustion engine and an electric motor, which uses energy stored in batteries. A hybrid electric vehicle cannot be plugged in to charge the battery. Instead, the battery is charged through regenerative braking and by the internal combustion engine. The extra power provided by the electric motor can potentially allow for a smaller engine.

(a)



(b) (c)

Fig. 1.3 (a) Hybrid-electric cars a classic emerging application for mechanical engineers in automotive industry, (b) Application of 3D printing in aerospace industry, (c) Robots for hull cleaning in marine industry.

5. **Aerospace industry:** Aerospace structures differ from other structures due to their high demand for performance and lightweight. 3D printing, has been proven to be an excellent manufacturing solution for producing components and parts that utilize significantly less material than other comparable, traditionally manufactured parts. Here, complex geometric shapes can be built that have great strength despite the reduced density in the material used. Reducing weight is paramount to the aerospace technology industry due to increasing performance in areas of speed, capacity, fuel consumption, emissions, and more. Fig. 1.3(b) shows the use of laser metal deposition (3D printing) to produce J-31 stealth fighter.

6. **Marine industry:** Robotics are already influencing maritime operations. Robots are used for many things in the maritime industry, from cleanup and maintenance to full-on driverless craft. Of particular importance is their use during hazardous or potentially dangerous situations. By replacing human laborers with robotics, the operations instantly become safer and often more streamlined. The U.S. Maritime Administration, for example, has partnered with SEA-KIT to create robotic oil-cleanup vessels. The job is incredibly dangerous for human workers, who see regular exposure to hazardous chemicals, toxic fumes and a high risk for fire or explosions. Robotics would be a much safer option.

   It's no secret that the hull or underside of sea vessels grow remarkably dirty highlighting *cleaning and maintenance issue* (Fig. 1.3(c)). It's also a task that can be dangerous, difficult and tedious. Traditionally, divers will do the work when a vessel is docked or in port. However, new robotics may be able to do the job instead. It's also a task that can be dangerous, difficult and tedious. Traditionally, divers will do the work when a vessel is docked or in port. However, new robotics may be able to do the job instead.

   Huge ships such as cargo or shipping vessels are difficult to *inspect* because of the surface area of the boat and its materials and colors. It can be challenging to detect cracks, corrosion and other serious complications, especially under the water where its dark and murky. It means that human inspectors have to invest considerable time pouring over every inch of a vessel – Hence the importance of robots realize in inspection.

1.2 SOURCES OF ENERGY

Energy Resources: Energy is defined as the capacity to do work. It is a primary requirement for day to day activities of human beings.

ENERGY- Capacity to do Work.

- Most of the energy that we use is mainly derived from conventional energy sources.
- Due to the vast demand for energy, the rate of depletion of these resources has reached alarmingly low levels.

- This situation has directed us to seek alternative energy sources such as solar, wind, ocean, biomass, Hydel, etc.

Energy Sources:

- The energy existing in the earth is known as capital energy.
- The energy that comes from outer space is called celestial or income energy.
- The capital energy sources are mainly, fossil fuels, nuclear fuels, and heat traps.
- Celestial energy sources are- electromagnetic, gravitational and particle energy from stars, planets, moon etc.
- Electromagnetic energy of the earth's sun is called direct solar energy. this results in wind, hydel, geothermal, biofuel, etc.
- Gravitational energy of earth's moon produces tidal energy.

1.3 Renewable Sources of Energy:

Energy sources which are continuously produced in nature and are essentially inexhaustible are called renewable energy sources. The following are the list of renewable energy sources are:

1. Direct solar energy
2. Wind energy
3. Tidal energy
4. Hydel energy
5. Ocean thermal energy
6. Bioenergy
7. Geothermal energy
8. Fuel wood
9. Fuel cells
10. Solid Wastes
11. Hydrogen

Non-Renewable Energy Sources:

Energy sources which have been accumulated over the ages and not quickly replaceable when they are exhausted.

1. Fossil fuels.

2. Nuclear Fuels.
3. Heat Traps.

Advantages of Renewable Energy Sources:

1. Inexhaustible.
2. Can be matched in scale to the need and can deliver quality energy.
3. Can be built near the load point.
4. Flexibility in the design of conversion systems.
5. Local self-sufficiency by harnessing locally available renewable energy.
6. Except for biomass, all other sources are pollution-free.

Disadvantages of Renewable Energy Sources:

1. Intermittent nature of availability of energy such as solar, wind, tidal, etc. is a major setback in the continuous supply of energy.
2. Solar energy received at the earth is dependent on local atmosphere conditions, time of the day, part of the year, etc.
3. Sources such as wind, tidal, etc. are concentrated only in certain regions.-
4. Technology is not fully developed to meet the present energy requirements.
5. Systems such as solar cells require advanced technologies and hence costlier.
6. Application to the transport sector has been found to be not viable as on today.

Advantages of Non-Renewable Energy Sources:

1. The initial cost is lower. Hence widely used.
2. Unit power costs are much lower and so are economical.
3. Sources are highly reliable.
4. Power generation technologies are well established.

Disadvantages of Non-Renewable Energy Sources:

1. The sources are getting depleted and soon will be exhausted.
2. They pollute the atmosphere.

3. They are not freely available.

1.4 Petroleum-based Fuels:

This formed mainly from ancient microscopic plants and bacteria that lived in the ocean and saltwater seas. These micro-organisms died and settled to the seafloor, they mixed with sand silt to form organic-rich mud which was gradually heated and compressed chemically transforming into petroleum. The liquid petroleum gases which are less dense than water move upwards through earth's crust. It passes through an impermeable layer of rock which traps the petroleum creating a reservoir of petroleum and natural gas.

Types of Fuels: - The important fuels are as follows-

1) Solid fuels, 2) Liquid fuels & 3) Gaseous fuels

Solid fuels

- Coal is the major fuel used for thermal power plants to generate steam.
- Coal occurs in nature, which was formed by the decay of vegetable matters buried under the earth millions of years ago under pressure and heat.
- This phenomenon of the transformation of vegetable matter into coal under earth's crust is known as Metamorphism.
- The type of coal available under the earth's surface depends upon the period of metamorphism and the type of vegetable matter buried, also the pressure and temperature conditions.
- The major constituents in coal moisture (5-40%), volatile matter (combustible & or incombustible substances about 50%) and ash (20-50%).
- The chemical substances in the coal are carbon, hydrogen, nitrogen, oxygen, and sulphur.
- In the metamorphism phenomenon, the vegetable matters undergo the transformation from peat to anthracite coal, with intermediate forms of lignite and bituminous coal.

Liquid Fuels

- All types of liquid fuels used are derived from crude petroleum and its by-products.

- The petroleum or crude oil consists of 80-85% C, 10-15% hydrogen, and varying percentages of sulphur, nitrogen, oxygen, and compounds of vanadium.
- The crude oil is refined by fractional distillation process to obtain fuel oils, for industrial as well as for domestic purposes.
- The fractions from light oil to heavy oil are naphtha, gasoline, kerosene, diesel and finally heavy fuel oil.
- The heavy fuel oil is used for the generation of steam. The use of liquid fuels in thermal power plants has many advantages over the use of solid fuels.

Some important advantages are as follows:

1. The storage and handling of liquid fuels are much easier than solid and gaseous fuels.
2. Excess air required for the complete combustion of liquid fuels is less, as compared to the solid fuels.
3. Fire control is easy and hence changes in load can be met easily and quickly.
4. There are no requirements for ash handling and disposal.
5. The system is very clean, and hence the labor required is relatively less compared to the operation with solid fuels.

Gaseous Fuels

- For the generation of steam in gas-fired thermal plants, either natural gas or manufactured gaseous fuels are used. However, manufactured gases are costlier than natural gas.
- Generally, natural gas is used for power plants as it is available in abundance. The natural gas is generally obtained from gas wells and petroleum wells.
- The major constituent in natural gas is methane, about 60-65%, and also contains small amounts of other hydrocarbons such as ethane, naphthenic and aromatics, carbon dioxide and nitrogen.
- The natural gas is transported from the source to the place of use through pipes, for distances to several hundred kilometers.
- The natural gas is colorless, odorless and non-toxic.

- Its calorific value ranges from 25,000 to 50,000 kJ/m^3, in accordance with the percentage of methane in the gas.
- The artificial gases are producer gas, water gas coke-oven gas; and the Blast furnace gas.
- Generally, power plants fired with artificial gases are not found.
- The gaseous fuels have advantages similar to those of liquid fuels, except for the storage problems.
- The major disadvantage of a power plant using natural gas is that it should be set up near the source; otherwise the transportation losses are too high.

1.5 Calorific values of fuels:

The calorific value or heat of combustion or heating value of a sample of fuel is defined as the amount of heat evolved when a unit weight (or volume in the case of a sample of gaseous fuels) of the fuel is completely burnt.

It is usually expressed in Gross Calorific Value (GCV) or Higher Heating Value (HHV) and Net Calorific Value (NCV) or Lower Heating Value (LHV).

Higher Calorific Value (or Gross Calorific Value - GCV, or Higher Heating Value - HHV) - the water of combustion is entirely condensed and that the heat contained in the water vapor is recovered Lower Calorific Value (or Net Calorific Value - NCV, or Lower Heating Value - LHV) - the products of combustion contains the water vapor and that the heat in the water vapor is not recovered

Combustion and Combustion Products:

Combustion or burning is the sequence of exothermic chemical reactions between a fuel and an oxidant accompanied by the production of heat and conversion of chemical species. The release of heat can produce light in the form of either glowing or a flame. Complete combustion of fuel is possible only in the presence of an adequate supply of oxygen.

Oxygen (O_2) is one of the most common elements on earth making up 20.9% of our air. Rapid fuel oxidation results in a large amount of heat. Solid or liquid fuels must be changed to a gas before they will burn in their normal state if enough air is present.

Most of the 79% of air (that is not oxygen) is nitrogen, with the traces of other elements. Nitrogen is considered to be a temperature reducing diluter that must be present to obtain the oxygen required combustion.

Nitrogen reduces combustion efficiency by absorbing heat from the combustion of fuels and diluting the flue gases. This reduces the heat available for transfer through the heat exchange surfaces. It also increases the volume of combustion by-products. Which then have to travel through the heat exchanger and up the stack faster to allow the introduction of the additional fuel-air mixture.

This nitrogen also can combine with oxygen (particularly flame temperatures) to produce oxides of nitrogen (NOx) which are toxic pollutants. Carbon, hydrogen, and sulphur in the fuel combine with oxygen in the air to form carbon dioxide, water vapor and sulphur dioxide, releasing 8084 kcals, 28922 kcals and 2224 kcals of heat respectively. Under certain conditions, carbon may also combine with the oxygen to form carbon monoxide, which results in the release of a smaller quantity of heat (2430 kcals/kg of carbon). Carbon burned to CO_2will produce more heat per unit of fuel than CO or smokes are produced.

1.6 SOLAR POWER PLANT

Solar radiation is radiant energy emitted by the sun from a nuclear fusion reaction that creates electromagnetic energy. The spectrum of solar radiation is close to that of a black body with a temperature of about 5800 K. About half of the radiation is in the visible short- wave part of the electromagnetic spectrum.

Solar Constant Isc:

This is the amount of energy received in unit time on a unit perpendicular to the suns direction at the mean distance of the earth from the sun. The surface of the earth receives about 1014kW of solar energy from the sun. One square meter of the land exposed to direct sun-light receives an energy equivalent of about 1.353 kW of power. This constant may increase by only 0.2 percent at the of each 11-year solar cycle. The radiant solar energy falling on the earth surface is directly converted into thermal energy. The surfaces on which the solar rays fall are called collectors.

Insolation:-Insolation is the amount of solar radiation reaching the earth. Also called Incident Solar Radiation. The maximum value is 1000 kW/m^2.

Components of Solar Radiation:

- Direct radiation
- Diffuse radiation
- Reflect radiation

Solar Thermal Energy harvesting:

Radiant solar energy is directly converted into thermal energy (heat energy) by using a collector. This process is called a Helio thermal process. The surface on which the solar rays fall is called a collector. The collector may be either flat plate collector or focusing collector. Fig. 1.4 shows the flat plate collector.

There are two types of collectors:

(a) Flat plate collectors

(b) Focusing collectors.

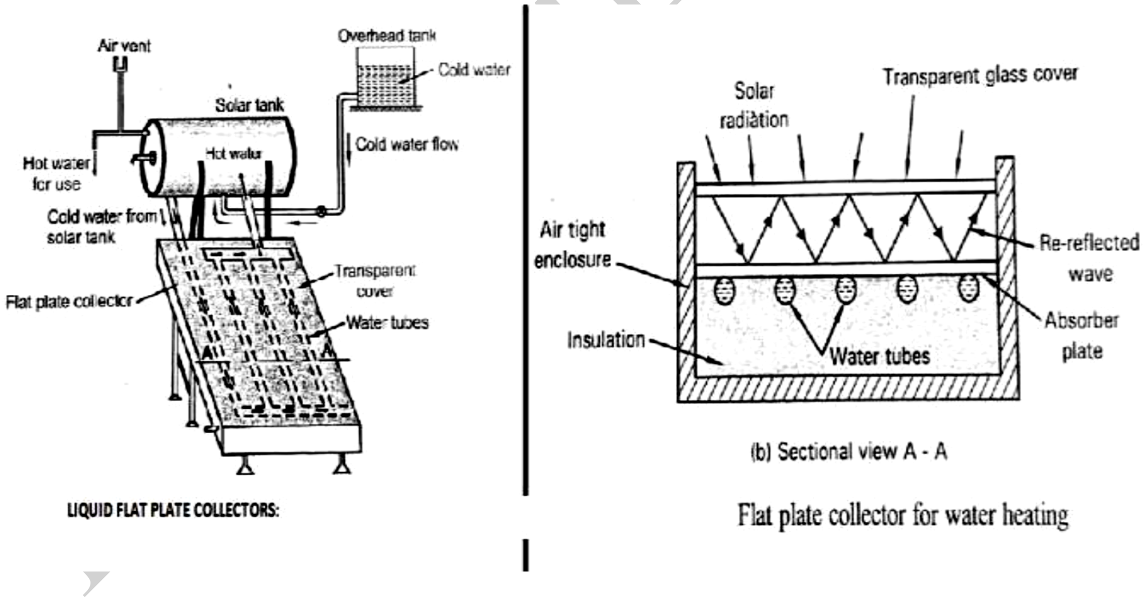


Fig. 1.4 Flat plate collector

It has the following components:

(a) Absorbing plate –

- Made of Copper, Aluminium or steel.
- It is coated with a material to enhance the absorption of solar radiation.
- From the absorbing plates, heat is transferred to tubes which carry either water or air.

(b) Water tubes –

- These are metallic tubes through which water circulates. Which are attached to the absorber plate.

(c) Transparent covers –

- Sheets of solar radiation transmitting materials placed above the absorbing plate.
- They allow solar energy to reach the absorbing plate while reducing convection, conduction and re-radiation heat losses.
- Made of a toughened glass, usually 4mm thick. This helps in reflecting the incident solar energy back to the absorber plate.
- Glass cover permits the entry of solar radiation as it is transparent for incoming short wavelengths.

(d) Insulation –

- It minimizes and protects the absorbing plate from heat losses.

Working – Sun's rays falling on the transparent covers are transmitted to the absorbing plate. The absorbing plate usually of Cu, Al or galvanized iron is painted dead black for maximum absorption. The collector (plate) will absorb the solar energy and transfer it to the fluid in the pipe beneath the collector plate.

Use of flat mirrors on the sides improves the output. Water from the overhead tank is made to flow through the water tubes. Solar rays pass through the transparent cover and fall on the absorber plate. Heat energy from the absorber plate is transferred to the cold water flowing through the tubes. Worm water rises above the cold water because of low density and flows into the heater tank.

1.7 SOLAR POND TECHNOLOGY:

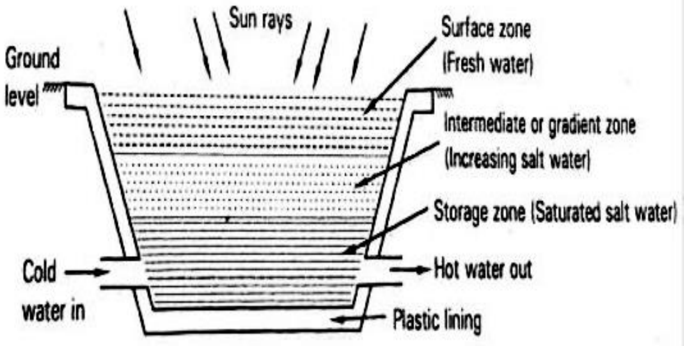


Fig. 1.5 Solar Pond

• A salinity gradient solar pond is an integral collection and storage device of solar energy is shown in Fig. 1.5.

• By virtue of having built-in thermal energy storage, it can be used irrespective of time and season.

• In an ordinary pond or lake, when the sun's rays heat up the water this heated water, being lighter, rises to the surface and loses its heat to the atmosphere.

• The net result is that the pond water remains at nearly atmospheric temperature.

• The solar pond technology inhibits these phenomena by dissolving salt into the bottom layer of this pond, making it too heavy to rise to the surface, even when hot.

• The salt concentration increases with depth, thereby forming a salinity gradient.

• The sunlight which reaches the bottom of the pond remains entrapped there.

• The useful thermal energy is then withdrawn from the solar pond in the form of hot brine. The pre-requisites for establishing solar ponds are a large tract of land (it could be barren), a lot of sunshine, and cheaply available salt (such as Sodium Chloride) or bittern.

• Generally, there are three main layers. The top layer is cold and has relatively little salt content.

• The bottom layer is hot -- up to 100°C (212°F) -- and is very salty.

• Separating these two layers is the important gradient zone.

Solar pond electric power plant:-

• The energy obtained from a solar pond is used to drive a Rankine cycle heat engine. The Fig. 1.5 shows the solar pond electric power plant

• Hot water from the bottom level of the pond is pumped to the evaporator where the working fluid is vaporized.

• This vapor then flows under high pressure to the turbine where it expands and work thus obtained runs an electric generator producing electricity.

• The vapor is then condensed through a cooling system and the liquid is pimped back to the evaporator and the cycle is repeated.

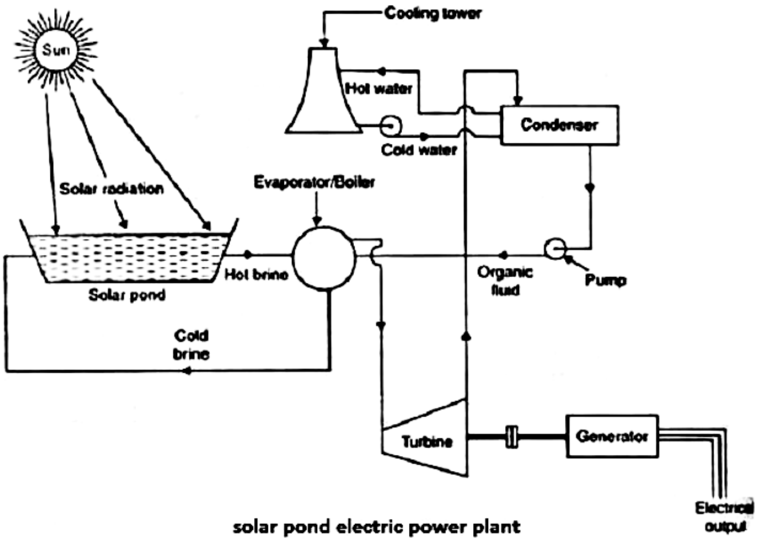


Fig. 1.6 Solar Pond electric power plant

Application of solar ponds:-

- Heating and cooling of buildings.
- Production of power
- Industrial process heat.

- Heating animal housing.
- Drying crops on farms.

1.8 PHOTOVOLTAIC CELL:

Solar energy can be directly converted to electrical energy by means of photovoltaic effect. The photovoltaic effect is defined as the generation of an electromotive force (EMF) as a result of the absorption of ionizing radiation. Devices which convert sunlight to electricity are known as solar cells or photovoltaic cells. Fig. 1.7 displays the photovoltaic cell. Solar cells are semiconductors, commonly used are barrier type iron-selenium cells.

- Iron-selenium cells consist of a metal electrode on which a layer of selenium is deposited.
- On top of this, a barrier layer is formed which is coated with a very thin layer of gold.
- The layer of gold serves as a translucent electrode through which light can impinge on the layer below.
- Under the influence of sunlight, a negative charge will build upon the gold electrode and a positive charge on the bottom electrode.
- This difference in charge will produce a voltage in proportion to the suns radiant energy incident on it.

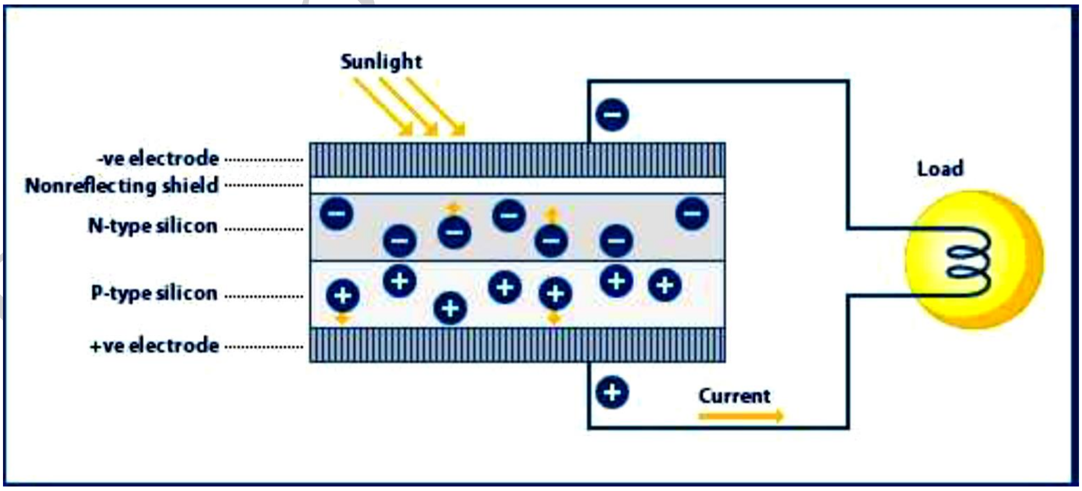


Fig. 1.7 Photovoltaic cell

A basic photovoltaic system for power generation:

This system consists of the following:

1. Solar array (solar cells)
2. Blocking diode
3. Battery storage
4. Inverter
5. Switches and load center.

- In the solar cell array due to the photovoltaic effect, electrical power (D.C.) will be produced in proportion to the suns radiant energy incident on it. This generated power will be stored in the battery storage.
- A blocking diode ensures that the battery would not discharge power back to the solar array during the period when there is no sunlight.
- An inverter converter converts the D.C power to A.C. and sends it to the load center.
- From the load center, A.C. power is distributed accordingly with the help of switches.

1.9 WIND ENERGY:

Wind energy is the energy contained in the force of the winds blowing across the earth surface. Wind energy is defined as the kinetic energy associated with the movement of large masses of air over the earth's surface. Schematic diagram of wind mill is shown below in Fig. 1.8.

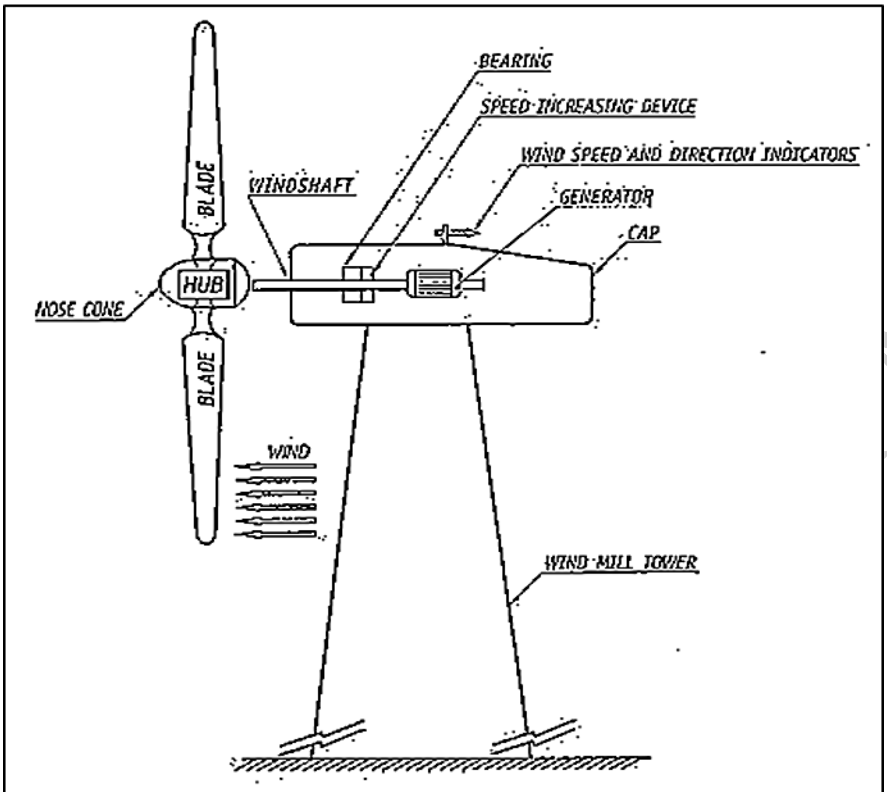


Fig. 1.8 Schematic diagram of wind mill

The circulation of the air in the atmosphere is caused by the non-uniform heating of the earth's surface by the sun. The air immediately above the warm area expands and becomes less dense. It is then forced upwards by a cool denser air which flows in from the surrounding areas causing wind.

Power in the wind:

Wind possesses kinetic energy by virtue of its motion Fig. 1.9 shows the working principle of wind mill. Any device capable of slowing down the mass of moving air, like a sailor propeller, can extract part of this energy and convert into useful work. The kinetic energy of one cubic meter of air blowing at a velocity V is given by

$E = 1/2\rho V^2 \quad J/m^2$

In one second, a volume element of air moves a distance of V m. The total volume crossing a plane, one square meter in area and oriented normal to the velocity vector in one second is, therefore, v m^3

The rate at which the wind energy is transferred, i.e., wind power is given by, P = EV

$$= 1/2\rho V^2 \quad W/m^2$$

No device, however well designed can extract all the wind energy because the wind would have to be brought to halt and this through the rotor. It has been found that for maximum power output the exit velocity is equal to one-third of the entrance velocity. Thus a maximum of 60% of the available energy in the wind is converted into mechanical energy.

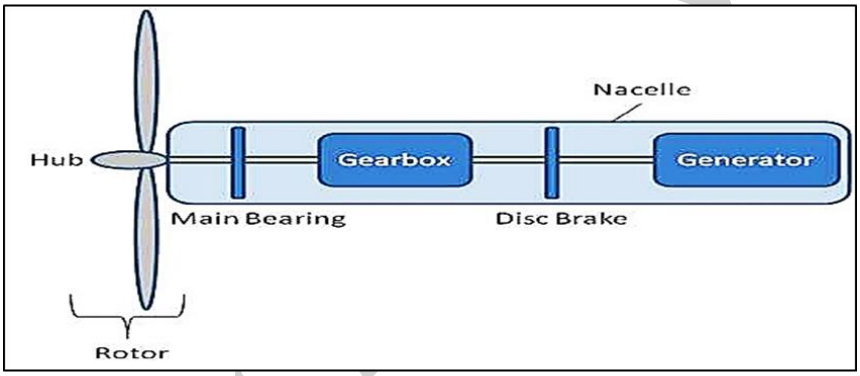


Fig. 1.9 Working principle of wind mill

A windmill is the oldest device built to convert the wind energy into mechanical energy used for grinding, milling and pumping applications. It consists of a rotor fitted with large-sized blades.

Merits:

- The wind is free and with modern technology, it can be captured efficiently.
- Once the wind turbine is built the energy it produces does not cause greenhouse gases or other pollutants.
- Many people find wind farms an interesting feature of the landscape
- Remote areas that are not connected to the electricity power grid can use wind turbines to produce their own supply.
- Wind turbines have a role to play in both the developed and third world.

- Wind turbines are available in a range of sizes which means a vast range of people and businesses can use.

De-merits:

- Wind turbines are noisy.
- The strength of the wind is not constant and it varies from zero to storm force.
- Only selected places it can be harnessed.

1.10HYDROPOWER PLANTS:

In hydroelectric power plants, the potential energy of water due to its high location is converted into electrical energy. The total power generation capacity of the hydroelectric power plants depends on the head of water and volume of water flowing towards the water turbine Fig. 1.10 shows the working principle of hydro power plant. The hydroelectric power plant also called a dam or hydropower plant is used for the generation of electricity from the water on a large scale basis. The dam is built across the large river that has a sufficient quantity of water throughout the river. In certain cases where the river is very large, more than one dam can be built across the river at different locations. The rainwater flowing like a river can be stored behind dams and released in a regulated way to generate hydropower.

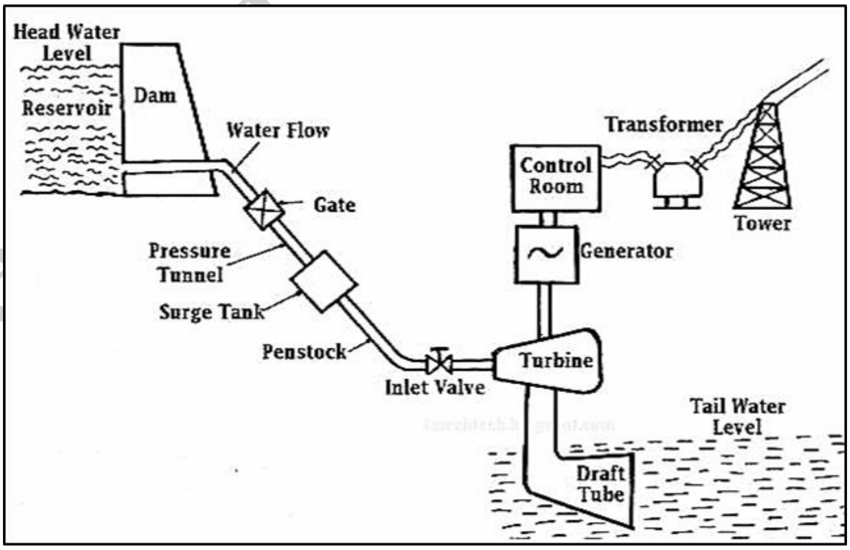


Fig. 1.10 Working principle of hydro power plant

Working Principle of Hydroelectric power plant

The water flowing in the river possesses two types of energy:

(1) The kinetic energy due to the flow of water and

(2) Potential energy due to the height of water.

In hydroelectric power and potential energy of water is utilized to generate electricity the formula for total power that can be generated from water in hydroelectric power plants due to its height is given.

The potential energy of water stored at height is converted into mechanical energy in a water turbine. The mechanical energy produced by the water turbine is converted into electrical energy. After doing useful work water is discharged from the turbine to the river through the water to the tailrace through a draft tube.

Merits: -

- Environmental friendly source,
- large scale power generation,
- The energy at free of cost.

Demerits: -

- Expensive to build the dam,
- Summer water may not sufficient to produce electricity.

1.11NUCLEAR POWER:-

Nuclear energy is the energy that holds the nucleus of an atom. The energy released during nuclear fission or fusion, especially when used to generate electricity.

Nuclear Fission: - Nuclear fission is the process of splitting a nucleus into two nuclei with smaller masses. Fission means “to divide”.

“The most common nuclear fuels are 235U. Not all nuclear fuels are used in fission chain reactions”

Chain Reaction: - A chain reaction is an ongoing series of fission reactions. Billions of reactions occur each second in a chain reaction.

- On earth, nuclear fission reactions take place in nuclear reactors, which use controlled chain reactions to generate electricity.
- Uncontrolled chain reactions take place during the explosion of an atomic bomb.

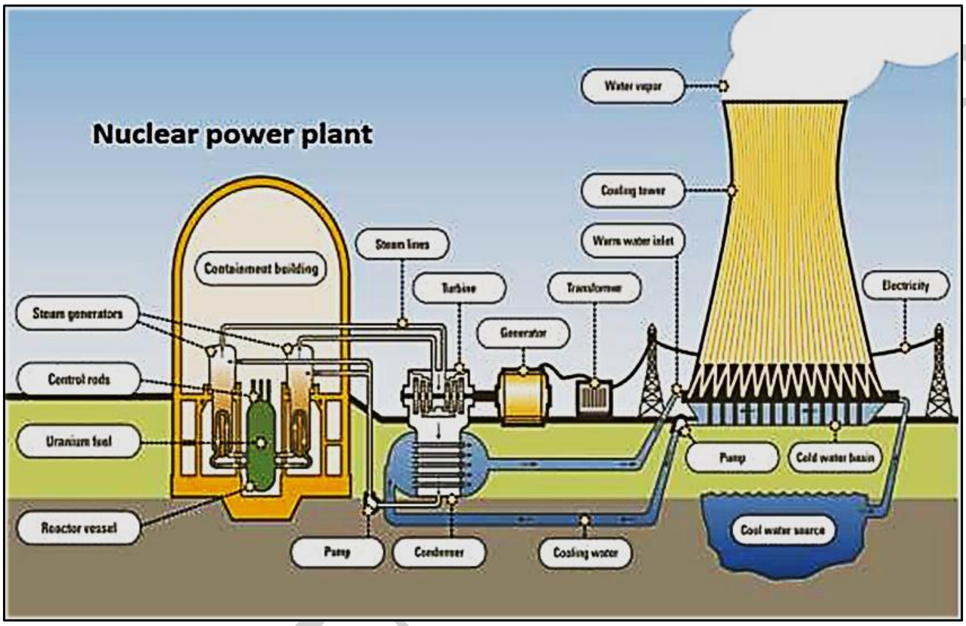


Fig. 1.11 Working principle of nuclear power plant

Nuclear Fusion: - Nuclear fusion is the combining of two nuclei with low masses to form one nucleus of the larger mass. Nuclear fusion reactions are also called thermonuclear reactions.

Working principle of a nuclear power station

The schematic diagram of a nuclear power station is shown in Fig 1.11. A generating station in which nuclear energy is converted into electrical energy is known as a nuclear power station.

The main components of this station are a nuclear reactor, control rods, steam generators, steam turbine, coolant pump, feed pump, condenser, and cooling tower.

NUCLEAR REACTOR:- A nuclear reactor is a device in which nuclear chain reactions are initiated, controlled, and sustained at a steady rate, as opposed to a nuclear bomb, in which the chain reaction occurs in a fraction of a second and is uncontrolled causing an explosion.

CONTROL RODS: - Control rods made of a material that absorbs neutrons are inserted into the bundle using a mechanism that can raise or lower the control rods. The control rods essentially contain neutron absorbers like boron, cadmium or indium.

STEAM GENERATORS: - Steam generators are heat exchangers used to convert water into steam from heat produced in a nuclear reactor core. Either ordinary water or heavy water is used as the coolant.

STEAM TURBINE: - A steam turbine is a mechanical device that extracts thermal energy from pressurized steam, and converts it into useful mechanical. Various high-performance alloys and superalloys have been used for steam generator tubing.

COOLANT PUMP: - The coolant pump pressurizes the coolant to pressures of the order of 155bar. The pressure of the coolant loop is maintained almost constant with the help of the pump and a pressurized unit.

FEED PUMP: - Steam coming out of the turbine, flows through the condenser for condensation and recirculate for the next cycle of operation. The feed pump circulates the condensed water in the working fluid loop.

CONDENSER: - Condenser is a device or unit which is used to condense vapor into liquid. The objective of the condenser is to reduce the turbine exhaust pressure to increase the efficiency and to recover high- quality feed water in the form of condensate & feedback it to the steam generator without any further treatment.

COOLING TOWER: - Cooling towers are heat removal devices used to transfer process waste heat to the atmosphere. Fig. 1.12 shows the working principle of nuclear power plant. Water circulating through the condenser is taken to the cooling tower for cooling and reuse. The reactor of a nuclear power plant is similar to the furnace in a steam power plant. The heat liberated in the reactor due to the nuclear fission of the fuel is taken up by the coolant circulating in the reactor. A hot coolant leaves the reactor at top and then flows through the tubes of the heat exchanger and transfers its heat to the feed water on its way. The steam produced in the heat exchanger is passed through the turbine and after the work was done by the expansion of steam in the turbine, steam leaves the turbine and flows to the condenser. The mechanical or rotating energy developed by the turbine is transferred to the generator which in turn generates the electrical energy and supplies to the bus through a step-up transformer, a circuit breaker, and an isolator. Pumps are provided to maintain the flow of coolant, condensate, and feed water.

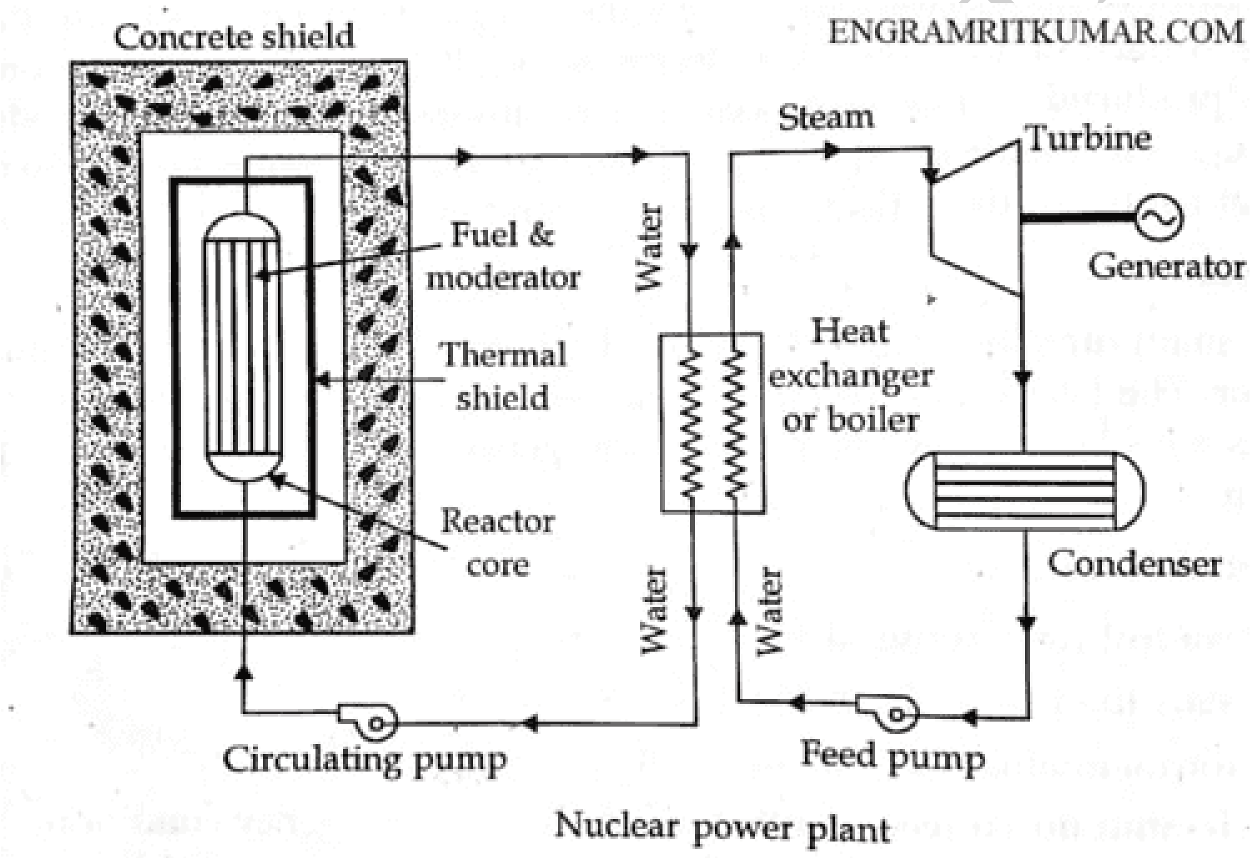


Fig. 1.12 Working principle of nuclear power plant

Advantage:-

- Nuclear power generation does emit relatively low amounts of carbon dioxide (CO_2).
- The emissions of greenhouse gases and therefore the contribution of nuclear power plants to global warming is therefore relatively little.

- This technology is readily available; it does not have to be developed first.
- It is possible to generate a high amount of electrical energy in one single plant.

Disadvantages:-

- The problem of radioactive waste is still an unsolved one.
- High risks: It is technically impossible to build a plant with 100% security.
- The energy source for nuclear energy is Uranium. Uranium is a scarce resource, its supply is estimated to last only for the next 30 to 60 years depending on the actual demand.

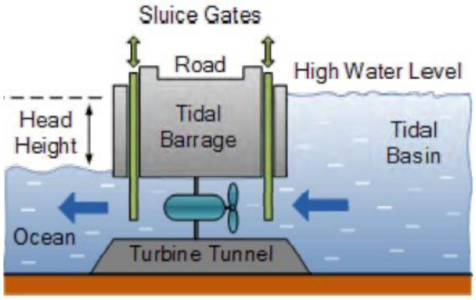
1.12TIDAL ENERGY: -

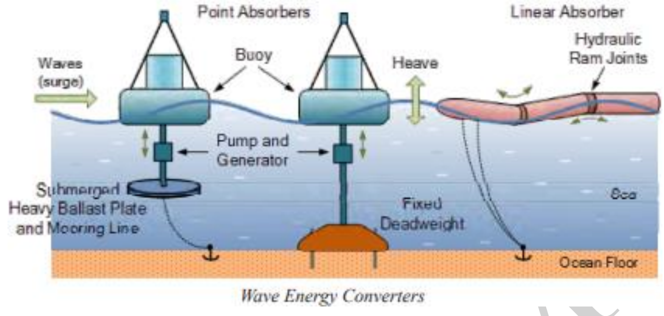
- Tidal energy is a renewable energy powered by the natural rise and fall of ocean tides and currents. Oceans occupy more than 70 percent of earth's surface and are an inexhaustible source of renewable energy. Ocean energy is the energy harnessed from ocean waves, tidal range (rise and fall) & tidal streams, temperature gradients and salinity gradients.
- As per study conducted by IIT Madras, Theoretical Potential for tidal Energy in India is 12500 MW, Promising locations are Gulf of Khambhat & Gulf of Kutch (GJ), Sunderbans (WB), Western Ghats (MH), etc. Theoretical Potential for Wave Energy in India is 41,000 MW, Promising locations are Western Coast of Maharashtra, Goa, Karnataka, Kerala, Kanyakumari, Southern tip of India, etc. However, resource survey at target locations i.e. Western Ghats, Eastern Ghats, etc. may be undertaken to assess/ validate actual potential.

(a) Tidal Energy: -

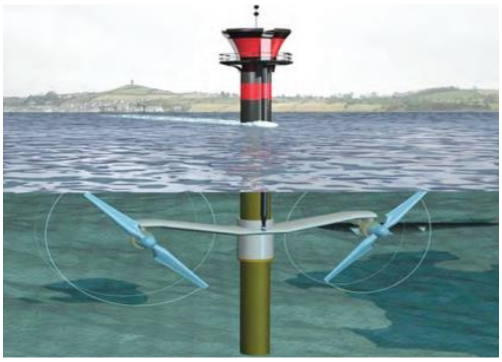
The tidal cycle occurs every 12 hours due to the gravitational pull of the moon. The difference in water level from low tide and high tide is potential energy that can be harnessed. Similar to hydropower generated from dams, tidal water is captured in a barrage across an estuary during high tide and forced through a turbine during low tide. The capital cost for tidal energy power plants is very high due to high civil construction that results in high power tariff. In order to harness power from the tidal energy, the height of high tide must be at least five meters (16 feet) greater than low tide.

(a)	(b)

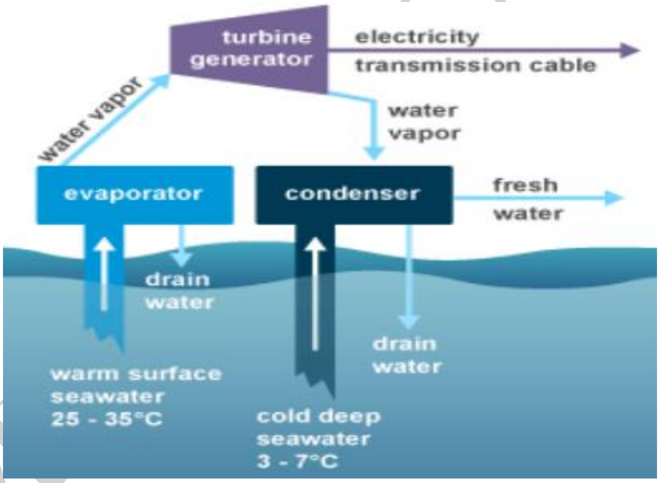

Sluice Gates
Road
High Water Level
Head Height
Tidal Barrage
Tidal Basin
Ocean
Turbine Tunnel


Point Absorbers
Linear Absorber
Hydraulic Ram Joints
Waves (surge)
Buoy
Heave
Pump and Generator
Submerged Heavy Ballast Plate and Mooring Line
Fixed Deadweight
Sea
Ocean Floor
Wave Energy Converters

(c)



(d)


turbine generator
electricity transmission cable
water vapor
water vapor
evaporator
condenser
fresh water
drain water
drain water
warm surface seawater 25 - 35°C
cold deep seawater 3 - 7°C

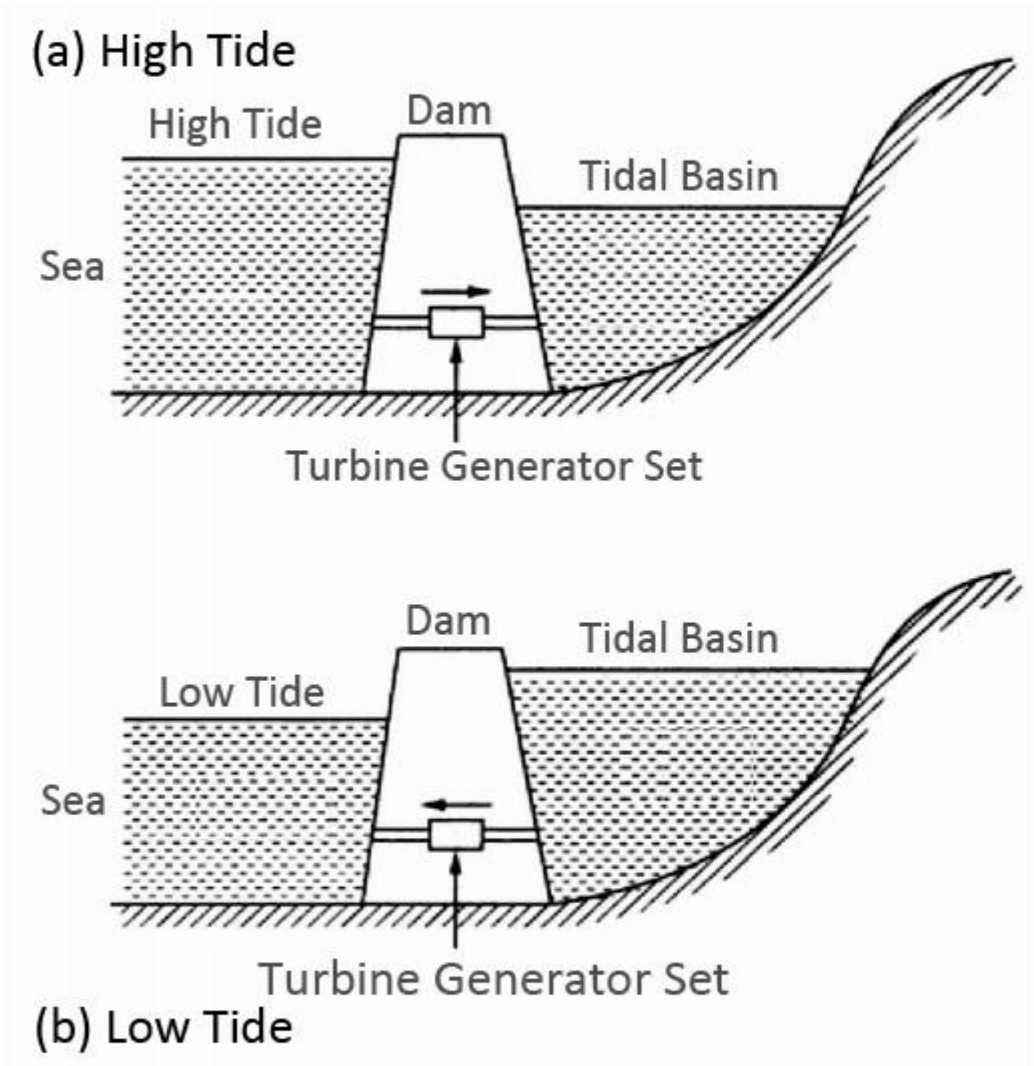


Fig. 1.13 Illustration of (a) Tidal energy, (b) Wave energy converters, (c) Ocean Current Turbine, (d) Ocean thermal energy converter.

(b) **Wave Energy: -**

Wave energy is generated by the movement of a device either floating on the surface of the ocean or moored to the ocean floor by the force generated by the ocean waves. Many different techniques for converting wave energy to electric power have been developed. Wave conversion devices floats on the surface have joints hinged together that moves with the waves. The kinetic energy pumps fluid through turbines and generates electric power. Moored wave energy conversion devices use pressure fluctuations produced in long tubes from the waves moving up and down. This wave motion drives a turbine.

(c) **Current Energy: -** Ocean current is ocean water moving in one direction. This ocean current is also known as the Gulf Stream. Kinetic energy can be captured from the Gulf Stream and other tidal currents with submerged turbines that are very similar in appearance to miniature wind turbines. Similar to wind turbines, the movement of the marine current moves the rotor blades to generate electric power.

(d) **Ocean Thermal Energy Conversion: -**

Ocean thermal energy conversion, or OTEC, uses ocean temperature differences from the surface to depths lower than 1,000 meters, to harness energy. A temperature difference of even 20°C can yield energy efficiently. Research focuses are on two types of OTEC technologies to extract thermal energy and convert it to electric power: closed cycle and open cycle. In the closed cycle method, a working fluid, such as ammonia, is pumped through a heat exchanger and vaporized. This vaporized steam runs a turbine. The cold water found at the depths of the ocean condenses the vapor back to a fluid where it returns to the heat exchanger. In the open cycle system, the warm surface water is pressurized in a vacuum chamber and converted to steam to run the turbine. The steam is then condensed using cold ocean water from lower depths.

STEAM FORMATION AND PROPERTIES:

Introduction: - All the substance under suitable conditions of temperature and pressure can exist in one of the three states via solid, liquid or gas. But water is one of the pure substances that exist in all the three phases namely

Solid-phase as Ice,
Liquid phase as Water and
Gaseous phases as vapor (steam)
Most of the practical problems in thermal engineering are concerned with liquid and gaseous phase rather than the solid phase. Water, which is liquid at normal temperature begins to boil to form steam when heat sufficiently.

Definition of Steam: Steam can be defined as it is a mixture of water and air or it can also be defined as vapor of water.

Formation of steam at constant pressure:

- Consider 1kg of water at 0^0c taken in a cylinder, fitted with a freely moving piston. A weight W is placed over the piston as shown in Fig. 1.24 (a). The weight of the piston and the weight 'W' placed over the piston exert a constant pressure 'P' on the water. Let 'V' be the volume occupied by the water in the cylinder. The condition of water 0^0c represented by a point 'A' on the temperature enthalpy (T-H) Diagram as shown in Fig. 1.24.

- On heating, the temperature of the water rises and at a certain temperature, water begins to boil (evaporate).

- The temperature at which water starts boiling is known as saturation temperature and is dented by 't_s'.

- The heating of water from 0^0c to the saturation temperature (t_s) is shown by the line AB on T-H diagram. At this temperature, there is a slight increase in the volume of water (V_f) as shown in Fig. 1.24 (b).

- When water is heated beyond the saturation temperature, there will be no rise in temperature, but the evaporation of water taken place. In other words, water starts converting into steam.

- At this stage, water exists as a two-phase mixture containing saturated liquid and water vapor occupying volume V_{fg} as shown in Fig. 1.24 (c). The steam in this condition is called wet steam.

- Evaporation of water continues at the same saturation temperature until the whole of the water is completely converted into steam. This process is shown by the line BC on T-H diagram.

- At point C, the steam formed does not contain water vapour and hence the steam in this state is called dry steam or dry saturated steam. The volume occupied by the dry steam is shown in Fig. 1.24(d).

- If heating is further contained at point C, the temperature of the steam increases above the saturated temperature is called superheat temperature dented by ‘t_{sup}’. The steam in this condition is called superheated steam. The process of heating the dry steam is called superheating, shown by the line CD on T-H diagram. The volume occupied by superheated steam is shown in Fig. 1.24 (e).

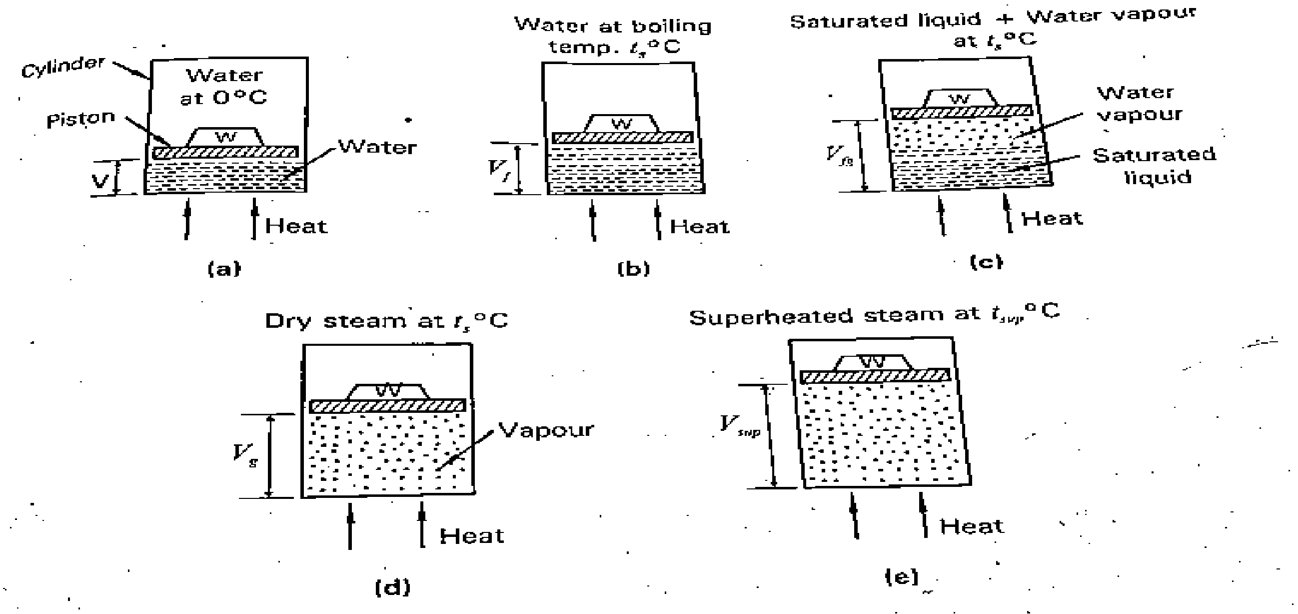


Fig. 1.24 Formation of steam at constant pressure

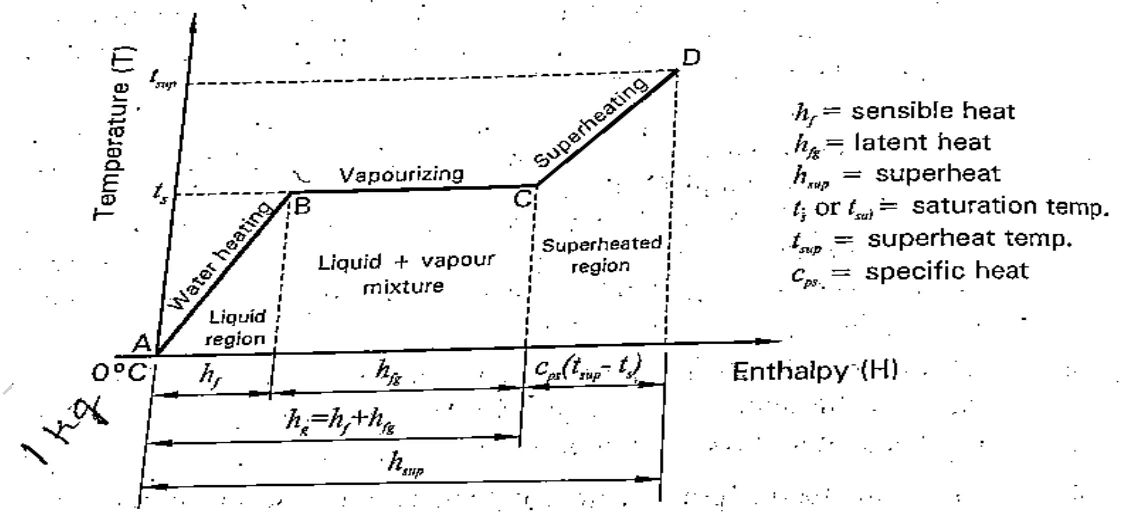


Fig. 1.25 Temperature-enthalpy (TH) diagram

TYPES OF STEAM / CONDITION OF STEAM

The steam as it is being generated can exist in 3 states as wet steam, dry saturated steam, and superheated steam.

- **Wet Steam:** It is defined as a two-phase mixture containing saturated liquid and vapor formed at the saturated temperature and a given pressure.

- **Dry Steam (Dry saturated steam):** Dry steam is pure steam that does not contain water particle in suspension. It is defined as the steam that exists completely in pure vapor form at the saturation temperature and at a given.

- **Superheated Steam:** It is defined as the steam which is heated beyond its dry saturated state to temperatures higher than its saturated temperature at the given pressure.

STEAM PROPERTIES

1. **Saturation temperature (t_s):** It is defined as the temperature at which the water begins to boil at constant pressure.

2. **Sensible heat (Total heat of water or Enthalpy of saturated water) (h_f):**

It is the amount of heat required to raise the temperature of 1 kg of water from 0^0C to the saturation temperature at a given pressure. It is also known as enthalpy of the liquid.

3. **Latent heat of evaporation (Enthalpy of evaporation) (h_{fg}):**

It is the amount of heat required to evaporate 1kg of water at saturation temperature to 1kg of dry steam at the same saturation temperature at constant pressure (given pressure).

4. **Enthalpy of superheat:** The amount of heat required to raise the temperature of dry saturated steam above its saturated temperature at a given pressure is called enthalpy of superheat.

5. **Dryness fraction of steam (x):** A wet steam has different proportions of water molecules and dry steam. Hence, the quality of wet steam is specified by the dryness fraction which indicates the amount of dry steam in the given quantity of wet steam

It is defined as the ratio of the mass of dry steam in a given quantity of wet steam to the total mass of wet steam.

Dryness fraction, $x = \frac{\text{mass of dry steam present in wet steam}}{\text{mass of wet steam}}$

- Dryness fraction, $x = \frac{mg}{mg+mf}$
- Let m_g= mass of dry steam
- m_f= mass of water molecules

- The dryness fraction of wet steam is lessthan1 (0<X<1)
- The dryness fraction of dry steam is1

6. Enthalpy of steam (h), kJ/kg:

Enthalpy of steam is the amount of heat energy contained in a unit mass of steam. It is the sum of the internal energy and work done at constant pressure (given pressure).

Enthalpy of Wet Steam (h_w): It is defined as the amount of heat required at a given pressure to convert 1 kg of water at 0^0C to 1 kg of wet steam at a specified dryness fraction.

$h_w = h_f + x h_{fg}$ kJ/kg

Where .h_f -sensible heat, h_{fg}-latent heat of evaporation, x -dryness fraction.

Enthalpy of Dry Saturated Steam (hg):

It is defined as the amount of heat required at a given pressure to convert 1 kg of water at 0^0C to 1 kg of dry saturated steam at the saturated temperature.

$h_g = h_f + h_{fg}$ kJ/kg

Where h_f -sensible heat,

h_{fg}-latent heat of evaporation

Enthalpy of Superheated Steam (h_{sup}): It is defined as the amount of heat required at a given pressure to convert 1 kg of water at 0^0C to 1 kg of superheated steam at the superheat temperature. It is the sum of enthalpy of dry steam and the amount of superheat.

$h_{sup}=h_g+C_{ps}(t_{sup}-t_s)$ kJ/kg $h_{sup}=h_f+h_{fg}+C_{ps}(t_{sup}-t_s)$kJ/kg

Where C_{ps}-is the specific heat of superheated steam**.**

t_{sup}-Superheat temperature.

t_S-saturation temperature.

hg-Enthalpy of dry saturated steam.

7. Specific volume of Steam (m^3 /kg): It is the volume occupied by the unit mass of a substance at a given temperature and pressure.

Specific Volume of Saturated water (V_f): It is defined as the volume occupied by 1 kg of water at the saturation temperature and at a given pressure.

Specific Volume of wet Steam (V_w):): It is the volume occupied by the saturated water and vapor at a given pressure. $V_w = xV_g$

Where V_g-Specific Volume of Dry Saturated Steam.

x -dryness fraction.

Specific Volume of Dry Saturated Steam (V_g): It is defined as the volume occupied by 1 kg of dry saturated steam at the saturation temperature and at a given pressure.

Specific Volume of superheated Steam (V_{sup}): It is defined as the volume occupied by 1 kg of superheated steam at the superheat temperature (t_{sup}) and at a given pressure.

Superheated steam behaves like a perfect gas. Therefore, according to Charles law, we have

$$\frac{V_{sup}}{t_{sup}} = \frac{V_s}{t_s}$$

$$V_{sup} = \frac{V_s}{t_s} t_{sup}$$

Where $t_{sup}$and t_s are in kelvin

8. Degree of superheat

It is defined as the difference between the superheat temperature (t_{sup}) and the saturation temperature (t_s). i.e., degree of super heat= t_{sup} -t_s

9. Density of steam

It is the mass of steam per unit volume of steam at the given pressure and temperature. The density of wet steam $\rho_w = \frac{1}{x\,V_g}$, Density of dry steam $\rho_g = \frac{1}{V_g}$

10. External work of evaporation

The fraction of the latent heat of vaporization which does an external work is called external work of evaporation.

External work of evaporation W=100.P $(V_g - V_f)$

Where P= Pressure in the bar.

At low pressure, V_f is very small and hence can be neglected. Hence W=100.P.V_g

- For wet steam of dryness fraction x, W_w=100.P.x.V_g
- For dry steam W_g=100.P.V_g
- For superheated steam W_{sup}=100.P.V_{sup}

11. Internal Energy of Steam: This actual energy stored in the steam is called internal energy of steam. It is defined as the difference between the enthalpy of the steam and the external work of evaporation.

Internal energy (U) = Enthalpy of steam -External work of evaporation-

- For wet steam, $U_w = h_f + h_{fg} - 100.P.x.V_g$ kJ/kg
- For dry steam $U_g = h_g - 100.P.V_g$ kJ/kg
- For superheated steam $U_{sup} = h_{sup} - 100.P.V_{sup}$ kJ/k

1.13 PRINCILE APPLICATIONS FOR STEAM:
Application of steam in diary industry:

What is steam used for?

Raw milk is processed into a wide variety of dairy products which include: pasteurised milk, cheese, butter and yoghurt. In the modern dairy, steam is used in a variety of processes to promote chemical reactions and physical changes in raw milk and to help maintain clean, sterile conditions.

The need for high quality steam

Steam is used because it is an efficient carrier of heat. It is produced in the boiler and carried to the dairy processing plant by a pipework distribution system. At each process steam transfers its heat and condenses back to condensate. A very important property of saturated steam is that its temperature is directly related to its pressure. Therefore, the temperature of many processes can be accurately controlled by controlling the pressure of the steam**.** Any entrained moisture or incondensable gases in the steam can lower its heat content and impair the heat transfer rate. Steam leaving the boiler house should contain as little moisture and incondensable gases as possible. This ensures that the maximum amount of heat is available and minimizes the risk of pipeline and equipment damage from water hammer. Figure 1.27 discuss the overview of application of steam in diary industry.

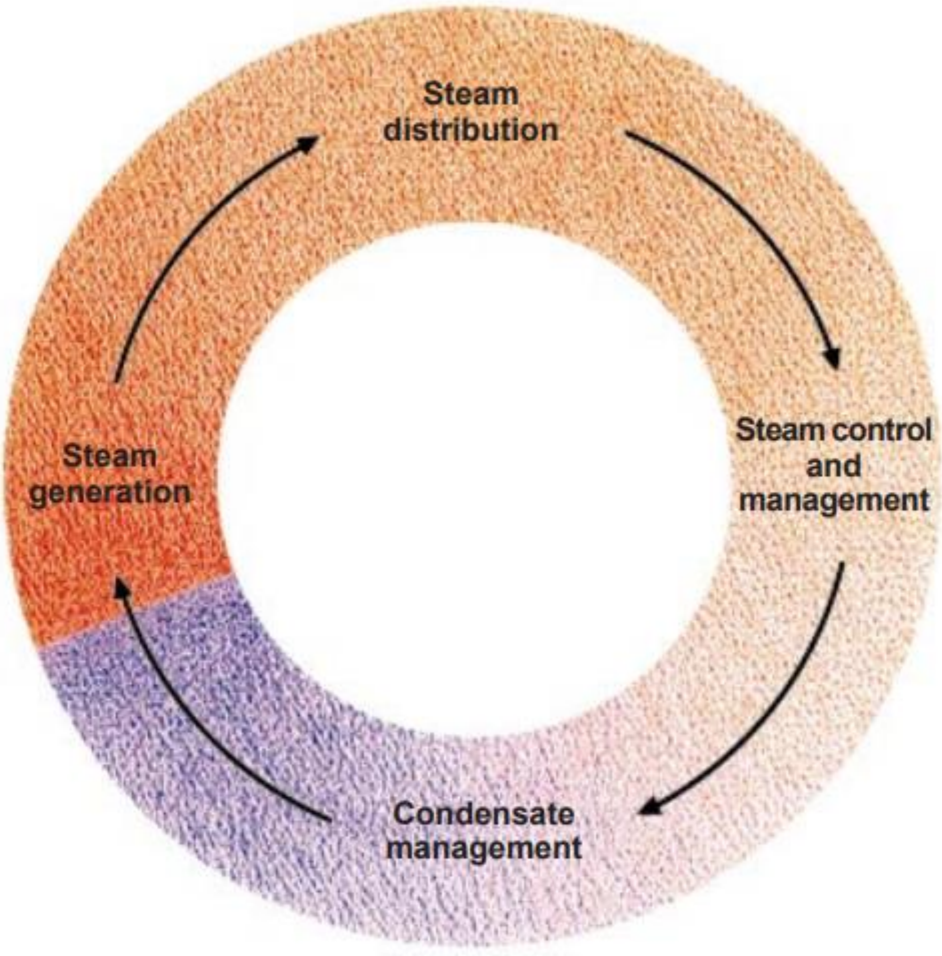
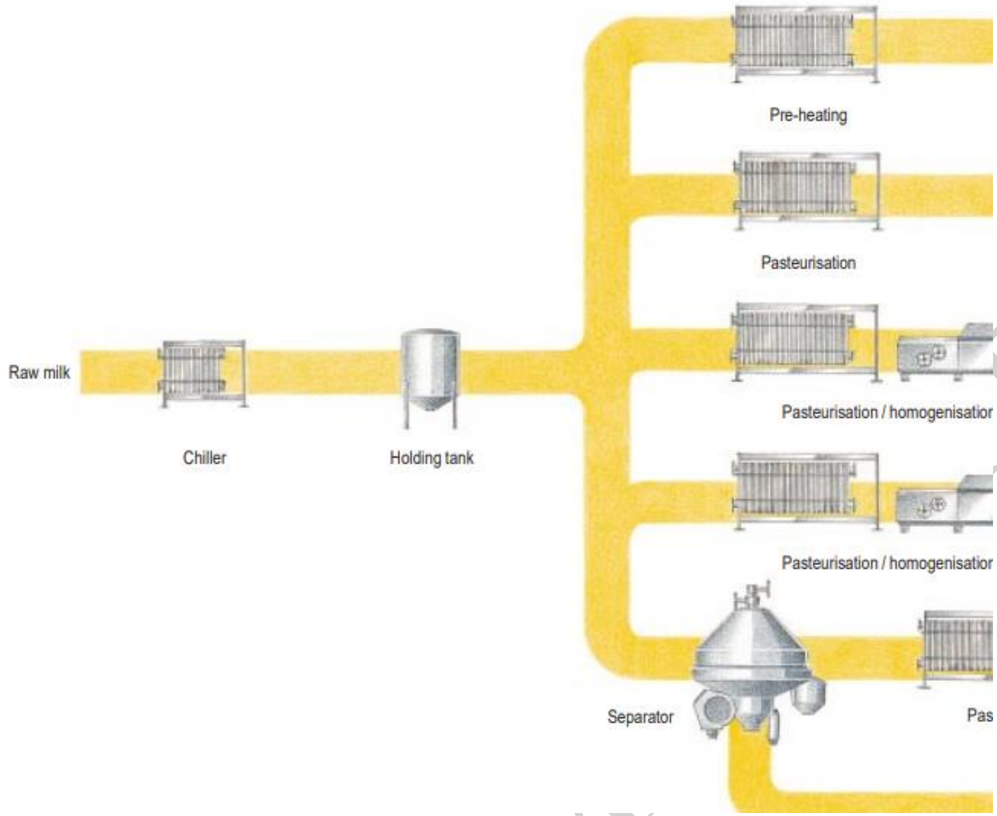
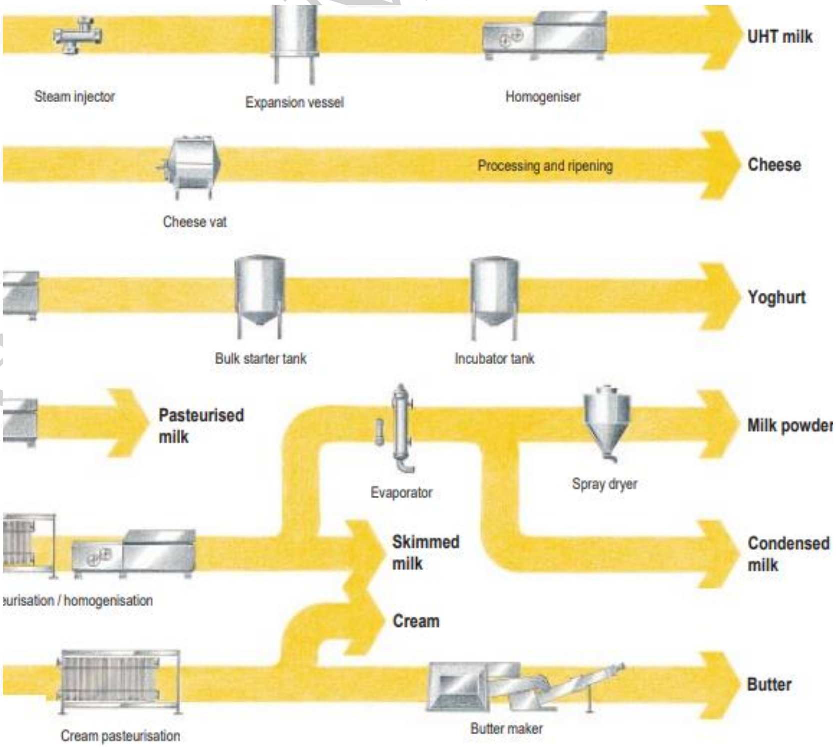


Fig. 1.26 The complete system for steam



Pre-heating
Pasteurisation
Raw milk
Chiller
Holding tank
Pasteurisation / homogenisatior
Pasteurisation / homogenisatior
Separator
Pas



Steam injector
Expansion vessel
Homogeniser
UHT milk
Cheese vat
Processing and ripening
Cheese
Bulk starter tank
Incubator tank
Yoghurt
Pasteurised milk
Evaporator
Spray dryer
Milk powder
Skimmed milk
Condensed milk
ırisation / homogenisation
Cream
Cream pasteurisation
Butter maker
Butter

Fig. 1.27 Overview for diary industry

Why Steam Technology Is Used in Paper Mills?

- In today's world of electrical energy, paper mills and box plants still prefer steam to deliver heat energy to their processes. Paper mills and corrugated packaging plants use rolls that are internally heated with steam. Maintaining a uniform temperature across the surface of the roll is essential for making quality product. Since steam is a gas, it fills the entire volume of the roll and evenly distributes heat as it condenses.
- **Steam Temperature is Exact**: At a given pressure, saturated steam always has the same temperature. By controlling the pressure, operators can set the exact temperature of the steam inside the roll. For example, at atmospheric pressure, the temperature is always 212° F (100° C). At 150 psig (10 bar) the temperature is always 366° F (185° C). As run rates increase or as heavier paper grades are produced, higher pressures and temperatures are needed. This predictability allows operators to control their process and change temperature as necessary.
- **Steam Carries Significant Energy**: High-speed industrial processes demand a lot of energy. The latent heat in steam is a very efficient way to carry large amounts of energy to the process. At 150 psig (10 bar) saturated steam carries 3.5 times the heat content, or enthalpy, of condensate. This energy is immediately released as steam contacts the inside surface of the roll and condenses.
- **Steam is efficient:** Most steam systems are powered by high-efficiency natural gas boilers, and natural gas is a relatively inexpensive form of energy in many parts of the world. The steam that is generated operates in an insulated, closed-loop system, and condensate is returned to the boiler for reuse. The steam generation is safely kept separate from the production process, but it's onsite proximity limits energy loss in steam delivery.

Application in sugar industry:

- Sugar is available in various forms, and the most widely consumed among them is granulated sugar, also known as table sugar. Table sugar with large crystals is known as coarse sugar, and the one with smaller crystals is called superfine sugar. Other types of sugar consumed are brown sugar, powdered sugar, pearl sugar, muscovado sugar, turbinado-style sugar, and demerara-style sugar. Sugar cane or sugar beet undergoes several stages of processing before sending it to markets and shops. The process stages in the sugar industry include the below steps

- **Washing:** Once the sugar cane or sugar beet is transported from farms to sugar mills, it is washed before further process. Washing takes place on belts sprayed with water or flue gases containing water. The products are washed by rotating and removing dirt in a rotating drum sprayed with water. Sugar cane is crushed through rollers or swing-hammer shredders and then sprayed with hot water. On the other hand, sugar beet is sliced as small stripes called cossettes that are soaked in hot water to swell plant cells for the extraction process.
- **Extraction:** Extraction of juice from sugar cane takes place through milling, in which a series of mills crush the sugar cane fiber to separate the juice from the bagasse that can be used as a fuel source. The juice collected is dark green in color and acidic with the sugar concentration that is measured. In the case of sugar beets, the cossettes are filled in tanks of 10 to 20 meters in length that transport sugar beet upwards through a rotating shaft as the sugar is extracted.
- **Purifying Juice:** In this stage, the sugar cane juice extracted is further purified in a tall tower-like structure. The sulfur dioxide vapor at the bottom starts rising in a process termed sulfitation. Soluble non-sugar material is further separated from sugar juice by the process of carbonation that consists of calcium carbonate or calcium sulfite that assists in precipitation. The juice is heated to denature the protein properties and then mixed with calcium hydroxide. Carbon dioxide bubbles are administered to reduce the alkalinity and the sludge formation that requires filtration to purify the juice. This process may take several hours, and the sludge is further filtered to remove the remaining sugar. The purified juice is later boiled in a series of evaporators till it reaches 50% to 65% of sugar concentration.
- **Crystallization:** Crystallization is a major process stage that relies on a steam boiler. In the crystallization process, a vacuum pan evaporates the syrup to saturate with sugar crystals through a process, termed seeding. This seed is pure sucrose suspended in alcohol and glycerin that is added to the syrup. The minute grains of sugar in the solution helps in extracting the sugar in the solution and forming it into crystals. With the boiling of the mixture in the vacuum pan, the crystals convert into a paste known as 'massecuite' that is a mixture of sugar crystal

and syrup. The mixture is further processed in a large container named ‘crystallizer’ to continue crystallization by stirring and cooling the massecuite.

- **Centrifugation:** The massecuite is transferred to a high-speed centrifuge to separate sugar crystals and molasses. The centrifuge rotates at 1000 to 2800 revolutions per minute to remove the molasses and retain the sugar in the centrifuge basket. After the process of centrifugation, the sugar is washed with water.
- **Drying:** Large hot air dryers are used to dry damp sugar crystals and reduce their moisture content to as low as 0.02% and then pass it through hot air in a granulator. The dried crystals are later segregated as per their sizes and packed to transfer to the market.
- **Role of Steam Boilers in Sugar Processing:** Steam boilers are pivotal in the processing operations of crystallization and drying in sugar mills. Boilers in sugar industry primarily use bagasse, coal, and biomass as fuel. Boilers with traveling grates can ensure proper combustion with fuels like coal and biomass, thus saving excess fuel costs. Additionally, boilers in sugar industry also generate electricity through cogeneration plants. For optimal performance of the steam boiler in sugar processing, it is advisable to reduce the excess air for the combustion of solid fuels. It helps in improving energy efficiency and reducing emissions. The excess air that reduces the boiler efficiency leads to carry over. Carryover causes erosion in equipment such as economizer, Induced Draft (ID) fan, etc., resulting in unexpected downtime. It is also essential to monitor the fuel quality and modify the amount of air required for complete combustion and preventing unburned fuels and stack losses.

Application in food processing industry:

Steam is used in a wide range of industries. Common applications for steam are, for example, steam heated processes in plants and factories and steam driven turbines in electric power plants, but the uses of steam in industry extend far beyond this.

Here are some typical applications for steam in industry:

- Heating/ Sterilization
- Propulsion/Drive

- Propulsion/Drive
- Motive
- Atomization
- Cleaning
- Moisturization
- Humidification-

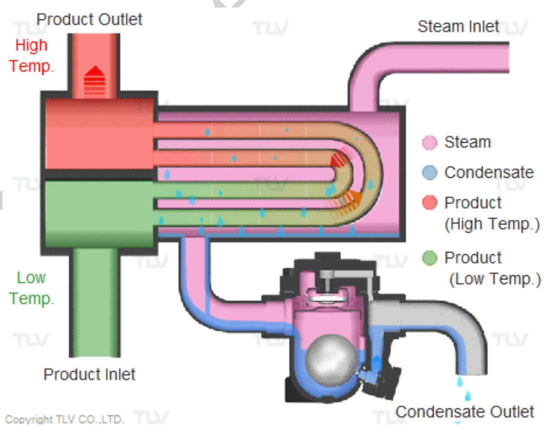
1. Steam For Heating:-

Positive Pressure Steam: Steam is typically generated and distributed at a positive pressure. In most cases, this means that it is supplied to equipment at pressures above 0 MPaG (0 psig) and temperatures higher than 100°C (212°F). Heating applications for positive pressure steam can be found in food processing factories, refineries, and chemical plants to name a few. Saturated steam is used as the heating source for process fluid heat exchangers, reboilers, reactors, combustion air preheaters, and other types of heat transfer equipment.

In a heat exchanger (Fig. 12.28(a)), steam raises the temperature of the product by heat transfer, after which it turns into condensate and is discharged through a steam trap.

Superheated steam heated to 200 – 800°C (392 - 1472°F) at atmospheric pressure is particularly easy to handle, and is used in the household steam ovens seen on the market today.

(a)



(b)

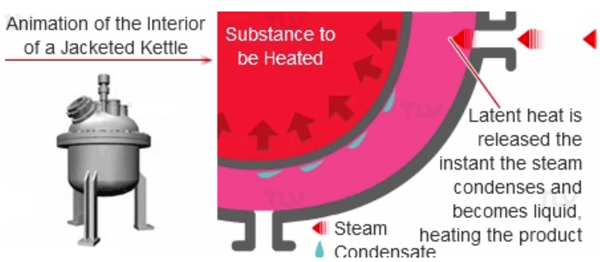


Fig. 1.28 Illustration of (a) Shell and tube heat exchanger, (b) Heating with latent (steam) heat.

Vacuum Steam: The use of steam for heating at temperatures below 100°C (212°F), traditionally the temperature range in which hot water is used, has grown rapidly in recent years.

When vacuum saturated steam (Fig. 12.28(b)) is used in the same manner as positive pressure saturated steam, the temperature of the steam can be quickly changed by adjusting the pressure, making it possible to achieve precise temperature control unlike applications using hot water. However, a vacuum pump must be used in conjunction with the equipment, because merely reducing the pressure will not drop it to below atmospheric pressure. Compared with a hot water heating system, this system offers fast, even heating. The set temperature is rapidly reached without causing unevenness in temperature

2. **Steam for Propulsion/Drive:** Steam is regularly used for propulsion (as a driving force) in applications such as steam turbines. The steam turbine is a piece of equipment that is essential for the generation of electricity in thermal electric power plants (Fig. 12.29(a)). In an effort to improve efficiency, progress is being made toward the use of steam at ever-higher pressures and temperatures. There are some thermal electric power plants that use 25 MPa abs (3625 psia), 610°C (1130°F) superheated, supercritical pressure steam in their turbines.

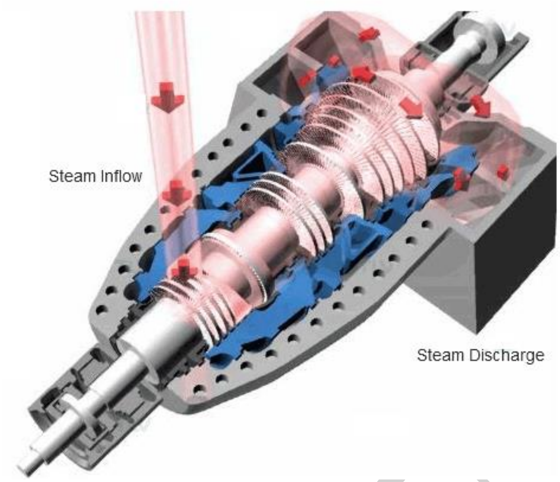
   Superheated steam is often used in steam turbines to prevent damage to equipment caused by the inflow of condensate. In certain types of nuclear power plants, however, the use of high temperature steam must be avoided, as it would cause problems with the material used in the turbine equipment. Instead, high pressure saturated steam is typically used. Where saturated steam must be used, separators are often installed in the supply piping to remove entrained condensate from the steam flow. Besides power generation, other typical propulsion/drive applications are usually for either turbine-driven compressors or pumps, ex. gas compressors, cooling tower pumps, etc. The driving force from the steam causes the fins to turn, which then causes the rotor on the attached power generator to rotate, and this rotation generates electricity.

3. **Steam as Motive Fluid:** Steam can also be used as a direct "motive" force to move liquid and gas streams in piping (Fig. 12.29(b)). Steam jet ejectors are used to pull vacuum on process equipment such as distillation towers to separate and purify process vapor streams. They are

also used for continuous removal of air from surface condensers, in order to maintain desired vacuum pressure on condensing (vacuum) turbines.

High pressure motive steam enters the jet ejector through the inlet nozzle and is then diffused. This creates a low pressure zone which entrains air from the surface condenser. In a similar type of application, steam is also the primary motive fluid for secondary pressure drainers, which are used for pumping condensate from vented receiver tanks, flash vessels, or steam equipment that experiences stall conditions.

(a) (b)



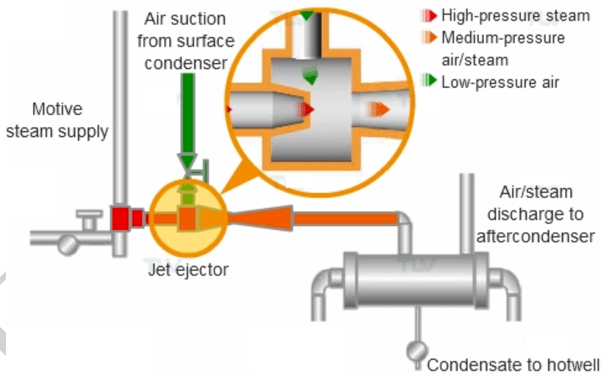


Fig. 1.29 (a) Generator Turbine, (b) Ejector for surface condenser

4. **Steam for atomization:** Steam atomization is a process where steam is used to mechanically separate a fluid (Fig. 1.30(a)). In some burners, for example, steam is injected into the fuel in order to maximize combustion efficiency and minimize the production of hydrocarbons (soot). Steam boilers and generators that use fuel oil will use this method to break up the viscous oil into smaller droplets to allow for more efficient combustion. Flares also commonly use steam atomization to reduce pollutants in the exhaust. In flares, steam is often mixed in with the waste gas before combustion.
5. **Steam for cleaning:** Steam is used to clean a wide range of surfaces. One such example from industry is the use of steam in soot blowers. Boilers that use oil or coal as the fuel source must be equipped with soot blowers for cyclic cleaning of the furnace walls and removing combusted deposits from convection surfaces to maintain boiler capacity, efficiency, and

reliability. Steam released out of the soot blower nozzle dislodges the dry or sintered ash and slag, which then fall into hoppers or are carried out with the combusted gasses.

(a) (b)

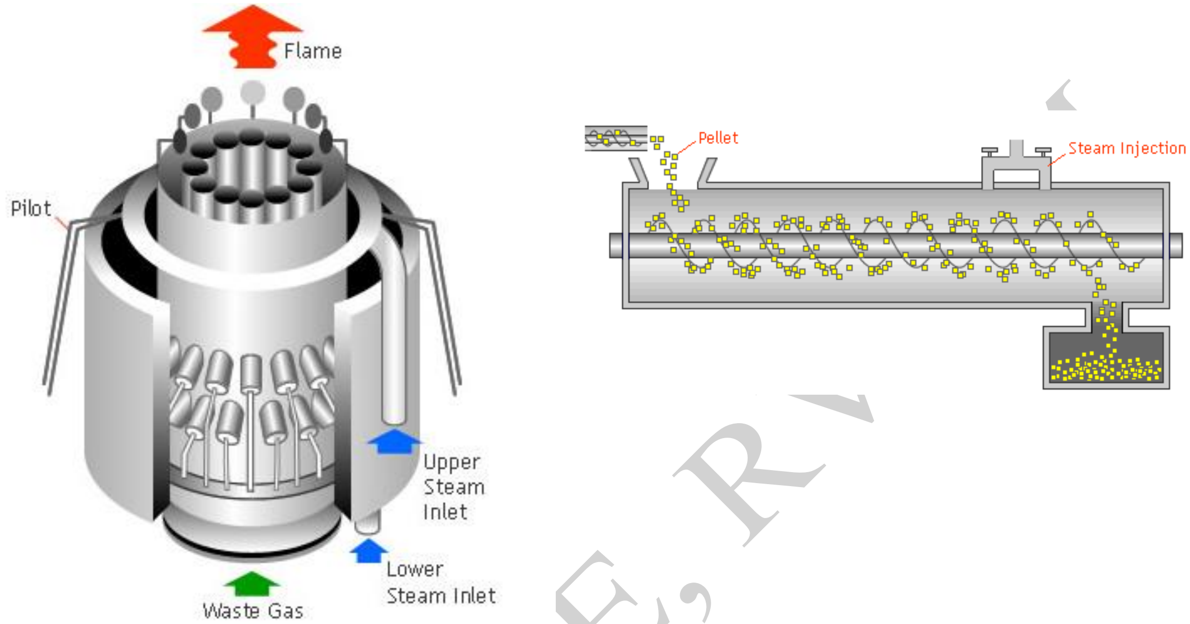


Fig. 1.30 (a) Steam assisted flare, (b) Pellet mill conditioner

6. **Steam for moisturization:** Steam is sometimes used to add moisture to a process while at the same time supplying heat. For example, steam is used for moisturization in the production of paper, so that paper moving over rolls at high speed does not suffer microscopic breaks or tears. Another example is pellet mills (Fig. 12.30(b)). Often mills that produce animal feed in pellet form use direct-injected steam to both heat and provide additional water content to the feed material in the conditioner section of the mill. The moisturizing of the feed softens the feed and partially gelatinizes the starch content of the ingredients, resulting in firmer pellets
7. **Steam for humidification:** Many large commercial and industrial facilities, especially in colder climates, use low pressure saturated steam as the predominant heat source for indoor seasonal heating. HVAC coils, often combined with steam humidifiers, are the equipment used for conditioning the air for indoor comfort, preservation of books and records, and infection control. When the cold air is heated by the steam coils, the relative humidity of the air drops, and it must then be adjusted to normal levels with addition of a controlled injection of dry

saturated steam into the downstream air flow. Steam is used to humidify air within an air duct before the air is distributed to other regions of a building.

1.14TURBINES

Prime Mover: Prime mover is a self-moving device which converts the available natural source of energy into mechanical energy of motion to drive the other machines (Fig. 1.31). The various types of prime movers which convert heat energy produced by the combustion of fuels into mechanical energy.

Eg: Turbines, Internal combustion Engines, External combustion Engines, etc……

Fig. 1.31 Role of prime mover

Turbine: A turbine can be defined as a power-producing machine. The device generates power by converting the kinetic energy of a stream of fluid (such as water, steam, or hot gas) into mechanical energy (in the form of rotation of shaft) through the principles of impulse and reaction. Turbines are used to drive electro generators to produce electricity and pump to supply fluid flow in a hydraulic system.

1. Steam turbine – The steam is used to run the turbine.
2. Gas turbine – Here the gases of the burnt fuel is used to run the turbine
3. Water Turbine – Here the water is used as a medium to run the turbine.

1.15Hydraulic Turbines (Water Turbines)

A water turbine is a hydraulic prime mover that converts the energy of falling water into mechanical energy in the form of rotation of the shaft. The mechanical energy, in turn, is converted into electrical energy by means of an electric generator.

Water turbines are classified based on the following factors:

1. Type of energy available at the inlet of the turbine:

(a) Impulse turbine: The energy available at the inlet of the turbine is only kinetic energy.

Example: Pelton wheel, Girad turbine, Banki turbine, etc.

(b) Reaction turbine: Both pressure energy and kinetic energy is available at the inlet of the turbine.

Example: Kaplan turbine, Francis turbine, Thomson turbine, etc.

2. Based on the head under which the turbine works:

a) High head turbine: Head of water available at the inlet of the turbine i.e., above 300 m.

Example: Pelton wheel.

b) Medium head turbine: Head of water available at the inlet of the turbine ranges from 50 m to 150 m.

Example: Francis turbine.

c) **Low head turbine**: Head of water at the inlet will be less than 50m. Example: Kaplan Turbine.

3. Based on the direction of flow of water through the runner:

a) Tangential flow turbine: Water flows along the tangent to the runner.

Example: Pelton wheel.

b) Axial flow turbine: Water flows in a direction parallel to the axis of rotation of the runner.

Example: Kaplan turbine.

c) Radial flow turbine: Water flows in a radial direction through the runner. Radial flow turbines are further classified into the inward radial flow and outward radial flow turbines.

Example: Thomson turbine, Old Francis turbine.

d) Mixed flow turbine: Water flows radially into the runner and leaves axially,

Example: Modern Francis turbine

Pelton Wheel Turbine (Tangential Flow Turbine) (Impulse Turbine) (High Head Turbine)

Principle:-Pelton wheel is a tangential flow impulse turbine, used for high heads and a small quantity of water flow. The turbine converts the pressure energy of water into kinetic energy entirely in the distributer.

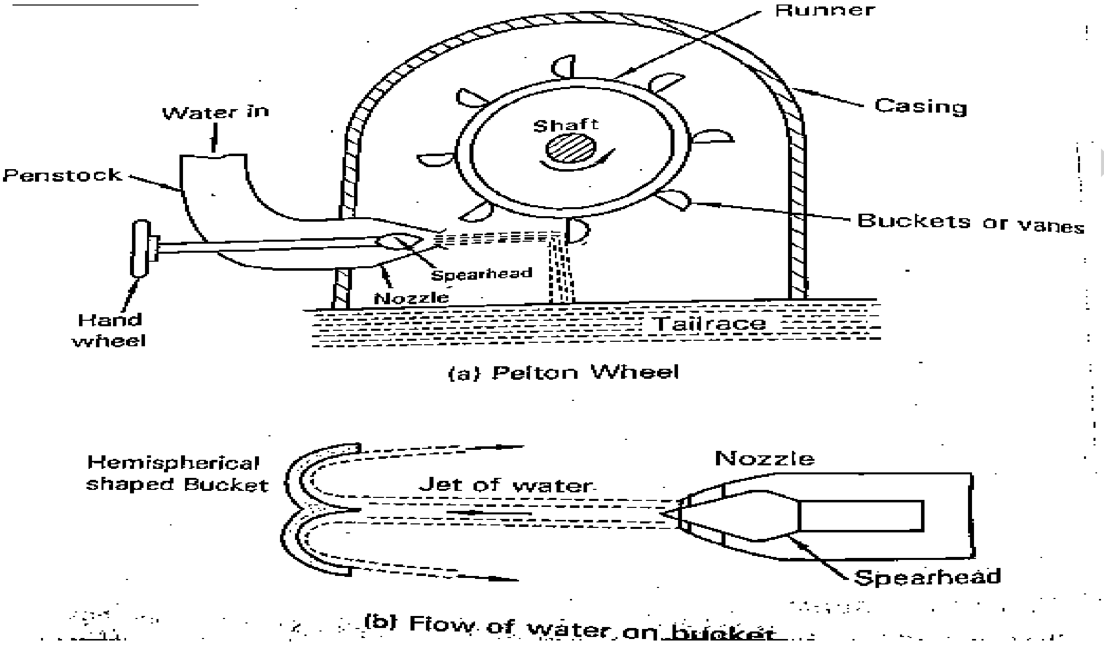


Fig. 1.32 Schematic representation of pelton wheel turbine

Fig. 1.32 shows the schematic diagram of a Pelton wheel. The Pelton wheel consists of the following parts: nozzle with spear head, shaft, rotor, buckets, casing, and tailrace.

Working:

- In operation, water from the reservoir (dam) having potential energy flows through the penstock and enters the nozzle.
- The water from a high head source is supplied to the nozzle provided with a spearhead, which controls the quantity of water flowing out of the nozzle
- As water flows through the nozzle, the potential energy of water is completely converted into kinetic energy.
- The high-velocity jet of water comes from the nozzle impinges on the curved blades; it is fixed around the runner wheel.
- The impulse force due to a high-velocity jet of water sets the runner wheel into rotary motion.

Hence, the shaft coupled to the runner wheels also rotates thereby doing useful work.

- The potential energy of the water is converted into mechanical work. After performing work, the water freely discharges to the tailrace.
- The work produced at the output shaft is used to drive a generator to produce electricity.
- Ex. Sharavathi (Karnataka), Jogindernagar(Himachal Pradesh), Koyana (Maharashtra)

1.16Francis Turbine (Mixed Flow Turbine) (Reaction Turbine) (Medium Head Turbine)

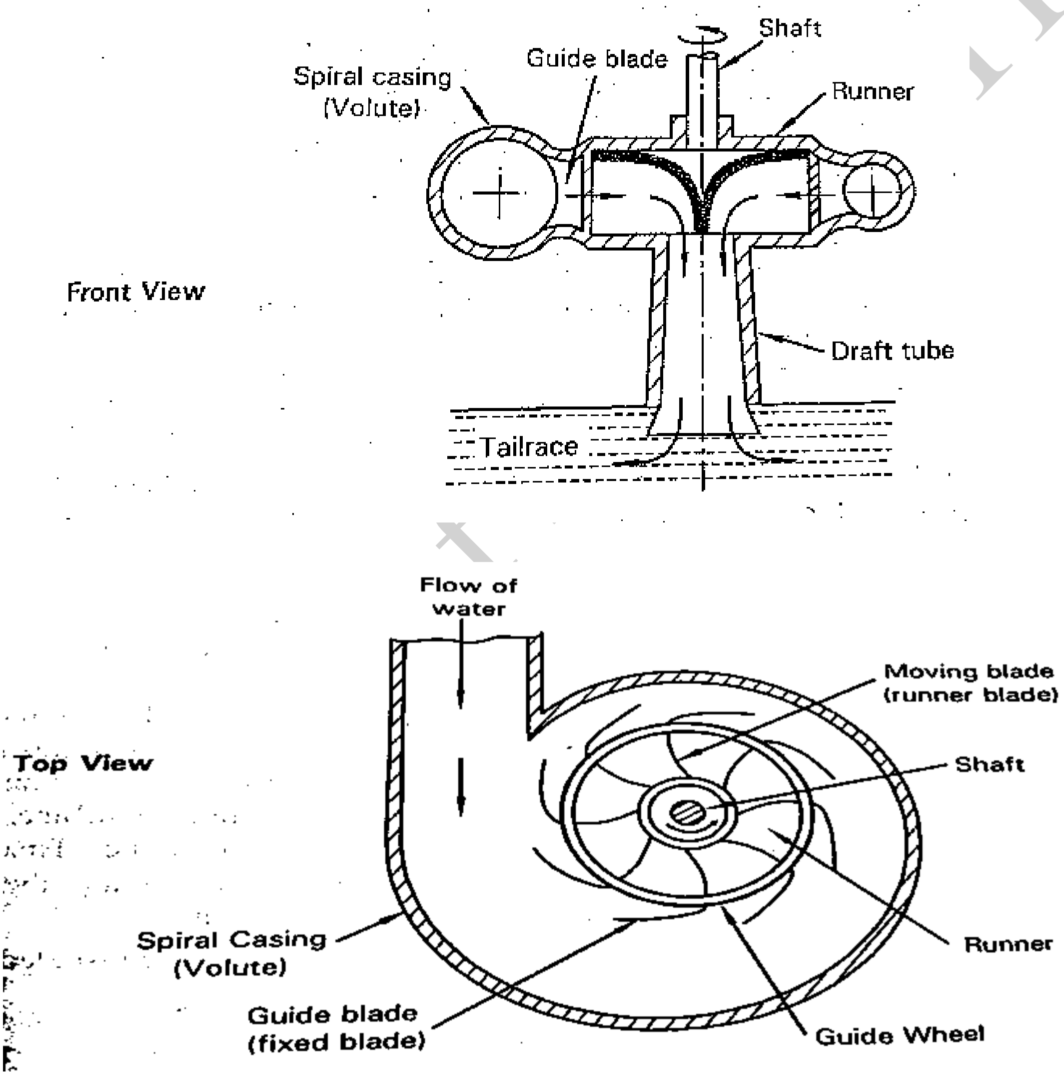


Fig. 1.33 Schematic representation of Francis turbine

Principle:-Francis turbine is a mixed flow reaction turbine used for medium heads in which water flows radially into the runner and leaves axially. Fig. 1.33 describes the schematic representation of Francis turbine.

Working:

Francis turbine consists of the following parts: a spiral casing (volute), runner, shaft, guide blade (fixed blade), guide wheel, moving blade (runner blade).

- A guide wheel is a stationary wheel around the runner of the turbine a number of blades are fixed around the circumference of the guide wheel gets deflected and then flows radially inwards to the outer periphery (outer diameter) of the runner. Water flows through the guide blades,
- In operation, water from the reservoir (dam) flows through the penstock and enters the spiral casing.
- As the water flows through the tapered spiral casing, the cross-sectional area of the spiral casing gradually decreases along the flow direction in order to distribute water uniformly around the entire perimeter of the runner.
- The water then moves over the moving blades in the radial direction and is finally discharged to the tailrace axially from the center of the runner via a draft tube. Draft tube gradually increasing area for discharging water from the exit of the turbine to the tailrace at low pressure.
- During its flow over the runner blades, the blade passages act as a nozzle, and the remaining part of the potential energy is converted into kinetic energy.
- The water leaves the blades at high velocity; there is a reaction force on the runner. This force sets the runner into rotary motion. Hence the shaft connected to the runner also rotates thereby doing useful work.
- Ex. Shivanasamudra (Karnataka), Gandhisagar (Rajasthan)

Kaplan Turbine (Propeller Turbine) (Low Head Reaction Turbine) (Mixed Flow Turbine)

Principle:-The Kaplan turbine is an axial flow reaction turbine and is used where a large quantity of water is available at the low head; all the parts of the turbines are similar to that of Francis turbines except the runner and the draft tube, the runner of the Kaplan turbine resembles with the propeller of the ship. Kaplan turbine consists of the following parts: guide vanes, runner vanes, shaft, spiral casing, tailrace, hub, and blade. Fig. 1.34 shows the schematic representation of Kaplan turbine.

Working:

- The turbine consists of a hub or boss fixed to a vertical shaft. The runner blades attached to the hub are adjustable and can be turned about their axis
- The runner has only 4 to 8 blades. Similar to Francis turbine, Kaplan turbine also has a ring of fixed guide blades at the inlet to the turbine.
- The inlet is a scroll-shaped tube surrounding the fixed blades.
- In operation, water from the reservoir flows through the penstock and enters the spiral casing. A part of the potential energy of water is converted into kinetic energy in the spiral casing.
- The water then moves through the guide blades (fixed blades), gets deflected and then flows axially through the runner blades as shown in the figure.
- During its flow over the runner blades, the blade passages act as a nozzle, and the remaining part of the potential energy is converted into kinetic energy.
- The water leaves the blades at high velocity; there is a reaction force on the runner. This force sets the runner into rotary motion. Hence the shaft connected to the runner also rotates thereby doing useful work.
- The water discharging at the center of the runner enters the draft tube whose end is immersed into the tailrace as in Francis turbine.

Ex. Tungabhadra (Karnataka), Nizamsagar (Andhra pradesh).

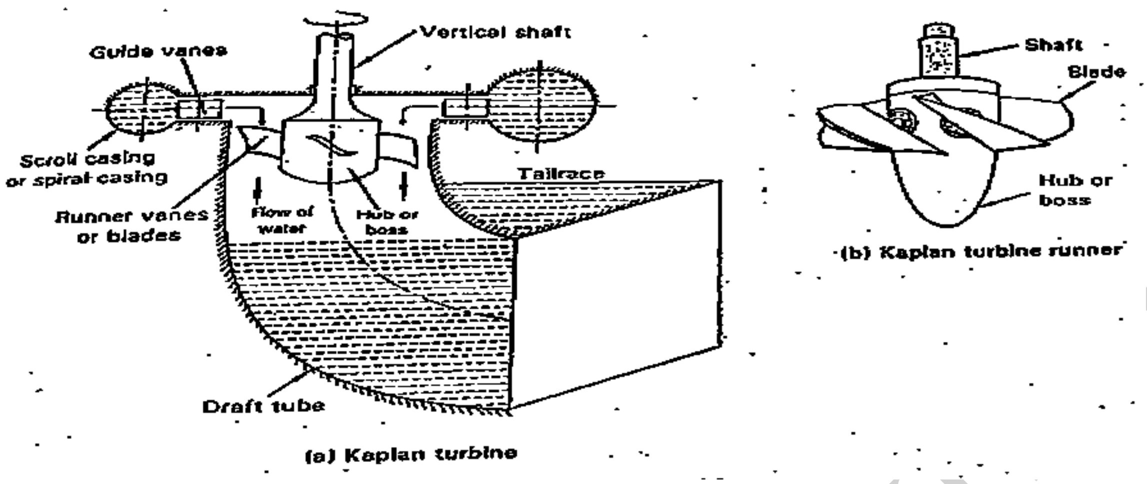


Fig. 1.34 Schematic representation of Kaplan turbine

Specification of hydraulic turbines

Hydraulic turbines are specified by the flowing criteria

- Water head
- DC/AC power rating
- The efficient and working life of power generator
- Power options: AC single-phase / three-phase and DC power
- Dimensions related to height, weight, length, and width.

1.17HYDRAULIC PUMPS

A hydraulic pump is a device that transfers energy to raise liquid form a lower level to a higher level or circulate a liquid in a closed system.

- Typical examples of pumps include pumping of water from a sump to an overhead tank, or circulating a coolant or lubricant oil to various moving parts of a machine.
- Pumps are especially used in pumping water for agriculture and irrigation works, municipal waterworks and drainage system.
- In steam power plant for condensing water, condensate, feed water into the boiler drum, etc.,

<u>Classification of pumps</u>

1. Centrifugal pumps, which makes use of centrifugal force of a rotary element known as an impeller to impart energy to the liquid.

2. Reciprocating pumps, which impart energy to the liquid by the reciprocating action of a piston or plunger inside the cylinder.

3. Rotary pump, which consists of rotating members, traps fluid in its closed casing thereby building and raising the pressure of the fluid, and in turn discharges the high-pressure fluid. The rotating members may be gears, vanes, screws, and lobe

Centrifugal pump

Principal:-centrifugal pumps make use of the centrifugal force of a rotary element known as an impeller to impart energy to the liquid. Fig. 1.35 shows the schematic representation of centrifugal pump.

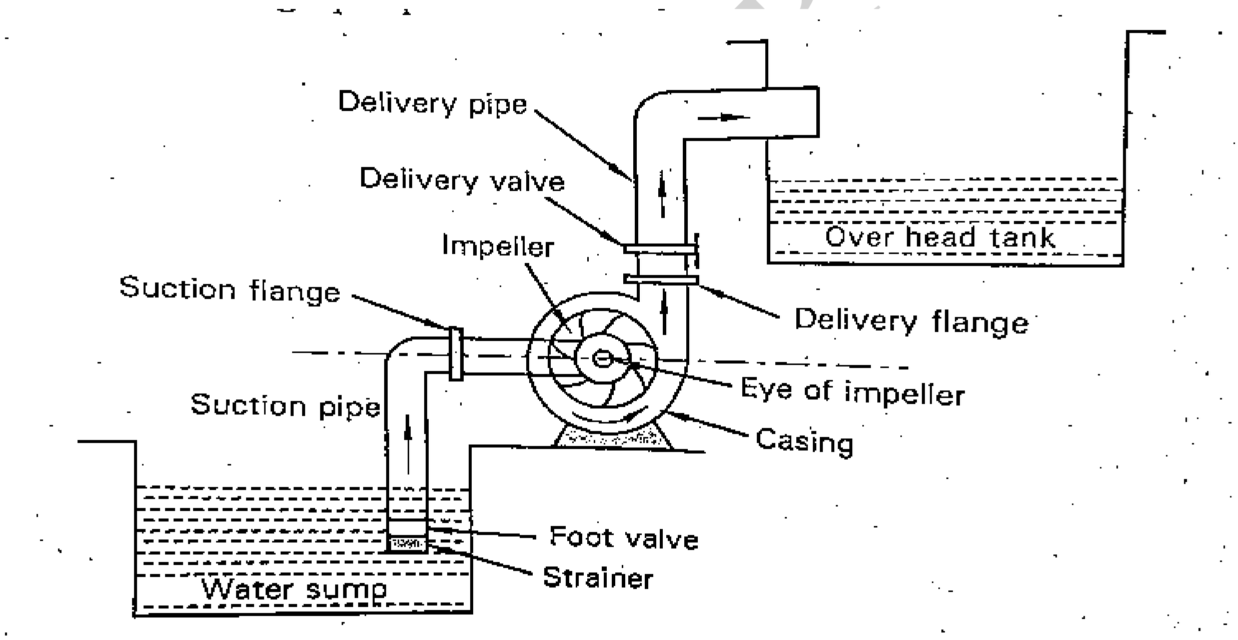


Fig. 1.35 Schematic representation of centrifugal pump

Construction

1. Impeller: is the principal rotating part of the pump. t is a wheel provided with a series of backward curved blades(vanes). The impeller is mounted on a shaft, which is connected to the shaft of the electrical motor.

2. Volute casing:-Is an airtight chamber surrounding the impeller**.** It is designed with its cross-section gradually increasing so that the velocity f flow decreases resulting in an increase in the pressure of the fluid.

3. Suction pipe:-

- Is a circular pipe with upper and connected to the center of the impeller, which is known as the eye of the impeller.
- The lower end of the suction pipe is immersed in the sump or reservoir from where the liquid is to be lifted up.
- The lower end of the suction pipe fitted with a foot valve and a strainer as shown in the figure.
- The strainer avoids the entry of any foreign matter into the suction pipe.
- The foot valve is a non-return or one-way valve that opens only in the upward direction so as to prevent the suction pie draining out when the pump is stopped. The foot valve also helps in priming of the pumps.

4. Delivery pipe: - Is also a circular pipe with its lower end connected to the outlet of the pumps, while the upper end is connected to the overhead tank. The delivery valve is closed prior to starting and stopping the pump in order to prevent any possible backflow from the delivery pipe and consequent damage to the pump assembly

Operation

- In operation, when the electrical motor is switched ON, the impeller rotates creating suction at the suction pipe.
- Due to suction created, the water from the sump starts flowing into the casing through the eye of the impeller.
- The centrifugal force created by the rotating impeller acts on the water causing it to flow radially outward and towards the outlet of the casing. As the water flows through the casing, its velocity reduces due to the increasing cross-sectional area of the casing.
- The decrease in velocity increases the pressure of the water flowing through the casing. The pressure reaches the maximum at the outlet of the pump (casing). The water flows through the delivery pipe into the overhead tank.

A partial vacuum is created near the eye of the impeller, which in turn causes the liquid from the sump (at atmospheric pressure) to rush through the suction pipe to replace the fluid that is being discharged. Thus, the water is pumped continuously from the sump to the tank through the delivery pipe.

Cavitation and Priming

Cavitation

- Centrifugal pumps refer to the phenomenon of formation of vapor bubbles of a flowing fluid in a region where the pressure of the liquid falls below its vapor pressure and the sudden collapsing of the vapor bubbles in a region of high pressure around the impeller.
- Cavitation can be identified by a clear audible noise and vibrations caused by the violent collapse of vapor bubbles.
- The collapse of the vapor bubbles creates high energy shocks waves inside the liquid, which then travel and strike the impeller causing significant damage to the impeller blades or pump housing. The power consumption for pump operation increases and also there is a decreased flow and pressure.

Following are precautionary measures taken in order to avoid cavitation in pumps

1. Lower the temperature of the water.
2. Ensure suitable liquid level in the suction side.
3. Suitable impeller design, like increasing the diameter of the eye of the impeller.
4. The net positive suction head available shall be higher than the net positive suction head required by the pump. This ensures that the pressure of the fluid at all points within the pumps remains above saturation pressure.

Priming

- Priming is the process of filling the liquid into the casing, suction pipe, and delivery pipe up to the delivery valve before starting the pumps, priming s required in order to remove the air trapped in the pump, thereby reducing the risk of pumps damage during star-up. A centrifugal must not be operated until it has been filled with liquid.
- The pressure developed inside the pump is directly proportional to the density of the liquid in it. The presence of air in the pump creates a small negative pressure at the suction pipe that

prevents suction of water from the water sump. In order to eliminate the trapped air, the pump is filled with liquid before starting it. When filled with liquid, the pump is sad to be primed.