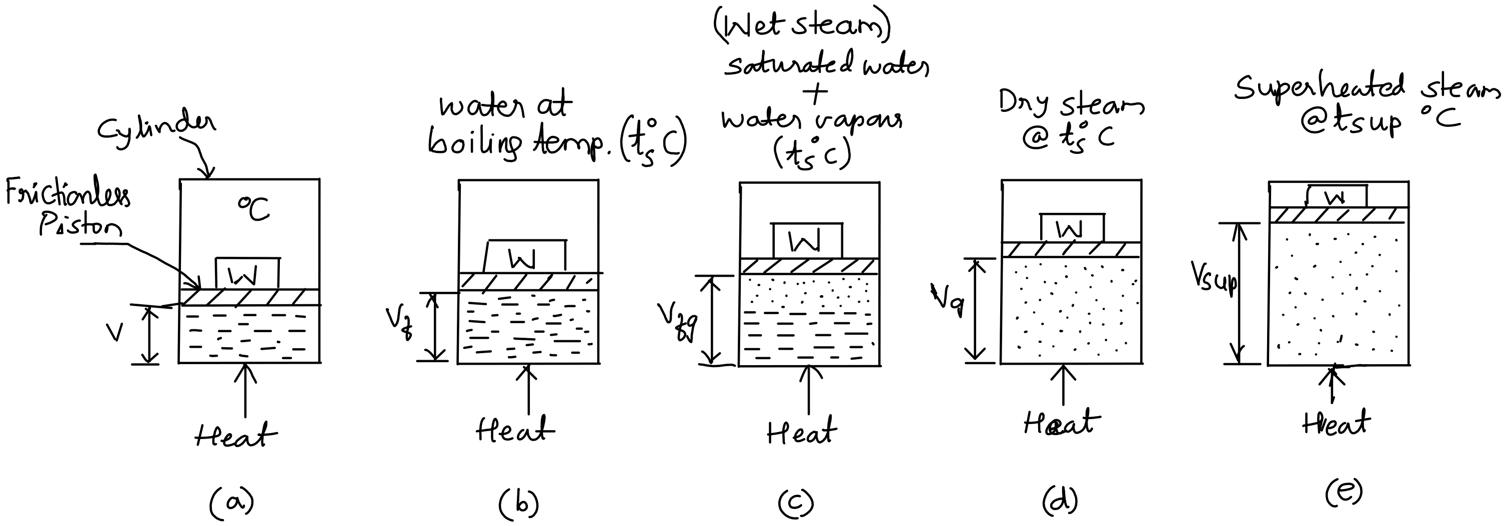
Elements of Mechanical Engineering [21ME1ESEME/21ME2ESEME]

Module 1

Steam: Gaseous phase (vapour) of water

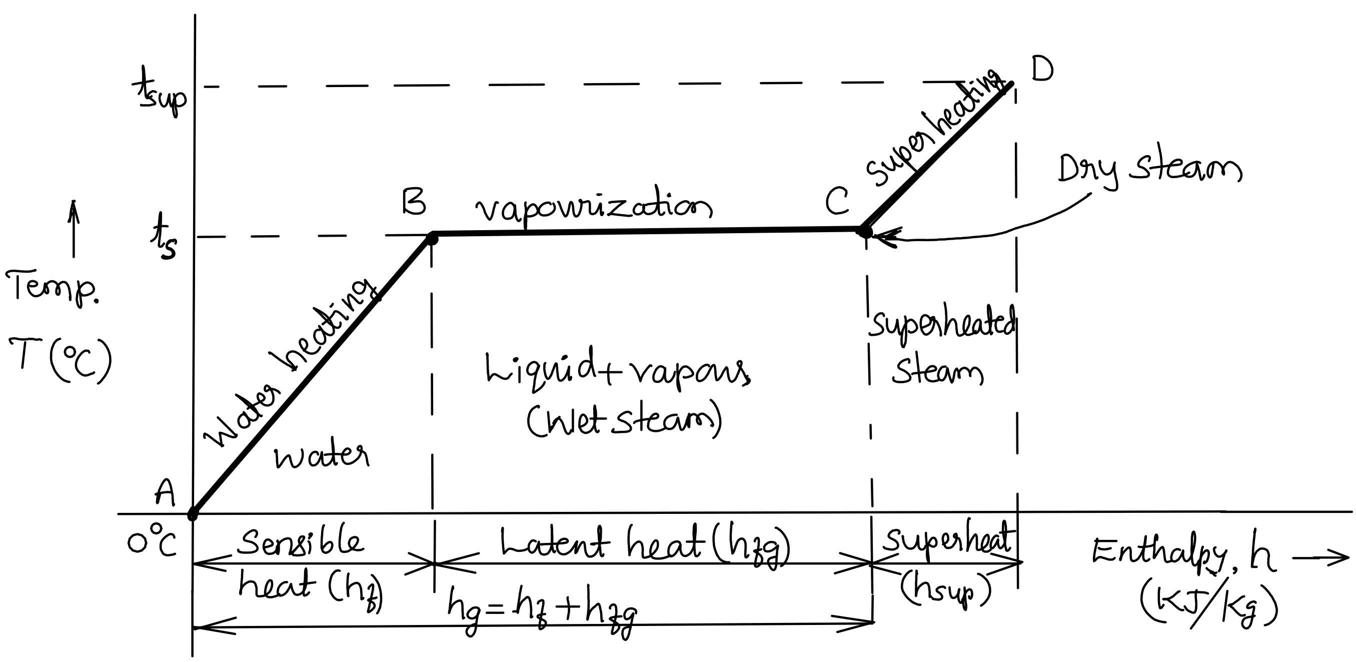
$$\text{Ice} \underset{\text{Freezing}}{\overset{\text{Melting}}{\rightleftharpoons}} \text{Water} \underset{\text{Condensing}}{\overset{\text{Vaporizing}}{\rightleftharpoons}} \text{Steam}$$

Formation of Steam [at constant Pressure]



Consider 1 kg of water at 0°C in a cylinder fitted with a frictionless (freely moving) piston as shown above (figure a).
A weight 'W' is placed on the piston to exert a constant pressure on water.
Let 'V' be the volume occupied by water. This state of water is represented by point 'A' in the Temperature-Enthalpy (T-h) diagram.

When water is heated at constant pressure, it is converted into steam. Various stages of this process are discussed below:



On heating, temperature of water rises and it begins to boil. Temperature at which it starts boiling is called <u>Saturation temperature</u> (t_s). Heating of water from 0°C to the saturation temperature is represented by the line AB on T–h diagram. There is a slight increase in the volume of water due to expansion (V_f) and is shown in figure (b).

On further heating beyond t_s, water starts evaporating to form steam. Substance here, is a two phase mixture of saturated water and vapour occupying volume V_{fg} (figure c). This steam is called "<u>Wet Steam</u>". Evaporation continues at same temperature (t_s) until whole of water completely gets converted into steam. This is represented by the line BC.

At point C, steam doesnot contain any liquid water molecules and hence called "<u>Dry Steam</u>".

Further continued heating increases the temperature of steam above t_s. This is called "Superheat temperature" (t_{sup}). Steam at t_{sup} is called "<u>Superheated Steam</u>". The process of heating dry steam beyond t_s is called Superheating, represented by the line CD.

<u>Types of Steam:</u>

<u>1. Wet Steam:</u> Two phase mixture containing saturated water and vapour (steam) formed at saturation temperature and constant pressure is called "wet steam".

<u>2. Dry saturated steam (Dry Steam):</u> Pure vapour or saturated steam at constant pressure having no water molecules in it, is called "Dry steam".

<u>3. Superheated steam:</u> Steam heated beyond its dry saturated state to higher temperatures (t_{sup}) at constant pressure is called "Superheated Steam.

Superheated steam contains more heat energy, hence capacity to do work is more. High temperature gives high thermal efficiency. As it doesnot contain moisture, corrosion is minimized.

Thermodynamic properties of Steam:

1. Sensible heat (h_f): Amount of heat required to raise the temperature of 1 kg of water from 0°C to saturation temperature (t_s) at constant pressure.

2. Latent heat (Enthalpy of evaporation, h_{fg}) : Amount of heat required to convert 1 kg of water at saturation temperature (t_s) to 1 kg of dry saturated steam at the same temperature and constant pressure.

3. Superheat (h_{sup}): Amount of heat required to raise the temperature of dry saturated steam above its saturated temperature at constant pressure.

$$\boxed{h_{sup} = C_{ps}(t_{sup} - t_s)}$$

where, C_{ps} = Specific heat of steam at constant pressure

$(t_{sup} - t_s)$ is called degree of superheat

4. Dryness fraction (x): The ratio of the mass of the actual dry steam (m_g) present in a known quantity of wet steam to the total mass of the mixture ($m_f + m_g$). x indicates the extent of dryness in steam.

$$\boxed{x = \frac{m_g}{m_f + m_g}}$$

where m_g = mass of dry steam

m_f = mass of suspended water molecules

For dry steam $x = 1$, For saturated water, $x = 0$

For wet steam $0 < x < 1$

The ratio of mass of the water particles/moisture (m_f) present in a known quantity of wet steam to the total mass of the mixture ($m_f + m_g$) is called as wetness fraction $(1-x)$.

5. Enthalpy of Steam: The amount of heat energy contained in a unit mass of steam (kJ/kg).

(i) Enthalpy of dry steam (h_g): Total amount of heat supplied to convert 1 kg of water at 0°C into 1 kg of dry steam at constant pressure.

$$\boxed{h_g = h_f + h_{fg}}$$

(ii) Enthalpy of wet steam (h): Total amount of heat supplied to convert 1 kg of water at 0°C to 1 kg of wet steam of specified dryness fraction (x) at constant pressure.

$$\boxed{h = h_f + x h_{fg}}$$

(iii) Enthalpy of superheated steam (h_{sup}): Total amount of heat supplied to convert 1 kg of water at 0°C to 1 kg of superheated steam of specified superheated temperature (t_{sup}) at constant pressure.

$$\boxed{h_{sup} = h_f + h_{fg} + C_{ps}(t_{sup} - t_s)}$$

6. <u>Specific volume</u>: Volume occupied by unit mass of steam (m^3/kg)
This is the reciprocal of density (kg/m^3).

(i) <u>Specific volume of saturated water (V_f)</u>: Volume occupied by 1 kg of water at saturation temperature and constant pressure.

(ii) <u>Specific volume of dry steam (V_g)</u>: Volume occupied by 1 kg of dry steam at saturation temperature and constant pressure.

(iii) <u>Specific volume of wet steam (V_{fg})</u>: Sum of the volume occupied by the dried up portion of steam (vapours) and the volume occupied by the suspended water molecules in 1 kg of wet steam at saturation temperature and constant pressure.

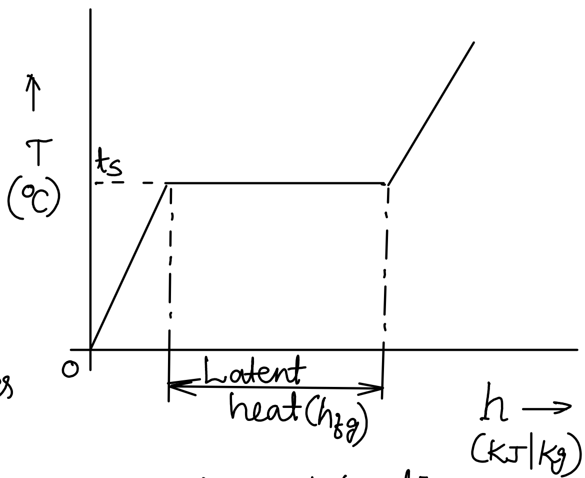
$$\boxed{V_{fg} = xV_g + (1-x)V_f}$$

(iv) <u>Specific volume of superheated steam (V_{sup})</u>: Volume occupied by 1 kg of superheated steam at specified superheated temperature and constant pressure.

$$\boxed{V_{sup} = V_g \frac{t_{sup}}{t_s}}$$ (Charle's law for ideal gas)

7. <u>External work of evaporation</u>:

Fraction of the latent heat of evaporation which does an external work by displacing the piston is called external work of evaporation.



8. <u>Internal latent heat</u>:
Fraction of the latent heat of evaporation which is utilized to change the phase of water to steam is called internal latent heat.
[Total latent heat = external work of evaporation + internal latent heat]

9. <u>Internal energy of steam</u>:
Actual energy stored in the steam which comprises of sensible heat and internal latent heat is called internal energy of steam.

Application of steam in industries:

1. Food processing
   - Agriculture
   - Sugar industry
   - Dairy industry

   - Used for cleaning
   - Used as heat source
   - Used for sterilization
   - Used for Moisturization

2. Propulsion/Drive:
   - Nuclear plants
   - Thermal electric power plants
   - Turbine driven compressors/pumps
   - Cooling tower pumps

   - To run steam turbines

3. Paper industry: To moisturize the paper so that it doesnot suffer microscopic breaks/tears when it moves over the rollers at high speed.

4. Piping systems: As direct motive force to move liquid and gas streams.

5. Cement industry: Waste heat from cement production process is used to run boilers and steam is generated. This steam can be used for any other application.

Sample questions

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1. Define the followings with respect to steam:
   a) Sensible heat b) Enthapy of dry steam
   c) Dryness fraction d) Internal energy [8 Marks]
2. With the help of T-h diagram, explain the formation of steam at constant pressure. [10 Marks]
3. Explain the process of formation of superheated steam at constant pressure with T-h diagram. [8 Marks]
4. With the help of T-h diagram define the following terms related to the formation of steam:
   a) Sensible heat b) Latent heat c) Amount of superheat
   d) Saturation temperature e) Dryness fraction f) Enthalpy of wet steam. [8 Marks]
5. Draw a labelled T-h diagram related to the formation of steam and define following terms: Specific volume, Amount of superheat, Enthalpy of dry steam, External work of evaporation, Internal latent heat. [8 Marks]
6. Explain the concepts of enthalpy, internal energy and specific volume. [6 Marks]
7. Explain the different industrial applications of steam. [6 Marks]
8. List the industrial applications of steam. [4 Marks]

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Module 1

Energy Sources and Power plants

Classification of energy sources:

Energy sources

- (Based on traditional use)
  - Conventional energy resources
  - Non-Conventional energy resources
- (Based on long term availability)
  - Renewable energy resources
  - Non-Renewable energy resources

Renewable sources

- Solar power
  - Solar Photovoltaic
  - Solar Thermal
- Wind power
- Geothermal power
- Hydel power
- Tidal power
- Biomass (Biogas, Biodiesel, Bioethanol etc)

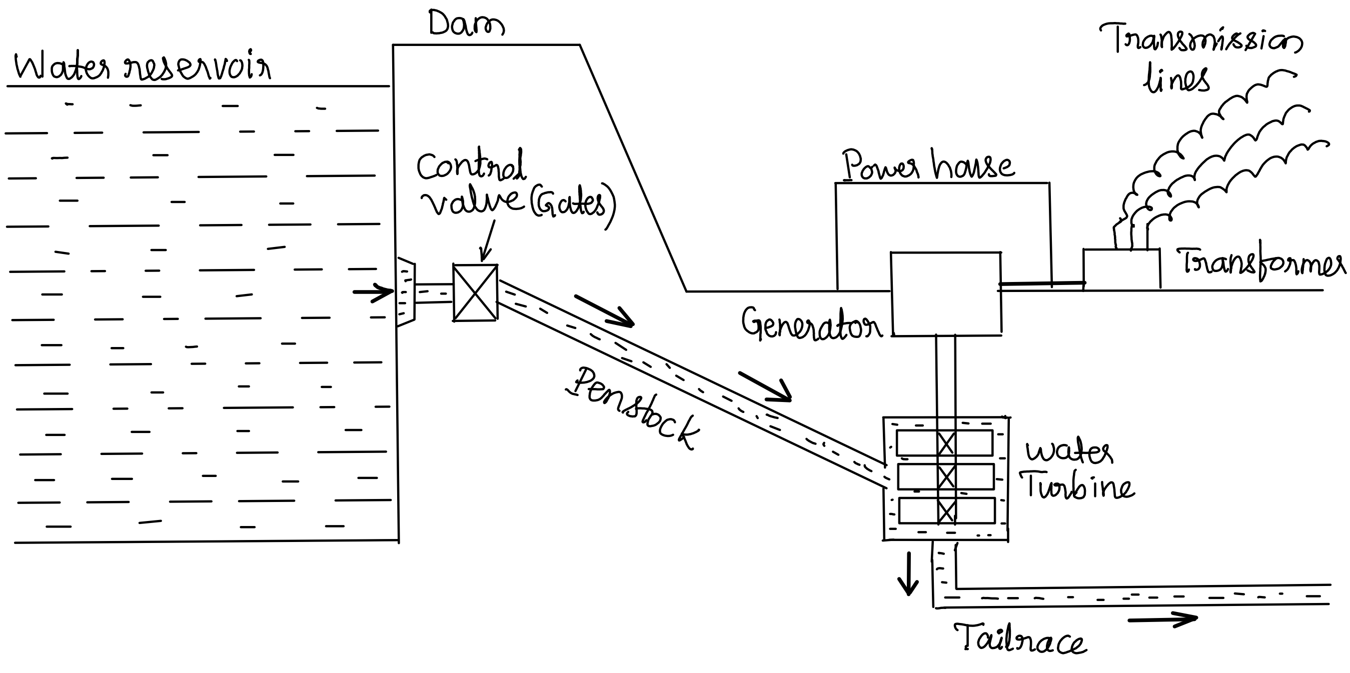
Non renewable sources

- Fossil fuels
  - Coal
  - Oil (Diesel, petrol, LPG etc)
  - Natural gas
  - Peat
- Nuclear power

Conventional energy resources	Non-Conventional energy resources
1. Energy resources that are in use over several decades. Ex: Fossil fuels, Hydel power, Nuclear power.	Energy resources which are started harvesting in recent years. Ex: Solar power, Wind power, Tidal power, Biomass energy etc.
2. Most of them are exhaustible.	Most of them are inexhaustible.
3. Most of them are hazardous to nature.	Most of them are eco-friendly.
4. Initial cost is more but reliable.	Initial cost is comparatively less but unreliable.
5. Energy transmission and maintenance costs are high.	Energy transmission and maintenance costs are low.
6. Not freely available.	Most of them are freely available in nature.

Renewable energy resources	Non-renewable energy resources
1. These are inexhaustible.	These are exhaustible.
2. These are freely available and environmental friendly.	These are not freely available and hazardous to environment.
3. Initial cost is high but maintenance cost is minimum.	Both initial and maintenance costs are high.
4. The energy concentration/availability varies from region to region.	Mostly constant in all regions.
5. Perfect energy utilization equipments are yet to be designed.	Competitive equipments or designs are progressing satisfactorily.
Ex: Solar power, Wind power, Tidal power, Hydel power, Geothermal, Ocean thermal, Bioenergy etc.	Ex: Fossil fuels, Nuclear power, ~~Heat traps~~, Natural gas.

Hydel power plant:



Construction:

Hydel power plant consists of dam, reservoir, penstocks, control gates, water turbines, generators, power house auxiliaries etc. as shown.

Dam is a barrier that stores water and creates a water head. Penstocks are open or closed conduits that carry water to the turbines. Generator is connected to the turbine shaft. Power house auxiliaries include governors, exciters, cranes, control panels etc.

Working:

Rain water flowing as river is stored to higher levels through dams that are built across the river. This stored water is released in a controlled way (using valves or gates), thus the potential energy of stored water is converted into mechanical energy in water turbines. This energy is further converted into electrical form by electric generators which are coupled to the turbines.

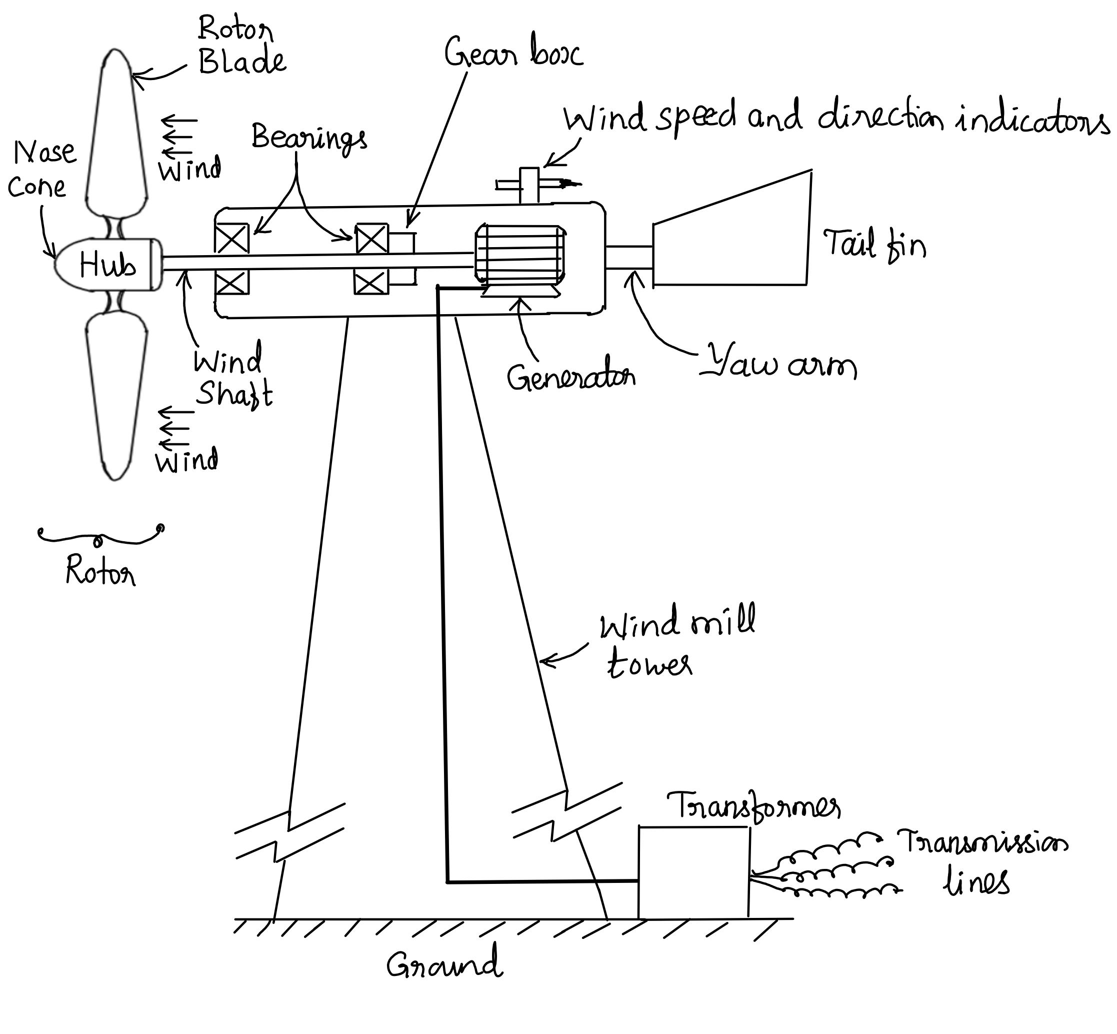
Advantages:

1. Low operating cost.
2. Fuel is not required.
3. Reliable.
4. Pollution free.
5. Renewable.
6. Life of the plant is more.
7. They are used for flood control and irrigation.

Disadvantages:

1. Capital cost is high.
2. Output depends on availability of water.
3. Building dams disturbs the ecosystem.

Wind power plant:



Construction:

A horizontal axis wind turbine consists of a rotor, shaft, bearings, gear box, generator, yaw arm, tail fin, indicators, tower, transformer etc. as shown.

Rotor is made up of 2 to 3 blades mounted on a central hub. Shaft connects rotor to generator. Bearings support the shaft. Gear box is for increasing the speed. The box or housing which contains all these parts is called Nacelle. Tower is the supporting structure of height 25m–50m. Motors and sensors are used to rotate the rotor according to the varying direction of wind.

Working:

When a mass of moving air flows in, the rotor rotates because of momentum transfer. Wind shaft connected to the generator rotates and electricity is generated. Bearings and speed increasing gear trains are used for smooth operation and to increase the performance. Thus, kinetic energy associated with the moving air is converted into electrical energy.
Brakes mounted near the gear boxes control the speed and avoid damages.
Yaw platform helps the nacelle to yaw in the direction of wind.

Advantages:

1. Air is free and inexhaustible.
2. It is clean source of energy and doesnot pullute the environment.
3. Low cost electricity.
4. Wind turbine can be used for more than 20 years.
5. Installation and maintenance cost is less.
6. Fast growing sector generating lot of employment in manufacturing, installation and maintenance.

Disadvantages:

1. Efforts are required to decide the location of installation.
2. Initial investment is comparatively high.
3. Useful only in coastal and hilly areas.
4. Noise pollution.
5. Birds die due to collision with blades.
6. Varying wind speed.

Solar Energy:

- Heliochemical process – Photosynthesis, Biogas plant
- Helioelectrical process – Photo voltaic cells.
- Heliothermal process – Collectors

Solar power plant – Heliothermal process:

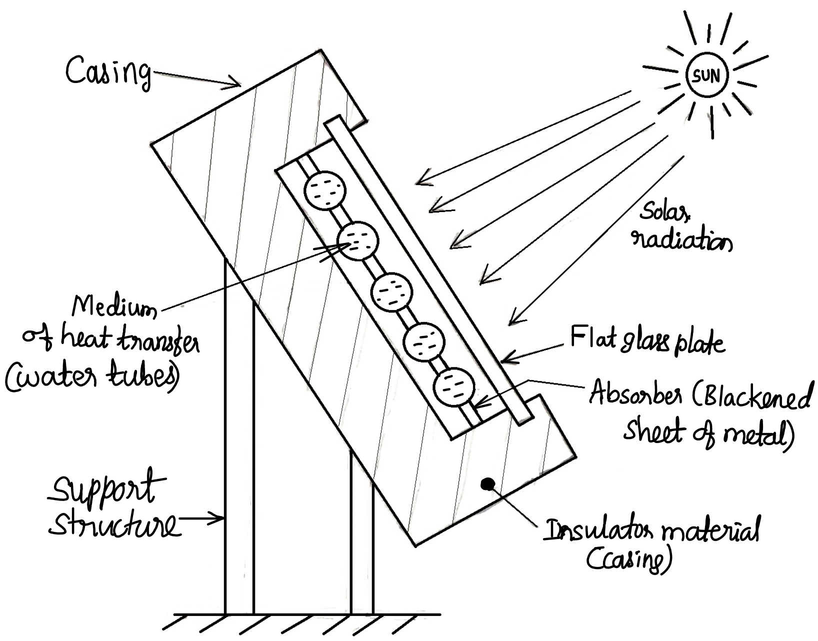
The radiant energy from sun falling on the surface of earth is converted into thermal energy by using solar collectors.

Solar collectors are the devices that collects and/or concentrates solar radiation. These are used for active solar heating and allow for the heating of water for any application. These collectors are generally mounted on the roof of buildings.

Types of solar collectors:

- Flat plate collectors
- Focus collectors
  - Line focus collectors (Parabolic troughs)
  - Point focus collectors (Parabolic dishes)
- Evacuated tube collectors

Flat plate collectors;

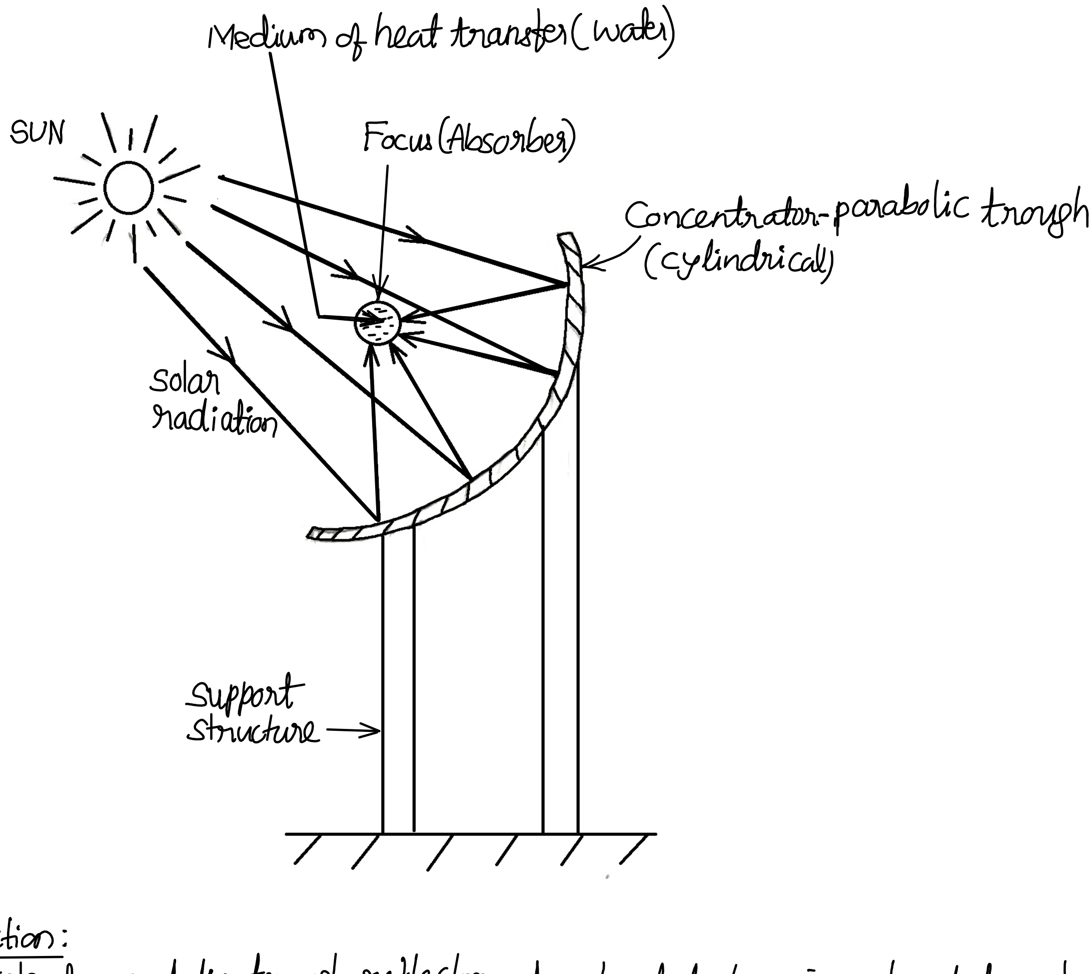


Construction: It consists of flat glass plate, water tubes, Absorber, insulating casing, foundation and support structure. Absorber is normally a blackened sheet of metal which absorbs sunlight and converts it into heat. Transparent flat glass plate and thermally insulated casing minimises the heat loss.

Working:
Heat generated in the absorber is transferred to the fluid medium (water, air or any other fluid) which flows inside the tubes. Heat energy is continuously transferred to the fluid after the blackened surface attains a temperature at which thermal equilibrium state is established between the rate at which the solar energy is being absorbed and the rate at which the heat energy is transferred to the fluid.

Flatplate collectors are used in low temperature applications such as cooking, water heating, drying of food grains/vegetables, seasoning of wood etc.

Parabolic (focussed) collectors:



Construction:
It consists of parabolic trough reflector, absorber tube/receiver, heat transfer medium, foundation and support structure. Receiver is positioned at the focus of the reflector. Oil is the most commonly used fluid medium. Focussing type collectors require tracking mechanism to follow the path of sun.

Working:
When sunlight falls on the reflector, it reflects the solar radiation and transfers it to the absorber tube. Absorber converts concentrated light energy into thermal energy by transferring the heat to the fluid flowing in the tube. With the help of tracking system, collector rotates so that it receives maximum sunlight as the sun moves.
These types of collectors are used for high temperature applications (industrial use).

Advantages of Solar energy:

1. Clean and renewable
2. Once installed, energy extraction is free of cost.
3. No pollution.
4. No noise. No moving parts.
5. Very little maintenance.
6. High return on investment, in long term.
7. Inexhaustible.

Disadvantages:

1. Solar panels are expensive
2. High initial investment.
3. Solar power stations do not match the power output of similar sized conventional power stations.
4. Battery technology is not fully evolved.
5. Intensity of sun light depends on: time of the day, the year, the altitude, the season, extent of cloud cover, atmospheric pollution etc. Hence energy extraction is not uniform.
6. Sun light is diffused.

Sample questions

1. Contrast the Renewable and Non-Renewable sources of energy with examples. [04 Marks]
2. Contrast the Conventional and Non-Conventional sources of energy with examples. [04 Marks]
3. Classify the following energy sources into Renewable and Non-Renewable sources: Coal, Wind, Nuclear, Solar, Oil, Geothermal, Natural gas, Biomass. [04 Marks]
4. List the different conventional and nn-conventional energy resources. State the advantages of non-conventional sourses over conventional sources. [06 Marks]
5. Draw a neat labelled sketch of hydro power plant. [04 Marks]
6. Identify the type of solar collector used for domestic solar water heater and draw a labelled sketch of the same. [04 Marks]
7. Explain the construction and working of a heliothermal process using dolar flat plate collector. [06 Marks]
8. Explain with sketch, how parabolic type of collector is used in solar energy conversion. [04 Marks]

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Module 1

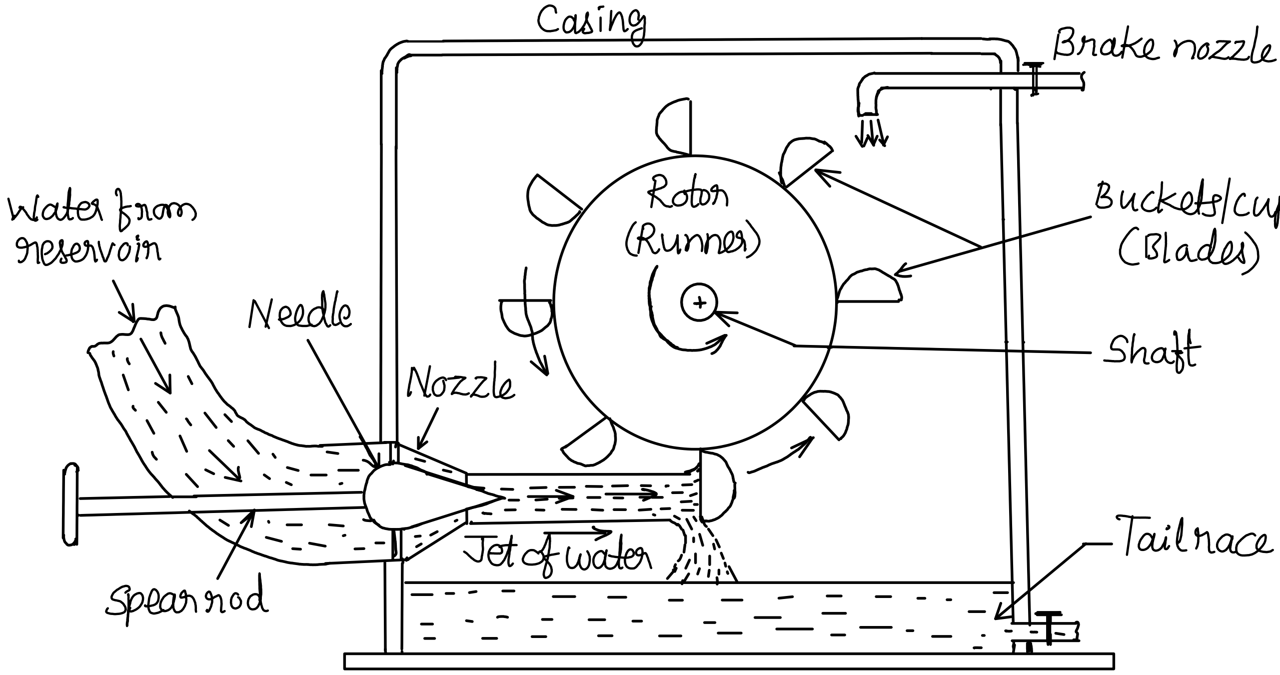
Introduction to basics of hydraulic turbines and pumps:

A turbine is a rotary engine that extracts energy from fluid flow. Broadly, turbines are classified into steam turbines, Gas turbines and Hydraulic turbines. Hydraulic or water turbines convert the kinetic and pressure energy of water into mechanical energy in the form of rotation of shaft.

Classification of Hydraulic turbines:

- Based on the type of energy available at the inlet
  - Impulse turbine
    Ex: Pelton wheel turbine
  - Reaction turbine
    Ex: Kaplan turbine
    Francis turbine
- Based on the head available at the inlet
  - High head turbine (100m – 1000m)
    Ex: Pelton wheel turbine
  - Medium head turbine (50m – 400m)
    Ex: Francis turbine
  - Low head turbine (Less than 50m)
    Ex: Kaplan turbine
- Based on the direction of flow
  - Tangential flow turbine
    Ex: Pelton wheel turbine
  - Axial flow turbine
    Ex: Kaplan turbine
  - Radial flow turbine
    Ex: Thomson turbine
  - Mixed flow turbine
    Ex: Francis turbine

Pelton wheel turbine:



Pelton wheel turbine is a tengential flow, high head, impulse turbine which can be run with small quantity of water.

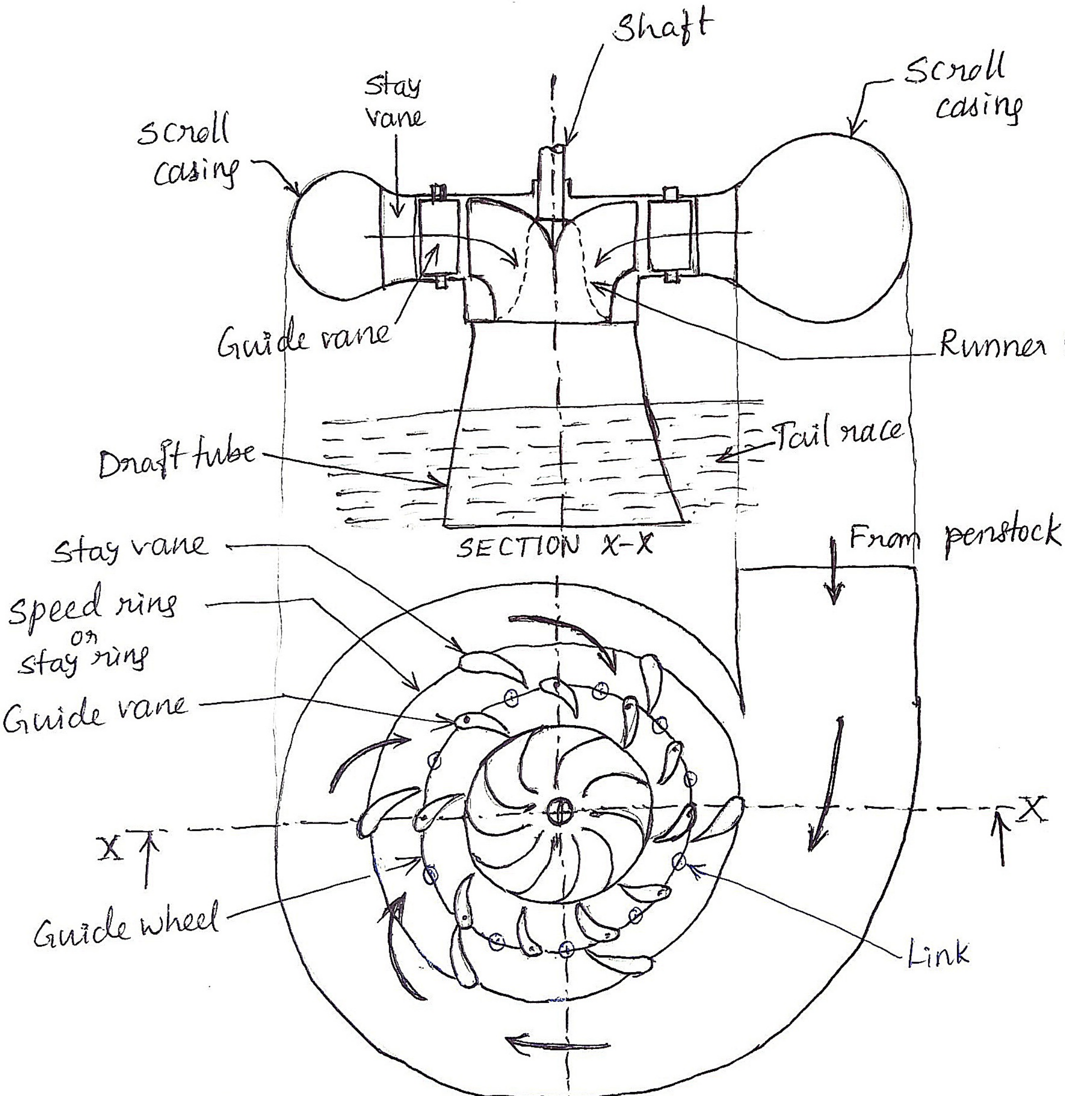
Construction:

Pelton wheel turbine consists of water inlet, nozzle, spear rod, casing, runner (rotor), Brake nozzle as shown. Runner is a circular disc mounted on the shaft. Hemispherical Pelton cups (buckets) are fixed around the runner. Spear rod in the nozzle controls the flow of water. Casing houses many parts and prevents splashing of water. Braking nozzle is for producing a jet of water in opposite direction.

Working:

Water from high head reservoirs flows through the penstock and reaches the nozzle. Needle in the nozzle controls the quantity of water flowing out of the nozzle. As the water flows through the nozzle, it is made to impinge on the cups (buckets) of the runner. The impulsive force of high velocity jet of water sets the runner into rotory motion, which in turn rotates the shaft. Only a few buckets will be struck by the jet at a time. As a result, runner rotates supplying power to the shaft. After imparting energy to the buckets, the water discharges freely into the tail race. Brake nozzle is used to slow down the speed of the runner quickly to rest, by direct water jet over the back of the buckets.

Francis turbine:



Francis turbine is a mixed flow, medium head, reaction turbine which runs with moderate amount of water. water enters radially and exit axially.

Construction:

Francis turbine consists of Penstock, scroll casing, Guide vanes, Runner and runner vanes, stay vanes and Draft tube as shown in the figure. A number of guide vanes are fixed around the circumference of the runner. Each guide vane can rotate about its pivot centre with the help of individual link and lever. Guide vanes are surrounded by stay vanes. Runner is mounted on the shaft. It is enclosed in a spiral (scroll) casing. This spiral casing ensures the uniform distribution of water around the runner. Exit of runner is attached to a draft tube.

Working:

Water from penstock is brought down to the turbine at high pressure. It enters into stay ring. Stay vanes pass the water smoothly and radially to the guide vanes. when water surrounds the runner completely, pressure decreases. The difference in pressure between the guide vanes and runner, drives the runner. Also, flow over moving blades impart kinetic energy to the runner. Runner rotates and useful mechanical energy can be extracted at the shaft.

Pelton wheel turbine	Francis turbine
1. Impulse turbine.	Reaction turbine.
2. High head, tangential flow turbine.	Medium head, mixed flow turbine.
3. Entire entegy of water is converted into kinetic energy before water enters into pelton turbine.	Energy is in the form of both kinetic and potential energies.
4. Pelton wheel has moving buckets mounted on the runner.	Water first flows through the guide blades which controls its direction on the moving blades.
5. Pressure of water is constant and equal to atmospheric pressure.	Pressure of water is reducing while it flows over the blades.
6. Work carried out on the bucket is due to change in kinetic energy.	Work is due to both kinetic and potential energies.
7. Force created on the vanes is due to kinetic energy.	Force generated is due to its kinetic energy and also reduction in pressure while flowing over the moving blades.

Pumps:

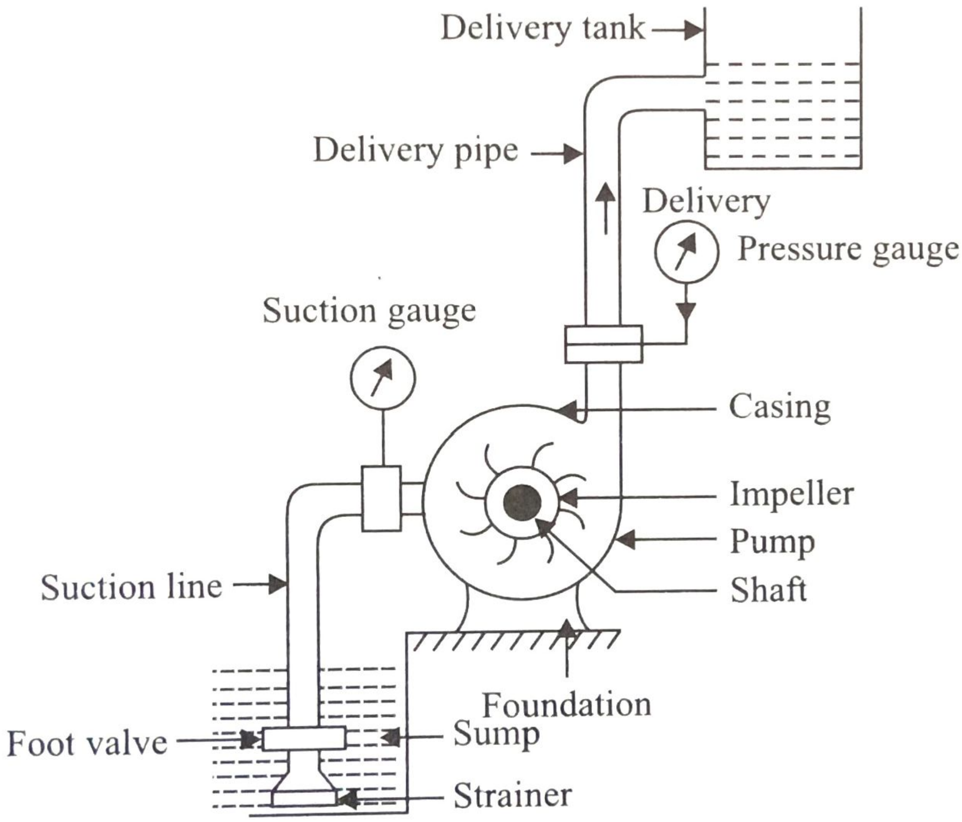
Hydraulic machines which converts the mechanical energy to hydraulic energy of the fluid in the form of pressure, kinetic and potential energies are called pumps. Electrical energy is generally used to operate pumps.

Pumps are broadly classified into dynamic pressure pumps and positive displacement pumps..

Pumps

- Dynamic pressure pumps
  - Centrifugal pump
  - Propeller pump
  - Turbine pump
- Positive displacement pump
  - Reciprocating pump
    - Piston pump
    - Diaphram pump
  - Rotary pump
    - Gear pump
    - Lobe pump
    - Screw pump
    - Vane pump
    - Rotary plunger pump

Single stage centrifugal pump:



Centrifugal pump works on a principle which states that if a fluid of a certain mass is given a force, it gets thrown outward radially.

Construction:

The major parts of the centrifugal pump include; sump, suction line, shaft, impeller, casing, discharge line, delivery tank, pressure gauges, etc. as shown. Suction pipe connects the sump to the suction eye of the pump with strainer, foot valve and suction gauge attached to it. Discharge pipe is connected to the highest level where the fluid has to be delivered. Impeller is mounted on the shaft.

Working:

Pump is normally driven by an electric motor. Fluid (such as water) enters into the suction eye (center) of the impeller. When impeller rotates, it spins the liquid present in the cavities between the vanes of the impeller in an outward direction and provides centrifugal acceleration. As the liquid leaves the eye of the impeller, a low pressure area is created causing more liquid to flow from the suction pipe. As the vanes of the impeller are curved, the fluid is pushed by the centrifugal force. Thus fluid gets discharged through the discharge line and fills the tank.

Sample questions

1. Classify hydraulic turbines and briefly explain the working of hydraullic impulse turbine. [10 Marks]
2. With a neat sketch, explain the working of Pelton wheel. [08 Marks]
3. Explain with a neat sketch, a mixed flow hydraulic turbine. [08 Marks]
4. Decide the appropriate hydraulic turbine in case of water flowing with medium head and radially into the runner. Explain its working with a neat sketch. [10 Marks]
5. Differentiate between Pelton wheel turbine and Francis turbine. [06 Marks]
6. Explain with a neat sketch, the construction and working of a single stage centrifugal pump. [08 Marks]