MODULE-I : Steam Power Plant & Combustion Process

TYPES OF ENERGY

There are various types of energy which, they include nuclear, electrical, thermal, chemical, and radiant energy. In addition, gravitational potential energy and kinetic energy that combines to produce mechanical energy.

Nuclear energy produces heat by fission on nuclei, which is generated by heat engines. Nuclear energy is the world's largest source of emission-free energy. There are two processes in Nuclear energy fission and fusion. In fission, the nuclei of uranium or plutonium atoms are split with the release of energy. In fusion, energy is released when small nuclei combine or fuse. The fission process is used in all present nuclear power plants, because fusion cannot be controlled. Nuclear energy is used to heat steam engines. A Nuclear power plant is a steam engine using uranium as its fuel, and it suffers from low efficiency. Electricity powers most factories and homes in our world. Some things like flashlights and Game Boys use electricity that is stored in batteries as chemical energy. Other items use electricity that comes from an electrical plug in a wall socket. Electricity is the conduction or transfer of energy from one place to another. The electricity is the flow of energy. Atoms have electrons circling then, some being loosely attached. When electrons move among the atoms of matter, a current of electricity is created.

Thermal energy is kinetic and potential energy, but it is associated with the random motion of atoms in an object. The kinetic and potential energy associated with this random microscopic motion is called ***thermal energy***. A great amount of thermal energy (heat) is stored in the world's oceans. Each day, the oceans absorb enough heat from the sun to equal the energy contained in 250 billion barrels of oil (Ocean Thermal Energy Conversion Systems).

Chemical energy is a form of energy that comes from chemical reactions, in which the chemical reaction is a process of oxidation. Potential energy is released when a chemical reaction occurs, which is called ***chemical energy.*** A car battery is a good example, because the chemical reaction produces voltage and current to start the car. When a plant goes through a process of photosynthesis, what the plant is left with more chemical energy than the water and carbon dioxide. Chemical energy is used in science labs to make medicine and to product power from gas.

Radiant energy exists in a range of wavelengths that extends from radio waves that many be thousands of meters long to gamma rays with wavelengths as short as a million-millionth (10^{-12}) of a meter. Radiant energy is converted to chemical energy by the process of photosynthesis.

The next two types of energy go hand and hand, ***gravitational potential energy*** and ***kinetic energy.*** The term energy is motivated by the fact that potential energy and kinetic energy are different aspects of the same thing, mechanical energy. Potential energy exists whenever an object which has mass has a position within a force field.

The potential energy of an object in this case is given by the relation $PE = mgh$, where PE is energy in joules, m is the mass of the object, g is the gravitational acceleration, and h is the height of the object goes.

Kinetic energy is the energy of motion. An object in motion, whether it be vertical or horizontal motion, has kinetic energy. There are different forms of kinetic energy vibrational, which is the energy due to vibrational motion, rotational, which is the energy due to rotational motion, and transnational, which is the energy due to motion from one location to the other. The equation for kinetic energy is ½ mv^2, where m is the mass and v is the velocity. This equation shows that the kinetic energy of an object is directly proportional to the square of its speed.

POWER DEVELOPMENT IN INDIA

The history of power development in India dates back to 1897 when a 200 kW hydro-station was first commissioned at Darjeeling. The first steam station was set up in Calcutta in 1899. By the end of 1920, the total capacity was 130 mW, comprising. Hydro 74 mW, thermal 50 mW and diesel 6 mW. In 1940, the total capacity goes to 1208 mW. There was very slow development during 1935-1945 due to Second World War. The total generation capacity was 1710 mW by the end of 1951. The development really started only after 1951 with the launching of the first five-year plan.

During the First Plan, construction of a number of Major River Valley Projects like Bhakra-Nangal, Damodar Valley, Hira Kund and Chambal Valley was taken up. These projects resulted in the stepping up of power generation. At the end of the First Plan, generation capacity stood at

lakh kW. Emphasis in Second Plan (1956-61) was on development of basic and heavy industries and related need to step up power generation. Installed capacity at the end of Second Plan reached 57 lakh kw. Comprising 3800 mW thermal and 1900 MW hydel.

During the Third Plan period (1961-66), emphasis was on extending power supply to rural areas.

A significant development in this phase was emergence of Inter-state Grid System. The country was divided into Five Regions to promote power development on a Regional Basis. A Regional Electricity Board was established in each region to promote integrated operation of constituent power system. Three Annual Plans that followed Third Plan aimed at consolidating programmes initiated during the Third Plan.

Fourth Plan envisaged need for central participation in expansion of power generation programmes at strategic locations to supplement activities in the State Sector. Progress during the period covering Third Plan, three Annual Plans and Fourth Plan was substantial with installed capacity rising to 313.07 lakh kW compression; 113.86 lakh kW from Hydro-electric Projects, 192.81 lakh kW from Thermal Power Projects and balance of 6.4 lakh kW from Nuclear Projects at the end of the Fifth Plan.

During the Sixth Plan, total capacity addition of 196.66 lakh kW comprising Hydro 47.68 lakh kW, Thermal 142.08 lakh kW and Nuclear 6.90 lakh kW was planned. Achievement, however, has been 142.26 lakh kW (28.73 lakh kW Hydro, 108.98 lakh kW Thermal and 4.55 lakh kW Nuclear) 72.3 per cent of the target.

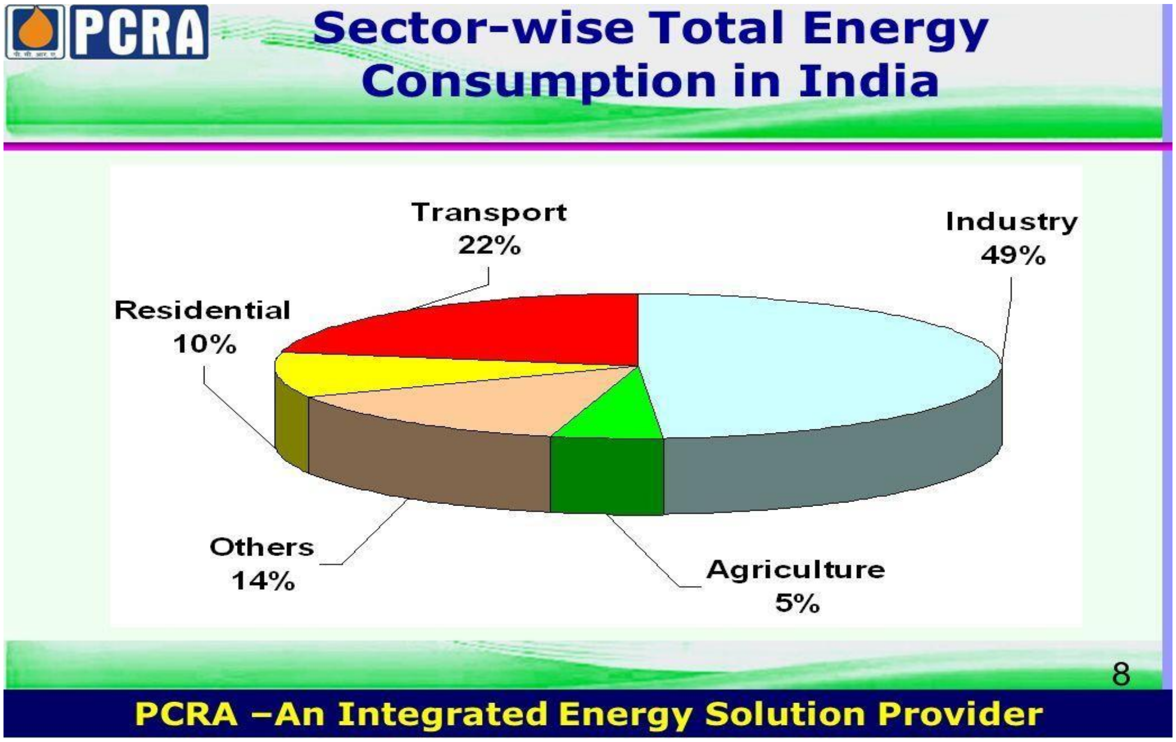
The Seventh Plan power programme envisaged aggregate generating capacity of 22,245 mW in utilities. This comprised 15,999 mW Thermal, 5,541 mW Hydro and 705 mW Nuclear of the anticipated 22,245 mW additional capacity. Central Sector Programme envisaged capacity addition of 9,320 Mw (7,950 mW Thermal, 665 mW Hydro and 705 mW Nuclear) during the Plan Period. During the Seventh Plan, 21401.48 mW has been added comprising 17104.1 mW Thermal 3,827.38 mW Hydro and 470 mW Nuclear. Year wise commissioning of Hydro, Thermal and Nuclear Capacity added during 1985-86 to 1989-90 is given in.

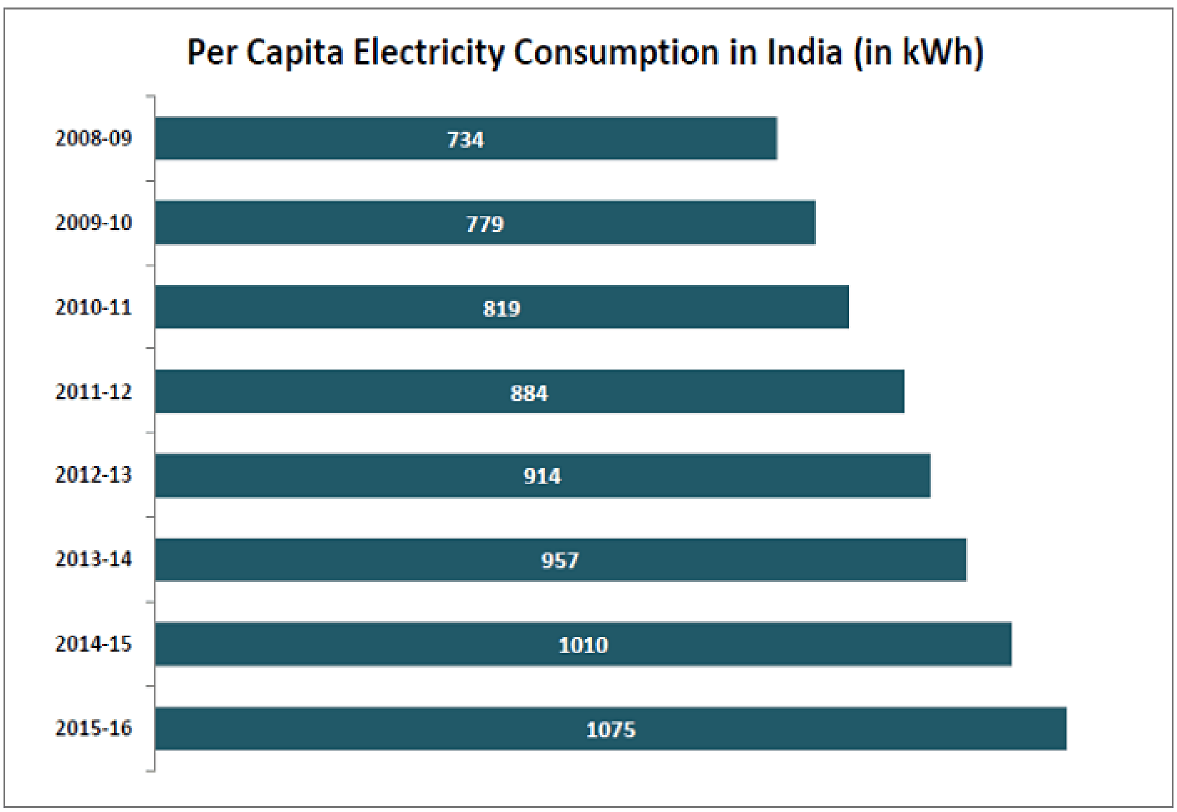
The Working Group on Power set up particularly the Planning Commission in the context of formulation of power programme for the Eighth Plan has recommended a capacity addition programme of 38,369 mW for the Eighth Plan period, out of which it is expected that the Central Sector Projects would add a capacity of 17,402 mW. The programme for the first year of the Eighth Plan (1990-91) envisages generation of additional capacity of 4,371.5 mW comprising 1,022 mW Hydro, 3,114.5 mW Thermal and 235 mW Nuclear.

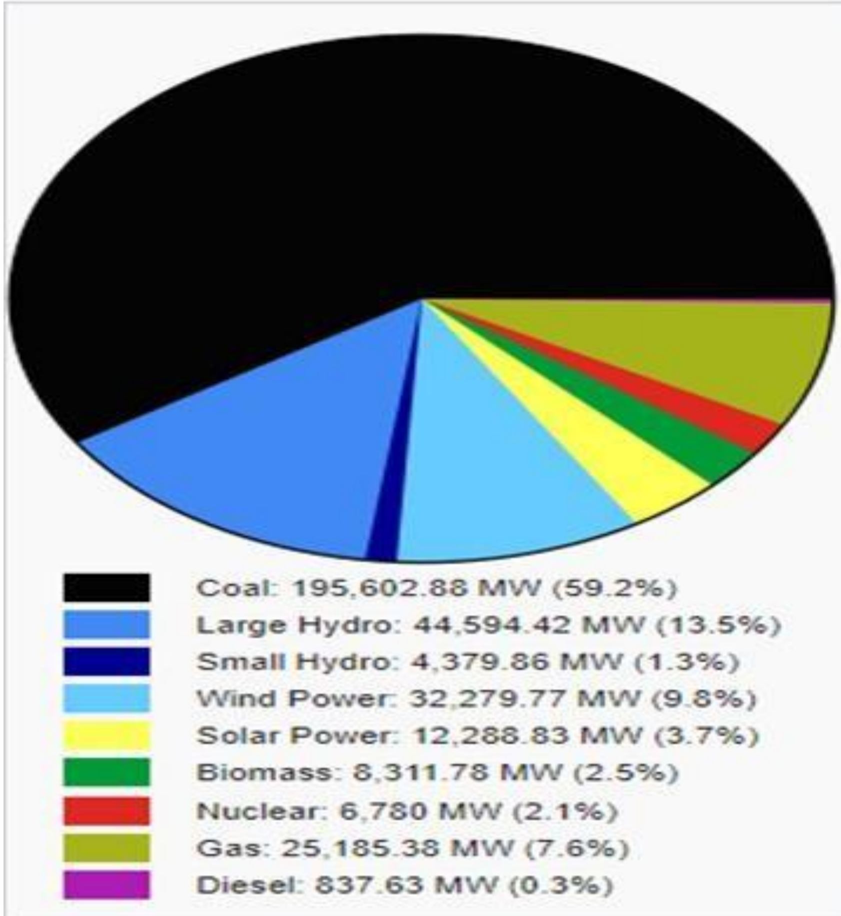
The subject ‘Power’ appears in the Concurrent List of the Constitution and as such responsibility of its development lies both with Central and state governments. At the Centre, Department of Power under the Ministry of Energy is responsible for development of Electric Energy. The department is concerned with policy formulation, perspective planning, procuring of projects for investment decisions, monitoring of projects, training and manpower development, administration and enactment of Legislation in regard to power generation, transmission and distribution. The depart-ment is also responsible for administration of the Electricity (Supply) Act, 1948 and the Indian Electricity Act, 191() and undertakes all amendments thereto. The Electricity (Supply) Act, 1948, forms basis of administrative structure of electricity industry. The Act provides for setting up of a Central Electricity Authority (CEA) with responsibility, inter-alia, to develop a National Power Policy and coordinate activities of various agencies and State Electricity Boards. The act was amended in 1976 to enlarge scope and function of CEA and enable of creation of companies for generation of electricity. The Central Electricity Authority advises Department of Power on technical, financial and economic matters. Construction and operation of generation and transmission projects in the Central Sector are entrusted to Central Power Corporations, namely, National Thermal Power Corpora-tion (NTPC), National Hydro-Electric Power Corporation (NHPC) and North-Eastern Electric Power Corporation (NEEPCU) under administrative control of the Department of Power. The Damodar Valley Corporation (DVC} constituted under the DVC Act, 1948 and the Bhitkra Beas, Management Board (BBMB) constituted under the Punjab Reorganization. Act, 1966, is also under administrative control of the Department of Power. In addition, the department administers Beas Construction Board (BCB) and National Projects Construction Corporation (NPCC), which are construction agencies and training and research organisations, Central Power Research Institute (CPRI) and Power Engineers Training Society (PETS). Programmes of rural electrification are within the purview of Rural Electrification Corporation (REC) which is a financing agency. ‘‘There are two joint venture Power Corporations under the administrative control of the Department of Power, namely, Nathpa jhakri Power Corporation and Tehri Hydro Development Corporation which are responsible for the execution of the Nathpa Jhakri Power Project and Projects of the Tehri Hydro Power Complex respectively. In addition to this, Energy Manage-ment Centre, an autonomous body, was established in collaboration with the European Economic Community, which is responsible for training, research, and information exchange between energy professionals. It is also responsible for conservation of energy programmes/activities in the Department of Power. Significant progress has been made in the expansion of transmission and distribution facilities in the Country. Total length of transmission lines of 66 kV and above increased from 10,000 ckt (circuit) km in December 1950 to 2.02 lakh ckt Km in March, 1990. Highest transmission voltage in the Country at present is 400 kV and above 19800 ckt km of 400 kV lines had been constructed up to March, 1990 and about 18000 ckt km of these are in actual operation. Prior to the Fourth Plan, Transmission Systems in the Country were developed more or less as state systems, as generating stations were built primarily in the State Sector. When State Transmission Systems had developed to a reasonable extent in the Third Plan, potentiality of inter-connected operation of individual state systems with other neighboring systems within the region (northern, western, southern, eastern and north-eastern) was thought of. Fairly well inter-connected systems at voltage of 220 kV with progressive overlay of 400 kV are presently available in all regions of the Country except North-eastern Region. With creation of Two Generation Corporations, namely National Thermal Power Corporation and National Hydro-Electric Power Corporation in 1975, the Centre had started playing an increasingly larger role in the development of grid systems. The 400 kV transmission systems being constructed by these organisa-tions as part of their generation projects, along with 400 kV inter-state and inter-regional transmission lines would form part of the National Power Grid. National Power Grid will promote integrated operation and transfer of power from one system to another with ultimate objective of ensuring optimum utilization of resources in the Country. India now has well integrated Regional Power Systems and exchange of power is taking place regularly between a large numbers of state systems, which greatly facilitates better utilization of existing capacity.

ENERGY CONSUMPTION AND STANDARD OF LIVING

- The energy consumption of a nation can be broadly divided into the following areas:
  - Domestic sector (houses and offices including commercial buildings)
  - Transportation sector
  - Agriculture sector
  - Industry sector
- ***Per capita energy consumption of a country is an index of the standard of living of the people of the country.***


PCRA
Sector-wise Total Energy Consumption in India
Transport 22%
Industry 49%
Residential 10%
Others 14%
Agriculture 5%
8
PCRA –An Integrated Energy Solution Provider


Per Capita Electricity Consumption in India (in kWh)
2008-09
734
2009-10
779
2010-11
819
2011-12
884
2012-13
914
2013-14
957
2014-15
1010
2015-16
1075

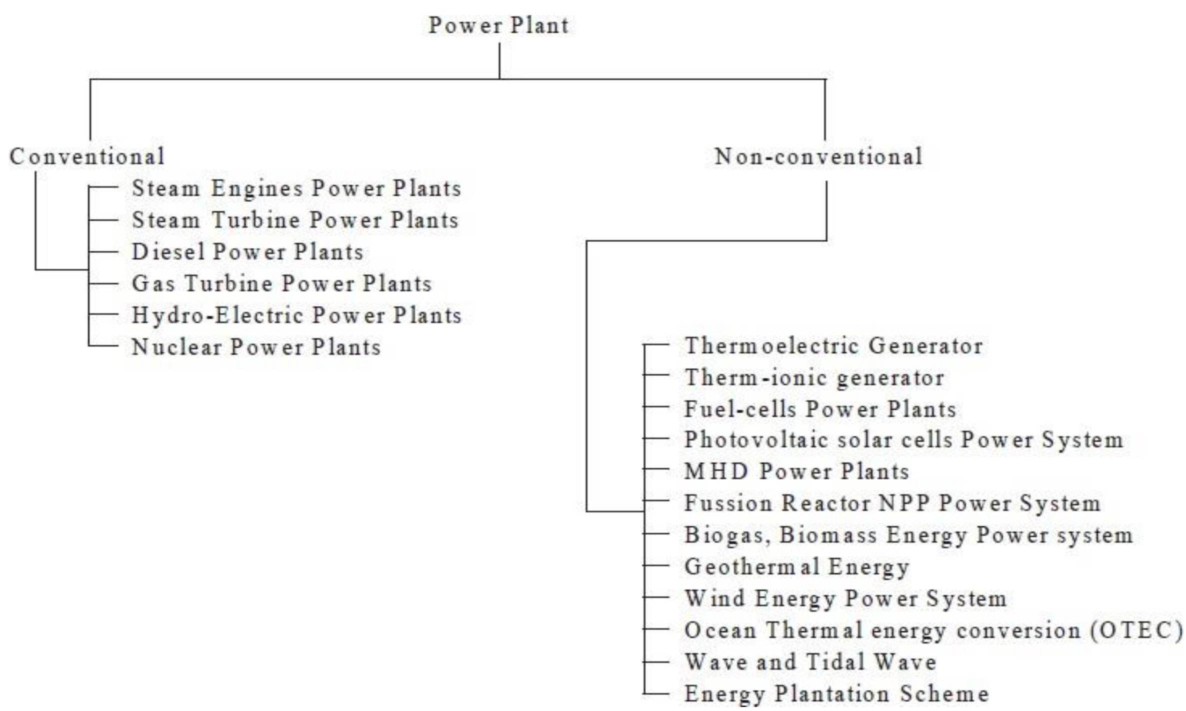


RESOURCES FOR POWER GENERATION

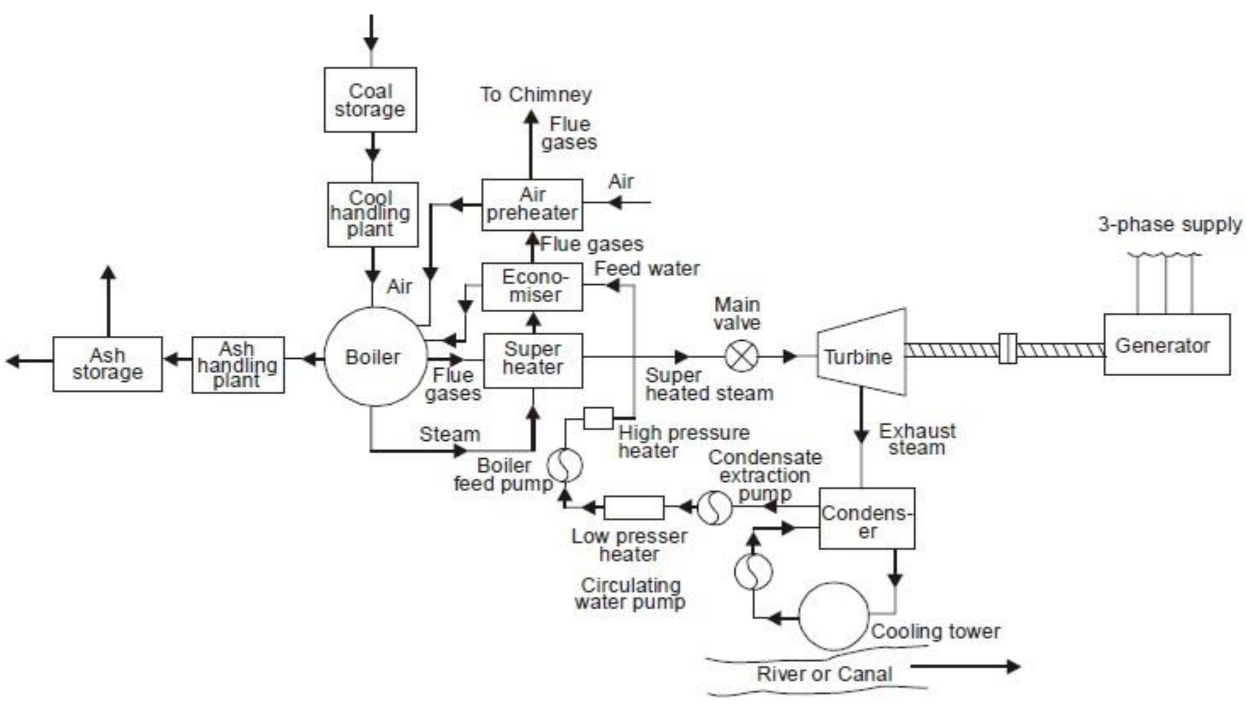
- ✓ Fuels
- ✓ Energy stored in water
- ✓ Nuclear energy
- ✓ Wind energy
- ✓ Solar energy
- ✓ Tidal energy
- ✓ Geothermal energy
- ✓ Thermoelectric power

POWER PLANT: A power plant may be defined as a machine or assembly of equipment that generates and delivers a flow of mechanical or electrical energy.

CLASSIFICATION OF POWER PLANTS



STEAM POWER PLANT LAYOUT:



A steam power plant must have following equipments:

1. A furnace to burn the fuel.
2. Steam generator or boiler containing water. Heat generated in the furnace is utilized to convert water in steam.
3. Main power unit such as an engine or turbine to use the heat energy of steam and perform work.
4. Piping system to convey steam and water.

In addition to the above equipment the plant requires various auxiliaries and accessories depending upon the availability of water, fuel and the service for which the plant is intended.
A steam power plant using steam as working substance works basically on Rankine cycle.

Fig. shows a schematic arrangement of equipment of a steam power station. Coal received in coal storage yard of power station is transferred in the furnace by coal handling unit. Heat produced due to burning of coal is utilized in converting water contained in boiler drum into steam at suitable pressure and temperature. The steam generated is passed through the superheater. Superheated steam then flows through the turbine. After doing work in the turbine die pressure of steam is reduced. Steam leaving the turbine passes through the condenser which maintain the low pressure of steam at the exhaust of turbine. Steam pressure in the condenser depends upon flow rate and temperature of cooling water and on effectiveness of air removal equipment. Water circulating through the condenser may be taken from the various sources such as river, lake or sea. If sufficient quantity of water is not available the hot water coming out of the condenser may be cooled in cooling towers and circulated again through the condenser. Bled steam taken from the turbine at suitable extraction points is sent to low pressure and high pressure water heaters.
Air taken from the atmosphere is first passed through the air pre-heater, where it is heated by flue gases. The hot air then passes through the furnace. The flue gases after passing over boiler and superheater tubes, flow through the dust collector and then through economizer, air pre-heater and finally they are exhausted to the atmosphere through the chimney.
Steam condensing system consists of the following:

(i) Condenser
(ii) Cooling water
(iii) Cooling tower

(iv) Hot well

(v) Condenser cooling water pump

(vi) Condensate air extraction pump

(vii) Air extraction pump

(viii) Boiler feed pump

(ix) Make up water pump.

WORKING OF DIFFERENT CIRCUITS:

The flow sheet of a thermal power plant consists of the following four main circuits:

(i) Feed water and steam flow circuit

(ii) Coal and ash circuit

(iii) Air and gas circuit

(iv) Cooling water circuit.

Coal and Ash Circuit:

- Coal Storage – Coal handling – Boiler – Ash handling plant – Ash storage

In this circuit, the coal from the storage is fed to the boiler through coal handling equipment for the generation of steam. Ash produced due to combustion of coal is removed to ash storage through ash-handling system.

Air and Gas Circuit:

- Air from atmosphere – Air preheater – Boiler – Superheater – Economizer – Air preheater – Chimney – Hot gas to atmosphere

Air is supplied to the combustion chamber of the boiler either through forced draught or induced draught fan or by using both. The dust from the air is removed before supplying to the combustion chamber. The exhaust gases carrying sufficient quantity of heat and ash are passed through the air-heater where the exhaust heat of the gases is given to the air and then it is passed through the dust collectors where most of the dust is removed before exhausting the gases to the atmosphere.

Feed Water and Steam Circuit:

- Condensate from condenser – CEP – LPH – BFP – HPH – Economizer – Boiler – Superheater – Turbine – Condenser

The steam generated in the boiler is fed to the steam prime mover to develop the power. The steam coming out of the prime mover is condensed in the condenser and then fed to the boiler with the help of pump. The condensate is heated in the feed-heaters using the steam tapped from different points of the turbine. The feed heaters may be of mixed type or indirect heating type. Some of the steam and water are lost passing through different components of the system, therefore, feed water is supplied from external source to compensate this loss. The feed water supplied from external source to compensate the loss. The feed water supplied from external source is passed through the purifying plant to reduce to reduce dissolve salts to an acceptable level. This purification is necessary to avoid the scaling of the boiler tubes.

Cooling Water Circuit:

- Makeup water + Cooled water from cooling tower – CWP – Condenser – Hot water to cooing tower

The quantity of cooling water required to condense the steam is considerably high and it is taken from a lake, river or sea. At the Columbia thermal power plant it is taken from an artificial lake created near the plant. The water is pumped in by means of pumps and the hot water after condensing the steam is cooled before sending back into the pond by means of cooling towers. This is done when there is not adequate natural water available close to the power plant. This is a closed system where the water goes to the pond and is re circulated back into the power plant. Generally open systems like rivers are more economical than closed systems.

POWER STATION DESIGN

Power station design requires wide experience. A satisfactory design consists of the following steps :

(i) Selection of site

(ii) Estimation of capacity of power station.

(iii) Selection of turbines and their auxiliaries.

(iv) Selection of boilers, and their auxiliaries.

(v) Design of fuel handling system.

(vi) Selection of condensers.

(vii) Design of cooling system.

(viii) Design of piping system to carry steam and water.

(ix) Selection of electrical generator.

(x) Design and control of instruments.

(xi) Design of layout of power station. Quality of coal used in steam power station plays an important role in the design of power plant. The various factors to be considered while designing the boilers and coal handling units are as follows:

(a) Slagging and erosion properties of ash.

(b) Moisture in the coal. Excessive moisture creates additional problems particularly in case of pulverized fuel power plants.

(c) Burning characteristic of coal.

(d) Corrosive nature of ash.

CHARACTERISTICS OF STEAM POWER PLANT

The desirable characteristic for a steam power plant are as follows:

(i) Higher efficiency.

(ii) Lower cost

(iii) Ability to burn coal especially of high ash content, and inferior coals.

(iv) Reduced environmental impact in terms of air pollution.

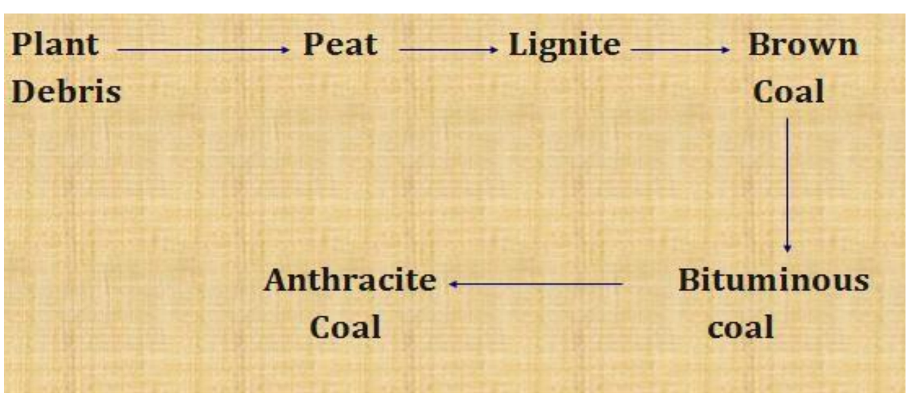
(v) Reduced water requirement.

(vi) Higher reliability and availability.

Fuels:

S. No	Type of fuel	Primary fuel	Secondary fuel
1		**Wood**	**Coke**
2	**Solid**	**Peat**	**Char Coal**
3		**Lignite coal**	**Briquettes**
4			**Gasoline**
5			**Kerosene**
6	**Liquid**	**Petroleum**	**Fuel Oil**
7			**Alcohol**
8			**Benzol**
9			**Shale Oil**
10			**Petroleum gas**
11	**Gas**	**Natural gas**	**Producer gas**
12			**Coal gas**
13			**Coke-Oven gas**

Stages of Coal Formation:



Types of coal:

S. No	Name	Composition	Calorific value
1.	Lignite	20 – 60 % Moisture + Remaining Carbon	21,000 KJ/kg
2.	Brown coal	20% Moisture + Remaining Carbon	Very low
3.	Bituminous Coal	78 – 90 % of C + 20 – 45 % Volatile matter + 4 – 6 % Moisture	31,600 KJ/kg
4.	Anthracite Coal	90 – 98 % of C + 8% Volatile matter	35,000 KJ/Kg

Ranking of Coal:

Factors Considered

- Size of the coal
- Heating value
- Ash content
- Ash softening temperature
- Sulphur content

Gaseous Fuels:

S. No	Name	Make	Calorific value
1.	Natural gas	Methane + Ethane	21,000 kJ/m³
2.	Coal gas	Hydrogen + Carbon Monoxide + Hydrocarbons	18,000 kJ/m³
3.	Coke Oven gas	Produced by the PYROLYSIS of Coal	20,000kJ/m³
4.	Blast furnace gas	Obtained from the SMELTING of Iron Ore	37.30 kJ/m³
5.	Producer gas	Formed during the burning of Coal, Coke or Peat with insufficient air	Low
6.	Sewer gas	Obtained from the Sewage disposal waste	High

COAL HANDLING

Coal delivery equipment is one of the major components of plant cost. The various steps involved in coal handling are as follows : (Fig.)

(*i*) Coal delivery (*ii*) Unloading

(*iii*) Preparation (*iv*) Transfer

(*v*) Outdoor storage (*vi*) Covered storage

(*vii*) In plant handling (*viii*) Weighing and measuring

(*ix*) Feeding the coal into furnace.

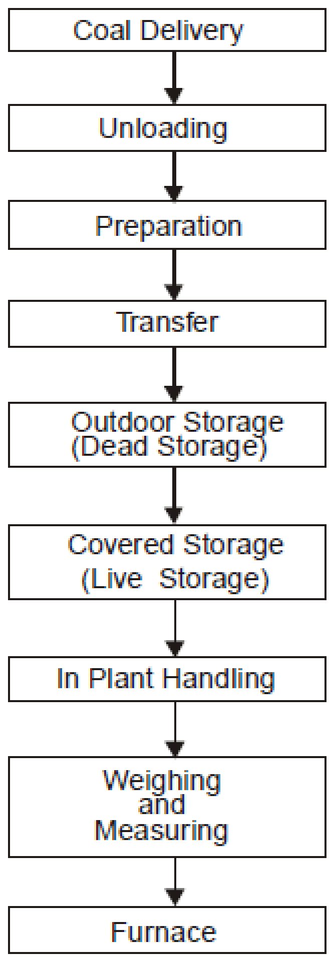


Fig. Steps in Coal Handling.

(i) **Coal Delivery.** The coal from supply points is delivered by ships or boats to power stations situated near to sea or river whereas coal is supplied by rail or trucks to the power stations which are situated away from sea or river. The transportation of coal by trucks is used if the railway facilities are not available.

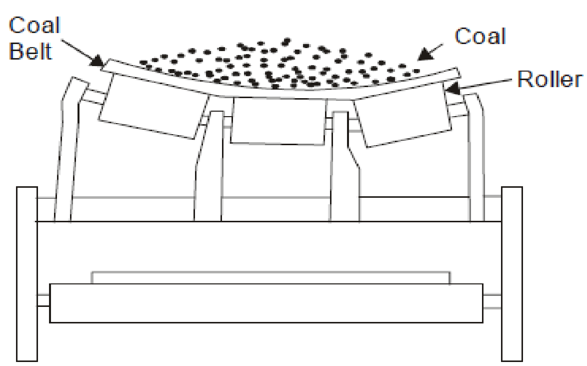
(ii) **Unloading.** The type of equipment to be used for unloading the coal received at the power station depends on how coal is received at the power station. If coal is delivered by trucks, there is no need of unloading device as the trucks may dump the coal to the outdoor storage. Coal is easily handled if the lift trucks with scoop are used. In case the coal is brought by railway wagons, ships or boats, the unloading may be done by car shakes, rotary car dumpers, cranes, grab buckets and coal accelerators. Rotary car dumpers although costly are quite efficient for unloading closed wagons.

(iii) **Preparation.** When the coal delivered is in the form of big lumps and it is not of proper size, the preparation (sizing) of coal can be achieved by crushers, breakers, sizers driers and magnetic separators.

(iv) **Transfer.** After preparation coal is transferred to the dead storage by means of the following systems :

1. Belt conveyors.	2. Screw conveyors.
3. Bucket elevators.	4. Grab bucket elevators.
5. Skip hoists.	6. Flight conveyor.

1. Belt conveyor: Fig. shows a belt conveyor. It consists of an endless belt. Moving over a pair of end drums (rollers). At some distance a supporting roller is provided at the center. The belt is made, up of rubber or canvas. Belt conveyor is suitable for the transfer of coal over long distances. It is used in medium and large power plants. The initial cost of the system is not high and power consumption is also low. The inclination at which coal can be successfully elevated by belt conveyor is about 20. Average speed of belt conveyors varies between 200-300 r.p.m. This conveyor is preferred than other types



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Advantages of belt conveyor

1. Its operation is smooth and clean.

2. It requires less power as compared to other types of systems.

3. Large quantities of coal can be discharged quickly and continuously.

4. Material can be transported on moderates inclines.

2. Screw conveyor. It consists of an endless helicoid screw fitted to a shaft (Fig.). The screw while rotating in a trough transfers the coal from feeding end to the discharge end. This system is suitable, where coal is to be transferred over shorter distance and space limitations exist. The initial cost of the system is low. It suffers from the drawbacks that the power consumption is high and there is considerable wear of screw. Rotation of screw varies between 75-125 r.p.m.

3. Bucket elevator. It consists of buckets fixed to a chain. The chain moves over two wheels. The coal is carried by the buckets from bottom and discharged at the top.

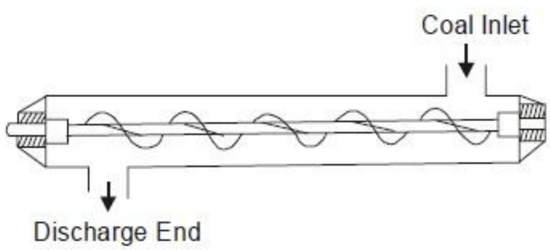


Fig. . Screw Conveyor.

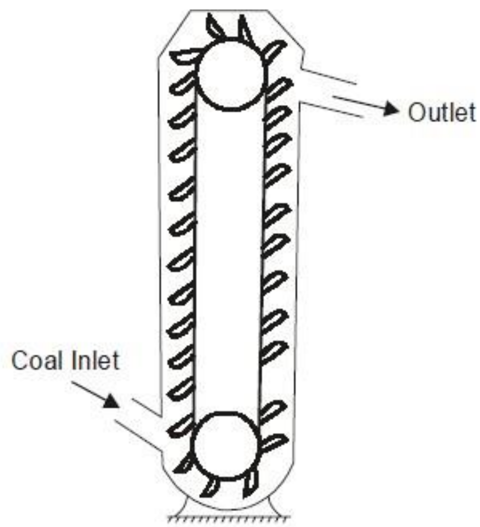


Fig. . Bucket Elevator.

4. Grab bucket elevator. It lifts and transfers coal on a single rail or track from one point to the other. The coal lifted by grab buckets is transferred to overhead bunker or storage. This system requires less power for operation and requires minimum maintenance.

The grab bucket conveyor can be used with crane or tower as shown in Fig. 4.6. Although the initial cost of this system is high but operating cost is less.

Fig. 4.6. Grab Bucket Elevator.

5. Skip hoist. It consists of a vertical or inclined hoistway a bucket or a car guided by a frame and a cable for hoisting the bucket. The bucket is held in up right position. It is simple and compact method of elevating coal or ash. Fig. 4.7 shows a skip hoist.

6. Flight conveyor. It consists of one or two strands of chain to which steel scraper or flights are attached'. which scrap the coal through a trough having identical shape. This coal is discharged in the bottom of trough. It is low in first cost but has large energy consumption. There is considerable wear.

Skip hoist and bucket elevators lift the coal vertically while Belts and flight conveyors move the coal horizontally or on inclines.

Fig. 4.8 shows a flight conveyor. Flight conveyors possess the following **advantages.**

(*i*) They can be used to transfer coal as well as ash.

(*ii*) The speed of conveyor can be regulated easily.

(*iii*) They have a rugged construction.

(*iv*) They need little operational care.

Disadvantages. Various disadvantages of flight conveyors are as follows :

(*i*) There is more wear due to dragging action.

(*ii*) Power consumption is more.

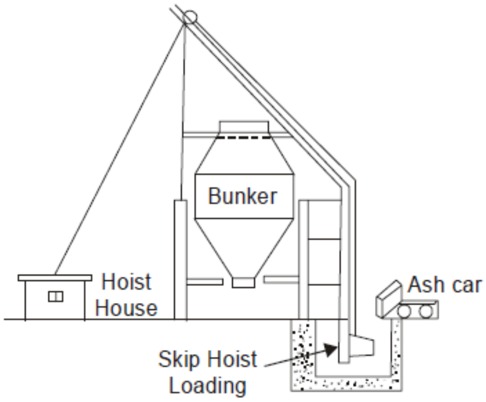


Fig. 4.7. Skip Hoist.

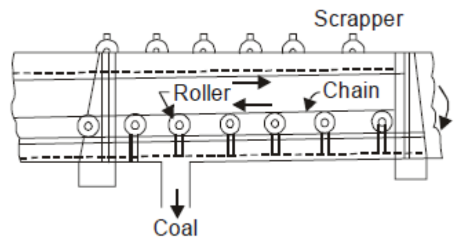


Fig. 4.8. Flight Conveyor.

(*iii*) Maintenance cost is high.

(*iv*) Due to abrasive nature of material handled the speed of conveyors is low (10 to 30 m/min).

(*v*) Storage of coal. It is desirable that sufficient quantity of coal should be stored. Storage of coal gives protection against the interruption of coal supplies when there is delay in transportation of coal or due to strikes in coal mines. Also when the prices are low, the coal can be purchased and stored for future use. The amount of coal to be stored depends on the availability of space for storage, transportation facilities, the amount of coal that will whether away and nearness to coal mines of the power station.

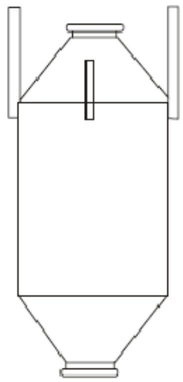
Usually coal required for one month operation of power plant is stored in case of power stations situated at longer distance from the collieries whereas coal need for about 15 days is stored in case of power station situated near to collieries. Storage of coal for longer periods is not advantageous because it blocks the capital and results in deterioration of the quality of coal.

The coal received at the power station is stored in dead storage in the form of piles laid directly on the ground.

The coal stored has the tendency to whether (to combine with oxygen of air) and during this process coal loss some of its heating value and ignition quality. Due to low oxidation the coal may ignite spontaneously. This is avoided by storing coal in the form of piles which consist of thick and compact layers of coal so that air cannot pass through the coal piles. This will minimize the reaction between coal and oxygen. The other alternative is to allow the air to pass through layers of coal so that air may remove the heat of reaction and avoid burning. In case the coal is to be stored for longer periods the outer surface of piles may be sealed with asphalt or fine coal.

The coal is stored by the following methods :

(*i*) *Stocking the coal in heats.* The coal is piled on the ground up to 10-12 m height. The pile top should be given a slope in the direction in which the rain may be drained off.



The sealing of stored pile is desirable in order to avoid the oxidation of coal after packing an air tight layer of coal.

Asphalt, fine coal dust and bituminous coating are the materials commonly used for this purpose.

(*ii*) *Under water storage.* The possibility of slow oxidation and spontaneous combustion can be completely eliminated by storing the coal under water.

Coal should be stored at a site located on solid ground, well drained, free of standing water preferably on high ground not subjected to flooding.

Fig. 4.9. Cylindrical Bucket.

(*vi*) In Plant Handling. From the dead storage the coal is brought to covered storage (Live storage) (bins or bunkers). A cylindrical bunker shown in Fig. 4.9. In plant handling may include the equipment such as belt conveyors, screw conveyors, bucket elevators etc. to transfer the coal. Weigh lorries hoppers and automatic scales are used to record the quantity of coal delivered to the furnace.

(*vii*) Coal weighing methods. Weigh lorries, hoppers and automatic scales are used to weigh the quantity coal. The commonly used methods to weigh the coal are as follows:

(*i*) Mechanical (*ii*) Pneumatic (*iii*) Electronic.

The Mechanical method works on a suitable lever system mounted on knife edges and bearings connected to a resistance in the form of a spring of pendulum. The pneumatic weighters use a pneumatic transmitter weight head and the corresponding air pressure determined by the load applied. The electronic weighing machines make use of load cells that produce voltage signals proportional to the load applied.

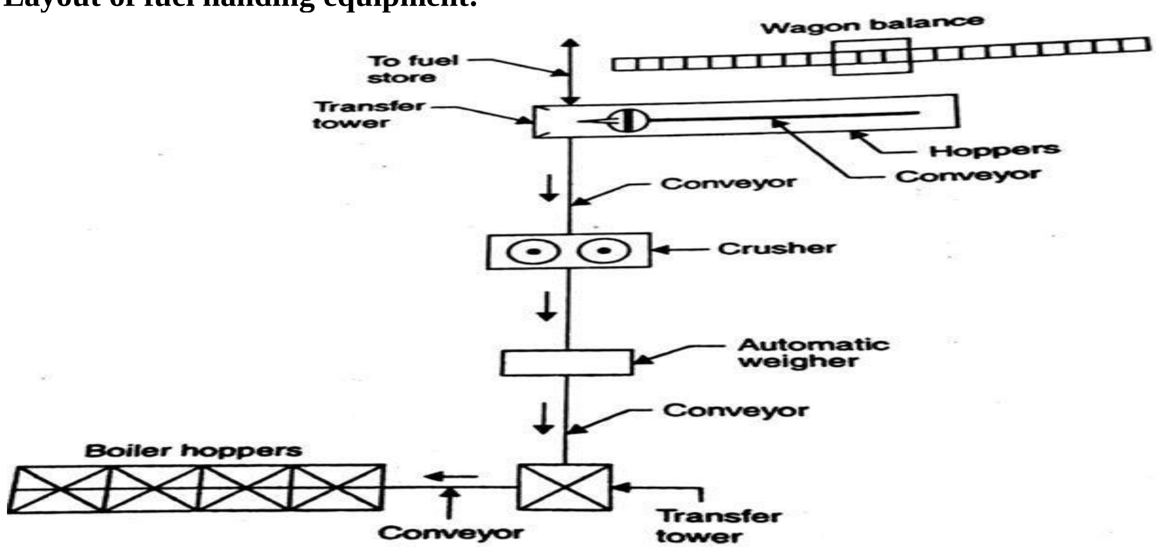
The important factor considered in selecting fuel handling systems are as follows:

(*i*) Plant flue rate

(*ii*) Plant location in respect to fuel shipping

(*iii*) Storage area available.

Layout of fuel handing equipment:



ASH HANDLING EQUIPMENT:

Mechanical means are required for the disposal of ash. The handling equipment should perform the following functions:

(1) Capital investment, operating and maintenance charges of the equipment should be low.

(2) It should be able to handle large quantities of ash.

(3) Clinkers, soot, dust etc. create troubles, the equipment should be able to handle them smoothly.

(4) The equipment used should remove the ash from the furnace, load it to the conveying system to deliver the ash to a dumping site or storage and finally it should have means to dispose of the stored ash.

(5) The equipment should be corrosion and wear resistant.

Fig. 4.33 shows a general layout of ash handling and dust collection system. The commonly used ash handling systems are as follows :

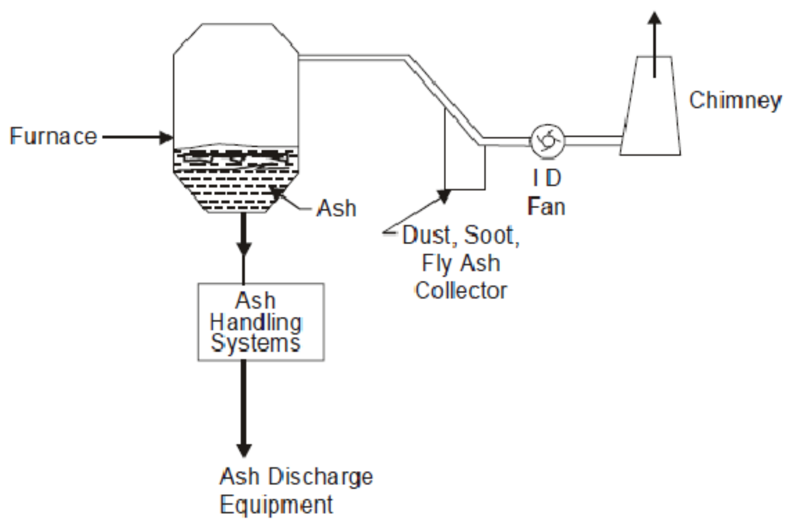


Fig. 4.33. Ash Handling and Dust Collections System.

(*i*) Hydraulic system

(*ii*) pneumatic system

(*iii*) Mechanical system.

The commonly used ash discharge equipment is as follows:

(*i*) Rail road cars

(*ii*) Motor truck

(*iii*) Barge.

The various methods used for the disposal of ash are as follows :

(*i*) **Hydraulic System.** In this system, ash from the furnace grate falls into a system of water possessing high velocity and is carried to the sumps. It is generally used in large power plants. Hydraulic system is of two types namely low pressure hydraulic system used for continuous removal of ash and high pressure system which is used for intermittent ash disposal. Fig. 4.34 shows hydraulic system.

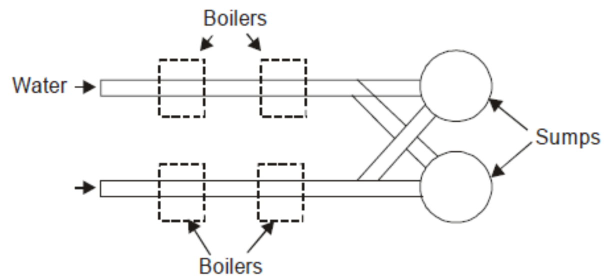


Fig. 4.34. Hydraulic System.

In this method water at sufficient pressure is used to take away the ash to sump. Where water and ash are separated. The ash is then transferred to the dump site in wagons, rail cars or trucks. The loading of ash may be through a belt conveyor, grab buckets. If there is an ash basement with ash hopper the ash can fall, directly in ash car or conveying system.

(*ii*) **Water Jetting.** Water jetting of ash is shown in Fig. 4.35. In this method a low pressure jet of water coming out of the quenching nozzle is used to cool the ash. The ash falls into a trough and is then removed.

(*iii*) **Ash Sluice Ways and Ash Sump System.** This system shown diagrammatically in Fig. 4.36 used high pressure (H.P.) pump to supply high pressure (H.P.) water-jets which carry ash from the furnace bottom through ash sluices (channels) constructed in basement floor to ash sump fitted with screen. The screen divides the ash sump into compartments for coarse and fine ash. The fine ash passes through the screen and moves into the dust sump (D.S.). Dust slurry pump (D.S. pump) carries the dust through dust pump (D.P), suction pipe and dust delivery (D.D.) pipe to the disposal site. Overhead crane having grab bucket is used to remove coarse ash. A.F.N represents ash feeding nozzle and S.B.N. represents sub way booster nozzle and D.A. means draining apron.

(*iv*) **Pneumatic system.** In this system (Fig. 4.37) ash from the boiler furnace outlet falls into a crusher where larger ash particles are crushed to small sizes. The ash is then carried by a high velocity air or steam to the point of delivery. Air leaving the ash separator is passed through filter to remove dust etc. so that the exhauster handles clean air which will protect the blades of the exhauster.

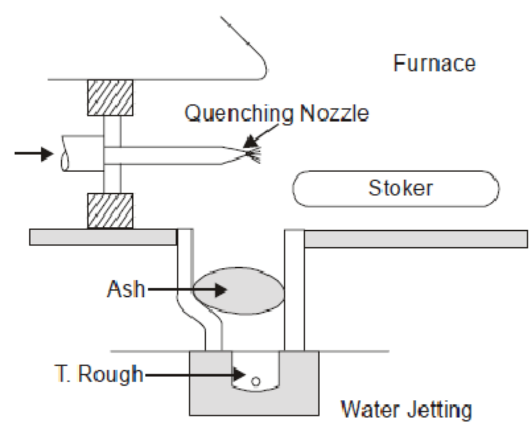


Fig. 4.35. Water Jetting of Ash.

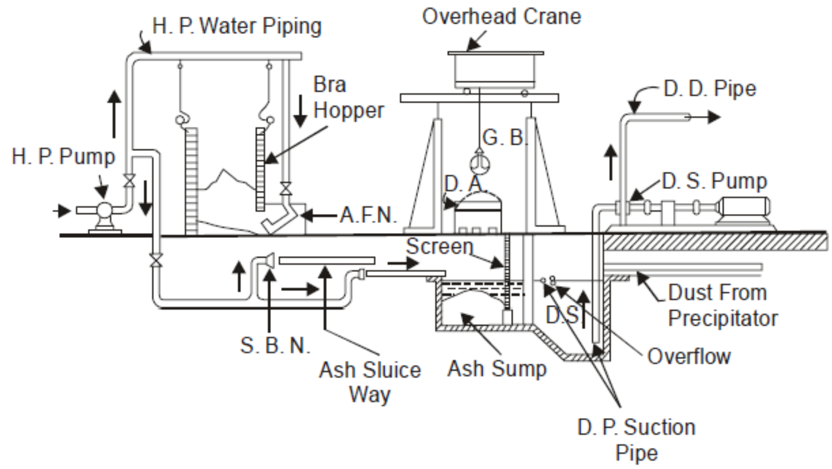


Fig. 4.36. Ash Sump System.

(*v*) **Mechanical ash handling system.** Fig. 4.38 shows a mechanical ash handling system. In this system ash cooled by water seal falls on the belt conveyor and is carried out continuously to the bunker. The ash is then removed to the dumping site from the ash bunker with the help of trucks.

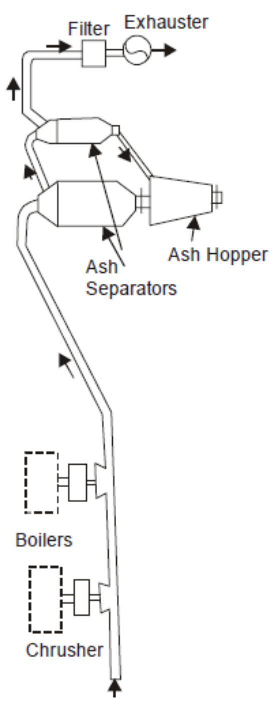


Fig. 4.37. Pneumatic System.

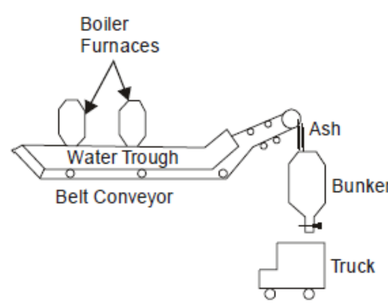


Fig. 4.38. Mechanical Ash Handling.

Combustion of Coal and AshHandling

Efficient Combustion of Coal: The factors which affect the efficient combustion of coal are as follows:

1. Type of coal. The important factors which are considered for the selection of coal are as follows:

(i) Sizing
(ii) Caking
(iii) Swelling properties
(iv) Ash fusion temperature.

The characteristics which control the selection of coal for particular combustion equipment are as follows :

(i) Size of coal
(ii) Ultimate and proximate analysis
(iii) Resistance of degradation
(iv) Grindability
(v) Caking characteristics
(vi) Slagging characteristics
(vii) Deterioration during storage
(viii) Corrosive characteristics
(ix) Ash Content.

The average ash content in Indian coal is about 20%. It is therefore desirable to design the furnace in such a way as to burn the coal of high ash content. The high ash content in coal has the following:

(i) It reduces thermal efficiency of the boiler as loss of heat through unburnt carbon, excessive clinker formation and heat in ashes is considerably high.
(ii) There is difficulty of hot ash disposal.
(iii) It increases size of plant.
(iv) It increases transportation cost of fuel per unit of heat produced.
(v) It makes the control difficult due to irregular combustion. High as content fuels can be used more economically in pulverized form. Pulverized fuel burning increases the thermal efficiency as high as 90% and controls can be simplified by just adjusting the position of burners in pulverized fuel boilers. The recent steam power plants in India are generally designed to use the pulverized coal.

2. Type of Combustion equipment. It includes the following:

(i) Type of furnace
(ii) Method of coal firing such as :
  (a) Hand firing
  (b) Stoker firing
  (c) Pulverized fuel firing.
(iii) Method of air supply to the furnace. It is necessary to provide adequate quantity of secondary air with sufficient turbulence.
(iv) Type of burners used.
(v) Mixing arrangement of fuel and air.

The flames over the bed are due to the burning of volatile gases, lower the volatile content in the coal, shorter will be the flame. If the volatiles burn up intensely high temperature is generated over the furnace bed and helps to burn the carbon completely and vice versa. For complete burning of volatiles and prevent unburnt carbon going with ash adequate quantity of secondary air with sufficient turbulence should be provided.

Types of Stokers: The various types of stokers are as follows

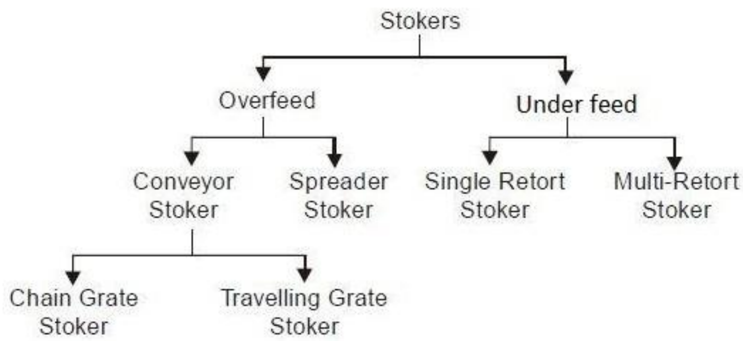


Fig. Types of stokers

Charging of fuel into the furnace is mechanized by means of stokers of various types. They are installed above the fire doors underneath the bunkers which supply the fuel. The bunkers receive the fuel from a conveyor.

MECHANICAL FIRING (STOKERS):

Mechanical stokers are commonly used to feed solid fuels into the furnace in medium and large size power plants.

The various advantages of stoker firing are as follows:

- Large quantities of fuel can be fed into the furnace. Thus greater combustion capacity is achieved.
- Poorer grades of fuel can be burnt easily.
- Stoker save labour of handling ash and are self-cleaning.
- By using stokers better furnace conditions can be maintained by feeding coal at a uniform rate.
- Stokers save coal and increase the efficiency of coal firing.

The main disadvantages of stokers are their more costs of operation and repairing resulting from high furnace temperatures.

Principles of Stokers: The working of various types of stokers is based on the following two principles

1. **Overfeed Principle:** According to this principle (Fig.) the primary air enters the grate from the bottom. The air while moving through the grate openings gets heated up and air while moving through the grate openings gets heated up and the grate is cooled. The hot air that moves through a layer of ash and picks up additional energy. The air then passes through a layer of incandescent coke where oxygen reacts with coke to form-CO_2 and water vapours accompanying the air react with incandescent coke to form CO_2, CO and free H_2. The gases leaving the surface of fuel bed contain volatile matter of raw fuel and

gases like CO_2, CO, H_2, N_2 and H_2O. Then additional air known as secondary air is supplied to burn the combustible gases. The combustion gases entering the boiler consist of N_2, CO_2, O_2 and H_2O and also CO if the combustion is not complete.

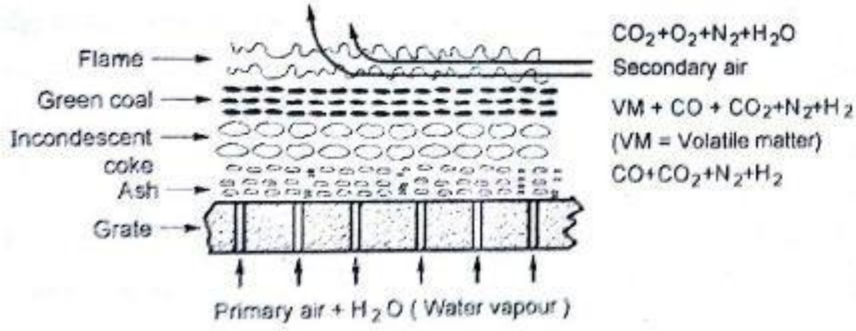


Fig. Principle of Overfeed stoker firing

2. Underfeed Principle. Fig. 4.14 shows underfeed principle. In underfeed principle air entering through the holes in the grate comes in contact with the raw coal (green coal).

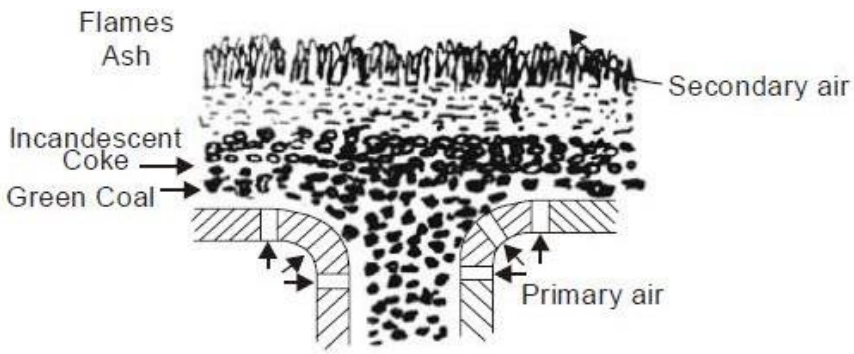


Fig. Principle of Underfeed stoker firing

Then it passes through the incandescent coke where reactions similar to over feed system take place. The gas produced then passes through a layer of ash. The secondary air is supplied to burn the combustible gases. Underfeed principle is suitable for burning the semi-bituminous and bituminous coals.

(i) **Chain Grate Stoker.** Chain grate stoker and traveling grate stoker differ only in grate construction.

A chain grate stoker (Fig.) consists of an endless chain which forms a support for the fuel bed.

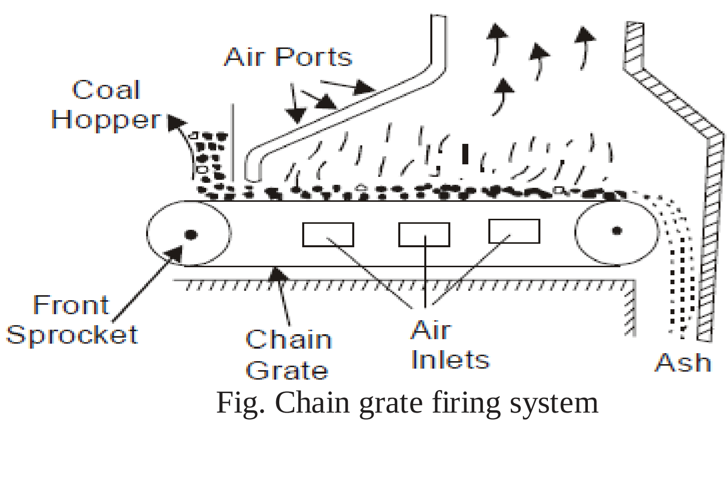


Fig. Chain grate firing system

The chain travels over two sprocket wheels, one at the front and one at the rear of furnace. The traveling chain receives coal at its front end through a hopper and carries it into the furnace. The ash is tipped from the rear end of chain. The speed of grate (chain) can be adjusted to suit the firing condition. The air required for combustion enters through the air inlets situated below the grate. Stokers are used for burning non-coking free burning high volatile high ash coals. Although initial cost of this stoker is high but operation and maintenance cost is low. The traveling grate stoker also uses an endless chain but differs in that it carries small grate bars which actually support the fuel fed. It is used to burn lignite, very small sizes of anthracites coke breeze etc. The stokers are suitable for low ratings because the fuel must be burnt before it reaches the rear of the furnace. With forced draught, rate of combustion is nearly 30 to 50 lb of coal per square foot of grate area per hour, for bituminous 20 to 35 pounds per square foot per hour for anthracite.

(ii) **Spreader Stoker.** A spreader stoker is shown in Fig. In this stoker the coal from the hopper is fed on to a feeder which measures the coal in accordance to the requirements. Feeder is a rotating drum fitted with blades. Feeders can be reciprocating rams, endless belts, spiral worms etc. From the feeder the coal drops on to spreader distributor which spread the coal over the furnace. The spreader system should distribute the coal evenly over the entire grate area. The spreader speed depends on the size of coal.

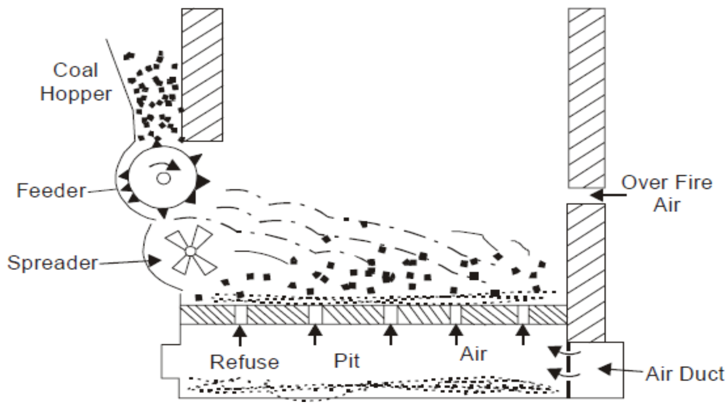


Fig. Spreader type stoker

Advantages

The various advantages of spreader stoker are as follows:

1. Its operation cost is low.
2. A wide variety of coal can be burnt easily by this stoker.
3. A thin fuel bed on the grate is helpful in meeting the fluctuating loads.
4. Ash under the fire is cooled by the incoming air and this minimizes clinkering.
5. The fuel burns rapidly and there is little coking with coking fuels.

Disadvantages

1. The spreader does not work satisfactorily with varying size of coal.
2. In this stoker the coal burns in suspension and due to this fly ash is discharged with flue gases which requires efficient dust collecting equipment.

(iii) **Multi-retort Stoker.** A multi-retort stoker is shown in Fig. The coal falling from the hopper is pushed forward during the inward stroke of stoker ram. The distributing rams (pushers) then slowly move the entire coal bed down the length of stoker. The length of stroke of pushers can be varied as desired. The slope of stroke helps in moving the fuel bed and this fuel bed movement keeps it slightly agitated to break up clinker formation. The primary air enters the fuel bed from main wind box situated below the stoker. Partly burnt coal moves on to the extension grate. A thinner fuel bed on the extension grate requires lower air pressure under it. The air entering from the main wind box into the extension grate wind box is regulated by an air damper. As sufficient amount of coal always remains on the grate, this stoker can be used under large boilers (up to 500,000 lb per hr capacity) to obtain high rates of combustion. Due to thick fuel bed the air supplied from the main wind box should be at higher pressure.

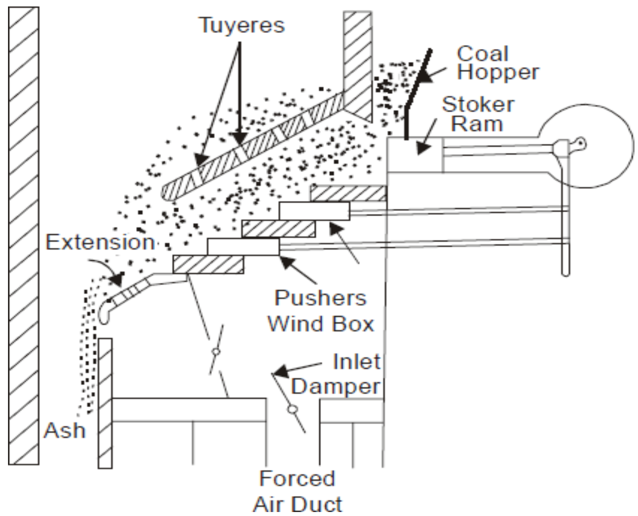


Fig. Multi retort stoker

PULVERIZED COAL:

Coal is pulverized (powdered) to increase its surface exposure thus permitting rapid combustion. Efficient use of coal depends greatly on the combustion process employed. For large scale generation of energy the efficient method of burning coal is confined still to pulverized coal combustion. The pulverized coal is obtained by grinding the raw coal in pulverizing mills. The various pulverizing mills used are as follows:

(i) Ball mill (*ii*) Hammer mill

(*iii*) Ball and race mill (*iv*) Bowl mill.

The essential functions of pulverizing mills are as follows:

(*i*) Drying of the coal (*ii*) Grinding

(*iii*) Separation of particles of the desired size.

Proper drying of raw coal which may contain moisture is necessary for effective grinding. The coal pulverizing mills reduce coal to powder form by three actions as follows:

(*i*) Impact (*ii*) Attrition (abrasion) (*iii*) Crushing.

Most of the mills use all the above mentioned all the three actions in varying degrees. In impact type mills hammers break the coal into smaller pieces whereas in attrition type the coal pieces which rub against each other or metal surfaces to disintegrate. In crushing type mills coal caught between metal rolling surfaces gets broken into pieces. The crushing mills use steel balls in a container. These balls act as crushing elements.

BALL MILL

A line diagram of ball mill using two classifiers is shown in Fig. It consists of a slowly rotating drum which is partly filled with steel balls. Raw coal from feeders is supplied to the classifiers from where it moves to the drum by means of a screw conveyor. As the drum rotates the coal gets pulverized due to the combined impact between coal and steel balls. Hot air is introduced into the drum. The powdered coal is picked up by the air and the coal air mixture enters the classifiers, where sharp changes in the direction of the mixture throw out the oversized coal particles. The over-sized particles are returned to the drum. The coal air mixture from the classifier moves to the exhauster fan and then it is supplied to the burners.

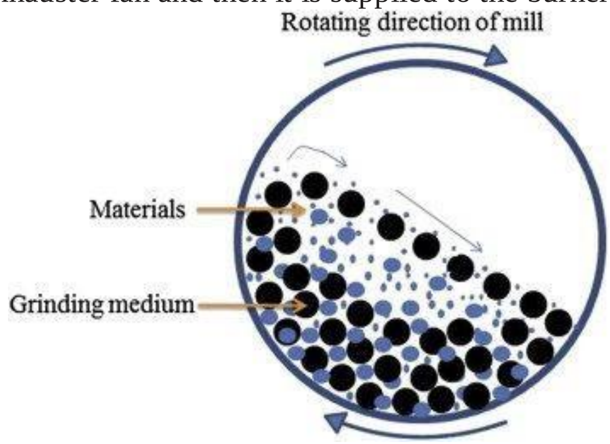


Fig. Ball Mill

Ball and Race Mill

Fig. shows a ball and race mill. In this mill the coal passes between the rotating elements again and again until it has been pulverized to desired degree of fineness. The coal is crushed between two moving surfaces namely balls and races. The upper stationary race and lower rotating race driven by a worm and gear hold the balls between them. The raw coal supplied falls on the inner side of the races. The moving balls and races catch coal between them to crush it to a powder. The necessary force needed for crushing is applied with the help of springs. The hot air supplied picks up the coal dust as it flows between the balls and races, and then enters the classifier. Where oversized coal particles are returned for further grinding, where as the coal particles of required size are discharged from the top of classifier. In this mill coal is pulverized by a combination of' crushing, impact and attrition between the grinding surfaces.

The advantages of this mill are as follows:

(*i*) Lower capital cost (*ii*) Lower power consumption
(*iii*) Lower space required (*iv*) Lower weight.

However in this mill there is greater wear as compared to other pulverizes.

The use of pulverized coal has now become the standard method of firing in the large boilers. The pulverized coal burns with some advantages that result in economic and flexible operation of steam boilers. Preparation of pulverized fuel with an intermediate bunker is shown in Fig. The fuel moves to the automatic balance and then to the feeder and ball mill through which hot air is blown. It dries the pulverized coal and carries it from the mill to separator.

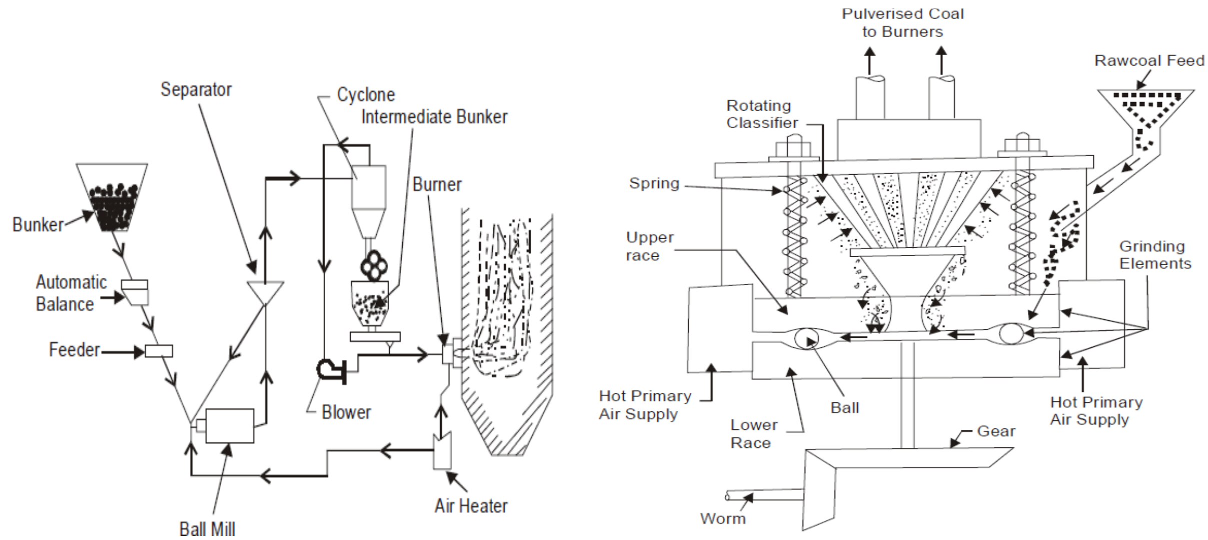
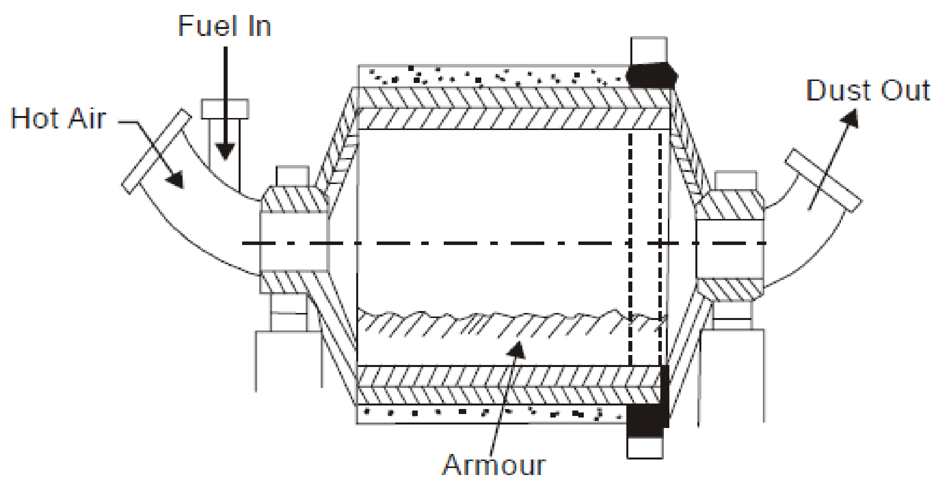


Fig. Ball and Race Mill

The air fed to the ball mill is heated in the air heater. In the separator dust (fine pulverized coal) is separated from large coal particles which are returned to the ball mill for regrinding. The dust moves to the cyclone. Most of the dust (about 90%) from cyclone moves to bunker. The remaining dust is mixed with air and fed to the burner. Coal is generally ground in low speed ball tube mill. It is filled to 20-35% of its volume, with steel balls having diameter varying from 30-60 mm. The steel balls crush and ground the lumps of coal. The average speed of rotation of tube or drum is about 18-20 r.p.m.



Advantages

The advantages of using pulverized coal are as follows:

a. It becomes easy to burn wide variety of coal. Low grade coal can be burnt easily.
b. Powdered coal has more heating surface area. They permit rapids and high rates of combustion.
c. Pulverized coal firing requires low percentage of excess air.
d. By using pulverized coal, rate of combustion can be adjusted easily to meet the varying load.
e. The system is free from clinker troubles.

f. It can utilize highly preheated air (of the order of 700°F) successfully which promotes rapid flame propagation.
g. As the fuel pulverizing equipment is located outside the furnace, therefore it can be repaired without cooling the unit down.
h. High temperature can be produced in furnace.

Disadvantages

1. It requires additional equipment to pulverize the coal. The initial and maintenance cost of the equipment is high.
2. Pulverized coal firing produces fly ash (fine dust) which requires a separate fly ash removal equipment.
3. The furnace for this type of firing has to be carefully designed to withstand for burning the pulverized fuel because combustion takes place while the fuel is in suspension.
4. The flame temperatures are high and conventional types of refractory lined furnaces are inadequate. It is desirable to provide water cooled walls for the safety of the furnaces.
5. There are more chances of explosion as coal burns like a gas.
6. Pulverized fuel fired furnaces designed to burn a particular type of coal cannot be used to any other type of coal with same efficiency.
7. The size of coal is limited. The particle size of coal used in pulverized coal furnace is limited to 70 to 100 microns.

Pulverized Coal Firing:

Pulverized coal firing is done by two system:
(i) Unit System or Direct System.
(ii) Bin or Central System.

Unit System: In this system (Fig.) the raw coal from the coal bunker drops on to the feeder. Hot air is passed through coal in the feeder to dry the coal. The coal is then transferred to the pulverizing mill where it is pulverized. Primary air is supplied to the mill, by the fan. The mixture of pulverized coal and primary air then flows to burner where secondary air is added. The unit system is so called from the fact that each burner or a burner group and pulveriser constitutes a unit.

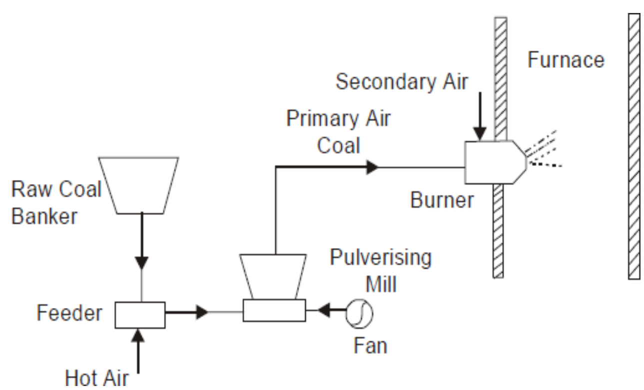


Fig. Unit or Direct system

Advantages

(i) The system is simple and cheaper than the central system.
(ii) There is direct control of combustion from the pulverizing mill.

(iii) Coal transportation system is simple.

Bin or Central System: It is shown in Fig. Crushed coal from the raw coal bunker is fed by gravity to a dryer where hot air is passed through the coal to dry it. The dryer may use waste flue gases, preheated air or bleeder steam as drying agent. The dry coal is then transferred to the pulverizing mill. The pulverized coal obtained is transferred to the pulverized coal bunker (bin). The transporting air is separated from the coal in the cyclone separator. The primary air is mixed with the coal at the feeder and the mixture is supplied to the burner.

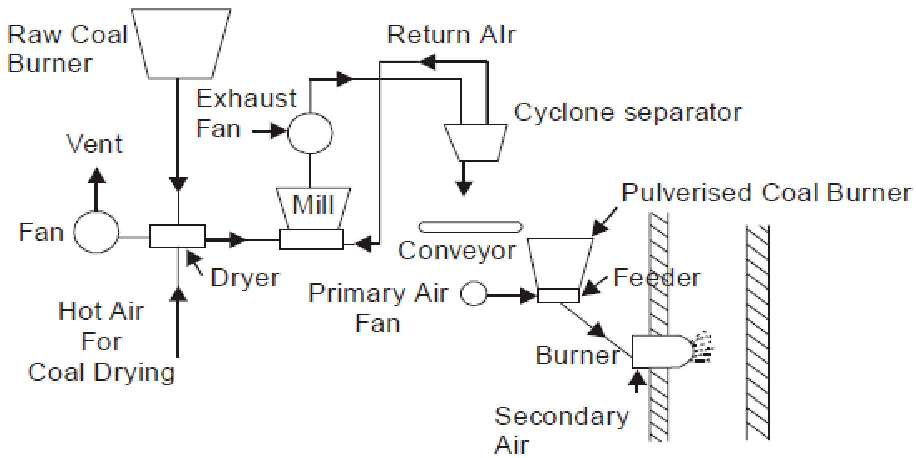


Fig. Bin system

Advantages

1. The pulverizing mill grinds the coal at a steady rate irrespective of boiler feed.
2. There is always some coal in reserve. Thus any occasional breakdown in the coal supply will not affect the coal feed to the burner.
3. For a given boiler capacity pulverizing mill of small capacity will be required as compared to unit system.

Disadvantages

- The initial cost of the system is high.
- Coal transportation system is quite complicated.
- The system requires more space.

The pulverized mill should satisfy the following requirements:

- It should deliver the rated tonnage of coal.
- Pulverized coal produced by it should be of satisfactory fineness over a wide range of capacities.
- It should be quiet in operation.
- Its power consumption should be low.
- Maintenance cost of the mill should be low.

Pulverized Coal Burners:

Burners are used to burn the pulverized coal. The main difference between the various burners lies in the rapidity of air-coal mixing *i.e.*, turbulence. For bituminous coals the turbulent type of burner is used whereas for low volatile coals the burners with long flame should be used. A pulverized coal burner should satisfy the following requirements:

(i) It should mix the coal and primary air thoroughly and should bring this mixture before it enters the furnace in contact with additional air known as secondary air to create sufficient turbulence.
(ii) It should deliver and air to the furnace in right proportions and should maintain stable ignition of coal air mixture and control flame shape and travel in the furnace. The flame shape is controlled by the secondary air vanes and other control adjustments incorporated into the burner. Secondary air if supplied in too much quantity may cool the mixture and prevent its heating to ignition temperature.
(iii) Coal air mixture should move away from the burner at a rate equal to flame front travel in order to avoid flash back into the burner.

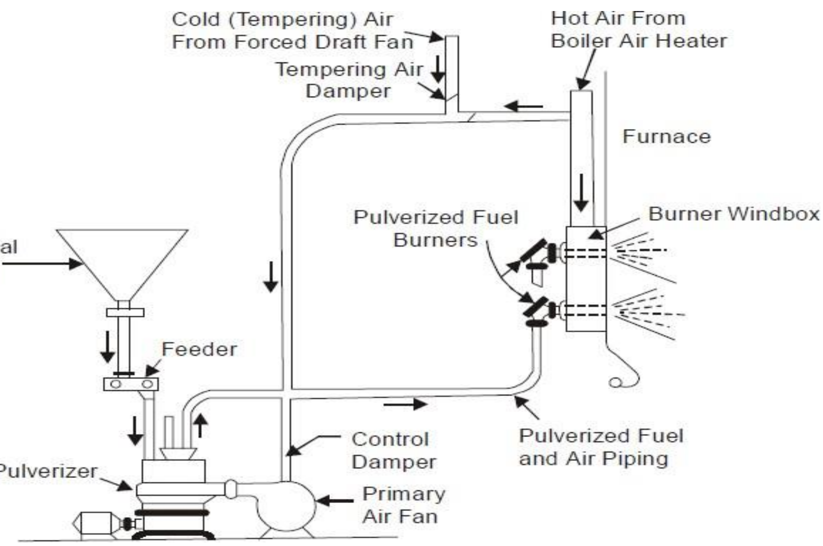


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Fig Pulverized Coal Burning system

The various types of burners are as follows:

- **Long Flame Burner (U-Flame Burner).** In this burner air and coal mixture travels a considerable distance thus providing sufficient time for complete combustion [Fig.(*a*)].
- **Short Flame Burner (Turbulent Burner).** It is shown in Fig.(*b*). The burner is fitted in the furnace will and the flame enters the furnace horizontally.
- **Tangential Burner.** A tangential burner is shown in Fig.(*c*). In this system one burner is fitted attach corner of the furnace. The inclination of the burner is so made that the flame produced are tangential to an imaginary circle at the centre.
- **Cyclone Burner.** It is shown in Fig.(*d*). This burner uses crushed coal intend of pulverized coal.

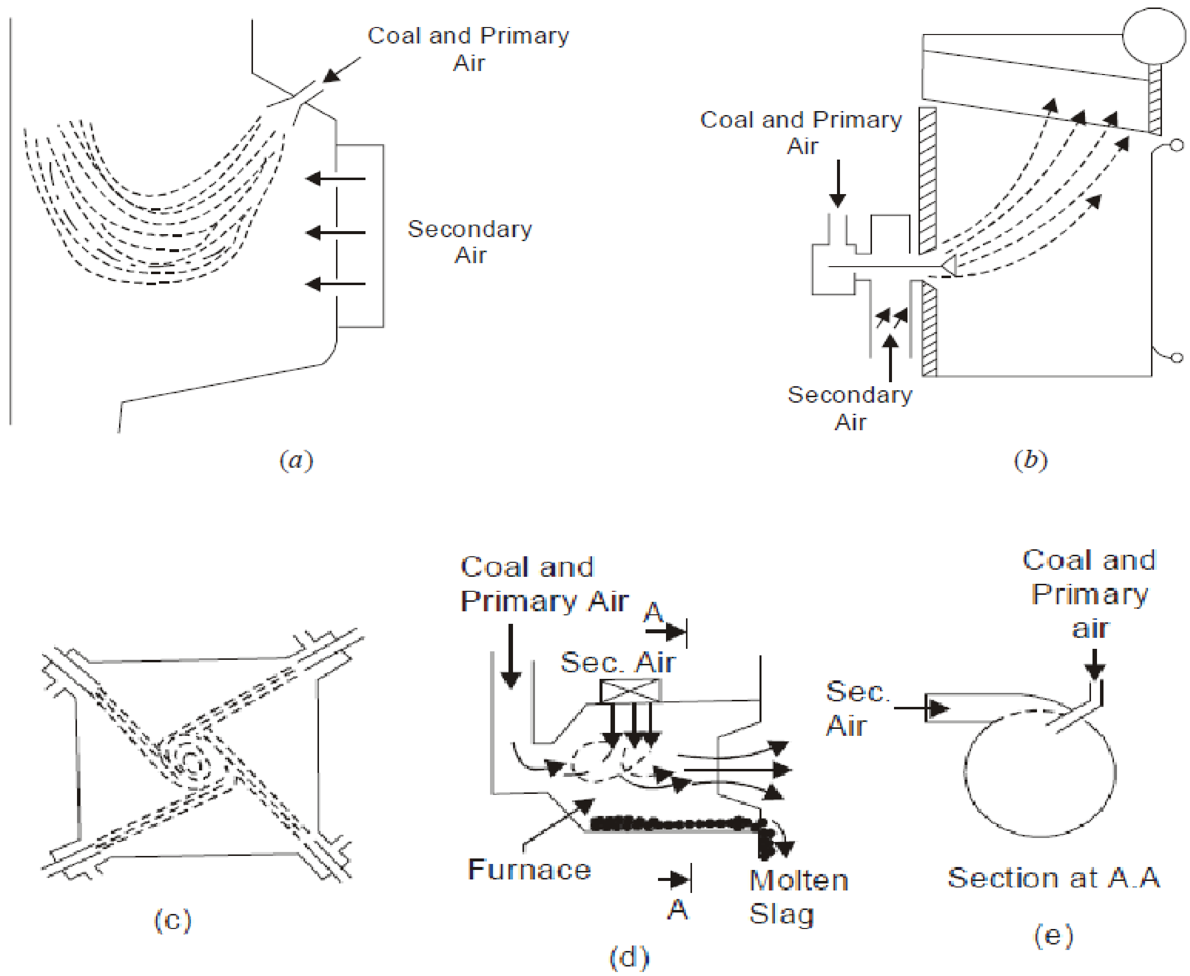


Fig. Pulverized Firing systems

Its advantages are as follows:

- It saves the cost of pulverisation because of a crusher needs less power than a Pulverizer.
- Problem of fly ash is reduced. Ash produced is in the molten form and due to inclination of furnace it flows to an appropriate disposal system.

Cooling Ponds and Cooling Towers

The main steam condenser performs the dual function of removing the heat from the hot steam coming from the turbine and keeping the turbine back pressure at the lowest possible level. Heat rejected by the steam should be done to atmosphere by transferring the latent heat of exhaust steam to cooling water exposed to atmosphere. This water supply is made by the following sources:

1. River or sea
2. Cooling ponds
3. Spray ponds
4. Cooling towers

River or Sea: Power plant is located on the bank of a river or lake or other natural water source. Water is supplied to the condenser from those water bodies directly for heat extraction from hot steam. After heat gain, the hot water is discharged back to the source.

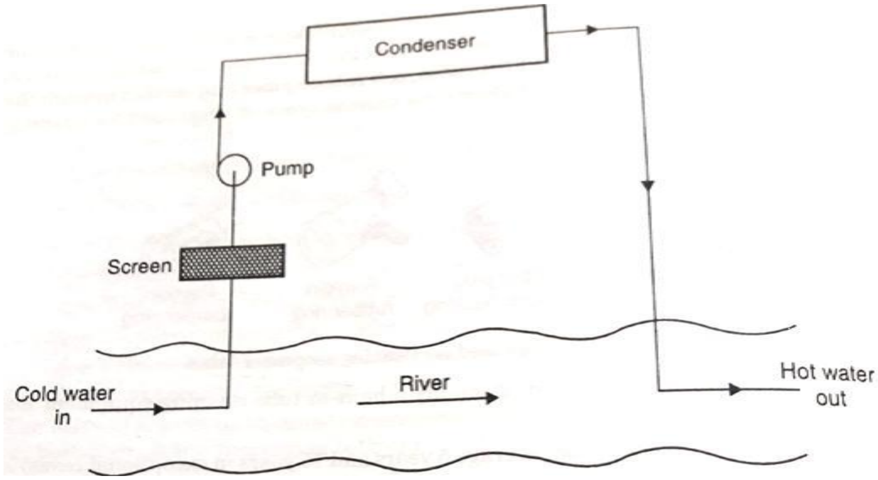


Fig. River Water Cooling System

Cooling Pond: It is a large shallow pool into which the hot water from the condenser is discharged and allowed to contact with atmospheric air. During the heat loss from hot water to air, some water is evaporated at the free stream surface. This cools the bottom layer of water, which is again sent to the condenser.

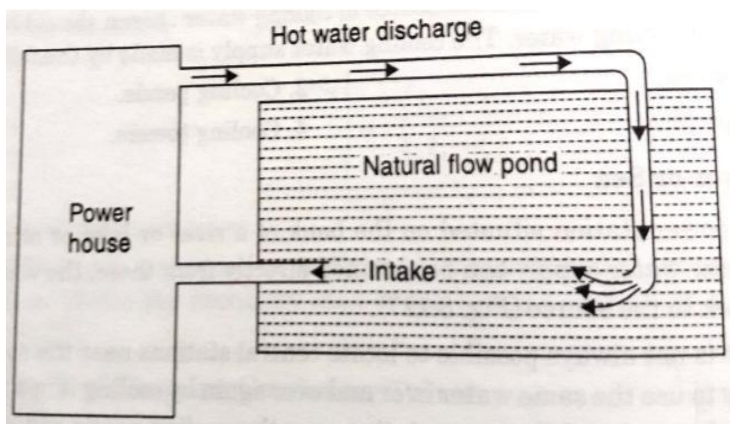


Fig. Non-directed Cooling Pond

Rate of heat loss by hot water can be improved by improving the circulation of water in cooling pond along the predefined direction. This also improves the contact between hot water and cold air.

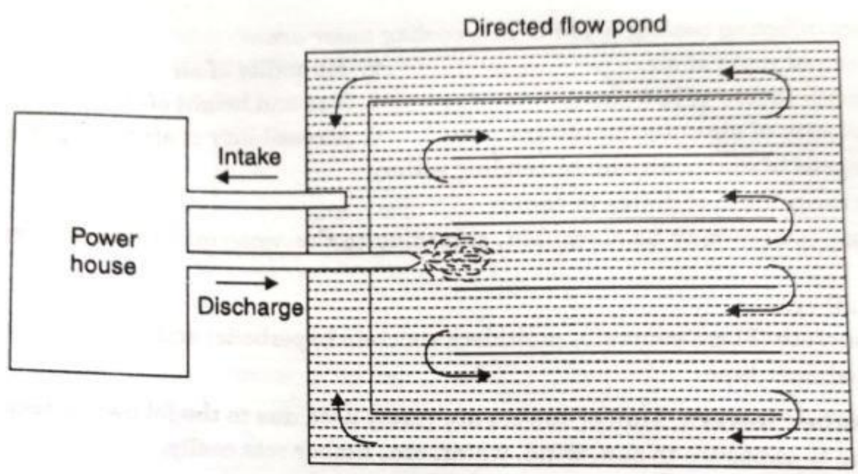


Fig. Directed flow cooling pond

Spray Pond: In this system hot water discharged from the condenser is sprayed through the nozzles fitted to a pipe over a pond of large area. During the circulation of air from atmosphere, sensible heat we well as latent heat is lost by the hot water resulting in the evaporation from the water surface. This results in cooling of water as well as loss increase in evaporation losses and windage.

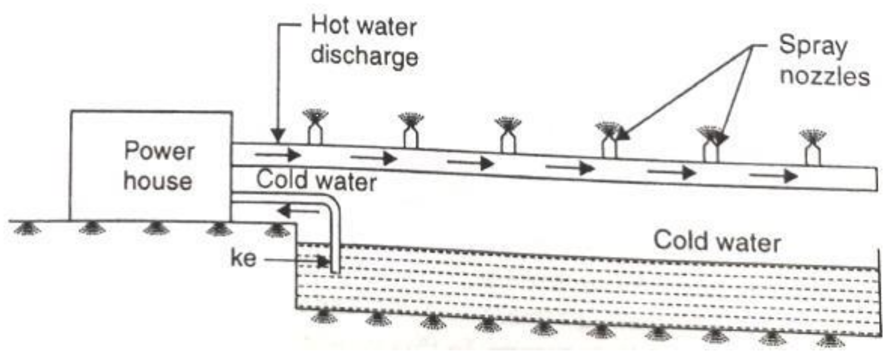


Fig. Spray pond

For the large rate of cooling, pond area required is very large. The performance of the system depends on the temperature of air and hence there is no control over the temperature of water.

Cooling Towers: In a cooling tower water is made to trickle down drop by drop so that it comes in contact with the air moving in the opposite direction. As a result of this some water is evaporated and is taken away by the air. In evaporation the heat is taken away from the bulk of water, which is thus cooled.

Classification of Cooling Towers:

- Based on Material of construction:

i. Timber
ii. Steel
iii. Concrete

- Based on Principle:

Natural draught cooling tower: Hot water from the condenser is pumped to the troughs and situated near the bottom. Trough spray the water falls in the form of droplets into a pond situated at the bottom of the tower. The air enters the cooling tower from air openings provided near the base, rises upward and takes the heat of falling water.

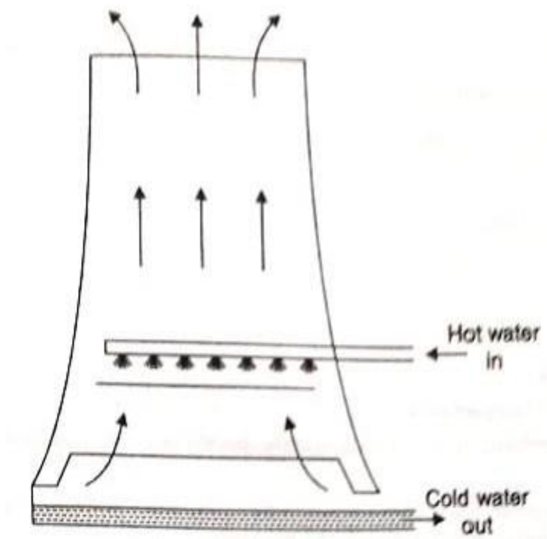


Fig. Natural Draught cooling tower

It has the advantages of low operating and maintenance cost, trouble free operation, less ground area required and structural stability (owing to larger height – 125 m and base diameter – 100 m, it has high capability of withstanding very high wind speeds).

High initial cost and performance depending on the dry bulb temperature of air (depending on the seasonal changes), are its drawbacks.

Saving in fan power, longer life and less maintenance favour the selection of this tower.

Mechanical Draught Cooling Tower: In this tower, propeller fan arranged at the bottom of the tower creates the necessary pressure difference for the flow of air along the cooling tower. Construction will be such that the sides of the tower are closed and form an air water tight structure, except fan openings at the base for the inlet of fresh air and outlet at the top for the exit of air and water vapour.

Hot water is sprayed from the top through the spray nozzles. Water falls down in the form of droplets and air enters the tower from the bottom in upward direction. Heat is lost by the water resulting in cooling of water, which is circulated back to the condenser. Some water is converted into vapour, which is lost to surroundings along with air from the top of tower.

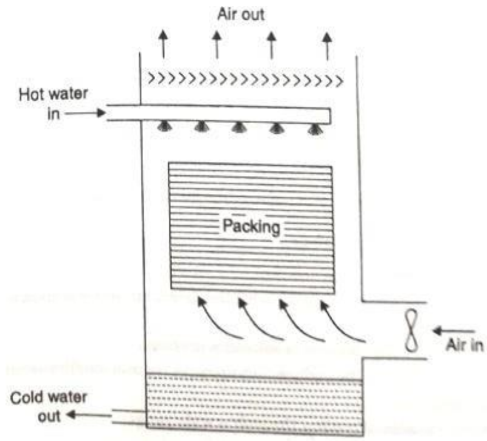


Fig. Forced draught cooling tower

S.No	Advantages	S.No	Disadvantages
1	More efficient.	1	The fan size is limited to 4m.
2	No problem of fan blade erosion.	2	Power requirement is high.
3	More safe.	3	In the cold weather, ice may form in the housing itself. The frost in the fan outlet can break the fan blades.
4	The vibration and noise are minimum.		

Induced Draught Cooling Tower: In this system, fan is located at the top of the cooling tower and draws the air through the cooling tower through all the louvers extending around the tower at its base. Air as enters the cooling tower, gains the heat from the hot water and leaves the tower as hot air along with water vapour.

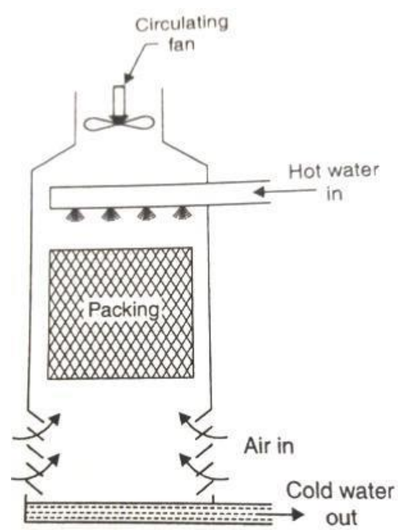


Fig. Induced Draught cooling tower

S.No	Advantages	S.No	Disadvantages
1	Less space is required.	1	Air velocity and distribution in the tower is non-uniform.
2	Capable of cooling through a wide range.	2	Higher H.P motor is required to drive the fan comparatively.
3	Initial investment is less (due to reduced pump capacity and smaller length of water pipes).		

Dry Cooling Towers: It is of two types.

i. **Direct system:** In this system, the exhaust steam from the turbine is passed through the cooling coils where it is condensed directly by means of circulating air.

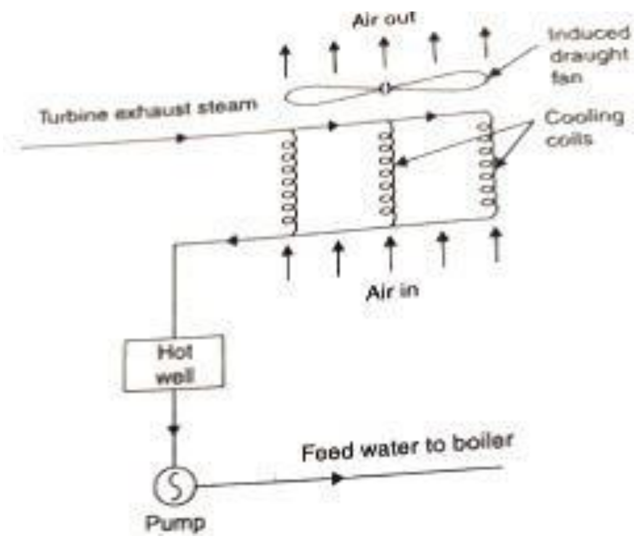


Fig. Direct system

Cooling coils constitute air cooled condenser. Air is drawn by a fan as shown in the diagram. After condensation of steam, the condensate is extracted by the condensate extraction pump and fed as feedwater to the boiler. To minimize the pressure drop, large size ducts are needed.

ii. **Indirect system:** In this system, steam enters the spray condenser from the top. Water is sprayed into the path of steam through spray nozzles. Due to the mixing of steam and loss of latent heat of steam to water, the steam condenses can forms condensate. Some part of condensate is feedback to boiler as feed water. Remaining water is cooled by passing the hot water through the cooling coils and by the circulation of cold air by the fan over the coils. The cooled water is passed through a hydraulic turbine where power is generated. The power is utilized to drive a circulating pump. The water coming from the turbine is supplied back to the spray condenser for the condensing of the steam.

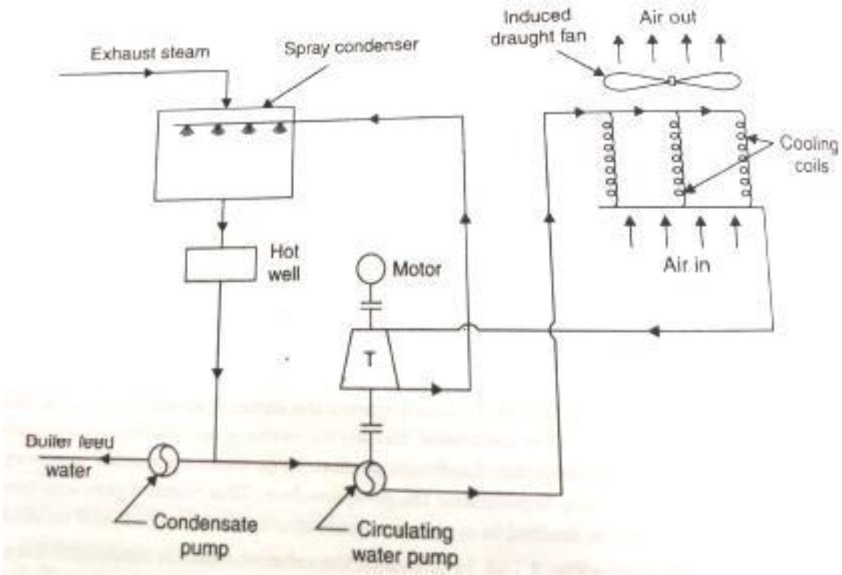


Fig. Indirect system

Draught

Draught is defined as small pressure difference causing flow of air and gases (in and out) through the boiler. It is essential to supply a sufficient quantity of air to support combustion in boilers and to remove the products of combustion. It works on the simple thermodynamic principle i.e. "the gas when heated expands in volume and decreases in density, in this condition it is displaced by a more dense gas".

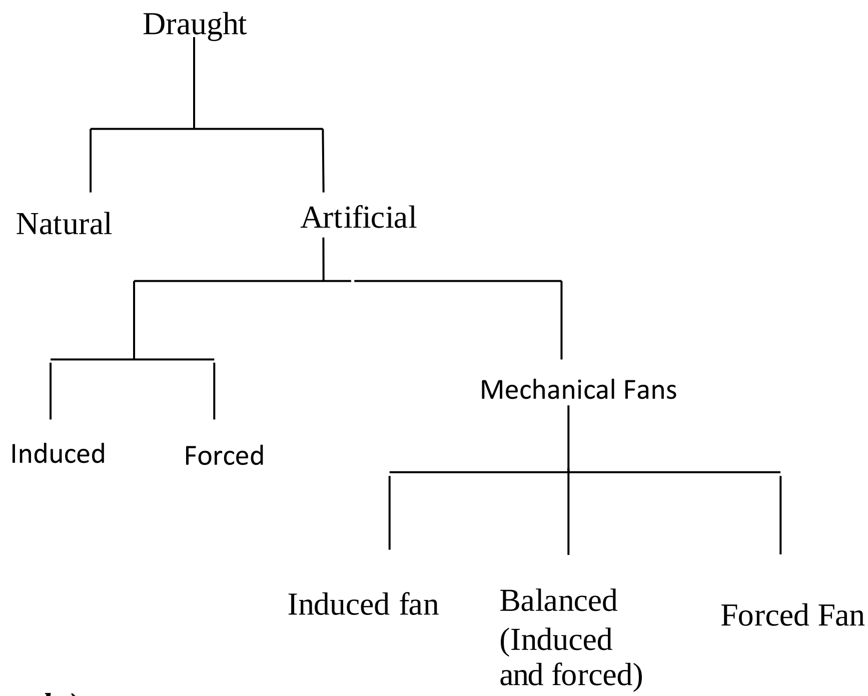
Thus draught producing equipment is designed to

- create a differential pressure sufficient to allow the desired volume of air flow into the furnace at the required velocity.
- to overcome the resistances of passages in the boiler.
- to discharge gases (i.e products of combustion) at a sufficient height in order to avoid pollution to atmosphere.

The amount of draught necessary for a certain boiler plant depends on the following:-

a. rate at which combustion takes place.
b. characteristics of the fuel and its depth on the grate.
c. design of the combustion chamber and the method of burning the fuel.
d. resistance in the flue gases circuit offered by baffles, tubes, super heaters, economizer, preheater, etc.

Types of Draught:-



Natural Draught (Chimney Draught):

Functions of a Chimney

- It produces a draught which forces the air to fuel bed and carries away the gaseous products of combustion out of the boiler.
- It discharges the products of combustion at desired height so that it does not pollute the surroundings.

Chimneys are generally built either by masonry, concrete or steel. Tall chimneys are usually built of masonry with special radial shaped bricks. To a smaller extent reinforce concrete also used employed in chimney erection. Steel chimney called as stacks, are used for low or short chimneys.

Artificial draught:

- The static draught required in a boiler installation varies from 25 to 350mm of the water column. In natural draught this is possible, but only by installing a very high chimney (which is not desirable for various reasons). When we create natural draught, it is dependent on climatic conditions.
- In order to obtain a draught which is independent of climatic conditions and which at the same time requires a chimney of lower height, we produce artificial draught.
- It may be mechanical or steam jet draught.
- Steam jet draught is used in locomotive and small installation while mechanical draught is used in central power station and boiler installations.
- The main purpose of the chimney in artificial draught is to discharge the gases up in the atmosphere to avoid pollution and to obey local by-laws. As the name suggests the draught is produced by artificial devices.

Advantages and Disadvantages of Artificial over Natural draught:

The advantages are:

a. Capable of consuming low grade fuel. Employing artificial draught system low grade fuel can be used for generating steam.
b. Increase in evaporative power of boiler. In employing the artificial draught system, the quantity of fuel burnt per square meter of the grate area is more than that of natural draught. In the use of mechanical draught, any type of mechanical stoker can be used while any desired rate of fuel consumption can be maintained. On account of the increase in the combustion rate of fuel, the steam raising capacity (i.e. evaporative power) is increased.
c. Easy control of combustion and evaporation. By regulating the rate of air supply, control of combustion and in turn control of evaporation is possible.
d. Reduction of chimney height. In the artificial draught system, the function of the chimney is to discharge the hazardous gases high up in the atmosphere in order to avoid the pollution of the lower atmosphere. Thus lower chimney height serves the purpose.
e. Prevention of smoke. Due to artificial draught, combustion is complete and hence there is less smoke.
f. Improved efficiency. In artificial draught, since the temperature of flue gases is lower, heat recovery devices such as the economizer or air pre heater, etc. can be incorporated. The devices considerably improve the thermal efficiency of the plant. For instance, the efficiency of a fan draught is 7% while that of natural 1%.

Disadvantages are:

a. More maintenance. Maintenance work is considerably increased by fan and other devices.
b. Cost of driving fan. The fan consumes power to drive it.
c. Upkeep of the machinery.

Induced Draught (fan type):

- In the induced draught system, a fan is located at or near the base of the chimney as shown in fig. The fan may have either steam or electricity drive. The function of the fan is to reduce the pressure over the fuel bed rather than that of atmosphere and, thus create a partial vacuum on its suction side. This partial vacuum created in the furnace and flues draw the products of combustion from the body of the flue and they pass up the chimney. This draught is generally used when the economizers and the air pre-heaters are incorporated in the boiler.

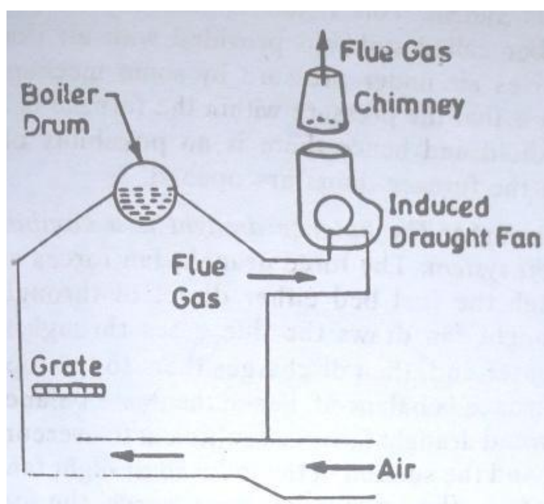


Fig. Induced draught

- The fan should be positioned such that the temperature of the gas handled is at its lowest. The best place to locate it is after the preheater. Since the fan handles a large volume of hot gases the bearing adjacent to the fan should be water jacketed. The tendency of air leak in this type of arrangement is maximum because the entire air and gas path from the furnace to the chimney base remains at lower pressure than atmospheric pressure.

Forced Draught (fan type):

Fig. shows a schematic diagram of forced draught system. In this system, a fan or a blower is installed near or at the base of the boiler to force the air, under pressure, through the coal bed and other passages, like furnaces, flues, economizer, air heater, etc. to the chimney.

These are generally two types of arrangement used in this type of artificial draught:-

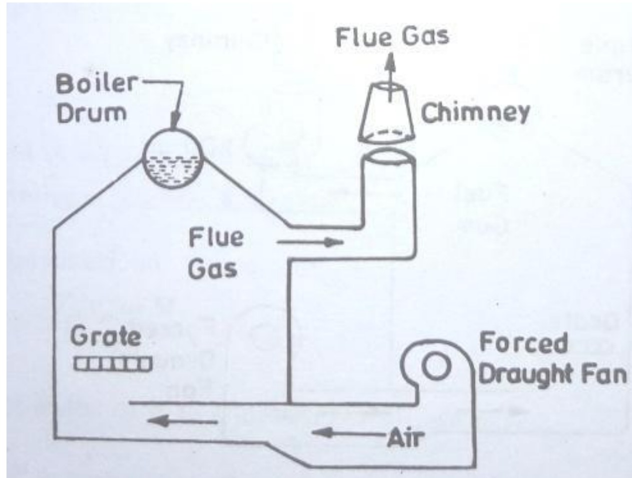


Fig. Forced Draught

a) ***Howden system***: In this system, the sucked air passing through an air pre heater enters an airtight chamber installed around the furnace front which serves as an air feeder. The chamber feeds air to ash pits (below the fire) and over the fire through valves and air distributing boxes. The furnace enclosure is securely sealed to prevent leakage of smoke and flames since the air inside are above atmospheric pressure. In order to shut off the draught automatic dampers are also fitted, so that when the door is opened, the outward rush of smoke and flame is prevented.
b) ***Closed Stokhold system***: This system is generally used in marine boilers. It has an air tight chamber called stokhold provided with air doors at entry and exit. The chamber receives air under pressure by some mechanical device. The advantage in this system is that the pressure within the furnace is always below the air pressure in the stokhold and hence there is no possibilities of any outrush of flames and smoke when the furnace doors are opened.

Balanced Draught:

Fig. shows a schematic diagram of a balanced draught system. The balance draught is a combination of the induced and forced draught system. The force draught fan forces air at a sufficient pressure to pass through the fuel bed either directs of through the air heater where the induced draught fan draws the flue gases through the boiler flues, economizer and pre-heater and, then discharges them to the top of the chimney. The pressure in the furnace is balanced, hence the name balanced draught. The air pressure from the forced draught fan is just sufficient to overcome the resistance offered by the fuel bed and the suction of the induced draught fan is just sufficient to draw the flue gases from the furnace. In other words,

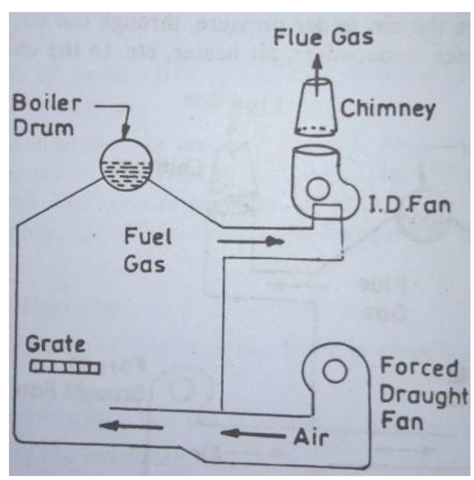


Fig. Balanced Draught

the forced draught fan overcomes the resistance in the air pre-heater and the chain grate stoker while the induced draught fan overcomes the draught losses through boiler, economizer, air pre-heater and connecting flues.

Advantages of Forced draught fan over Induced:

i. Smaller fan size and less power required. The force draught fan handles cold air, therefore, the fan size and power required for the same quantity of draught are 1/3 to 1/2 that of the induced.
ii. No water cooled bearings. It does not require water cooled bearings as it handles cold air.
iii. Less leakage. The tendency of air leak into the boiler furnace is minimized.

No heat loss. There is no loss of heat because of the inrushing of cold through the furnace doors.

Dust Handling Systems

Layout of Dust and Ash handling systems

Coal is burned in the presence of air producing ash and hot gases.

- The hot gases are passed through the dust collectors to keep the pollutants in less concentration before the gases being discharged to the atmosphere through the chimney.

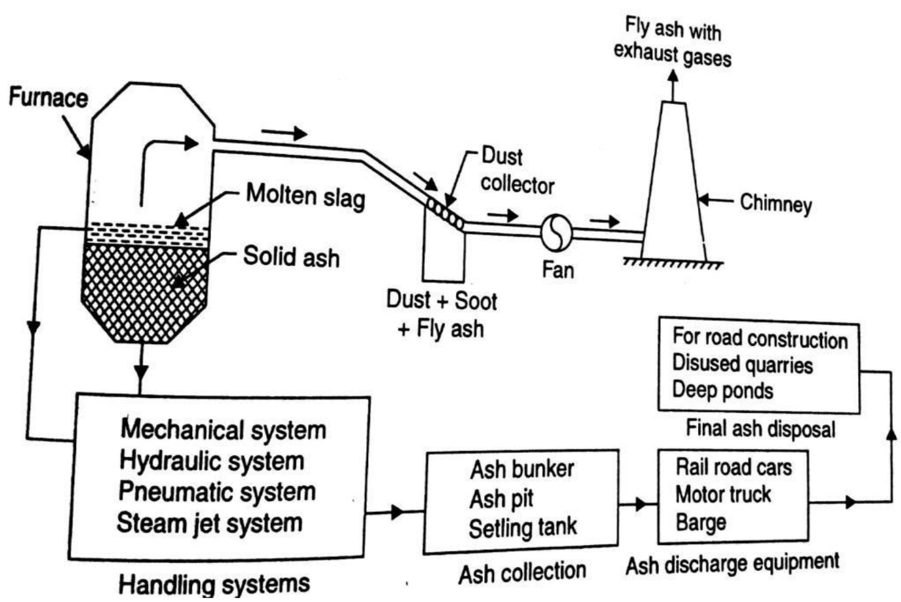


Fig. Ash Handling System

- The ash from the boiler is collected in either dry or wet form through the ash handling systems. It is carried in motor trucks or in rail road cars and supplied to the various industries, which can be used in the preparation of bricks or cement etc.,

Composition of Ash:

- Size of the ash particles varies from 1 – 150 µm
- Silicon Dioxide – 30 – 60%

- Aluminium Oxide – 15 – 30%
- Magnesium oxide – Small amounts
- Sulphur Trioxide – Small amounts

Classification of Dust Particles:

If the combustion is improper, then smoke will be generated. If dust particles are mainly fine ash particles, they are called as Fly-Ash. If dust particles contains Fly-ash intermixed with some quantity of carbon-ash material, it is called as cinder.

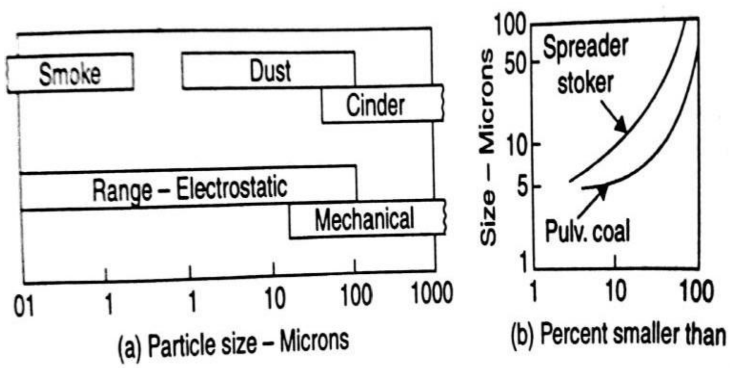


Fig. Types of Dust particles and their size

Classification of Dust Collectors

- Mechanical dust collectors
    - Wet collectors
        - Spray type
        - Packed type
        - Impingement type
    - Dry type
        - Gravitational separators
        - Cyclone separators
- Electrical dust collectors
    - Rod type
    - Plate type

Mechanical Dust Collectors:

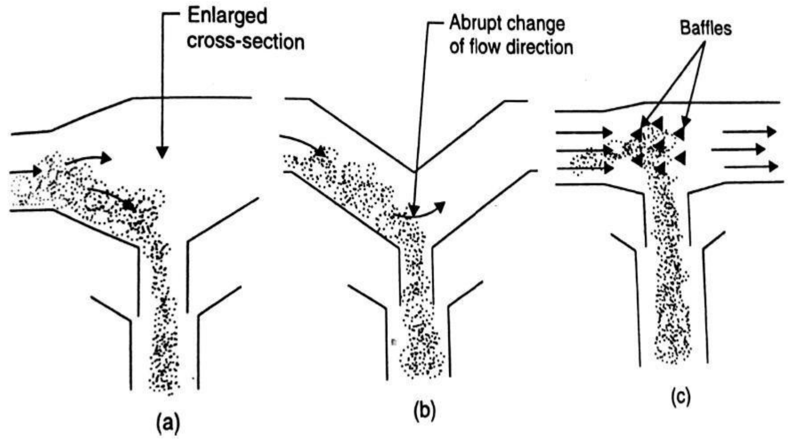


Fig. Principle of Mechanical Dust Collector

In mechanical collectors, different principles will be followed.

Fig. (a) Shows a sudden enlargement of duct cross-sectional area. This slows down the heavy dust particles and allows settling at the bottom, while the light dense particles move on.

Fig. (b) Shows a sudden change in the direction of gas flow. The heavier particles tend to keep going in the original direction and so settle out due to loss of kinetic energy.

Fig. (c) Shows arrangement of impingement baffles in the duct cross-sectional area. Upon hitting the baffles the heavy particles comes to rest and settle down. But the light dense particles move on with the gas.

Cyclone Dust Collector:

The cyclone is a separating chamber wherein high speed gas is passed tangential to the circular surface. This creates rotation of the gas generating the effect of centrifuging the particles from the carrying gases. Heavier particles move outwards away from the centre whereas lighter particles are moved inward due to the formation of vortex flow. Heavier particles are collected at the hopper of the collector and cleaner light gas moves upwards. The performance of the collector is affected by the gas volume, particulate loading, inlet velocity and temperature, diameter to height ratio of cyclone and dust characteristics.

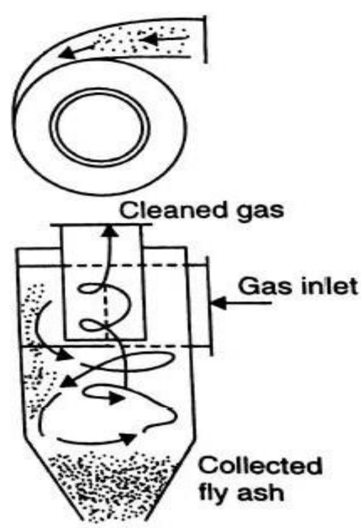


Fig. cyclone collector

Advantages:

- rugged in construction
- maintenance costs are low
- efficiency increases with increase in load
- easy to remove bigger size particles

Disadvantages:

- power consumption is more
- comparatively high pressure loss
- should be located outside the boiler room
- as the fineness of the particles increases the collection efficiency decreases

Cinder Catcher:

Gas with dust particles is passed through the vertical baffles which contains fine holes of different sizes. Hence these act as sieves and arrest the passage of dust particles through it. Hence dust particles of different sizes are collected in the hopper of the cinder catcher and clean gas is led to chimney.

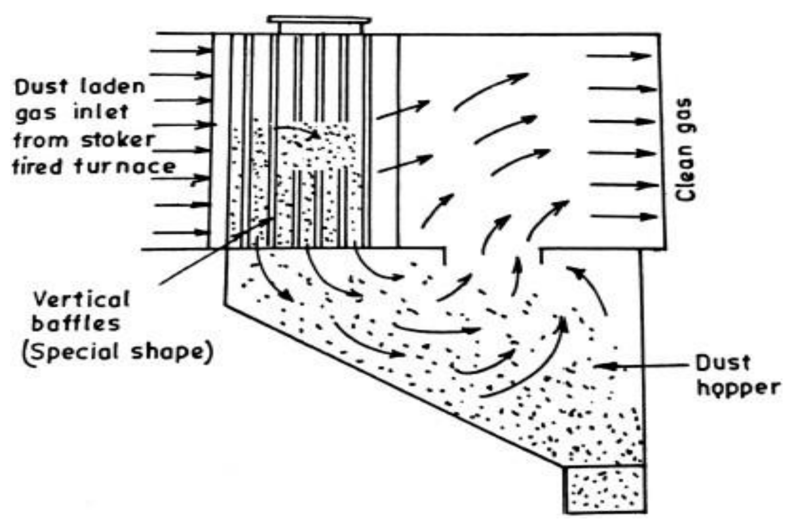


Fig. Cinder Catcher

Electrostatic Precipitator

It is also called as Cotrell Precipitator. Basic elements of an electrostatic precipitator are:

- Source of high voltage
- Ionizing and collecting electrodes
- Dust removal mechanism

- Shell to house the elements

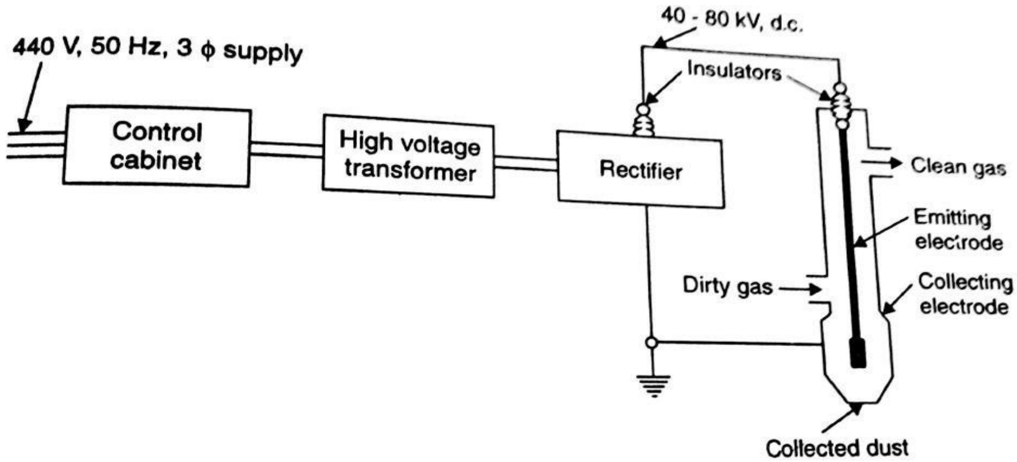


Fig. Principle of Electrostatic Precipitator

The precipitator has two electrodes which are grounded. These are insulated from each other and maintain an electrostatic field between them at high voltage. The high voltage system maintains a negative potential of 30,000 – 60,000 volts with the collected electrodes. When the gas is passed between them, the dust particles get ionized and get attracted to the electrode of opposite charge. The plates are vibrated periodically using a cam mechanism. Because of this the dust accumulated on the plates is dropped and collected in the ash pit.

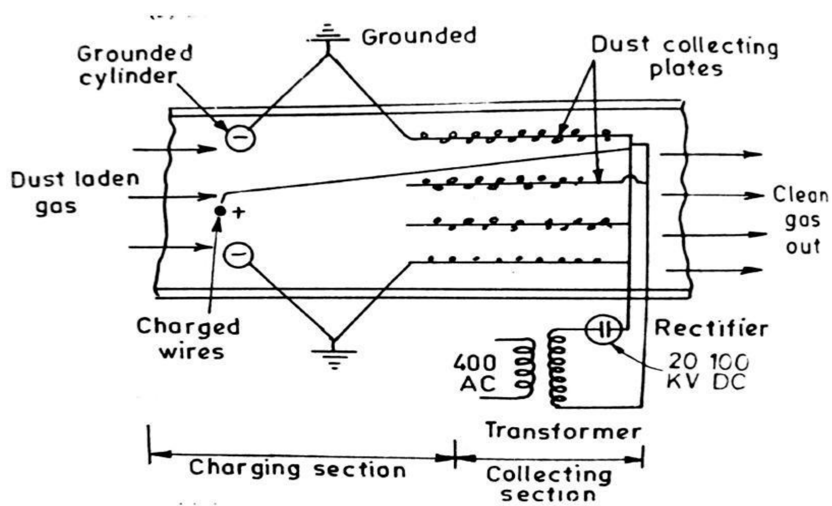


Fig. Mechanism of Electrostatic Precipitator

Dry type and wet type collectors are existing in practice. In a wet type collector, thin water film flows over the inner surface of the electrodes and absorbs the dust particles. The dust collection efficiency of electrostatic precipitator is higher than 98%.

The inlet gas should be free from papers and oil films. Otherwise this results in generation of spark between electrodes.

Advantages:

- easy operation
- draught loss is less (1cm of water)
- most effective for high dust loaded gas
- maintenance cost is less
- collected dust will be in dry form and can be removed either dry or wet.

Disadvantages**:**

- more space is required
- necessary to protect the entire collector from sparking
- running charges are high
- capital cost of equipment is high
- if the gas velocity exceeds the designed value, collector efficiency decreases

Feed Water Treatment

Water is one of the most important raw materials in power plants. Even rain, snow, hail, treated municipal supplies contain impurities in one form or other.

Classification of Impurities in Water

1. **Visible impurities**
   (a) Microbiological growth – presence of microorganism cause clogging troubles.
   (b) Turbidity and sediments – Turbidity is the suspended insoluble matter whereas sediments are the coarse particles which settle down in stationary water.
2. **Dissolved gases**
   (a) Carbondioxide (b) Oxygen (c) Nitrogen
   (d) Methane (e) Hydrogen sulphide
3. **Mineral salts**
   (a) Iron and manganese (b) sodium and potassium salts
   (c) Fluorides (d) silica
4. **Mineral Acids** – Presence is objectionable and may result in chemical reaction with boiler material.

5. **Hardness:** These are the dissolved salts of calcium and magnesium existing as bicarbonates, chlorides, sulphates called as hardness etc., They forms very hard surface which resists the heat transfer and clogs the passages in pipes.

Troubles caused by Impurities

- Scale formation
- Corrosion
- Carryover
- Embrittlement

Scale formation: These are the dissolved salts of calcium and magnesium existing as bicarbonates, chlorides, sulphates called as hardness etc., They forms very hard surface called as scale. Calcium sulphate has more tendencies to forms the scale.

It forms due to

- ✓ Decrease of solubility of salts and calcium and magnesium with increases of temperature.
- ✓ Crystallization of scale-forming salts from a locally super-saturated layer of water lying on the heating surface.

Effects of Scale formation:

- ✓ It resists the heat transfer from gas to water and to attain required temperature for water, gas temperature is to be increased. This inturn results in overheating, blistering, and rupturing.
- ✓ It clogs the passages in pipes and thus requires increased pressure to maintain water delivery.

Scale removal:

- ✓ Tubes are cleaned by pushing electric-powered rotary brushes and cutters through them during the boiler overhaul.

Corrosion:

Causes:

- ✓ Due to the low acid or pH in addition to the presence of dissolve oxygen and carbon dioxide in the boiler feed water.
- ✓ Oxygen enters through to makeup condenser leakage and condensate pump packing.
- ✓ Carbon Dioxide comes out of bicarbonates on heating and by combining with water it forms carbonic acid. Carbonic acid reacts with iron and other metals to form their bicarbonates. At elevated temperatures, CO_2 is released from these bicarbonates and this is a cyclic process.

Effects: It produces

- ✓ Pits, grooves and cracks or a general wastage of wall material.
- ✓ It results in ultimate failure of the metal parts.

Remedies to reduce Corrosion:

- ✓ Adding the alkali salts to neutralize the acids in water and raise the pH value.
- ✓ Effect of CO_2 is neutralized by the addition of Ammonia for neutralizing the amines in water.
- ✓ Anti-corrosive coatings will be applied on the internal surfaces of boilers and economizers.

Carryover: Water solids carried over in the steam leaving a boiler drum are called “carry-over”.

Causes:

- ✓ It may originate from mechanical or chemical causes.
- ✓ Foaming – formation of bubbles on the water surface and may fill the drum steam space.
  - It is due to the presence of sodium alkalinity, or finely divided calcium phosphate or oil.
- ✓ Priming – refers to vigorous and periodic surging of water in the boiler drum and throws the water slug into the leaving steam.
  - It is causes by the excessive steaming rate, too high or fluctuating water level, and improper boiler-water circulation.

Effects:

- Superheater deposits may reduce the heat transfer and raise the tube-metal temperatures.
- Deposits on turbine blades reduce efficiency and capacity and may unbalance rotor.
- Deposits forming on governing valves raise a serious hazard.

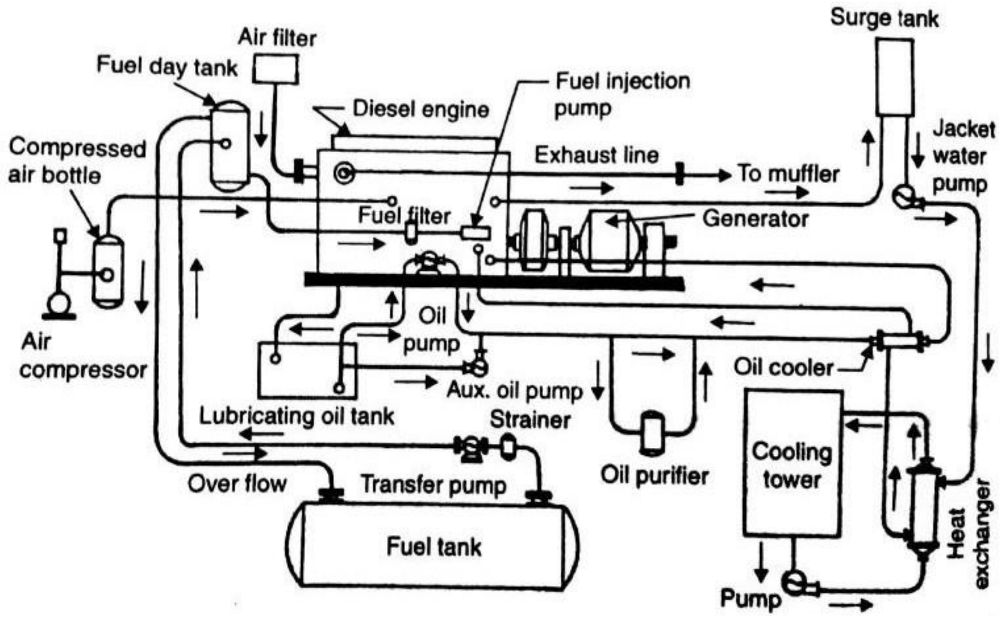
MODULE II: Diesel Power Plant & Gas Turbine Plant

I.C. Engine Power Plant

Factors Considered for Site Selection

- Foundation sub-soil condition - It should be able to absorb the force developed in the operation of power plant i.e. good damping characteristics.
- Access to the site – The plant should be easily accessible.
- Distance from the load centre – Plant should be located nearer to the load center to reduce the transmission losses as well as cost of power transmission.
- Availability of water – Plant should be located nearer to the water bodies like canals or rivers for supplying the cooling water.
- Fuel transportation – Plant should be located nearer to the source of fuel. It reduces the delays in fuel supply as reduces the cost of fuel supplied to the power plant.

Layout of Diesel Power Plant



Working: The plant is equipped with a supercharger i.e. compressor. It supplies the compressed air to the engine after proper filtering. This reduces the work of compression in the engine. The compressed air is compressed in the engine and at the end of compression diesel oil is sprayed through a fuel injector. The diesel oil is supplied from the fuel tank to the fuel pump after passing through the filter. The fuel pump increases the pressure and supplies to the common rail. In these engines, common rail direct injection system is used. From this high pressure fuel is supplied to individual injectors of corresponding cylinders. The fuel is sprayed as a jet into the cylinder of the engine through the fuel injector. Once the fuel is sprayed, it is burnt in the presence of hot and high pressure air producing high pressure and hot gases. These gases when expanded, produces mechanical energy as output. The shaft of the engine is coupled to the shaft of generator, thus producing the electrical energy as output.

In general the engine capacity is very large, thus requiring large quantity of fuel to participate in combustion process. This requires more lubrication and engine cooling water.

Lubrication system: The lubricant is stored in a storage tank. A fuel pump pressurizes the lubricant so that the oil can be supplied to various parts of the engine. The lubricant oil is passed through the oil purifier where all the eroded metal particles and sand particles as well as carbon deposits if any found are separated and the filtered oil is passed through oil cooler. Here oil is cooled by circulating cooling water. After cooling the oil is circulated through various parts of the engine. By gaining the heat the oil temperature increases and supplied back to the storage tank. This process continues.

Cooling system: Water is circulated in the cooling water jackets. The water gains the heat and the hot water is supplied to the heat exchanger after passing through the surge tank. For creating this circulation, one jacket water pump is used. This hot water is cooled in the heat exchanger by the preheated water coming by the cooling of lubricant oil. After cooling, the water is circulated into the cooling water jackets in the engine. But the hot water is passed through the cooling tower where it is cooled by the circulation of cold air from atmosphere. This cooled water is circulated by the pump to the oil cooler for cooling the lubricant oil. This process continues.

Advantages of Diesel Power Plant:

- Less floor area is occupied
- Less amount of cooling water is needed
- Overall capital cost is less
- Can start easily and put on to load
- Can burn wide range of fuels
- More efficient in the range of 150 MW
- Can respond to varying loads easily
- Design and installation are very simple
- No problem of ash handling
- Lubrication is economical when compared with steam power plant

Drawbacks of Diesel Power Plant:

- High operating cost
- High maintenance and lubrication cost

- Cannot be constructed in large capacity
- Noise is a serious problem
- Life of the plant is small
- Cannot supply overloads continuously
- Not economical where the fuel is to be imported

Applications of Diesel Power Plant

- Peak load plants
- Standby units
- Central stations
- Mobile plants
- Starting stations

Fuel injection systems

In the diesel engines, the heat available in the air after compression is sufficiently enough to burn the fuel completely. The fuel will be sprayed at the end of compression with the help if a fuel injector. The fuel is supplied with high pressure (developed by a fuel pump) to the nozzle. In the nozzle, the pressure energy is converted in to kinetic energy and finally the liquid fuel completes out of the nozzle in the form of fine spray.

Requirements

- The fuel injection should occur at the correct moment.
- It should supply the fuel in correct quantity as required by the varying engine loads.
- The injected fuel must be broken in to very fine droplets *(Proper atomization).*
- The spray pattern should ensure proper mixing of fuel and air.
- It should supply equal quantities of metered fuel to all the cylinders in multi-cylinder engines.
- The beginning and ending of the fuel injection should be sharp.

Elements of fuel injection systems

- Pumping elements – to supply fuel from the tank to cylinder
- Metering elements – to meter the fuel supply as per load and speed
- Distribution elements – to divide the metered fuel equally among the cylinders
- Timing controls – to adjust the start and stop of the injection
- Mixing elements – to atomize and distribute the fuel within the combustion chamber

Types of fuel injection systems

1. ***Air-injection system*** – A multistage compressor is used to supply high pressure air to the engine. This high pressure air forces the fuel in to the cylinder. This method is capable of producing better atomization and penetration of fuel resulting in higher mean effective pressure.
2. ***Solid injection system*** – Here the liquid fuel is directly injected in to the combustion chamber without the aid of compressed air. Hence, it is termed as airless mechanical injection system or solid injection. Every solid injection system must have a pressurizing unit (the pump) and the atomizing unit (the injector).

(a) Individual pump and injector

In this system, each cylinder is provided with one pump and one injector. Each pump may be placed close to the cylinder. The high-pressure pump plunger is actuated by the cam and produces the fuel pressure necessary to open the injector valve at the correct time. The quantity of fuel injected is again controlled by the effective stroke of the plunger.

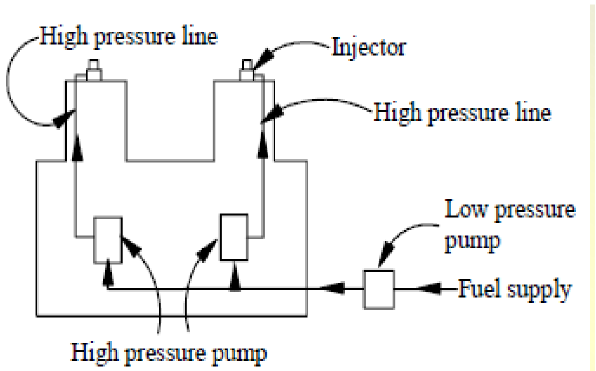


Fig. 1.18 Individual pump and injector

(b) Unit injector system

In this system, the set of injector and low pressure pump forms a single unit. The low pressure pump supplies the diesel oil by increasing the pressure to the fuel injector. At the top, the plunger is activated by the rocker arm thereby the fuel is sprayed into the engine according to the required timing. The amount of fuel to be supplied is controlled by the effective stroke of the plunger.

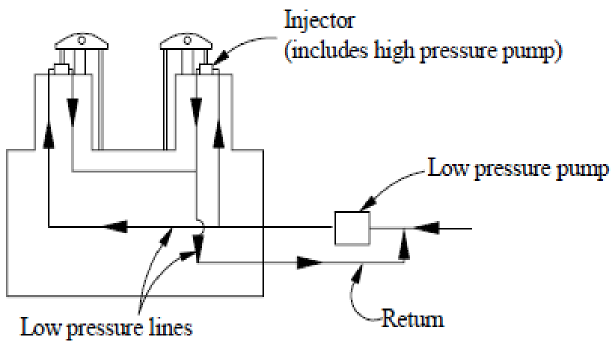
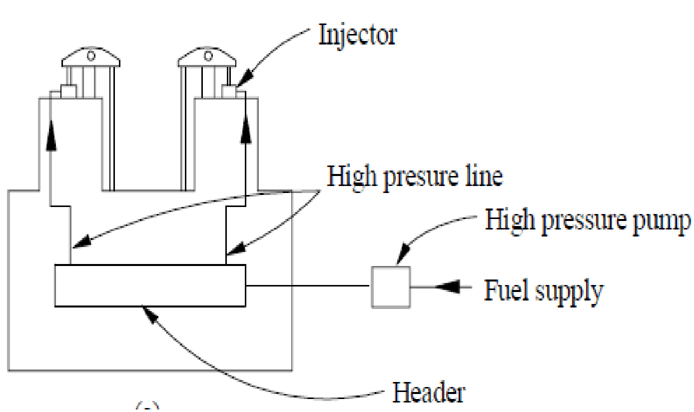


Fig. 1.19 Unit injector system

(c) Common rail system



In this system, a high pressure pump supplies fuel to a fuel header as shown (accumulator). The high pressure in the header forces the fuel to each of the nozzles located in the cylinders. At a proper time, a mechanically operated (by means of push rod and rocker arm) valve allows *Fig. 1.20 Common rail injector system* the fuel to enter the cylinder through the nozzle.

(d) **Distributor system**

In this system, there will be single pump which increases the pressure of the oil. It also regulates the quantity of fuel supplied to each cylinder at correct timing. This pressurized oil is supplied to a single distributor which distributes to all the cylinders available. The number of injection strokes per cycle for the pump is equal to the number of cylinders. Because of single distributor, uniform distribution to each cylinder is ensured.

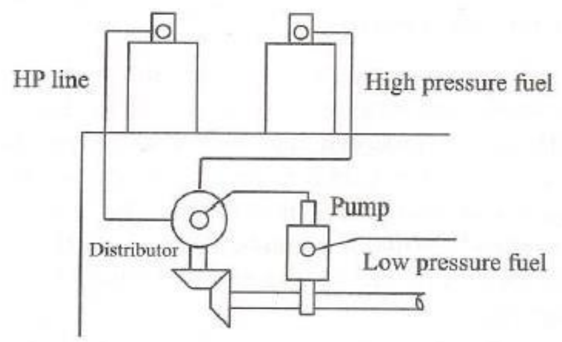


Fig. 1.20 Distributor system

Friction and lubrication

IC engine is made of moving parts. Duo to continuous movement of two metallic surfaces over each other, there is wearing of moving parts, generation of heat and loss of power in the engine. Lubrication of moving parts is essential to prevent all these harmful effects.

Total Engine friction

Knowledge of engine friction is essential for calculating the mechanical efficiency. It is defined as the difference between indicated power and brake power. It includes the power required to drive the compressor and the power required to drive engine auxiliaries such as oil pump, coolant pump and fan etc.,

$$F.P = I.P - B.P$$

Total engine friction can be divided into five components.

a. Crank shaft friction - Main bearings, front and rear bearing oil seals
b. Reciprocating friction - Connecting rod bearings, piston assembly
c. Valve train - Camshafts, cam followers, valve actuation mechanisms
d. Auxiliary components - Oil, water and fuel pumps, alternator
e. Pumping loss - Gas exchange system (air filter, intake, throttle, valves, exhaust pipes, after-treatment device, muffler) Engine fluid flow (coolant, oil)

Purpose of lubrication-

1. To reduce the frictional resistance of the engine to a minimum to ensure maximum mechanical efficiency
2. To protect the engine components against wear
3. To serve as a cooling agent by picking up heat, thereby reducing the overheating of the components
4. To form a seal between piston rings and the cylinder walls to prevent blowby (leaking of the combustion gases in to the crank case below the piston and piston rings).

Desired Properties of lubricants

a. It should have good non-foaming characteristics.
b. It should be non-toxic and non-inflammable.
c. It should have good cleaning ability.
d. It should have high strength to prevent the metal to metal contact and seizure under heavy load.
e. It should not react with the lubricating surfaces.
f. It should have oiliness to ensure adherence to the bearings and for less friction and wear when the lubrication is in the boundary region, and as a protective covering against corrosion.
g. It should not have the tendency to form deposits by reacting with air, water, fuel or the products of combustion.
h. It should have a low pour point to allow the flow of the lubricant at low temperatures to the oil pump.
i. It should have reasonable viscosity which can be varied with respect to the loads. ***High load applications require high-viscosity oils whereas high speeds require low viscosity oils.***

Engine lubrication system

The lubricating system of an engine is an arrangement of mechanisms which maintains the supply of lubricating oil to the rubbing surfaces of an engine at correct pressure and temperature. The parts which require lubrication are

(a) Cylinder walls and piston (b) Piston pin (c) Cooling fan
(d) Crankshaft and connecting rod bearings (e) Camshaft bearings
(f) Valve operating mechanism (g) Water pump and Ignition mechanism

Types of lubricating systems

Used in Two-stroke

1. Mist lubrication system
2. Wet sump lubrication system
3. Dry sump lubrication system

Used in Four-stroke

1. ***Mist lubrication system***

In 2-stroke engines, the charge is compressed in the crank case, and as such it is not suitable to have the lubricating oil in the sump. Therefore, such engines are lubricated by adding 3% to 6% oil in the fuel tank itself. The oil and fuel mixture is inducted through the carburetor. The fuel gets vaporized and the oil, in the form of mist, goes into the cylinder through the crank case. The oil that impinges the crankcase walls lubricates the main and connecting rod bearings, and rest of the oil lubricates the piston, piston rings and cylinder. *The main advantage with this system lies in the simplicity and low cost as the system does not require any oil pump, filter etc., It is mainly employed in 2-stroke engines.*

Disadvantages

a. This system requires a thorough mixing of the lubricant with the charge, for effective lubrication.
b. It causes heavy exhaust smoke due to burning of lubricant oil partially or fully and also forms deposits on the piston crown and exhaust ports which affect engine efficiency.
c. Since the oil comes in close contact with acidic vapors produced during the combustion process, gets contaminated and may result in the corrosion of bearing surface.
d. During closed throttle operation as in the case of the vehicle moving down the hill, the engine will suffer from insufficient lubricant as the supply of fuel is less. ***This is an important limitation of the system.***

In the modern engines, the lubricant oil is directly injected into the carburetor and the quantity of oil is regulated.

2. ***Wet sump lubrication system***

In the wet sump lubricating system, the bottom of the crank case contains an oil sump that serves as the oil supply reservoir. Oil dripping from the cylinders and bearings flows by gravity back into the sump and re-circulated through the engine lubrication system. Fig.

1.14 presents the splash and circulating pump system. Its working principle is explained in detail as given below;

The lubricating oil is charged in the bottom of the engine crankcase and maintained at a predetermined level. The oil is drawn by a pump and delivered through a distributing pipe extending the length of the crankcase into splash troughs located under the big end of the connecting rods. A splasher is provided under each connecting rod cap which dips into the oil in the trough at every revolution of the crank shaft and the oil is splashed all over the interior of the crank case, into the pistons and on to the exposed portions of the cylinder walls. A hole is drilled through the connecting rod cap through which oil will pass to the bearing surface. Oil pockets are also provided to catch the splashing oil over all the main bearings and also over the camshaft bearings.

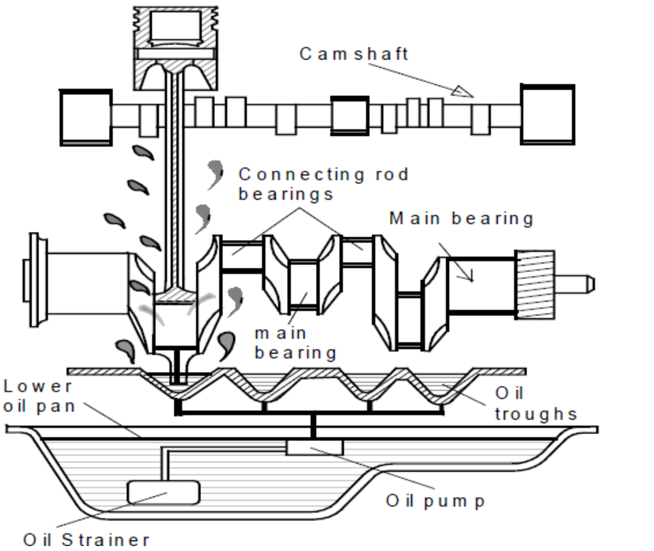


Fig. 1.14 Splash and circulating pump system

From the pockets, the oil will reach the bearings surface through a drilled hole. The oil dripping from the cylinders is collected in the sump where it is cooled by the air flowing around. The cooled oil is again re-circulated.

It is mainly employed in 4-stroke engines, in relatively small engines, such as in automobiles.

3. <u>Dry sump lubrication</u>

Lubricant oil stored in the tank is supplied under pressure to the various bearings of the engine. Lubricant gaining heat from the cylinder walls and at the bearings drips into the oil sump. It is filtered after passing through the filter and then supplied back to the supply tank with the help of a pump.

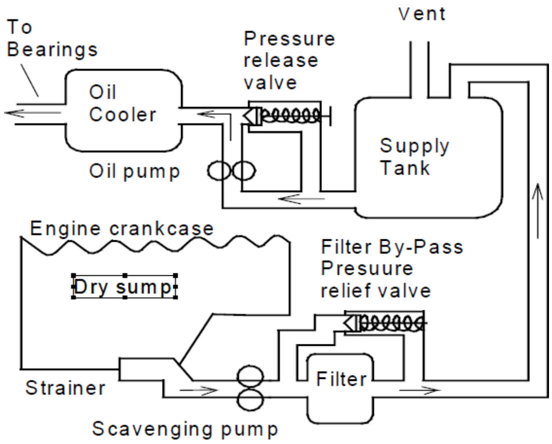


Fig. 1.15 Dry sump lubrication

If the filter is clogged, the relief valve opens and permits the oil to reach the supply tank. Separate oil cooler is provided to cool the hot lubricant before supplying to various bearings again.

Cooling systems in an Internal Combustion engine

We know that in case of Internal Combustion engines, combustion of air and fuel takes place inside the engine cylinder and hot gases are generated. The temperature of gases will be around 2300-2500°C. This is a very high temperature and may result into burning of oil film between the moving parts and may result into seizing or welding of the same. Even this result in the enormous expansion of various components, thereby increasing the stresses developed in them. So, this temperature must be reduced to about 150-200°C at which the engine will work most efficiently. Too much cooling is also not desirable since it reduces the thermal efficiency. So, the object of cooling system is to keep the engine running at its most efficient operating temperature. It is to be noted that the engine is quite inefficient when it is cold and hence the cooling system is designed in such a way that it prevents cooling when the engine is warming up and till it attains to maximum efficient operating temperature, then it starts cooling.

It is also to be noted that:

- About 20-25% of total heat generated is used for producing brake power (useful work).
- Cooling system is designed to remove 30-35% of total heat.
- Remaining heat is lost in friction and carried away by exhaust gases.

There are mainly two types of cooling systems:

(a) Air cooled system (b) Water cooled system.

Air cooled system

In this system fins or extended surfaces are provided on the cylinder walls, cylinder head, etc. Heat generated due to combustion in the engine cylinder will be conducted to the fins and when the air flows over the fins, heat will be dissipated to air. The amount of heat dissipated to air depends upon:

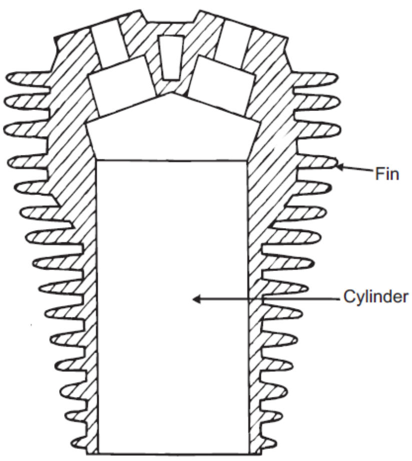


Fig. *1.10 Air cooled engine with fins*

i. Amount of air flowing through the fins.
ii. Fin surface area.
iii. Thermal conductivity of metal used for fins.

Advantages of Air Cooled System

i. Radiator/pump is absent hence the system is light.
ii. In case of water cooling system there are leakages, but in this case there are no leakages.
iii. Coolant and antifreeze solutions are not required.
iv. This system can be used in cold climates, where if water is used it may freeze.

Disadvantages of Air Cooled System

i. Comparatively it is less efficient.
ii. It is used in aero planes and motorcycle engines where the engines are exposed to air directly.

Air cooled system is generally used in small engines say up to 15-20 kW and in aero plane engines.

Water cooled system

(a) Direct or Non-return system

It is used for large installations where plenty of water is available. The cold water available is passed through the cooling jacket of the engine where it gains the heat from hot cylinder walls. This hot water is directly rejected to the surroundings without cooling.

(b) Forced re-circulated water system:

In this method, cooling water jackets are provided around the cylinder, cylinder head, valve seats etc. The water when circulated through the jackets, it absorbs heat of combustion. This hot water will then be cooling in the radiator partially by a fan and partially by the flow developed by the forward motion of the vehicle. The cooled water is again re-circulated through the water jackets.

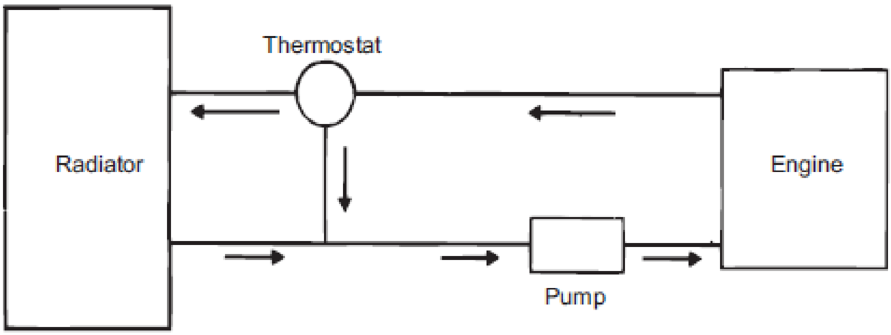


Fig. 1.11 Forced re-circulated water system

Water cooling system mainly consists of:

(a) Radiator (b) Thermostat valve (c) Water pump (d) Fan

(e) Water Jackets (f) Antifreeze mixtures.

Radiator - When the water is flowing down through the radiator core, it is cooled partially by the fan which blows air and partially by the air flow developed by the forward motion of the vehicle. It is to be noted that radiators are generally made out of copper and brass and their joints are made by soldering.

Thermostat Valve - It is a valve which prevents flow of water from the engine to radiator, so that engine readily reaches to its maximum efficient operating temperature. After attaining maximum efficient operating temperature, it automatically begins functioning. Generally, it prevents the water above 70°C.

Water Pump - It is used to pump the circulating water. Impeller type pump will be mounted at the front end. Pump consists of an impeller mounted on a shaft and enclosed in the pump casing. The pump casing has inlet and outlet openings. The pump is driven by means of engine output shaft only through belts. When it is driven water will be pumped.

Fan - It is driven by the engine output shaft through same belt that drives the pump. It is provided behind the radiator and it blows air over the radiator for cooling the hot water coming from the engine.

Water Jackets - Cooling water jackets are provided around the cylinder, cylinder head, valve seats and any hot parts which are to be cooled. Heat generated in the engine cylinder, conducted through the cylinder walls to the jackets. The water flowing through the jackets absorbs this heat and gets hot. This hot water will then be cooled in the radiator.

Antifreeze Mixture - In western countries if the water used in the radiator freezes because of cold climates, then ice formed has more volume and produces cracks in the cylinder blocks, pipes, and radiator. So, to prevent freezing antifreeze mixtures or solutions are added in the cooling water. The ideal antifreeze solutions should have the following properties:

(a) It should dissolve in water easily.

(b) It should not evaporate.

(c) It should not deposit any foreign matter in cooling system.

(d) It should not have any harmful effect on any part of cooling system.

(e) It should be cheap and easily available.

(f) It should not corrode the system.

No single antifreeze satisfies all the requirements. Normally following are used as antifreeze solutions:

(a) Methyl, ethyl and isopropyl alcohols. (b) A solution of alcohol and water.

(c) Ethylene Glycol. (d) A solution of water and Ethylene Glycol (e) Glycerin along with water, etc.

Advantages

(a) Uniform cooling of cylinder, cylinder head and valves.

(b) Specific fuel consumption of engine improves by using water cooling system.

(c) If we employ water cooling system, then engine need not be provided at the front end of moving vehicle.

(d) Engine is less noisy as compared with air cooled engines, as it has water for damping noise.

Disadvantages

(a) It depends upon the supply of water.

(b) The water pump which circulates water absorbs considerable power.

(c) If the water cooling system fails then it will result in severe damage of engine.

(d) The water cooling system is costlier as it has more number of parts. Also it requires more maintenance and care for its parts.

(c) Thermosyphon system

In this system, a fan rotated by the crankshaft draws cold air from outside through the radiator. The radiator is connected to the engine block by means of two pipes. The hot water passes through some thin pipes built in the radiator. The cold air flows over the surface of these water pipes thereby the hot water loses the heat to cold air. Thus water gets cooled and circulated back to cool the engine to pass through the cooling jacket.

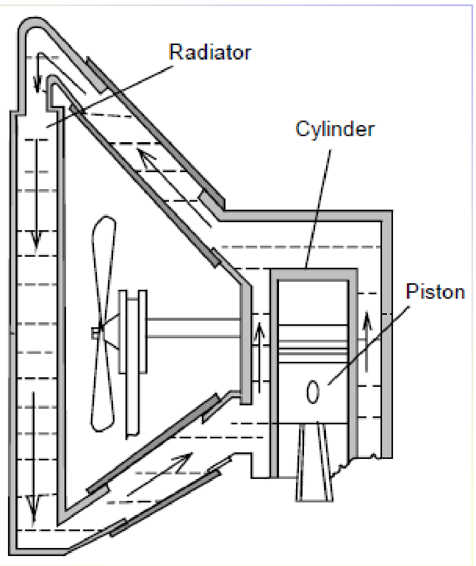


Fig. 1.12 Thermosyphon system

(d) Evaporative Cooling:

In this system, water is allowed to flow through the cooling jacket in the cylinder, where it gains the heat and converts to steam. This steam is sent to the radiator where the steam is condensed by rejecting the heat to the air flowing over the surfaces of pipes in radiator. The condensed steam i.e. liquid water is supplied back to the engine for cooling in next cycle.

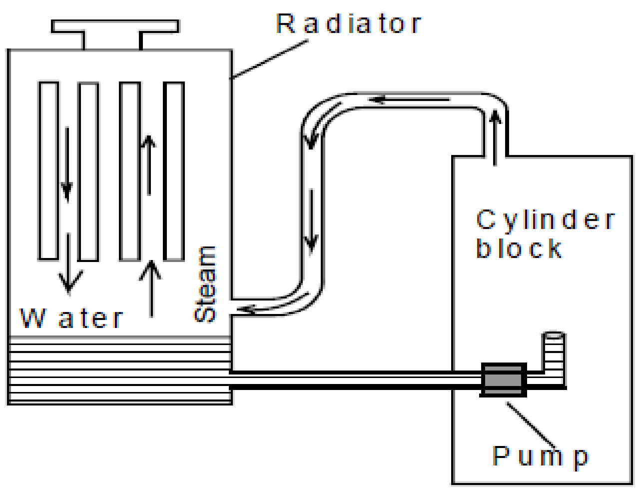


Fig. .13 Evaporative Cooling

This system is mainly used in cooling of industrial engines.

In many cases, the water cooling is more preferred than air cooling, especially in high capacity engines. The reason is the specific heat of water, which is 4 times higher than that of air. Because of this, the water can absorb more heat compared to air, with fewer rises in temperature. This cools the engine to lesser temperature in short span of time.

Supercharging:

Gas Turbines

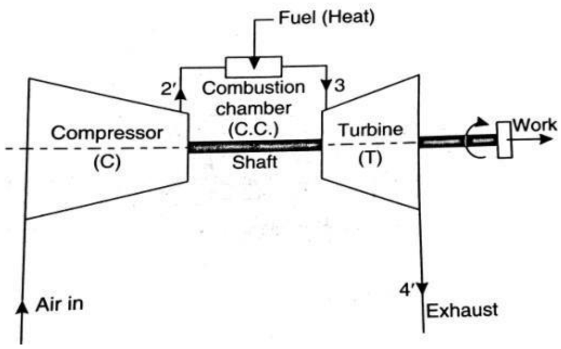
Gas turbine is an external combustion engine which converts the enthalpy of gases expanding in it into mechanical energy as output. Gas turbines as classified as:

A. **On the basis of combustion process**
   (i) Continuous combustion or constant pressure type: The cycle working on this principle is called Joule or Brayton cycle.
   (ii) The explosion or constant volume type: The cycle working on this principle is known as Atkinson cycle.
B. **On the basis of the action of expanding gases similar to steam turbine**
   (i) Impulse turbine and (ii) Impulse reaction turbine.
C. **On the basis of path of working substance**
   (i) Open cycle gas turbine (working fluid enters from atmosphere and exhaust to
   (ii) atmosphere.)
   (iii) Closed cycle gas turbine (working fluid is confined within the plant), and
   (iv) Semi-closed cycle (part of the working fluid is confined within the plant and another part flows from and to the atmosphere)
D. **On the basis of direction of flow**
   (i) Axial flow and (ii) Radial Flow

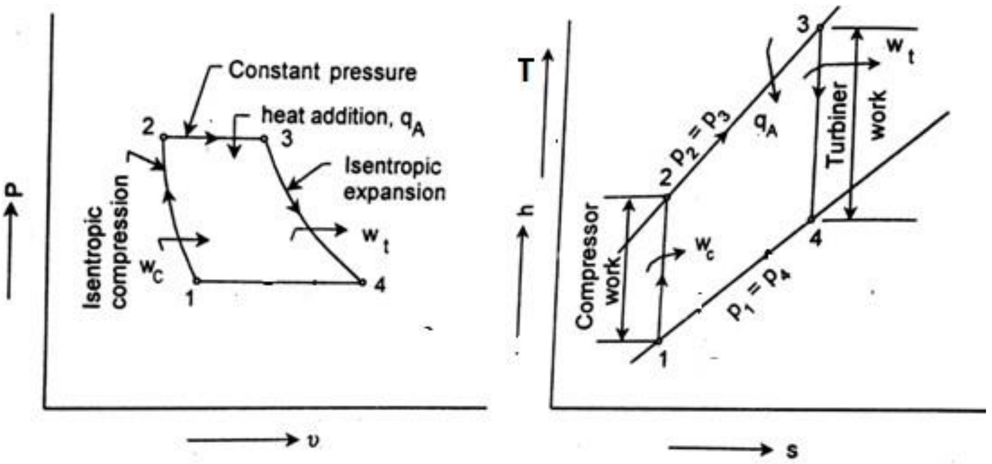
I. **Applications of Gas turbines**
   a. Locomotive propulsion
   b. Central power stations
   c. Utility plants (b) combined cycle and cogeneration plants (c) stand by plants for hydro installations.
   d. Industrial gas turbines: In Natural or crude oil pumping in the form of driver of compressors or pumps
   e. Space applications: Turbo jet, turbo prop, ram jet, pulse jet, rocket
   f. Marine applications.

(i) Simple open cycle Gas Turbine:(constant pressure heat addition)

Atmosphere air is compressed from p_1 to a high pressure p_2 in the compressor and delivered to the burner or combustion chamber (CC) where fuel is injected and burned. The combustion process occurs nearly at constant pressure. Due to combustion heat is added to the working fluid and temperature of working fluid rises



from T_2 to T_3. The products of combustion from the combustion chamber are expanded in the turbine from p2 to atmosphere pressure p1, and then discharges into atmosphere. The turbine and compressor are mechanically coupled, so the network is equal to the difference between the work done by the turbine and work consumed by compressor.



Representation of Open cycle on P-V and h-s (T-s) planes

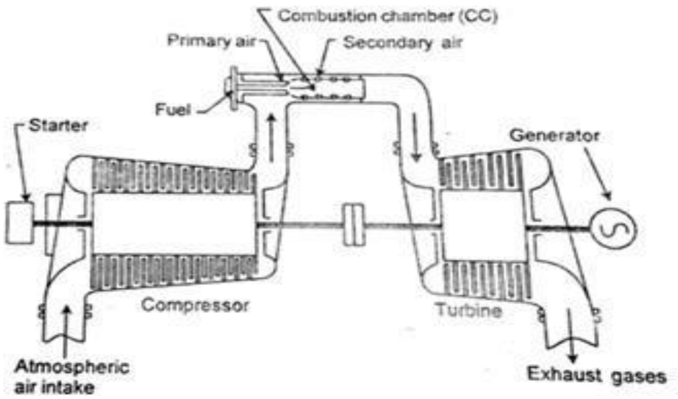


Fig. Arrangement of Components in gas turbine plant

Heat supplied= $h_3 - h_2 = c_p(T_3 - T_2)$

Heat rejected= $h_4 - h_1 = c_p(T_4 - T_1)$

Net work=Heat supplied –Heat rejected= $c_p[(T_3 - T_2) - (T_4 - T_1)]$

Work done by turbine= $h_3 - h_4 = c_p(T_3 - T_4)$

Work consumed by compressor= $h_2 - h_1 = c_p(T_2 - T_1)$

Thermal Efficiency = net work/Heat supplied

$$= \frac{c_p[(T_3 - T_2) - (T_4 - T_1)]}{c_p(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

We know that $\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma - 1}{\gamma}}$ & $\frac{T_3}{T_4} = \left(\frac{p_3}{p_4}\right)^{\frac{\gamma - 1}{\gamma}}$

On simplificaation, we get

$$\eta_{th} = 1 - \frac{T_1}{T_2}$$

$$\eta_{th} = 1 - \frac{1}{\left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}} = 1 - \frac{1}{\left(r_p\right)^{\frac{\gamma-1}{\gamma}}}$$

Actual cycle:

In practice, reversible adiabatic compression and expansion are not possible due to the existing irreversibility. Hence the processes are not reversible and adiabatic.

In the case of a compressor, during compression process the temperature of the gas increases and alters the intermolecular friction. In addition, the external irreversibilities also tends to increase the temperature of the gas. The net effect is actual temperature becoming greater than the ideal value obtained in isentropic compression. Because of this reason, the specific heat of the gas increases resulting in higher work input to the compressor in practice (than that supplied in isentropic compression).

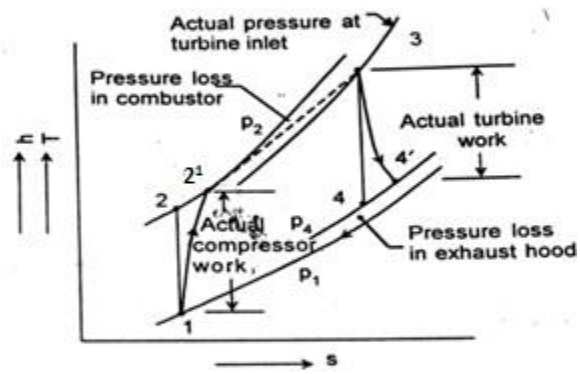


Fig.Representation of actual cycle on T-s plane with the efficiencies of compressor, turbine and pressure drops

1 – 2 is isentropic compression. 1 – 2′ is actual compression.

3 – 4 is isentropic expansion. 3 – 4′ is actual expansion.

η_c =Isentropic compression work/Actual compression work

$$\eta_c = \frac{T_2 - T_1}{T_2^1 - T_1}$$

In the case of a turine, during expansion process the temperature of the gas decreases and alters the intermolecular friction. In addition, the external irreversibilitiestends to increase the temperature of the gas. The net effect is increase in the temperature of gas at the outlet of the gas turbine which will be greater than the ideal value obtained in isentropic expansion.This results in decrease of enthalpy drop in the turbine. Because of this reason, lesser work output is obtained from the turbine (than that obtained in isentropic expansion).

Turbine Efficiency=Actual turbine work/Isentropic Turbine work

Actual turbine work= $h_3 - h_4^1 = c_{pg}\left(T_3 - T_4^1\right)$

Turbine efficiency= $\eta_t = \frac{T_3 - T_4^1}{T_3 - T_4}$

The effect of decrease in efficiency of compressor and turbine results in decrease of thermal efficiency of the cycle.

II. Methods for improving the efficiency of Gas turbine:

(i) Intercooling

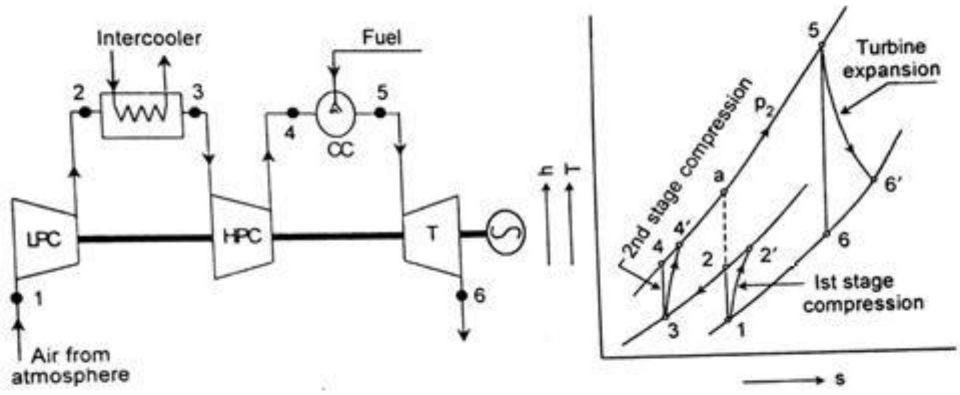


Fig. Gas turbine with multistage compression and process representation on T-s plane

Instead of increasing the entire pressure in a single compressor, the pressure rise is obtained in stages. Initially the air is compressed in low pressure compressor from pressure p_1 to p_2. Now the air is cooled at constant pressure in the intercooler at constant pressure i.e. $p_2=p_3$. The cooled air is compressed in the high pressure compressor from pressure p_3 to p_4.

Theoretically

- Work input with Inter cooling $= c_p\left[(T_2 - T_1) + (T_4 - T_3)\right]$
- Work ratio=Net work/Gross work out put.

  = (Work of Expansion-work of compression)/Work of expansion

  Work of expansion, i.e turbine work $= h_5 - h_6 = c_p(T_5 - T_6)$

  Compressor work $= (h_2 - h_1) + (h_4 - h_3)$

  $= c_p\left[(T_2 - T_1) + (T_4 - T_3)\right]$

So thermal efficiency $= \dfrac{(T_5 - T_6) - (T_4 - T_3) - (T_2 - T_1)}{T_5 - T_4}$

For minimum compression work in the compressor or maximum work out put in this cycle, only the compressor is responsible. And here $T_3=T_1$.

$$c_p\left[(T_2 - T_1) + (T_4 - T_3)\right] = c_p T_1\left[\frac{T_2}{T_1} - 1 + \frac{T_4}{T_1} - 1\right]$$

$$= c_p T_1\left[\left(\frac{p_x}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 1 + \left(\frac{p_2}{p_x}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$

Let $c_p T_1 = A$ and $\frac{\gamma - 1}{\gamma} = a$

$$w_c = A\left[\left(\frac{p_x}{p_1}\right)^a + \left(\frac{p_2}{p_x}\right)^a - 2\right]$$

For minimum work, differentiate w_c wrt p_x and equal to zero.

$$a p_x^{a-1} \frac{1}{p_1^a} - a p_2^a p_x^{-a-1} = 0$$

$$\frac{p_x^{\frac{a-1}{a}}}{p_1^{\frac{a-1}{a}}} = \frac{p_2^{\frac{a-1}{a}}}{p_x^{\frac{a-1}{a}}}$$

$$p_x = \sqrt{p_1 p_2}$$

- Heat supplied with Inter cooling= $c_p(T_5 - T_4)$
- Heat supplied without Inter cooling= $c_p(T_5 - T_a)$

Effects of intercooling:

- Decrease in wor supplied in compression.
- Increase of net work delivered by the plant
- Increase of work ratio
- Thus heat supplied when intercooling is used is greater than with no intercooling. Although the network out put is increased by intercooling, it is found that the increase in heat to be supplied causes the thermal efficiency to decrease.

(ii) Reheating:

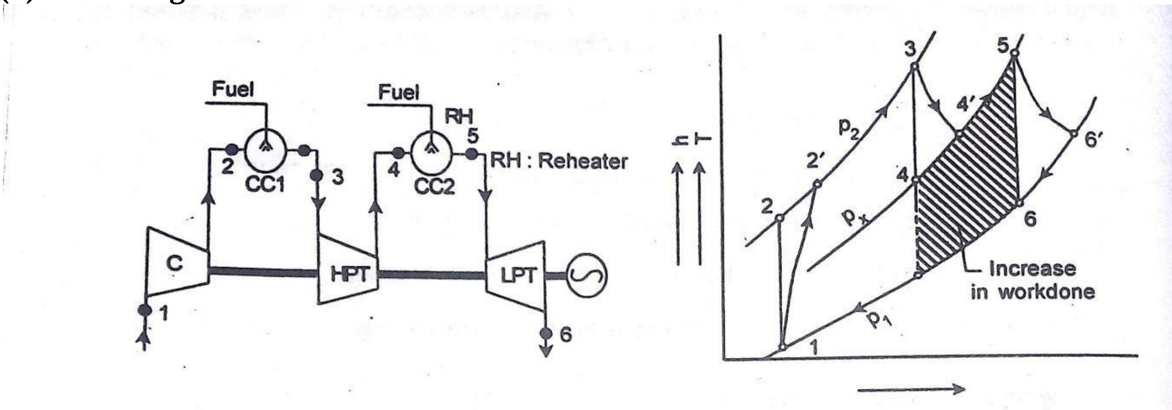


Fig. Schematic diagram of reheating process and Process representation on T-s plane

By reheating or adding heat to the gases after they have passed through a part of the rows of the turbine blading, a further increase in work done is obtained. In reheating, the gas temperature, which has dropped due to expansion is brought back to approximately the initial temperature for the expansion in the next stage.

Theoritically, Net work = $(h_3 - h_4) + (h_5 - h_6) - (h_2 - h_1)$

Heat supplied= $(h_3 - h_2) + (h_5 - h_4)$

$$\eta_{th} = \frac{(h_3 - h_4) + (h_5 - h_6) - (h_2 - h_1)}{(h_3 - h_2) + (h_5 - h_4)}$$

For maximum work output, there must ve an optimum pressure at which reheating should be done. As we know, the compressor work W_c is not effected by reheating, so for the maximum output, we have to find the condition where turbine work W_t is maximum.

$$W_t = c_p(T_3 - T_4) + c_p(T_5 - T_6)$$

$$= c_p T_3\left[1 - \left(\frac{p_x}{p_2}\right)^{\frac{\gamma-1}{\gamma}}\right] + c_p T_5\left[1 - \left(\frac{p_1}{p_x}\right)^{\frac{\gamma-1}{\gamma}}\right]$$

Here T_3= and c_p, T_3, p_1,p_2 are constants. The only variable is p_x.

Let $c_p T_3 = A$ and $\frac{\gamma - 1}{\gamma} = a$

Then $w_t = A\left[2 - \left(\frac{p_x}{p_2}\right)^a - \left(\frac{p_1}{p_x}\right)^a\right]$

For maximum work, differentiate the above equation with respect to p_x and equate to zero.

$$a p_x^{a-1} \frac{1}{p_2^a} - a p_x^{-a-1} p_1^a = 0$$

$$\frac{p_x^{a-1}}{p_2^a} = \frac{p_1^a}{p_x^{a+1}}$$

or

$$p_x = \sqrt{p_1 p_2}$$

or

$$\boxed{\left(\frac{p_x}{p_1}\right) = \left(\frac{p_2}{p_x}\right)}$$

Effects of reheating

- Increase in the work output of the turbine
- Increase in the heat supplied

(iii) Open cycle Gas turbine with regeneration:

In this method, the air delivered by the compressor passes through a heat exchanger utilizing the gases exhausted from the turbine. The heated air then passes into the combustion chamber and part of it is employed to burn the fuel. Since some heat is added already to the air in the heat exchanger itself, so the same turbine gas inlet temperature is achieved with lower fuel consumption. Hence the thermal efficiency is accordingly higher.

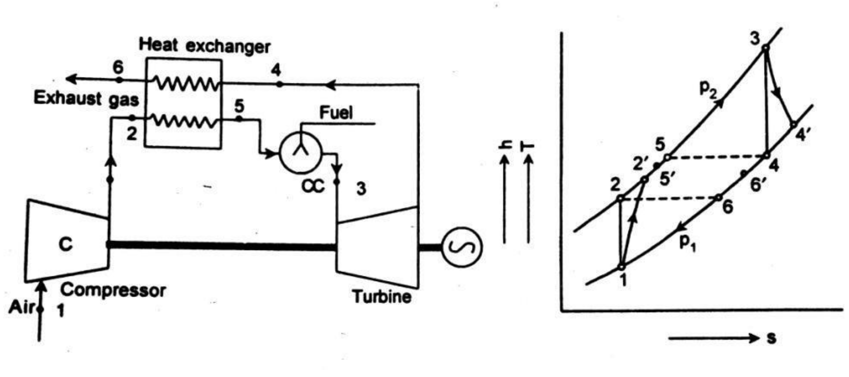


Fig. Regenerative cycle with process representation on T-s plane

$W_{net} = (h_3 - h_4) - (h_2 - h_1) = c_p(T_3 - T_4) - c_p(T_2 - T_1)$

Heat supplied $= h_3 - h_5 = c_p(T_3 - T_5)$

Thermal Efficiency $= \eta_{th} = \frac{c_p(T_3 - T_4) - c_p(T_2 - T_1)}{c_p(T_3 - T_5)}$

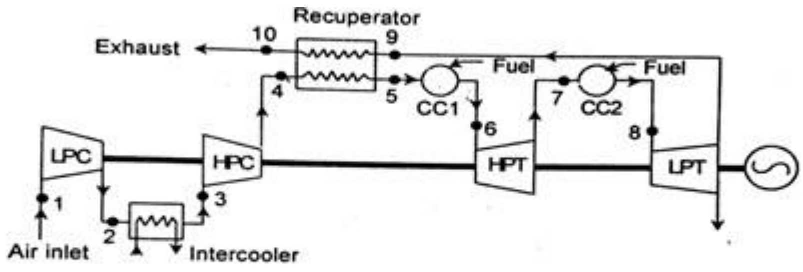
Effectiveness,

$$\varepsilon = \frac{T_5 - T_2}{T_4 - T_2}$$

Effects of Regeneration

- Decrease of heat supplied in combustion chamber
- Increase of thermal efficiency

IV. Open cycle gas turbine with Inter cooling, reheat and regeneration:



OGTC with Intercooling, Reheat and Regeneration. (Complete Cycle)

Fig. Layout of combined cycle

Initally the air is compressed in low pressure compressor from pressure p_1 to p_2, which is then cooled in an intercooler such that the temperature after cooling T_3 is equal to temperature before compression in L.P compressor at constant pressure $p_3=p_2$.After cooling the air is again compressed in the high pressure compressor raising the pressure from p_3 to p_4. The compressed air gains the heat from hot gases coming form the L.P turbine in regenerator raising its temperature from T_4 to T_5. Prehetaed air enters the combustion chamber-1 where the fuel is burned in its presence. The temperature of the hot gases entering the high pressure turbine is T_6. The gases expand in the H.P turbinewith a pressure drop from p_6 to p_7 thus delivering the work output. After expansion, the gases are again heated in the combusiton chamber-2 at constant pressure $p_7=p_8$ such that the temperature after heating is equal to the temperature before expansion in the H.P turbine i.e. $T_8=T_6$. The reheated gases are expanded in the low perssure turbine with a pressure drop from p_8 to p_9. Now the gases are passed through the regenerator where the available heat is trasferred to the compressed air before passing through the combustion chamber-1.

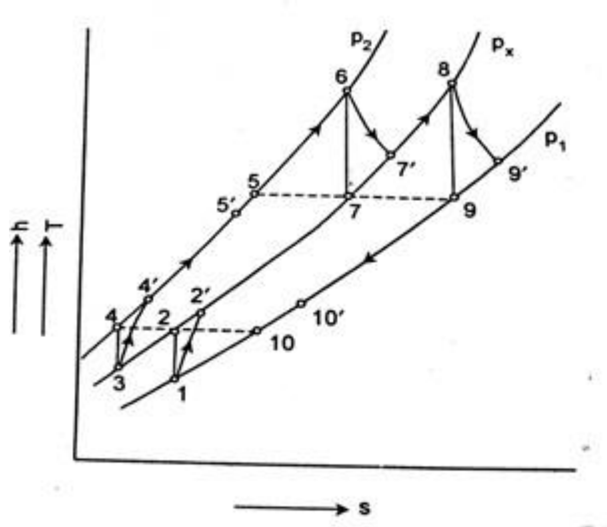


Fig. Representation of combined cycle

Net work supplied to compressor, $W_C = m_a c_{pa} [(T_2 - T_1) + (T_4 - T_3)]$

Work delivered by turbine, $W_T = m_g c_{pg} [(T_6 - T_7) + (T_8 - T_9)]$

Net work delivered by the turbine, $W_{net} = W_T - W_C$

Heat supplied, $Q_S = m_f \times cv$

Thermal efficiency, $\eta_{th} = \dfrac{W_{net}}{Q_s}$

V. Effect of Operating Variables on Thermal Efficiency

The thermal efficiency of actual open cycle depends on the following thermodynamicvariables:

a. Pressure ratio
b. Turbine inlet temperature (T_3)
c. Compressor inlet temperature (T_1)
d. Efficiency of the turbine ($\eta_{turbine}$)
e. Efficiency of the compressor (η_{comp}).

a. Effect of turbine inlet temperature and pressure ratio:

If the permissible turbine inlet-temperature (with the other variables being constant) of anopen cycle gas turbine power plant is increased its thermal efficiency is amply improved. A practicallimitation to increasing the turbine inlet temperature, however, is the ability of the materialavailable for the turbine blading to withstand the high rotative and thermal stresses.For a given turbine inlet temperature, as the pressure ratio increases, theheat supplied as well as the heat rejected are reduced. But the ratio of change of heat supplied isnot the same as the ratio of change heat rejected. As a consequence, there exists an optimumpressure ratio producing maximum thermal efficiency for a given turbine inlet temperature.As the pressure ratio increases, the thermal efficiency also increases until it becomes maximumand then it drops off with a further increase in pressure ratio. Further, as theturbine inlet temperature increases, the peaks of the curves flatten out giving a greater range ofratios of pressure optimum efficiency.

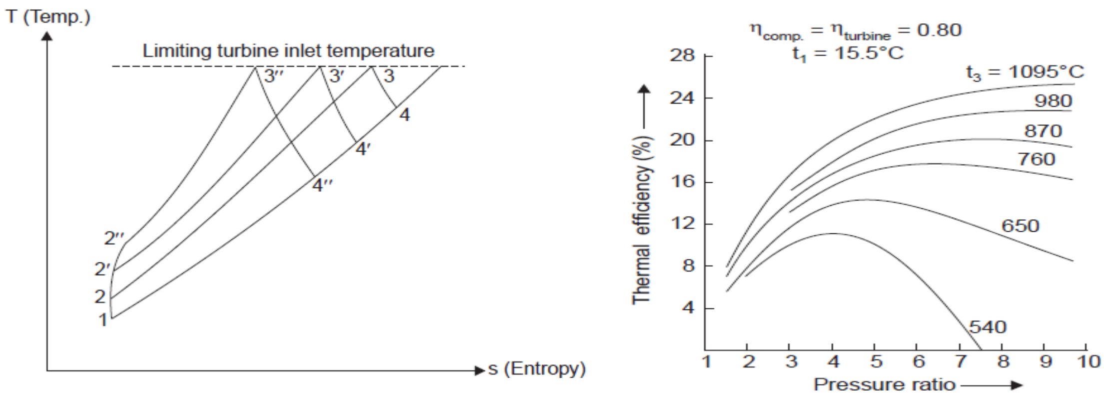
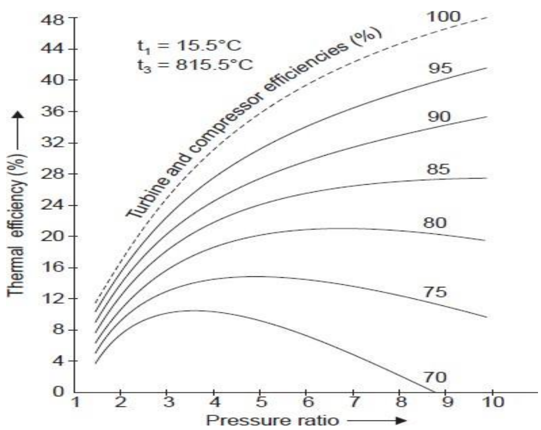


Fig. Effect of pressure ratio and turbine inlet temperature

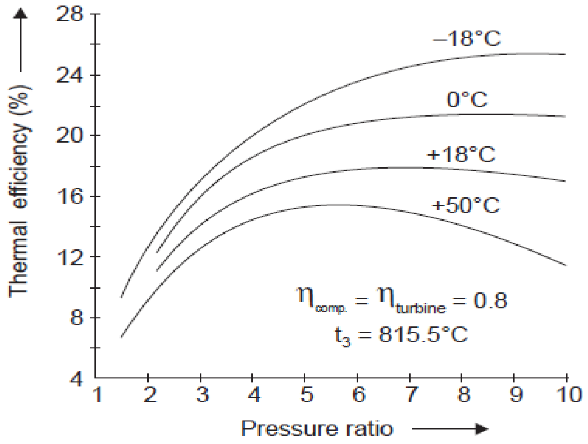
b. Effect of turbine and compressor efficiencies:

The thermal efficiency of the actual gas turbine cycle is very sensitive to variations in the efficiencies of the compressor and turbine. There is a particular pressure ratio at which maximum efficiencies occur. For lower efficiencies, the peak of the thermal efficiency occurs at lower pressure ratios and vice versa.

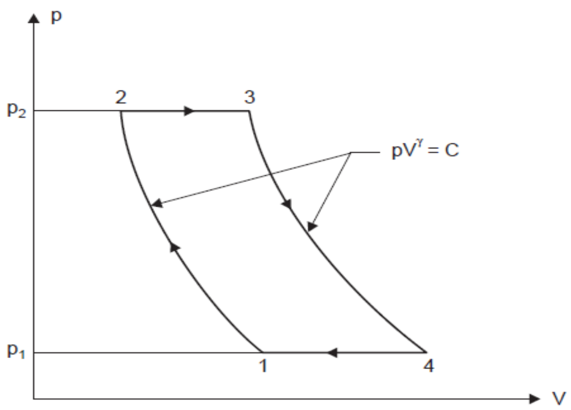


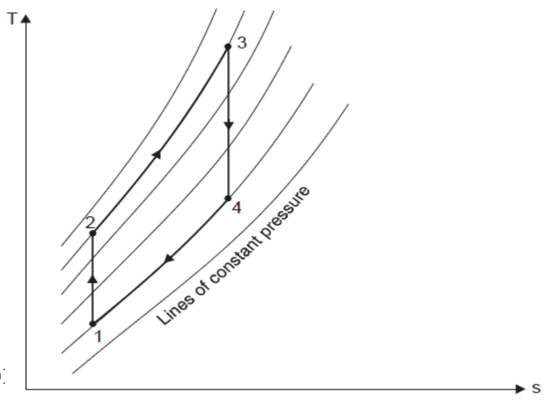
c. Effect of compressor inlet temperature:

Refer Fig. 12with the decrease in the compressor inlet temperature there is increase in thermal efficiency of the plant. Also the peaks of thermal efficiency occur at high pressure ratios and the curves become flatter giving thermal efficiency over a wider pressure ratio range.



Closed Cycle Gas Turbine (Constant pressure or joule cycle):
Fig. shows a gas turbine operating on a constant pressure cycle in which the closed system consists of air behaving as an ideal gas. The various operations are as follows:
Operation 1-2: The air is compressed isentropically from the lower pressure p_1 to the upper pressure p_2, the temperature rising from T_1 to T_2. No heat flow occurs.
Operation 2-3: Heat flow into the system increasing the volume from V_2 to V_3 and temperature from T_2 to T_3 whilst the pressure remains constant at p_2.
Heat received = $mc_p(T_3 - T_2)$.
Operation 3-4: The air is expanded isentropically from p_2 to p_1, the temperature falling from T_3 to T_4. No heat flow occurs.
Operation 4-1: Heat is rejected from the system as the volume decreases from V_4 to $V_1$and the temperature from T_4 to T_1 whilst the pressure remains constant at p_1.
Heat rejected = $mc_p(T_4 - T_1)$





$$\eta_{air\text{-}standard} = \frac{\text{Work done}}{\text{Heat received}}$$

$$= \frac{\text{Heat received/cycle} - \text{Heat rejected/cycle}}{\text{Heat received/cycle}}$$

$$= \frac{mc_p(T_3 - T_2) - mc_p(T_4 - T_1)}{mc_p(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

Now, from isentropic expansion

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_2 = T_1 (r_p)^{\frac{\gamma-1}{\gamma}}, \text{ where } r_p = \text{Pressure ratio}$$

Similarly $\quad \dfrac{T_3}{T_4} = \left(\dfrac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$ or $T_3 = T_4 (r_p)^{\frac{\gamma-1}{\gamma}}$

$$\eta_{air\text{-}standard} = 1 - \frac{T_4 - T_1}{T_4(r_p)^{\frac{\gamma-1}{\gamma}} - T_1(r_p)^{\frac{\gamma-1}{\gamma}}} = 1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}$$

Constant volume combustion gas turbine cycle

In a constant volume combustion turbine, the compressed air from an air compressor C is admitted into the combustion chamber D through the valve A. when the valve A is closed, the fuel is admitted into the chamber by means of a fuel pump P. Then the mixture is ignited by means of a spark plug S. The combustion takes place at constant volume. The valve B opens and the hot gases flow to the turbine T, and finally they discharged, into atmosphere. The energy of the hot gases is thereby converted into mechanical energy. For continuous running of the turbine these operations are repeated.

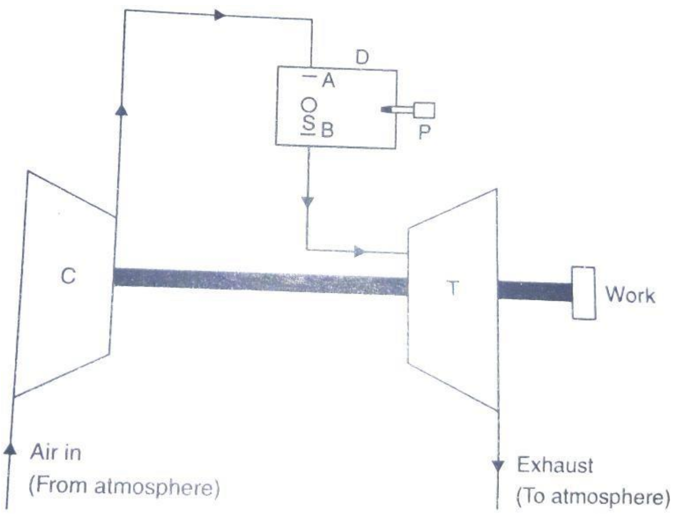


Fig. Constant volume gas turbine arrangement

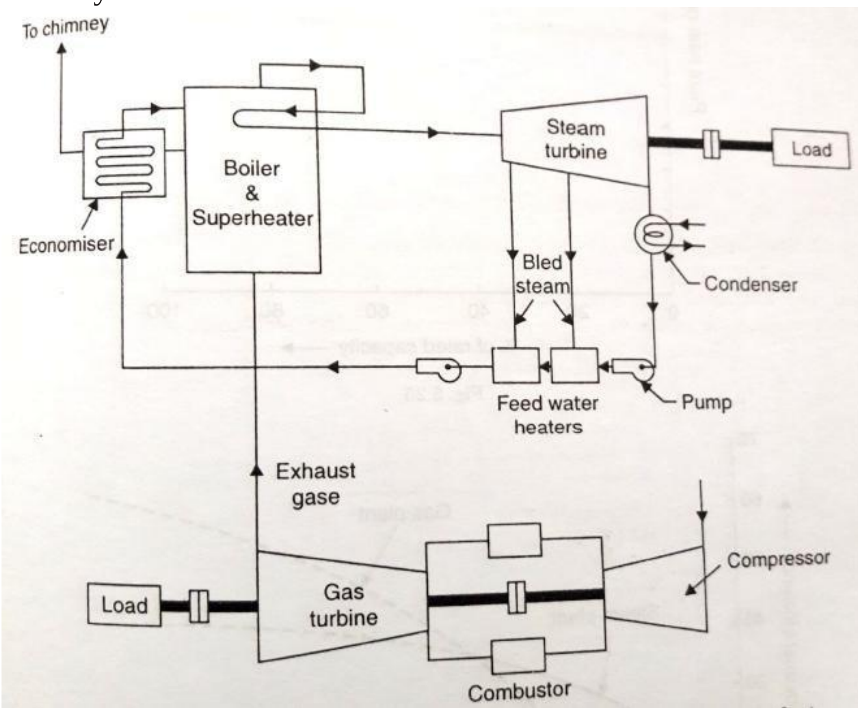
Combines Cycle Power Plants

To improve the cycle efficiency and recover the waste heat, gas turbine power plants are operated in association with steam power plants as well as diesel engine power plants.

Combination of Gas Turbines with Steam Power Plants:

1. **Feed water heating with exhaust gases:**

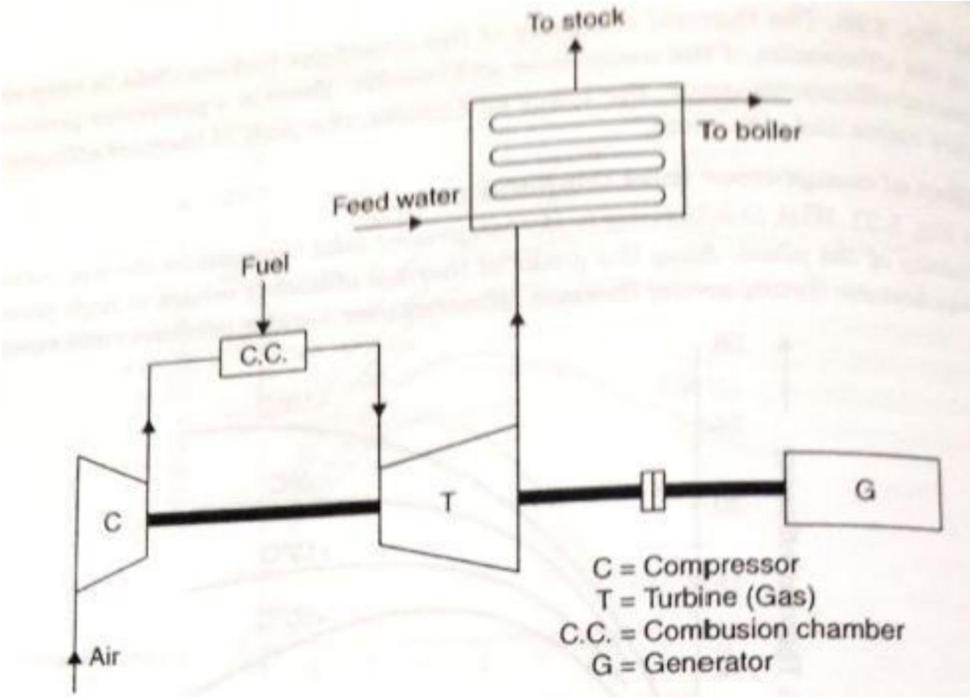
   In this arrangement, the hot gases released from the turbine are passed through a part of boiler (economizer) where the feed water passes through the tubes in it. By gaining the heat from hot gases, the feed water temperature increases and it thus reduces the heat supplied in the boiler. After losing the heat the gases are released into the atmosphere through the chimney.



2. **Employing the gases from a supercharged boiler to expand in a gas turbine:**

   In this arrangement, compressed air is supplied to the boiler furnace at a pressure of 5 bar to participate in combustion process. This results in the production of pressurized hot gases, resulting in increase in the rate of heat transfer to water. This also reduces the size of boiler required. After heating water, the gas is expanded in a gas turbine to produce the power output.

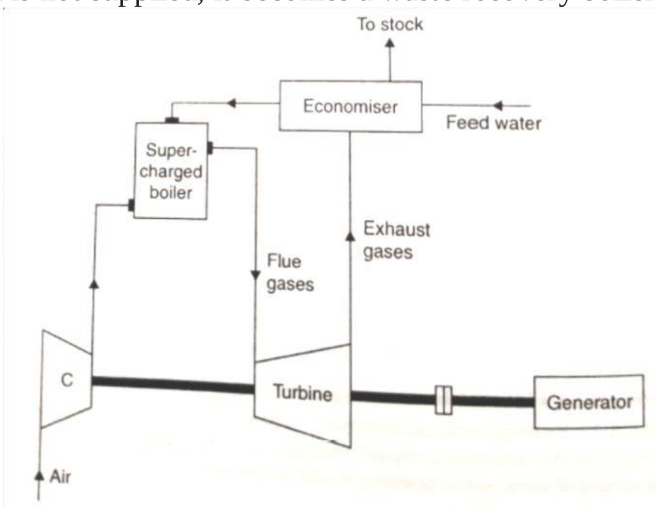
   This also eliminates the necessity of forced and induced draught fans in the boiler plant. This also reduced the power consumption in the power plants thereby increasing the net power produced.



3. **Employing the gases as combustion sir in the steam boiler:**

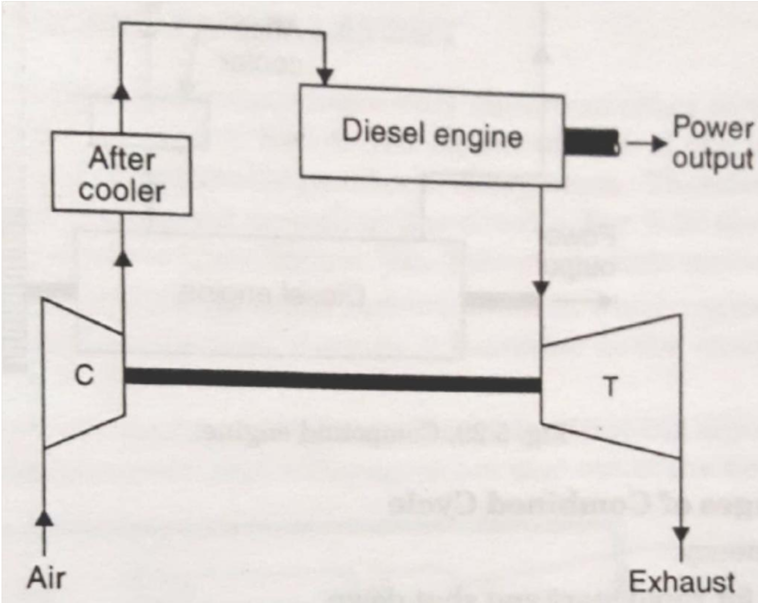
Waste gases released from the turbine are supplied to the boiler, where addition fuel is burnt in the presence of additional air supplied. This increases the temperature of the hot gases thereby improving the rate of heat supplied and steam generation than in a conventional steam boiler. It also improves the overall thermal efficiency by 5%.

If additional fuel is not supplied, it becomes a waste recovery boiler.

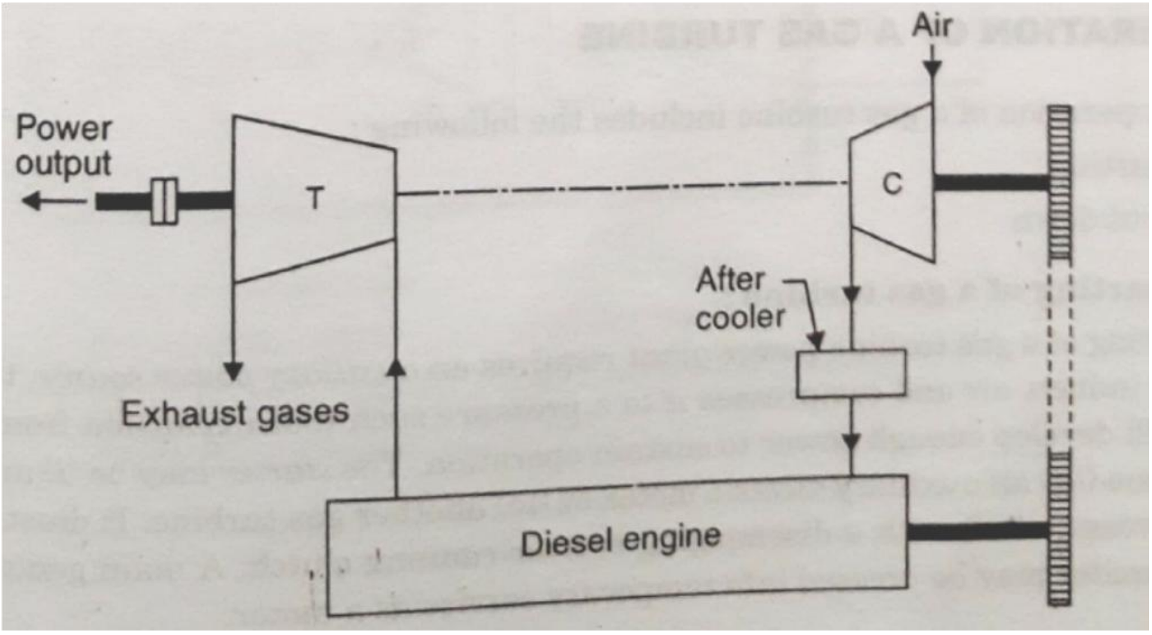


Combination of Gas Turbines and Diesel engines:

1. **Turbo-charging:** Here the exhaust gases released from the diesel engine are expanded in a gas turbine and some extra power is produced. This extra power is utilized to run a compressor. The compressor produces compressed air, which is supplied to the diesel engine in suction process. Power developed by the diesel engine is supplied to the load centers.

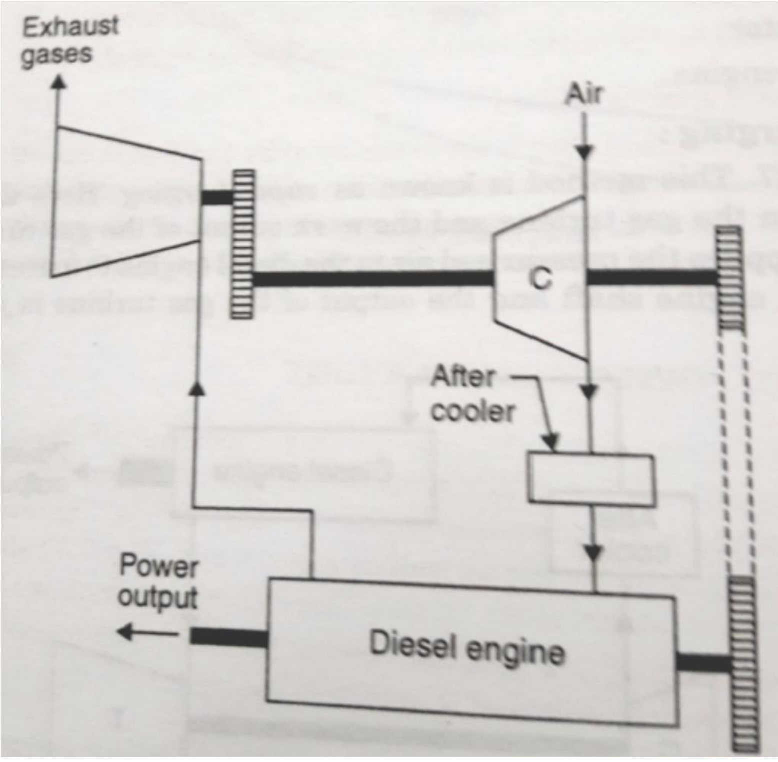


2. **Gas-generator:** Here compressed air is supplied to the diesel engine after cooling the air in aftercooler. Power is supplied to the compressor with the help of a gear drive



from the diesel engine. The gas turbine supplies the power.

3. **Compound Engine:** Power is supplied to the compressor from both diesel engine and gas turbine, through gear drives.


Exhaust gases
Air
C
After cooler
Power output
Diesel engine

MODULE-III

Hydro Power Plant, Power fromNon-Conventional Sources

Hydro power plant :

INTRODUCTION

- In hydro-electric plants energy of water is utilised to move the turbines which in turn run the electric generators. The energy of water utilised for power generation may be kinetic or potential. The *kinetic energy* of water is its energy in motion and is a function of mass and velocity, while the *potential energy* is a function of the difference in level/head of water between two points. In either case continuous availability of a water is a basic necessity ; to ensure this, water collected in natural lakes and reservoirs at high altitudes may be utilised or water may be artificially stored by constructing dams across flowing streams. The ideal site is one in which a good system of natural lakes with substantial catchment area, exists at a high altitude. *Rainfall is the primary source of water* and depends upon such factors as temperature, humidity, cloudiness, wind etc. The usefulness of rainfall for power purposes further depends upon several complex factors which include its intensity, time distribution, topography of land etc. However it has been observed that only a small part of the rainfall can actually be utilised for power generation. A significant part is accounted for by *direct evaporation*, while another similar quantity *seeps* into the soil and forms the underground storage. Some water is also absorbed by

CLASSIFICATION OF HYDRO-ELECTRIC POWER PLANTS

Hydro-electric power stations may be *classified* as follows :

A. According to availability of head :

1. High head power plants
2. Medium head power plants
3. Low head power plants.

B. According to the nature of load :

1. Base load plants
2. Peak load plants.

C. According to the quantity of water available :

1. Run-of-river plant without pondage
2. Run-of-river plant with pondage
3. Storage type plants
4. Pump storage plants
5. Mini and micro-hydel plants

A. *According to availability of head :*

The following figures give a rough idea of the heads under which the various types of plants work :

(*i*) High head power plants	100 m and above
(*ii*) Medium head power plants	30 to 100 m
(*iii*) Low head power plants	25 to 80 m.

Note. It may be noted that figures given above overlap each other. Therefore it is difficult to classify the plants directly on the basis of head alone. The basis, therefore, technically adopted is the *specific speed* of the turbine used for a particular plant.

5.6.1. High Head Power Plants

These types of plants work under heads ranging from 100 to 2000 metres. Water is usually stored up in lakes on high mountains during the rainy season or during the season when the snow melts. The rate of flow should be such that water can last throughout the year.

Fig. 5.2 shows high head power plant layout. Surplus water discharged by the spillway cannot endanger the stability of the main dam by erosion because they are separated. The tunnel through the mountain has a surge chamber excavated near the exit. Flow is controlled by head gates at the tunnel intake, butterfly valves at the top of the penstocks, and gate valves at the turbines. This type of site might also be suitable for an underground station.

The *Pelton wheel* is the common primemover used in high *head power plants*.

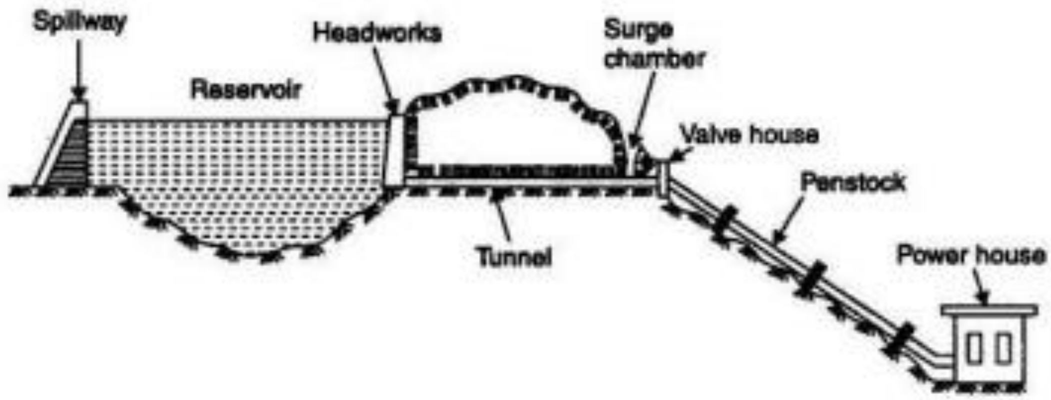


Fig. 5.2. High head power plant layout. The main dam, spillway, and powerhouse stand at widely separated locations. Water flows from the reservoir through a tunnel and penstocks to the turbines.

5.6.2. Medium Head Power Plants

Refer Fig. 5.3. When the operating head of water lies between 30 to 100 metres, the power plant is known as medium head power plant. This type of plant commonly uses *Francis turbines*. The forebay provided at the beginning of the penstock serves as water reservoir. In such plants, the water is generally carried in open canals from main reservoir to the forebay and then to the power-house through the penstock. The forebay itself works as a surge tank in this plant.

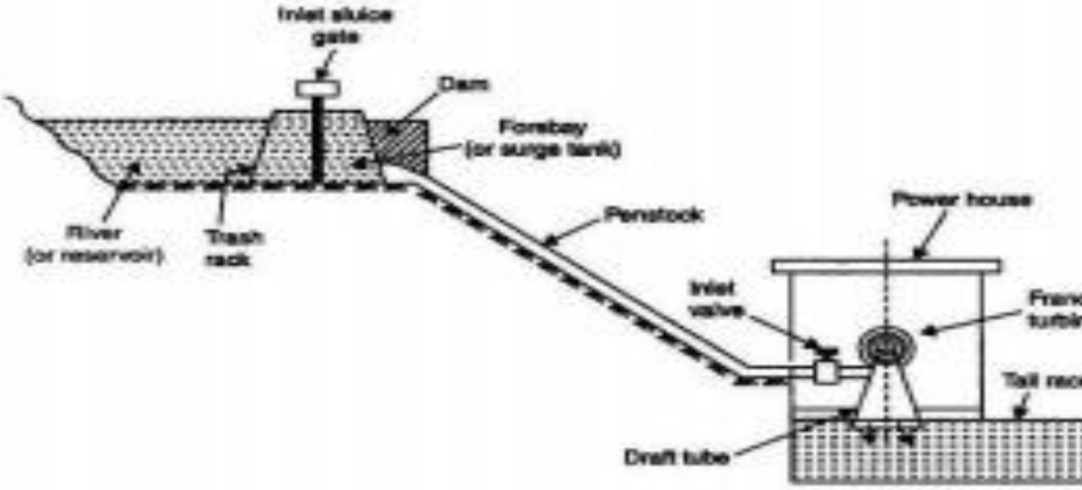


Fig. 5.3. Medium head power plant layout.

5.6.3. Low Head Power Plants

Refer Fig. 5.4. These plants usually consist of a dam across a river. A sideway stream diverges from the river at the dam. Over this stream the power house is constructed. Later this channel joins the river further downstream. This type of plant uses vertical shaft Francis turbine or Kaplan turbine.

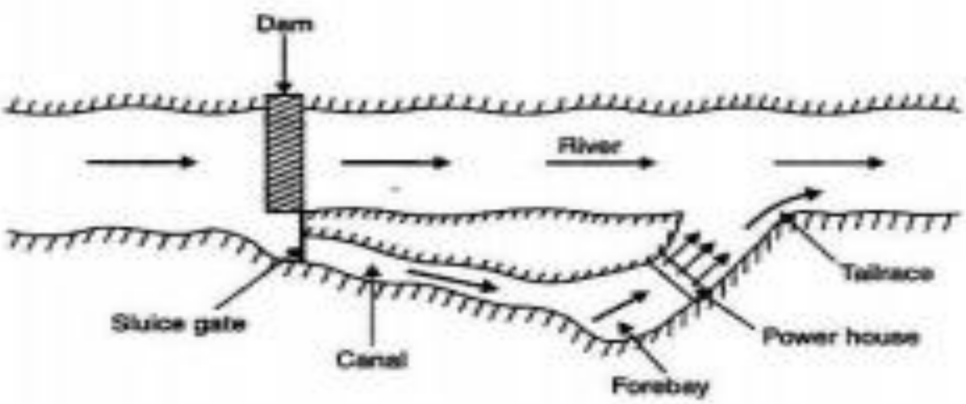


Fig. 5.4. Low head power plant layout.

5.6.9. Pumped Storage Plants

Refer to Fig. 5.5.

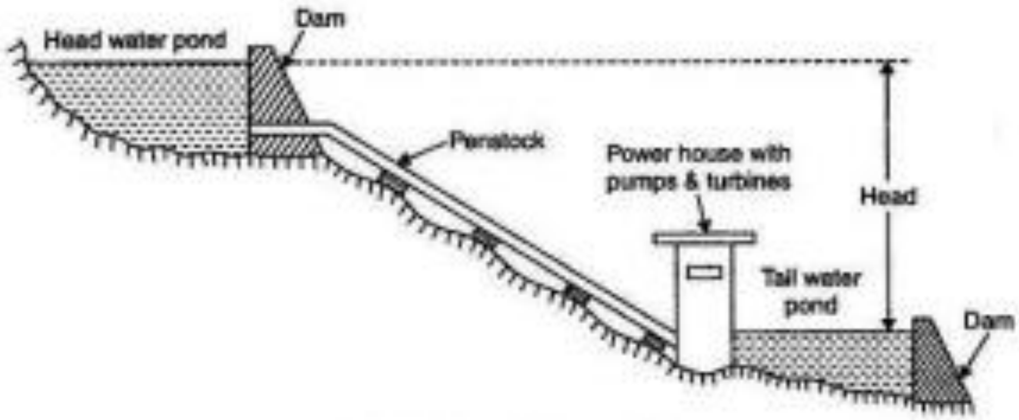


Fig. 5.5. Pumped storage plant.

Pumped storage plants are employed at the places where the quantity of water available for power generation is *inadequate*. Here the water passing through the turbines is stored in *'tail race pond'*. During low load periods this water is pumped back to the head reservoir using the extra energy available. This water can be again used for generating power during peak load periods. Pumping of water may be done seasonally or daily depending upon the conditions of the site and the nature of the load on the plant.

Such plants are *usually interconnected* with steam or diesel engine plants so that off peak capacity of interconnecting stations is used in pumping water and the same is used during peak load periods. Of course, the energy available from the quantity of water pumped by the plant is *less* than the energy input during pumped operation. Again while using pumped water the *power available is reduced* on account of losses occuring in primemovers.

Advantages. The pump storage plants entail the following *advantages* :

1. There is substantial increase in peak load capacity of the plant at comparatively low capital cost.
2. Due to load comparable to rated load on the plant, the operating efficiency of the plant is high.
3. There is an improvement in the load factor of the plant.
4. The energy available during peak load periods is higher than that of during off peak periods so that inspite of losses incurred in pumping there is *over-all gain*.
5. Load on the hydro-electric plant remains uniform.
6. The hydro-electric plant becomes partly independent of the stream flow conditions.

Under pump storage projects almost 70 percent power used in pumping the water can be recovered. In this field the use of *"Reversible Turbine Pump"* units is also worth noting. These units can be used as turbine while generating power and as pump while pumping water to storage. The generator in this case works as motor during reverse operation. The efficiency in such case is high and almost the same in both the operations. With the use of reversible turbine pump sets, additional capital investment on pump and its motor can be saved and the scheme can be worked more economically.

SOURCES OF ENERGY

- **Renewable energy:** Energy obtained from natural and persistent flows of energy occurring in the immediate environment, such energy may also be called Green Energy or Sustainable Energy.

- **Non-renewable energy:** Energy obtained from static stores of energy that remain underground unless released by human interaction. Examples are nuclear fuels and fossil fuels of coal, oil and natural gas, such energy supplies are called finite supplies or Brown Energy.

Non-Renewable/Conventional sources	Renewable/Non- conventional sources
Solids, Liquids, Gases	Solar, Wind, Bio-mass, Geothermal, Ocean, Tidal, Wave, Direct energy conversion

There are five ultimate primary sources of useful energy:

- The Sun.
- The motion and gravitational potential of the Sun, Moon and Earth.
- Geothermal energy from cooling, chemical reactions and radioactive decay in the Earth.
- Human-induced nuclear reactions.
- Chemical reactions from mineral sources.

Availability of these Renewable Sources of energy

SOLAR ENERGY:

Sun is the primary source of energy. The earth receives 1.6×10^{18} units of energy from the Sun annually, which is 20,000 times the requirement of mankind on the earth. Some of the solar energy causes evaporation of water, leading to rains and creation of rivers. Some of it is utilized in photosynthesis which is essential for life on earth.

Three broad categories of possible large scale applications of solar power are

- The heating and cooling of residential and commercial buildings
- The chemical and biological conversion of organic material to liquid, solid and gaseous fuels and
- Conversion of solar energy to electricity.

For developing solar energy two ways have been explored viz., the glass lens and the reflector.

- These devices concentrate the solar rays to a focal point which is characterized by a high degree of heat which can be utilized to boil water and generate steam.
- The reflector is the better of the two methods due to the convenience with which it can be manufactured in different shapes and sizes.
- If an arrangement is provided to turn the reflector with the sun, so that the rays can constantly concentrate at the focal point, a continuous supply of heat is made available during the hours of the day.

WIND POWER:

- Wind power is capable of exploitation for pumping water from deep wells or for generating small amounts of electric energy.
- Modern windmills are capable of working on velocities as low as 3-7 kmph while maximum efficiency is attained at 10-12 kmph.
- A normal working life of 20 to 25 years is estimated for windmills.
- In India, the wind velocity along coastline has a range 10-16 kmph
- No fuel provision and transport are required in wind energy systems are non-polluting.
- The power that can be theoretically obtained from the wind, is proportional to the cube of its velocity and thus high wind velocities are most important. The power developed using this law, in atmospheric condition where the density of air is 1.2014 kg/cu meter, is given as
- Power developed = $13.14 \times 10^{-6}\ A\ V^{3}$ KW
  Where A is the swept area in sq. meter and V the wind velocity in Km/hr.

GEO-THERMAL ENERGY:

- Many geothermal power plants are operating throughout the world. Although larger geothermal power plants are in operation in America today, it is to the credit of the Italians that the first impressive breakthrough in geothermal power exploitation was achieved.
- The oldest geothermal power station is near Larderello in Italy, installed capacity of 380 MW. In New Zealand geothermal power accounts for 40% of the total installed capacity, whereas in Italy it accounts for 6%.
- It is a common knowledge that the earth's interior is made of a hot fluid called 'magma'. The outer crust of the earth has an average thickness of 32 Km and below that, is the magma.
- The average increase in temperature with depth of the earth is 1°C for every 35 to 40 metre depth.
- At a depth of 3 to 4 Km, water boils up and at a depth of about 15 Km, the temperature is, in the range of 1000°C to 1200°C. If the magma finds its way through the weak spots of the earth's crust, it results into a volcano.

- At times, due to certain reasons the surface water penetrates into the crust, where it turns into steam, due to intense heat, and comes out in the form of springs or geysers.
- Move over, the molten magma also contains water, which it releases in the form of steam, which could be utilized for electric power generation.

TIDAL ENERGY:

- Tidal or lunar energy as it is sometimes called has been known to mankind since time immemorial. Various devices, particularly the mills were operated using tidal power.
- In the past water supply of London was pumped to a water tower by a mill operated by the tidal power.
- The tidal power has been used to irrigate fields in Germany and to saw firewood in Canada.
- Tides are caused by the combined gravitational forces of Sun and Moon on the waters of the revolving Earth.
- When the gravitational forces due to the Sun and the Moon add together, tides of maximum range, called spring tides, are obtained. On the other hand, when the two forces oppose each other, tides of minimum range called neap tides, are obtained. In one year there are approximately 705 full tidal cycles.

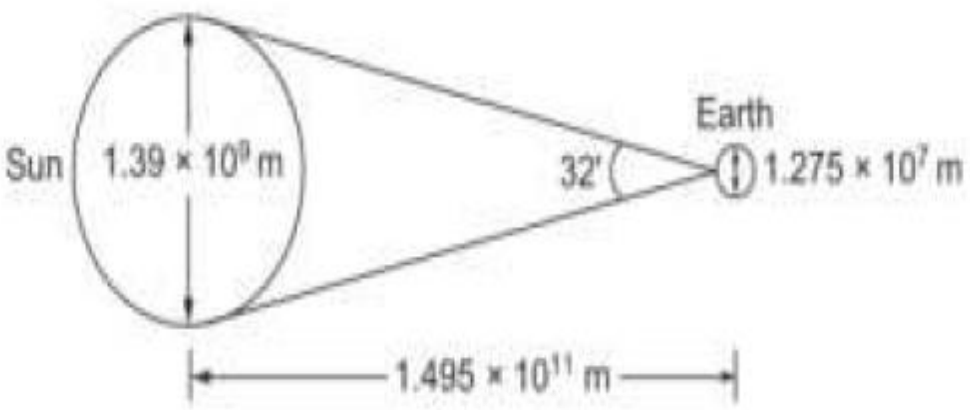
OCEAN THERMAL ENERGY:

- OTEC utilizes the difference in temperature between warm, surface seawater and cold, deep seawater to produce electricity.
- Ocean Thermal Energy Conversion (OTEC) is a process which utilizes the heat energy stored in the tropical ocean. The world's oceans serve as a huge collector of heat energy.
- OTEC requires a temperature difference of about 20^0C.
- In one, simple form of OTEC a fluid with a low boiling point (e.g. ammonia) is used and turned into vapor by heating it up with warm seawater.
- The pressure of the expanding vapor turns a turbine and produces electricity. Cold sea water is then used to re-liquefy the fluid.
- One important bi-product of many of these techniques is fresh water.

SOLAR ENERGY

- Sun is the basic source of energy for Earth and solar energy is available in the form of Electromagnetic Radiations.
- Sun is a large sphere of very hot gases, heat being generated by the various fusion reactions in it.
- Diameter of Sun is 1.39 x 10^6km and diameter of Earth is 1.27 x10^4km at an average distance of 1.495x10^{11} m from the earth.
- As observed from the earth, the sun rotates on its axis about once in every four weeks, though it does not rotate as a solid body.
- Sun subtends an angle of only 32' at Earth's surface (because of large distance between them).
- The direct/beam radiation received from the Sun on the earth is almost parallel.
- The surface of the sun is maintained at a temperature of approximately 5800°K.
- The sun is, in effect, a continuous fusion reactor with its constituent gases as the containing vessel' retained by gravitational forces. The most accepted fusion reaction is in which hydrogen (i.e. four protons) combines to form helium (i.e. one helium nucleus); the mass of the helium nucleus is less that of the four protons, mass having been lost in the reaction and converted to energy.

$$4H^1 \rightarrow He^4 + 2\beta^+ + 2\nu + 25 \text{ Mev}, \qquad E = mc^2$$

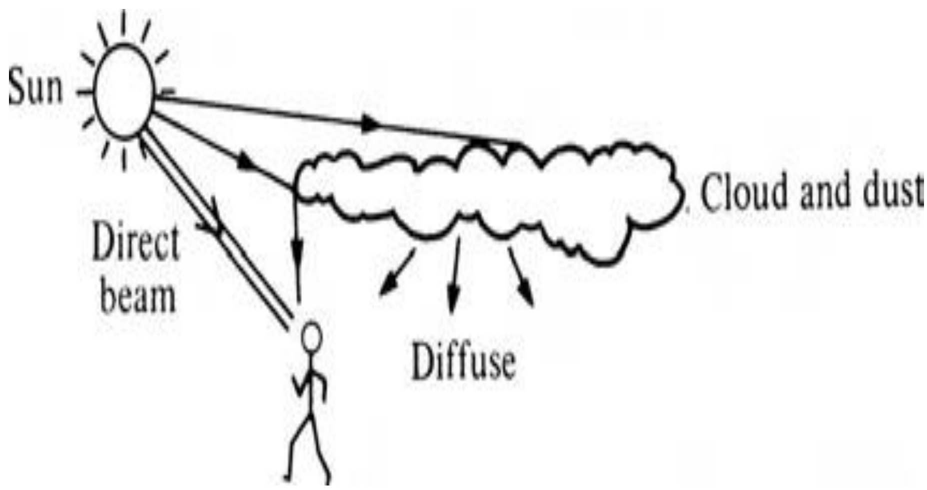


SOLAR ENERGY ON EARTH SURFACE

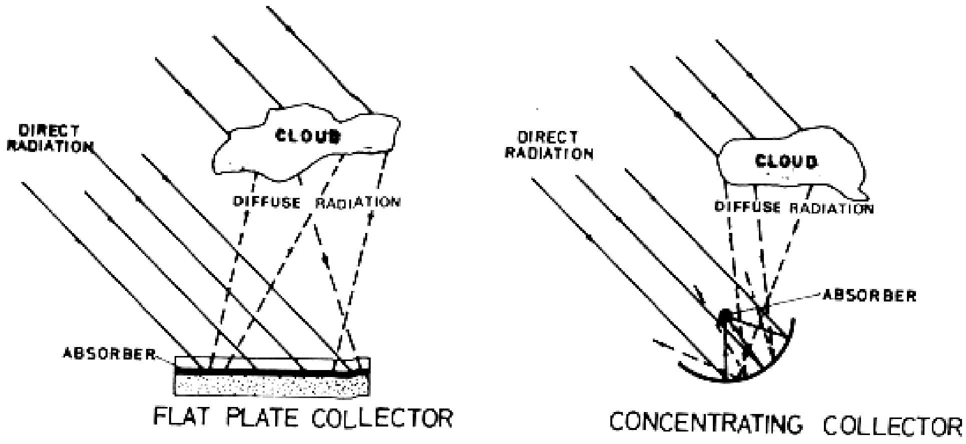
- The earth is surrounded by an atmosphere containing various gases, dust and other suspended particles, water vapor and clouds of various types. The solar radiation during its passage in the atmosphere gets partly absorbed, scattered and reflected in different wavelength bands selectively.
- Radiation gets absorbed in water vapor, Ozone, CO_2, O_2 in certain wavelengths.

- Radiation gets scattered by molecules of different gases and small dust particles known as Rayleigh scattering where the intensity is inversely proportional to the fourth power of wavelength of light ($l \alpha 1/\lambda^4$).
- If the size of the particles are larger than the wavelength of light then Mie Scattering will takes place.
- There will be a reflection of radiation due to clouds, particles of larger size and other material in the atmosphere.
- Considerable amount of solar radiation also gets absorbed by clouds which are of several types.
- Some radiation gets reflected back in the atmosphere due to reflection from the ground, from the clouds, and scattering. This fraction of radiation reflected back is called albedo of the ground and on an average the albedo is 0.3.
- The solar radiation which reaches on the earth surface unattenuated (after scattering, reflection and absorption) is called direct radiation or beam radiation.
- The radiation which gets reflected, absorbed or scattered is not completely lost in the atmosphere and comes back on the surface of the earth in the short wavelength region and called sky or diffuse solar radiation.
- The sum of the diffuse and direct radiation on the surface of the earth is called global or total solar radiation.

Global radiation = Direct Radiation + Diffuse Radiation.



- Direct / Beam Radiation: Solar radiation that does not get absorbed or scattered but reaches the ground directly from the Sun. It produces shadow when interrupted by an opaque object.
- Diffuse Radiation: Solar radiation received after its direction has been changed by reflection and scattering in the atmosphere.



Factors Governing availability of solar energy on the earth

- Earth sun distance
- Tilt of the earth's axis
- Atmospheric Attenuation/Absorption

Factors Affecting Solar Energy availability on a collector surface

- Geographic location
- Site location of collector
- Collector orientation and tilt
- Time of day
- Time of year
- Atmospheric conditions
- Type of collector

SOLAR CONSTANT

- SOLAR CONSTANT (I_{sc}): The rate at which Energy is received from the Sun on a unit area perpendicular to the rays of Sun. at a mean distance of the Earth from the Sun.
- Up to 1970, a standard value of I_{sc} = 1353 W/m2, and now the revised value is I_{sc} = 1353 W/m2 and the difference between two values is only 1 percent.

The standard values of solar constant are expressed in three common units

- I_{sc} = 1353 W/m2 or 1.353KW/m2
- I_{sc} = 116.5 Langley's (calories per sq.cm)per hour or 1165 Kcal per sq.m per hour
- I_{sc} = 429.2 Btu per sq. ft. per hour

- The **extraterrestrial radiation** is defined as the radiations outside the earth's atmosphere and it is not affected by changes in atmospheric conditions.
- The solar radiation that reaches the earth's surface after passing through the earth's atmosphere is known as **terrestrial radiation**.

- The term **solar insolation** (incident solar radiation) is defined as the solar radiation received on a flat horizontal surface on the earth.

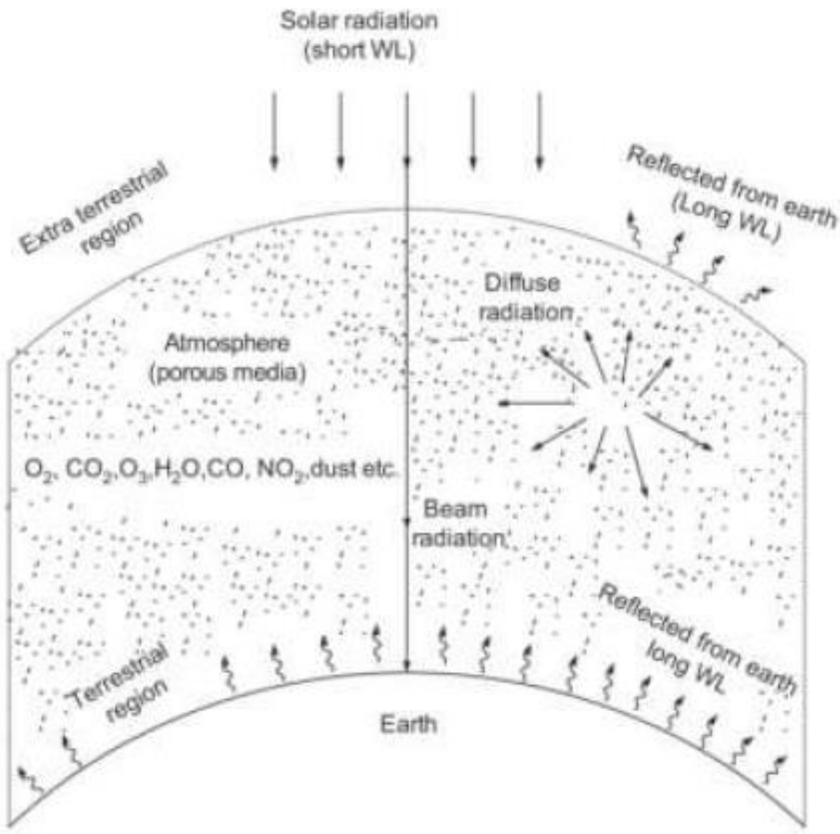


Fig. 4.3 *Propagation of solar radiation through the atmosphere*

VARIATION IN EXTRA-TERRESTRIAL FLUX

- Due to variation in Earth-Sun distance throughout the year the Extra-terrestrial Flux varies, which can be calculated from the equation

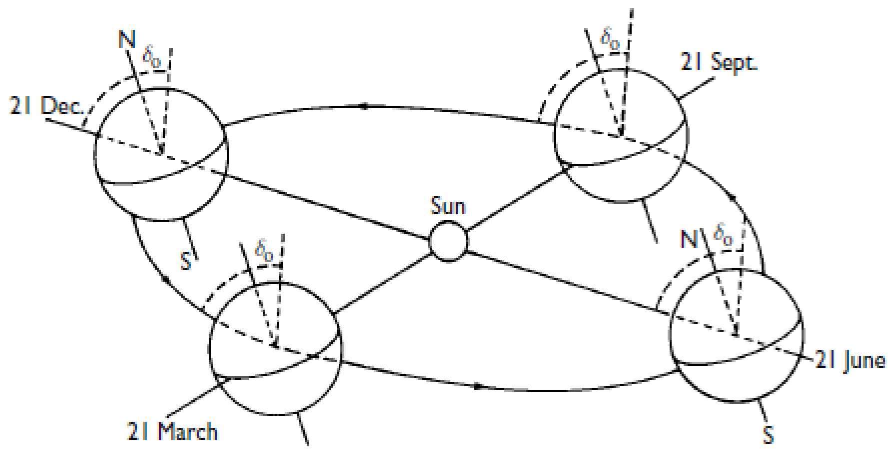
$$I = Isc\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]$$

Where, n = the number of day of the year

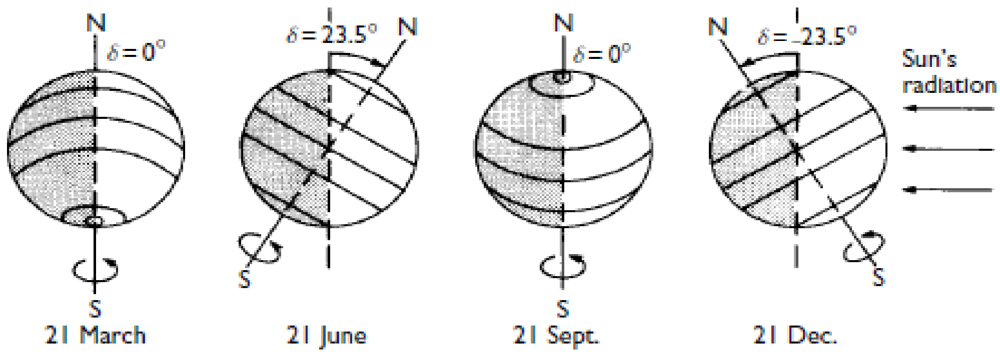
I=intensity of solar radiation that reaches the earth

I_{sc} = Solar Constant= 1353W/m^2

EARTH REVOLUTION

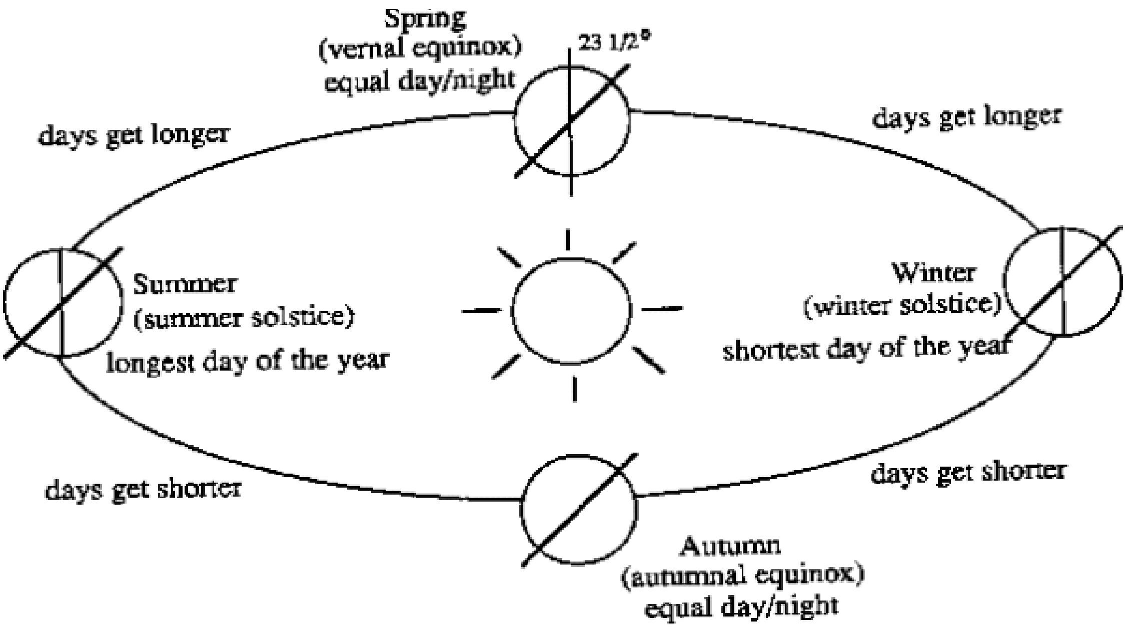


- The orbit of the Earth around the Sun is called an Earth revolution.
- This celestial motion takes 365.26 days to complete one cycle.
- Earth's orbit around the Sun is not circular, but oval or elliptical.
- On this plane the Earth's axis is not at right angles to this surface. but inclined at an angle of about 23.5° from the perpendicular
- An elliptical orbit causes the Earth's distance from the Sun to vary over a year. Yet, this phenomenon is not responsible for the Earth's seasons.
- This variation in the distance from the Sun causes the amount of solar radiation received by the Earth to annually vary by about 6%.



POSITIONS IN EARTH'S REVOLUTION

- On January 3, Perihelion, Earth is closest to the Sun (147.3 million km).
- On July 4, Aphelion, Earth is farthest from the Sun (152.1 million km).



- Figure shows a side view of the Earth in its orbit about the Sun on four important dates: June solstice, September equinox, December solstice, and March equinox.
- Angle of the Earth's axis in relation to the Ecliptic Plane and the North Star on these four dates remains unchanged.
- During the two equinoxes, the circle of illumination cuts through North Pole and South Pole.
- On the June solstice, the circle of illumination is tangent to the Arctic Circle (66.5° N) and the region above this latitude receives 24 hours of daylight. The Arctic Circle is in 24 hours darkness during the December solstice

SPECTRAL DISTRIBUTION OF SOLAR RADIATION

- Spectrum of electromagnetic radiation striking Earth's atmosphere divided into five regions :
- Ultraviolet C (UVC)-Mostly absorbed by Lithosphere.
- Ultraviolet B (UVB)- Mostly absorbed by atmosphere
- Ultraviolet A (UVA) - Considered less damaging to the DNA
- Visible range or light - 400 to 700 nm
- Infrared range - An important part of the electromagnetic radiation reaching Earth.

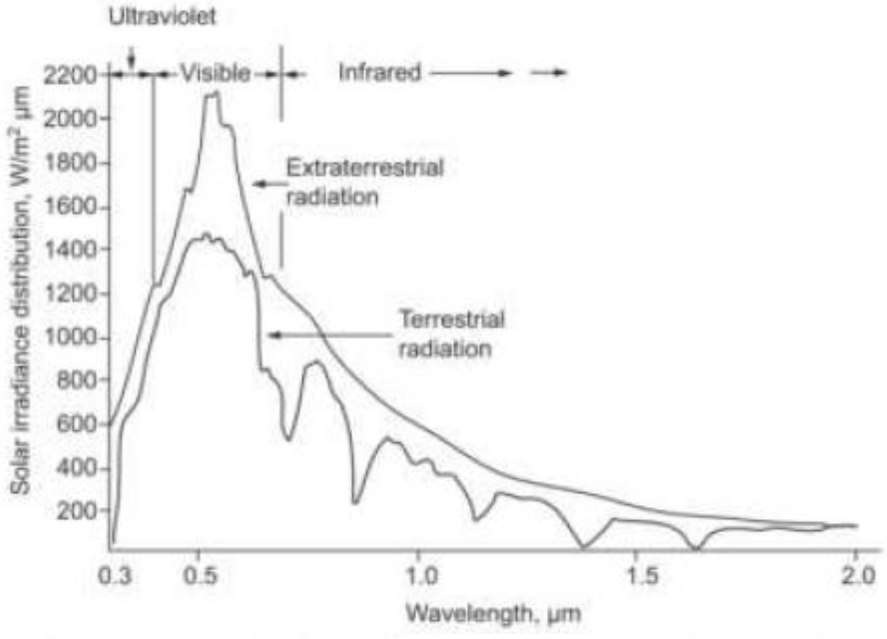


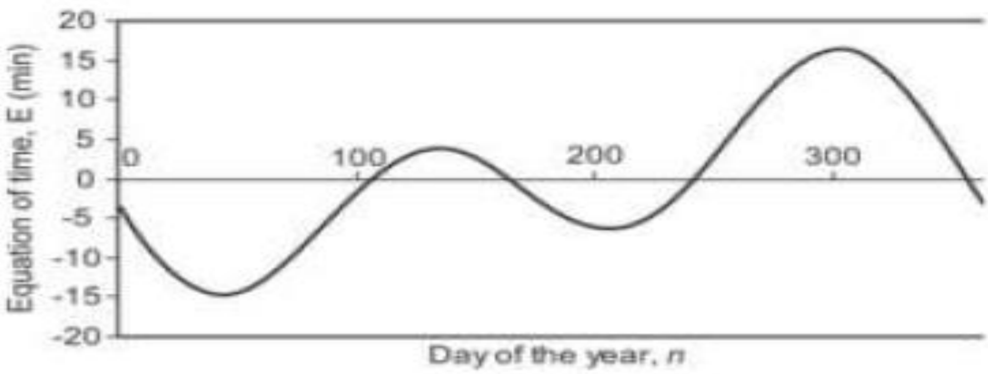
Fig: Spectral distribution

LOCAL SOLAR TIME

- Due to difference in Longitude between a location and the meridian on which the standard Time is based has a magnitude of 4 minutes for every degree difference in Longitude.
- Due to Equation of Time as Earth's orbit and rate of rotation are subject to small perturbations.
- Local solar time = Standard time±4(Standard time longitude- longitude of location)+(Equation of time correction)

$$Lst = ST \pm 4(Ls - Lloc) = E$$

- Equation of time is taken from graph below



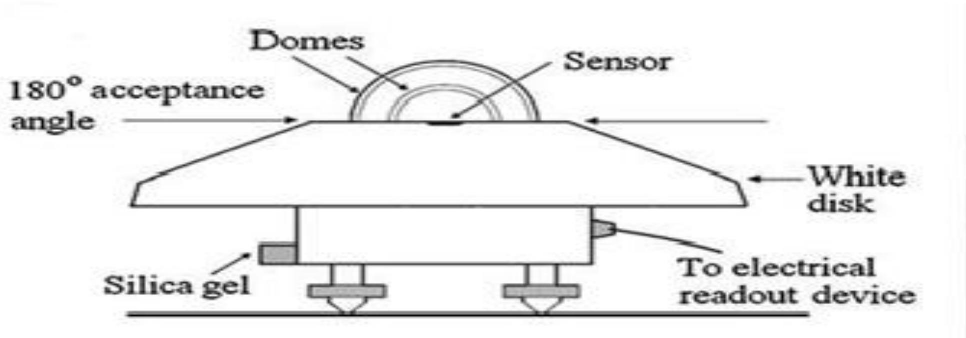
SOLAR RADIATION MEASUREMENT

Solar radiation can be measured by using two devices. They are

1. Pyranometer
2. Pyrheliometer

➢ Pyrheliometer can be used to measure beam radiation only

Pyranometer

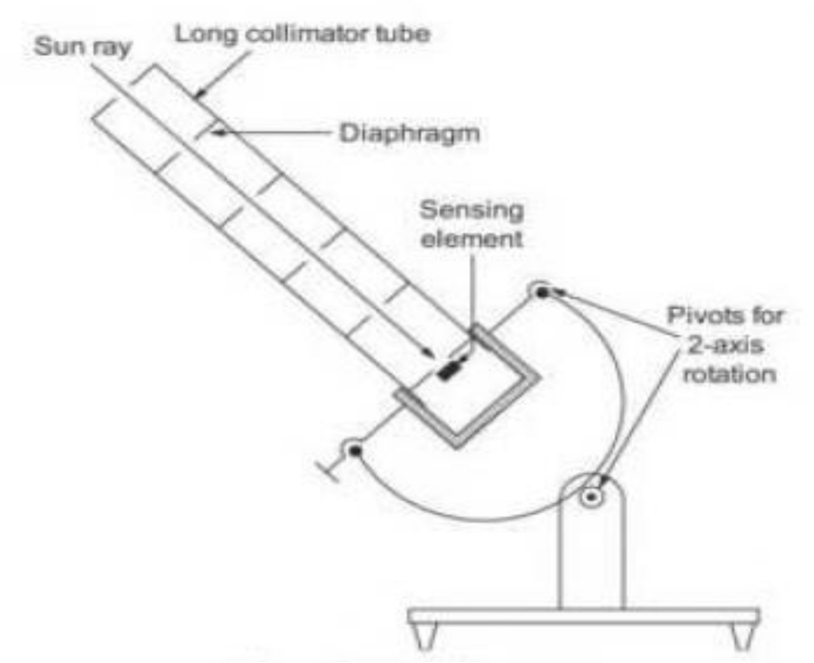


Pyranometer

- Pyranometer can be used to measure total or global radiation.
- Pyranometer consists of a black surface which heats up when exposed to solar radiation.
- Its temperature increases until the rate of heat gain by solar radiation equals the rate of heat loss by convection, conduction and re radiation.
- The hot junctions of a thermopile are attached to the black surface, while the cold junctions are located in such a way that they do not receive the radiation.
- As a result, an emf is generated.
- This emf which is usually in the range of 0 to 10 mV can be read, recorded or integrated over a period of time and is a measure of the global radiation.

Pyrheliometer

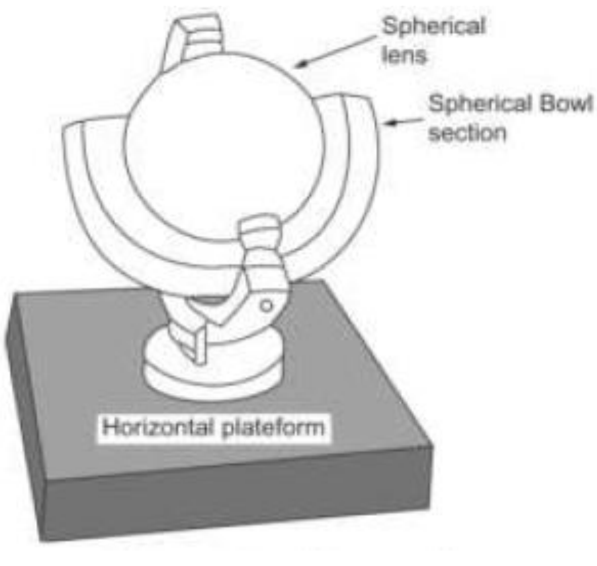
- Pyrheliometer can be used to measure beam radiation only.
- Pyrheliometer consists of a black absorber plate at the base of a tube as shown in figure below.
- The tube is aligned with the direction of the sun’s rays with the help of a two-axis tracking mechanism and and an alignment indicator.
- Thus the black plate receives only beam radiation and a small amount of diffuse radiation falling within the acceptance angle of the instrument.



Pyrheliometer

Sunshine recorder

- The sun's rays are focused by a glass sphere to a point on a card strip held in a groove in a spherical bowl mounted concentrically with the sphere.
- Whenever there is a bright sun shine, the image is formed in intense enough to burn a spot on the card strip.
- Though the day as the sun moves across the sky the image moves along the strip.
- Thus a, a burnt trace whose length is proportional to the duration of sunshine is obtained on the strip.

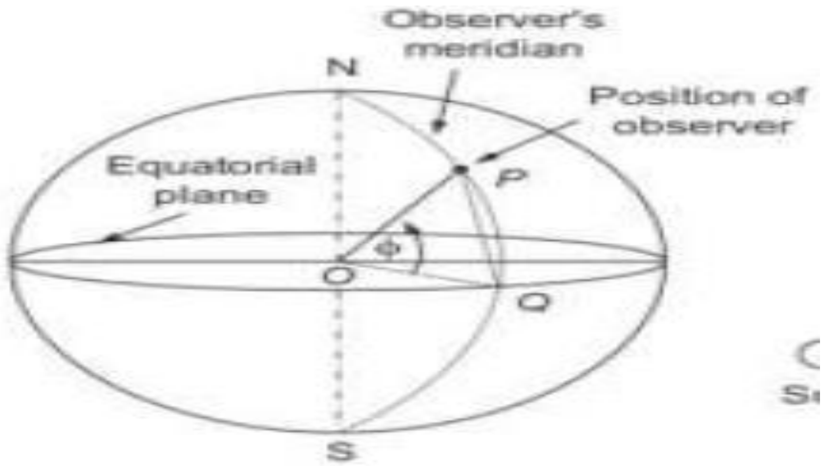


Sunshine recorder

SOLAR RADIATION GEOMETRY

Latitude or Angle of Latitude (φ):

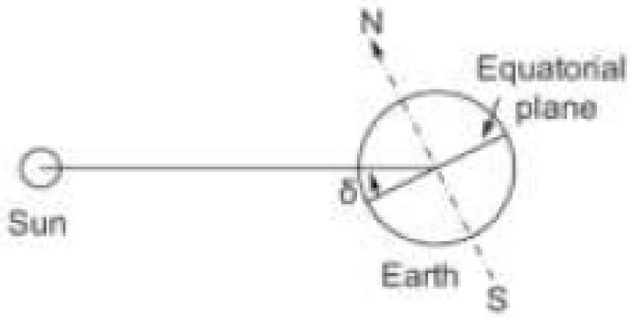
- The latitude of a location on the earth's surface is the angle made by a radial line joining the given location to the centre of the earth with its projection on the equator plane. The latitude is positive for northern hemisphere and negative for southern hemisphere.



Declination angle (δ):

- If a line is drawn between the center of the earth and the sun, the angle between this line and the earth's equatorial plane is called the declination angle. It is positive when measured above the equatorial plane in the northern hemisphere.

$$\delta = 23.45 * \sin[\tfrac{360}{365}(284 + n)] \text{ degrees}$$



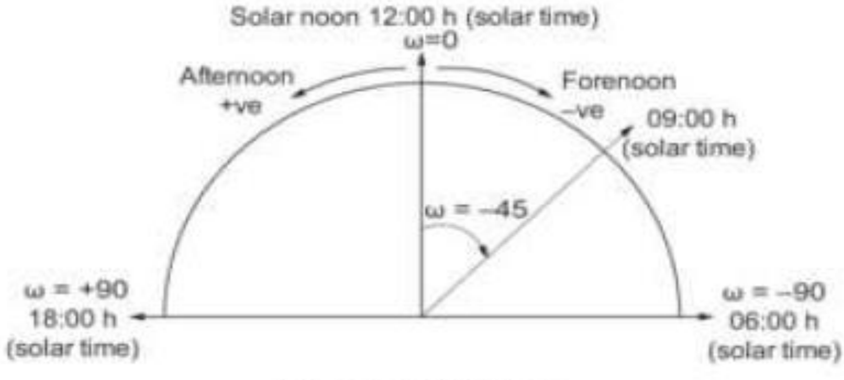
Hour Angle (ω):

- The hour angle at any moment is the angle through which the earth must turn to bring the meridian of the observer directly in line with the sun's rays.
- In other words, it is the angular distance between the meridian of the observer and the meridian whose plane contains sun.

$$\boldsymbol{\omega} = [T_s - 12{:}00] \times 15$$

Where, **ω** = Hour angle in degrees

T_s = Solar time



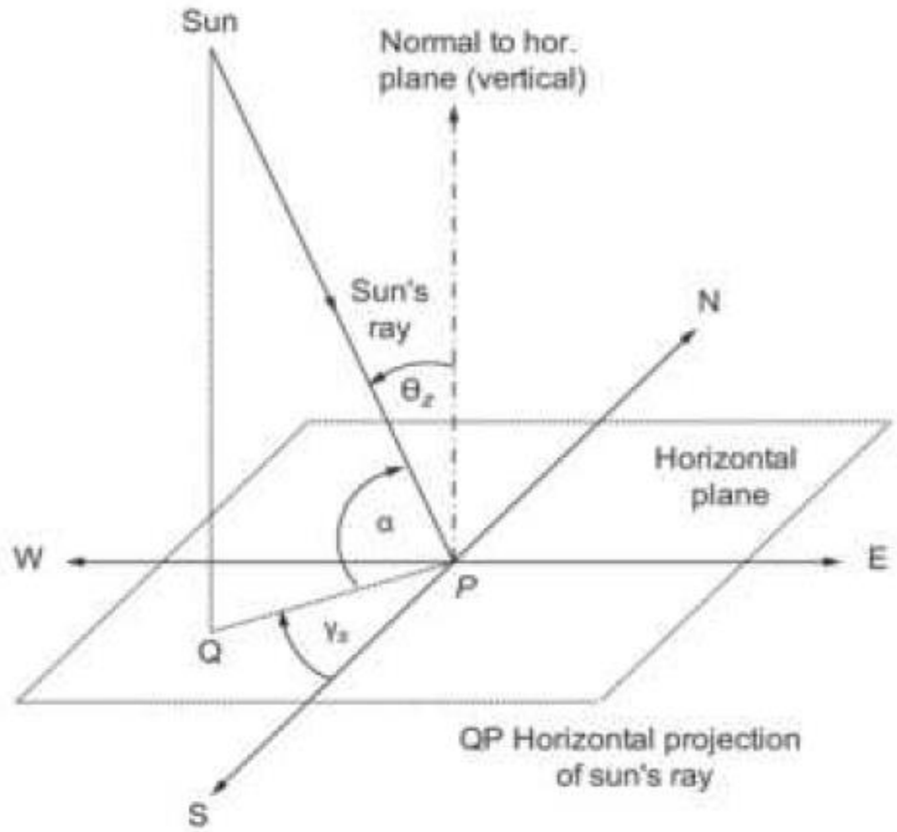
Note:ω positive (+ve) in afternoon and negative (-ve) in forenoon since at solar noon the hour angle is zero.

Inclination Angle or solar altitude angle (α):

- The angle between the central ray from the sun and its projection on a horizontal surface is known as the inclination angle.

Zenith Angle (θ_z):

- It is the angle between the sun's ray and the perpendicular (normal) to the horizontal plane.

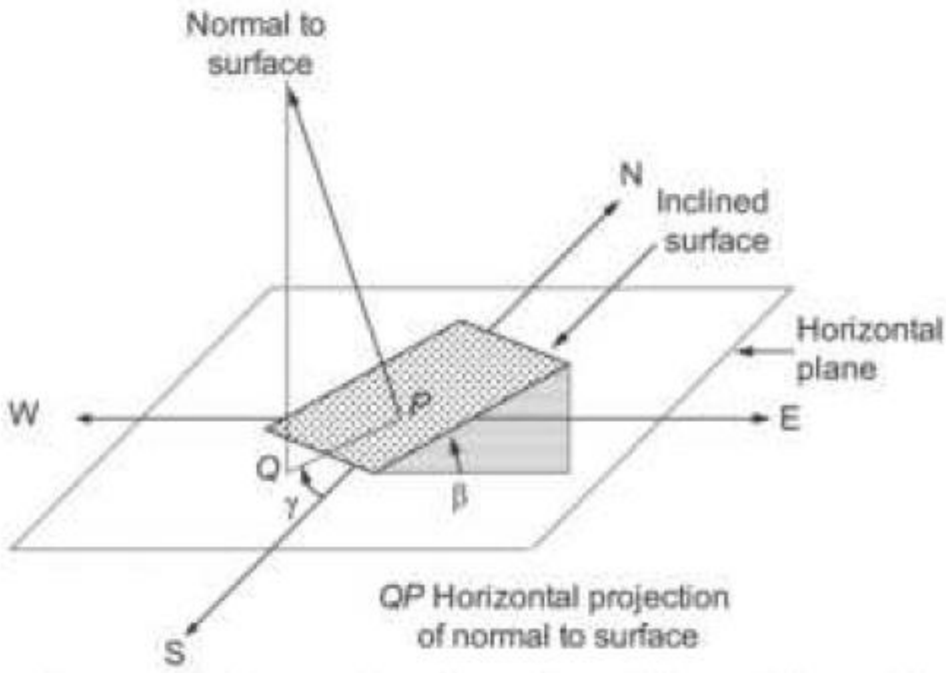


Solar Azimuth Angle (γs):

- It is the angle on a horizontal plane, between the line due south and the projection of the sun's rayon the horizontal plane. It is taken as positive (+ve) when measured from south towards west.

Slope or Tilt Angle (β):

- It is the angle between the inclined plane surface of collector and the horizontal. It is taken to be positive for the surface sloping towards south.

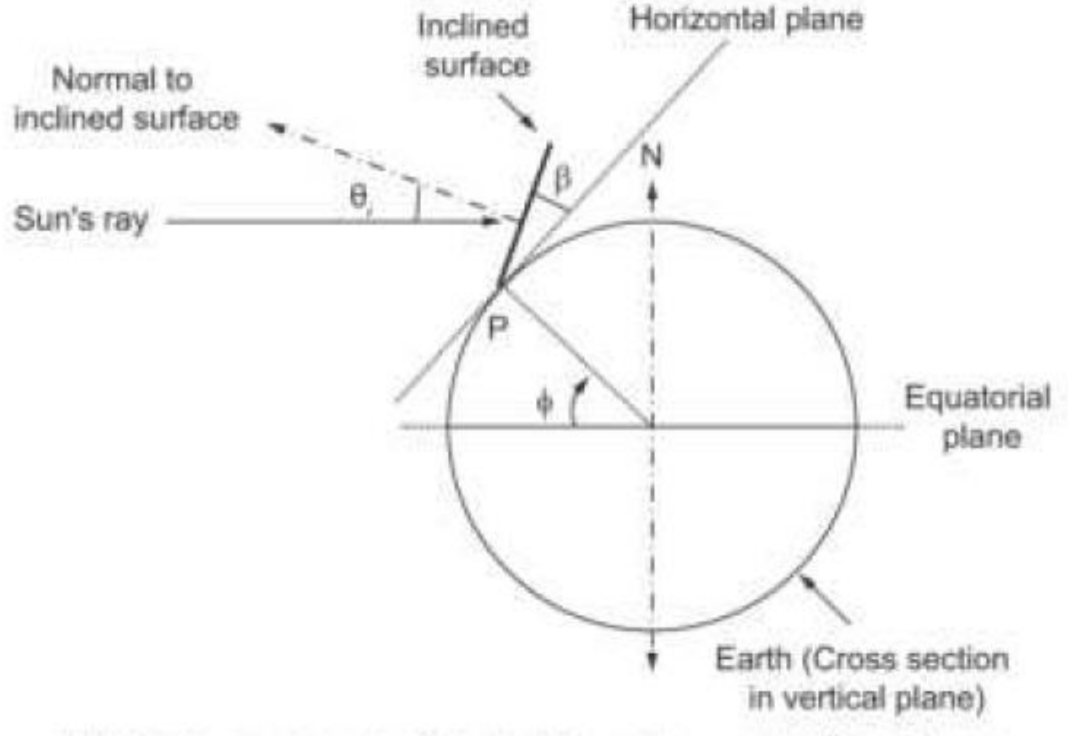


Surface Azimuth Angle (γ):

- It is the angle in the horizontal plane, between the line due south and the horizontal projection of the normal to the inclined plane surface of collector. It is taken as positive +ve when measured from south towards west.

Angle of Incidence (θ_i):

- It is the angle between the sun's ray incident on the plane surface (collector) and the normal to that surface.



Expression for **θi**can be given as,

$$\text{Cos}\ \theta_i = (\cos\varphi\ \cos\beta + \sin\varphi \sin\beta \cos\gamma)\cos\omega\cos\delta + \ \cos\delta\sin\omega\sin\beta\sin\gamma + \sin\delta\,(\sin\varphi\cos\beta - \ \cos\varphi\sin\beta\cos\gamma)$$

Special cases:

i. For surface facing due south, $\gamma = 0$

$$\text{Cos}\ \theta_i = \cos(\varphi - \beta)\cos\omega\cos\delta + \sin\delta\sin(\varphi - \beta)$$

ii. For a horizontal surface $\beta = 0$, $\theta_i = \theta_z$

$$\text{Cos}\ \theta_z = \cos\varphi\cos\omega\cos\delta + \sin\delta\sin\varphi$$

iii. For a vertical surface facing due south

$$\text{Cos}\ \theta_i = -\sin\delta\cos\varphi + \cos\omega\cos\delta\sin\varphi$$

SOLAR RADIATION ON TILTED SURFACES

This flux is the sum of the beam and diffuse radiation falling directly on the surface and the radiation reflected onto the surface from the surroundings.

BEAM RADIATION

The ratio of the beam radiation flux falling on a tilted surface to that falling on a horizontal surface is called the tilt factor for that falling on a horizontal surface is called tilt factor for beam radiation. It is denoted by the symbol r_b. For the case of a tilted surface facing south (i.e. $\gamma = 0°$).

$$\cos\theta = \cos(\varphi - \beta)\cos\omega\cos\delta + \sin\delta\sin(\varphi - \beta)$$

While for a horizontal surface

$$\mathrm{Cos}\,\theta_z = \cos\varphi\cos\omega\cos\delta + \sin\delta\sin\varphi$$

Hence $r_b = \frac{\cos\theta}{\mathrm{Cos}\,\theta_z} = \frac{\cos(\varphi-\beta)\cos\omega\cos\delta+\sin\delta\sin(\varphi-\beta)}{\cos\varphi\cos\omega\cos\delta+\sin\delta\sin\varphi}$

Similarly expressions for r_b can be derived for other situations in which the tilted surface is oriented in a different direction with the tilted factor r_b

DIFFUSE RADIATION

The ratio of the diffuse radiation flux falling on the tilted surface to that falling on a horizontal surface. We have for a tilted surface with a slope β,

$$r_d = \frac{1 + cos\beta}{2}$$

REFLECTED RADIATION

Since $\frac{1+cos\beta}{2}$ is the reflected radiation shape factor for a tilted surface with respect to the sky, it follows that $\frac{1-cos\beta}{2}$ is the radiation shape factor for the surface with respect to the surrounding ground and that the reflectivity is ρ, the tilt factor for reflected radiation is given by

$$r_r = \rho\left[\frac{1 - cos\beta}{2}\right]$$

Flux on tilted surfaces

The flux I_r falling on a tilted surface at any instant is thus given by

$$I_r = I_b r_b + I_d r_d + (I_b + I_d) r_r$$

The ratio of the daily radiation falling on such a surface (H_T) to the daily global radiation on a horizontal surface (H_g) is given by an equation,

$$\frac{H_T}{H_g} = \left[1 - \frac{H_d}{H_g}\right] R_b + \frac{H_d}{H_g} R_d + R_r$$

For a south facing surface ($\gamma = 0^o$), Liu and Jordan show that

$$R_b = \frac{\omega_{st}\sin\delta\sin(\varphi - \beta) + \cos\delta\sin\omega_{st}\cos(\varphi - \beta)}{\omega_s\sin\delta\sin\varphi + \cos\varphi\sin\omega_s\cos\delta}$$

$$R_d = r_d = \frac{1 + cos\beta}{2}$$

$$R_r = r_r = \rho\left[\frac{1-cos\beta}{2}\right]$$

Where, ω_{st} and ω_s are the sunrise or sunset hour angles (expressed in radians) for the tilted surface and a horizontal surfaces respectively.

Assignment-Cum-Tutorial Questions

A. Questions testing the remembering / understanding level of students

I) Objective Questions

1. Which process is responsible for production of energy in the sun?

(a) Nuclear fission reaction (b) Nuclear fusion reaction

(c) Exothermal chemical reaction (d) All of the above

2. Which one of the following statements is not true for solar energy?

(a) It is a dilute form of energy. (b) Its availability is diurnal.

(c) Availability at any instant of time is uncertain.

(d) Its harnessing at large scale is easy.

3. At solar noon, the hour angle is

(a)$+90^0$ (b)-90^0 (c) 0^0 (d) $+180^0$

4. Diffused radiation

(a) has no unique direction (b) has a unique direction

(c) has short wavelength as compared to beam radiation

(d) has larger magnitude as compared to beam radiation

5. On the representative day of each month, the extraterrestrial daily radiation may be taken as equal to

(a) beam radiation at the location

(b) diffused radiation at the location

(c) global radiation at the location

(d) monthly average, daily extraterrestrial radiation at the location

6. A horizontal surface receives

(a) no reflected component of radiation

(b) 50% of the reflected component of radiation

(c) 50% of the diffused component of radiation

(d) 50% of the beam component of radiation

7. on September 21, the declination angle will be

(a) zero (b)+23.45^0 (c)-23.45^0

(d)+180^0

8. A vertical surface receives

(a) no reflected component of radiation

(b) 50% of the reflected component of radiation

(c) 100% of diffused component of radiation

(d) 50% of the beam component of radiation

II) Descriptive Questions

1. What are the disadvantages of solar energy?

2. Define solar irradiance, solar constant, extraterrestrial and terrestrial radiations.

3. What is the standard value of solar constant?

4. What are the indirect forms of solar energy?

5. Define solar irradiance, solar constant, extraterrestrial and terrestrial radiations

6. What are the indirect forms of solar energy?

7. What do you understand by the earth's albedo?

8. How is the energy continuously being produced in the sun?

9. What is the difference between pyrheliometer and pyranometer?

10. Describe the percentage-wise distribution of various components in extraterrestrial radiation.

11. Explain the depletion process of solar radiation as it passes through the atmosphere to reach the surface of the earth.

12. At what wavelengths the radiation emitted from the sun and that reflected from earth are centered?

B. Question testing the ability of students in applying the concepts.

I) Multiple choice Questions

1. At the inclination angle of 30°, what will be magnitude of the zenith angle?

(a) 30° (b) 120° (c) 150° (d) 60°·

2. For 1 degree change in longitude, the change in solar time is

(a) 4 minutes (b) 4 seconds (c) 1 minute (d) 1 hour

3. The percentage of the incoming radiation reflected back to space by the earth is

(a) 10% (b) 20% (c) 30% (d) 40%

4. Air mass ratio is minimum

(a) when the sun is at zenith (b) at sunrise (c) at sunset (d) at noon

5. Calculate hour angle on June 21 and surface located at Bombay ($19^o\ 07^I$ N, 72^o51^I E) And inclined at an angle of 10^o

(a) $+94^o$ (b)$+ 93.5^o$ (c) -93.5^o (d) -94^o

6. Calculate solar time corresponding to 1430h at Bombay ($19^o\ 07^I$ N, 72^o51^I E) on July 1

(a) 1347h (b) 1340h (c) 1352h (d) 1344h

II) Problems:

1. a) Define declination angle, hour angle, zenith angle and solar azimuth angle.

b) Calculate the number of day light hours at Bangalore on 21 June and 21December in a leap year. The latitude of Bangalore is 12^o58^I N.

2. (a) Define solar Azimuth angle, Angle of incidence and Zenith angle.

(b) Calculate the angle of incidence on a horizontal plane surface of a location whose longitude and latitude are $88^0 21^1$E and $22^0 32^1$N respectively at 11:00Hrs on June 1. The standard IST longitude is $81^0 44^1$E

3. Calculate the sunset hour angle and day length at location latitude of 35^0 N, on February 14

4. (a) Determine the altitude and azimuth angle at 3 pm (IST) on June 15, for Mumbai (latitude 18^0 54'N, longitude 72^0 49'E).

(b) For above location, determine the angle of incidence over a south facing surface with tilt angle of 150 with the horizontal.(c) Also calculate the hour of the sunrise and the length of the day.

5. An inclined surface, facing due south, tilted at 60^0 with horizontal is location at latitude $27^0 54'$ N and longitude 78^0 5'E on March 22 at 1 PM (IST). The reflection co-efficient of the ground is 0.2. Calculate total radiator received at the surface. Also calculate the values of conversion factors for diffuse and reflected components.

6. Calculate total radiation at an inclined surface facing due south, tilted at 35^0 with horizontal at a location with latitude $26^0 52'$on Jan 3 at 12 Noon (solar time). The reflected co-efficient of the ground is 0.2. Calculate the values of conversion factors for beam, diffuse and reflected components.

7. Calculate the monthly average total daily radiation falling on flat plate collector by a tilting angle $30^0$from the ground at New Delhi $28^0 35^1$N and $77^0 12^1$E in the month of November. Assume ground reflectivity as 0.2.

8. Calculate the monthly average of the daily global radiation on the horizontal surface at Gulbarga (34.05° N, 74.38° E), during the month of October if the average sunshine hour per day is 5 hours

C. Questions testing the analyzing / evaluating ability of students

1. Calculate the angle of incidence on a horizontal plane surface at Kolkata, at 14:00 h (1ST) on 21 March in a leap year. The longitude and latitude of Kolkata are 88° 20'E and 22° 32' N respectively. The standard longitude of 1ST is 81° 44' E.

2. Estimate the daily global radiation on a horizontal surface at Baroda (22° 13'N, 73° 13' E) during the month of March. If constants a and b are 0.28 and 0.48 respectively and average sunshine hours for day is 9.5

3. Calculate the angle made by beam radiation with the normal to a flat-plate collector, tilted by 30° from the horizontal, pointing due south, located at New Delhi, at 11:00 h (1ST), on 1 June. The latitude and longitude of New Delhi are 28° 35' N and 77° 12' E respectively. The standard 1ST longitude is 81° 44' E

4. Drive an expression for solar day length.

5. Analyze the demand for renewable energy sources in brief.

6. Compare various measuring instruments for solar radiation and list out the best instrument for measuring solar radiations

7. Derive an expression for solar radiation on tilted surface?

ESSENTIAL SUBSYSTEMS IN A SOLAR ENERGY PLANT

1. **Solar collector**: Solar collectors are used to collect the solar energy and convert the incident radiations into thermal energy by absorbing them. This heat is extracted by flowing fluid (air or water or mixture with antifreeze) in the tube of the collector for further utilization in different applications. The collectors are classified as;

- Non concentrating collectors
- Concentrating (focusing) collectors

Non-Concentrating Collectors

In these collectors the area of collector to intercept the solar radiation is equal to the absorber plate and has concentration ratio of 1. Flat Plate Collectors (Glaze Type) Flat plate collector is most important part of any solar thermal energy system. It is simplest in design and both direct and diffuse radiations are absorbed by collector and converted into useful heat. These collectors are suitable for heating to temperature below 100^{o}C.

Advantages

- It utilizes the both the beam as well as diffuse radiation for heating.
- Requires less maintenance.

Disadvantages

- Large heat losses by conduction and radiation because of large area.
- No tracking of sun.
- Low water temperature is achieved.

Concentrating Collectors

Concentrating collector is a device to collect solar energy with high intensity of solar radiation on the energy absorbing surface. Such collectors use optical system in the form of reflectors or refractors. These collectors are used for medium (100-300^{o} C) and high-temperature (above 300^{o}C) applications such as steam production for the generation of electricity. The high temperature is achieved at absorber because of reflecting arrangement provided for concentrating the radiation at required location using mirrors and lenses. These collectors are best suited to places having more number of clear days in a year.

FLAT PLATE COLLECTORS: These are non concentrating type collectors, these are having five main components as follows.

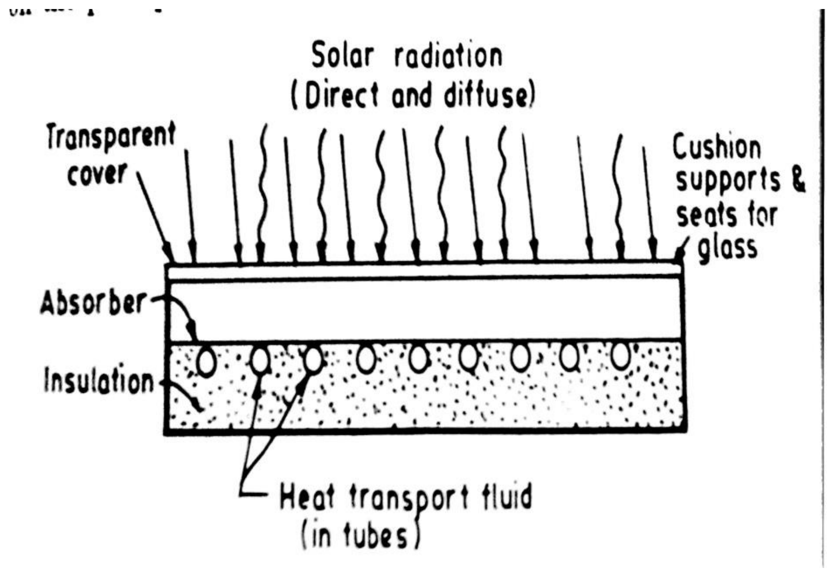
i) A transparent cover which may be one or more sheets of glass or radiation transmitting plastic film or sheet.

ii) Tubes, fins, passages or channels are integral with the collector absorber plate or connected to it, which carry the water, air or other fluid.

iii) The absorber plate, normally metallic or with a black surface, although a wide variety of other materials can be used with air heaters.

iv) Insulation, which should be provided at the back and sides to minimize the heat losses. Standard insulating materials such as fiber glass or styro-foam are used for this purpose.

v) The casing or container which encloses the other components and protects them from the weather.



2. **Energy transport medium**: Substances such as water/ steam, liquid metal or gas are used to transport the thermal energy from the collector to the heat exchanger or thermal storage. In solar PV systems energy transport occurs in electrical form.

3. **Energy storage**: Solar energy is not available continuously. So we need an energy storage medium for maintaining power supply during nights or cloudy periods. There are three major types of energy storage

- Thermal energy storage
- Battery storage
- Pumped storage hydro-electric plant.

4. **Energy conversion plant**: Thermal energy collected by solar collectors is used for producing steam, hot water, etc. Solar energy converted to thermal energy is fed to steam-thermal or gas-thermal power plant.

5. **Power conditioning, control and protection system**: Load requirements of electrical energy vary with time. The energy supply has certain specifications like voltage, current, frequency, power etc. The power conditioning unit performs several functions such as control, regulation, conditioning, protection, automation, etc.

Subsystems in solar thermal energy conversion plants

1. **Alternative or standby power supply**: The backup may be obtained as power from electrical network or standby diesel generator.

SOLAR ENERGY STORAGE

Energy can be stored in various forms and the storage methods are classified on the basis of the form in which it is stored. Some of the important energy storage methods are the following

1. Mechanical energy storage
   a. Pumped storage

b. Flywheel storage
c. Compressed air storage
2. Chemical energy storage
   a. Batteries storage
   b. Hydrogen storage
   c. Reversible chemical reaction storage
3. Electromagnetic energy storage
4. Electrostatic energy storage
5. Thermal (Heat) energy storage
   a. Sensible heat storage
   b. Latent heat storage
6. Biological storage

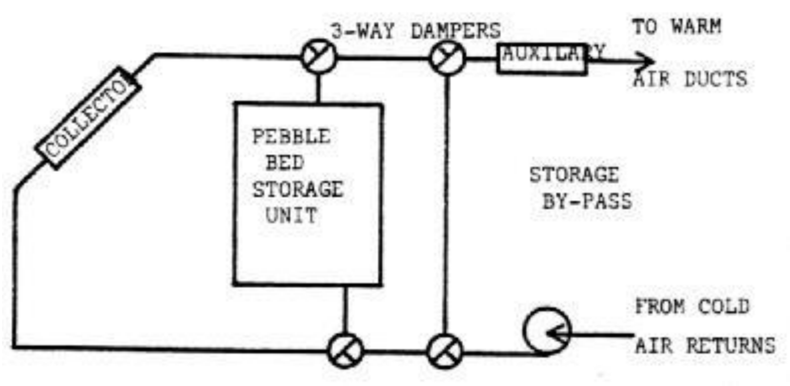
THERMAL ENERGY STORAGE

Sensible heat: Sensible heat is heat exchanged by a body or thermodynamic system that changes the temperature, and some macroscopic variables of the body, but leaves unchanged certain other macroscopic variables, such as volume or pressure.

Latent heat: The heat required to convert a solid into a liquid or vapor, or a liquid into a vapor, without change of temperature.

SENSIBLE HEAT STORAGE

In this type of storage, thermal energy is stored by virtue of heat capacity and the change in temperature of the material during the process of charging and discharging. The temperature of the storage material rises when energy is absorbed and drops when energy is withdrawn. The charging and discharging operation in a sensible heat storage system can be expected to be completely reversible for an unlimited number of cycles over the lifespan.



On the basis of heat-storage media, sensible heat storage system can be classified as

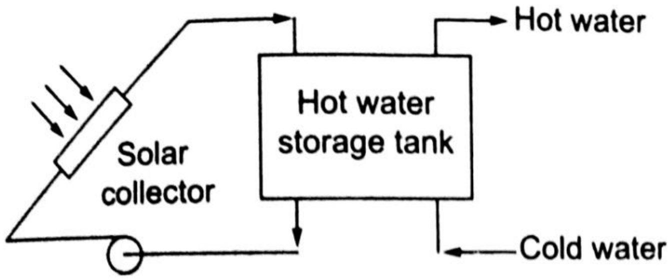
i) Liquid media storage
ii) Solid media storage
iii) Dual media storage

LIQUID MEDIA STORAGE

In this the solar energy is absorbed and stored by a liquid, of all the available liquids, water can be considered to be the most suitable liquid media for storage below 100^0 C.

Short-term thermal energy storage in water

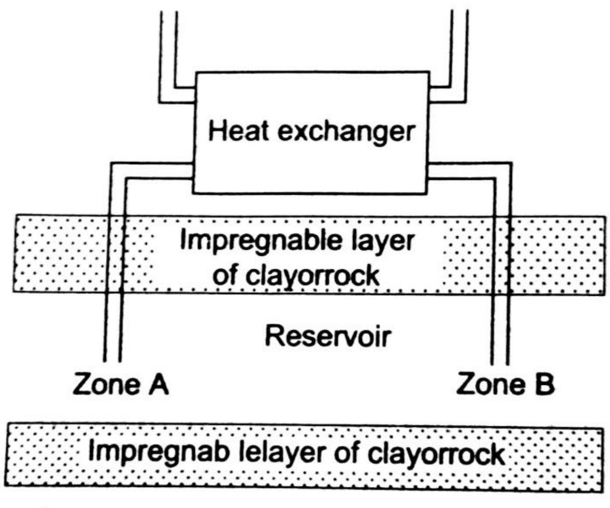
A short term thermal energy storage system consists of hot water stored in a well-insulated tank. Storage in this manner is economical only for a few days since the heat losses become



prohibitive over long durations. Though water is the best choice as a heat-storage medium in a space-heat system; other liquids such as oils, liquid metals and molten salts have also been used in solar thermal power plants.

Long term thermal storage in underground layers

Large size and long term storage of hot in underground reservoirs is possible without the use of special insulating materials. Here cold ground water from zone A is heated by passing through a heat exchanger and return zone B where it is stored. In the discharge mode, the hot water from zone B flows back to the heat exchanger where it gives out the heat and return to the zone A**.**



Advantages

1. It is abundant and inexpensive
2. It is easy to handle, non toxic, and non combustible
3. Its flow can takes place by thermo-siphon action
4. It has high density, high specific heat, good thermal conductivity and low viscosity.
5. Can be used both as storage medium as well as working medium
6. Charging and discharging of heat can occur simultaneously

7. Control of water system is flexible

Disadvantages

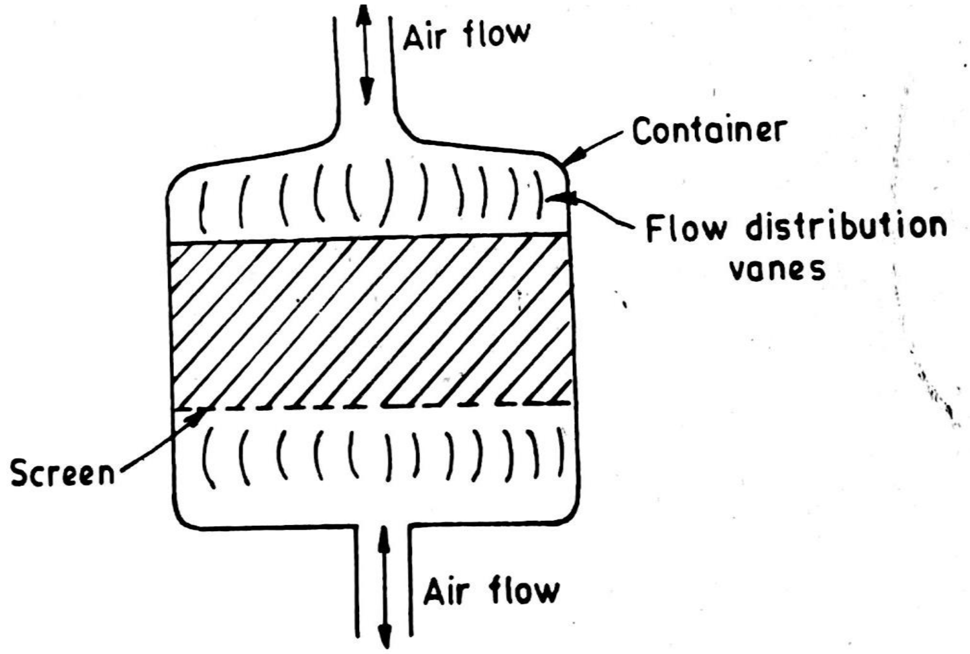
1. Limited temperature range (0^0 C to 100^0 C)
2. Corrosive medium
3. Low surface tension (leaks easily)

SOLID MEDIA STORAGE (Packed bed storage)

It utilizes the heat capacity of a bed of loosely packed solid materials such as rocks,, metals, concrete, sand, bricks, etc., to store energy. A fluid, usually air, is circulated through the bed to add or remove energy. Flow is maintained through the bed in one direction, during addition of heat and in the opposite direction during removal of heat. Here, energy can be used at low or high temperature since these will neither freeze nor boil. The energy change for 50^0 C is about 10 Wh/kg for most rocks, concrete and iron ore.

Components in a packed bed storage system

1. container
2. Screen to support the bed
3. Support for the screen, inlet and outlet ducts



Advantages

1. Rocks are abundant, low cost, easy to handle, non toxic and non combustible
2. High storage temperatures are possible
3. Heat exchanger can be avoided
4. No freezing problem
5. No corrosion

Disadvantages

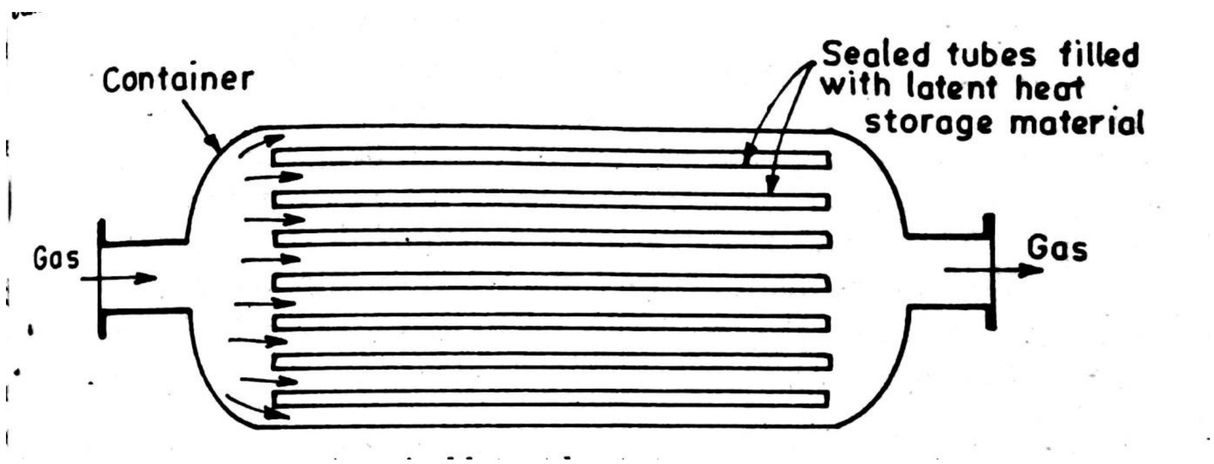
1. Storage volumes are large
2. High pressure drop
3. Simultaneous charging and discharging are not possible

Dual media storage

In dual media storage, both solid and liquid sensible heat storage materials are used. These solid and liquid materials maybe combined in a number of ways. One of them is jointly use the bedrock and water tanks (With water tank surrounded by Bed rock).

LATENT HEAT STORAGE (STORAGE IN PHASE CHANGE MATERIALS)

In this class of storage, energy is stored by virtue of latent heat of change of phase of the storage medium. Phase change materials have considerably higher thermal energy storage densities as compared to sensible heat storage materials and are able to absorb or release large quantities of energy at a constant temperature.



Therefore, these systems are more compact but more expensive than sensible heat-storage systems. Various phase changes that can occur are

Solid-Solid: Heat is stored as the material is transformed from one crystalline form to another. These transitions involve small volume changes, however most of them have small latent heats.

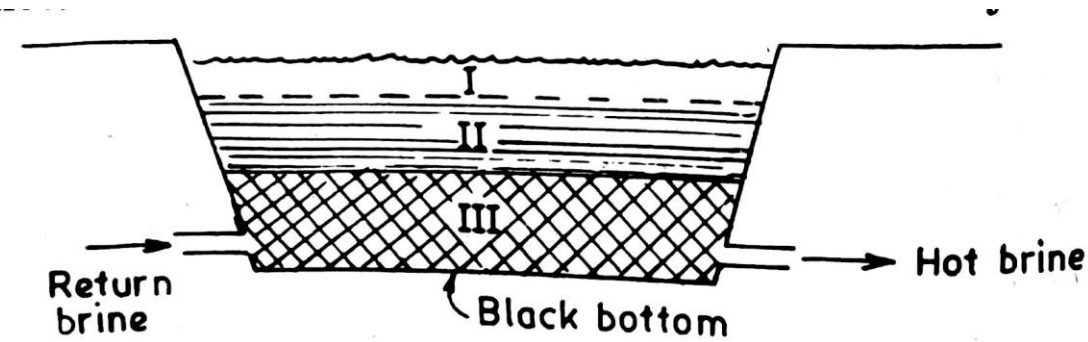
Solid-Liquid: includes storage in salt hydrates. Certain inorganic salts, which are soluble in water and form crystalline salt hydrates, are employed.

Solid-Gas & Liquid-Gas:

Solid-gas and liquid-gas transformations are not employed in spite of large latent heat as large changes in volume make the system complex and impracticable.

SOLAR POND

A natural or artificial body of water for collecting and absorbing solar radiation energy and storing it as heat. Thus a solar pond combines solar energy collection and sensible heat storage.



(i) Surface convective zone.
(ii) Non-convective zone.
(iii) Storage zone.

A solar pond is a mass of shallow water about I or 2 meters deep with a large collection area, which acts a heat trap. It contains dissolved salts to generate a stable density gradient. Part of the incident radiation entering the pond surface is absorbed throughout the depth and the remainder which penetrates the pond is absorbed at the black bottom. If the pond were initially filled with fresh water, lower layers would heat up, expand and rise to the surface.

Because of the convective mixing and heat loss at the surface, only a small temperature rise in the pond could be realized. On the other hand convection can be eliminated by initially creating a sufficiently strong salt concentration gradient. With the convection suppressed, the heat is lost from the lower layers only by conduction. Because of the relatively conductivity, the water acts as an insulator and permits high temperature to develop in the bottom layers. At the bottom of the pond, a thick durable plastic liner is laid.

HEATING AND COOLING OF BUILDINGS

Because of the large heat storage capability in the lower convective zone of the solar pond, it has ideal use for heating even at high latitude stations and for several cloudy days.

PRODUCTION OF POWER

A solar pond can be used to generate electricity by driving a thermo-electric device or an organic Rankine cycle engine (a turbine powered by evaporating an organic fluid with a low boiling point). Even low temperatures heat that is obtained from solar ponds can be converted into electric power.

INDUSTRIAL PROCESS HEAT

Industrial process heat is the thermal energy used directly in the preparation and of treatment of materials and goods manufactured by industry. The solar pond can play a significant role supplying the process heat to industries thereby saving oil, natural gas, electricity, and coal.

DESALINATION

The low cost thermal energy can used to desalt or otherwise purify water for drinking or irrigation. Multi-flash desalination units along with a solar pond is an attractive proposition for getting distilled water because the multi-flash desalination plant below 100^0 C which can well be achieved by a solar pond. This system will be suitable at places where portable water is in short supply.

HEATING ANIMAL HOUSING AND DRYING CROPS ON FARMS

Low grade heat can be used in many ways on farms, which have enough land for solar ponds.

HEAT FOR BIOMASS CONVERSION

Site built solar ponds could provide heat to convert biomass to alcohol or methane. While no solar ponds have been used for this purpose, it is an ideal coupling of two renewable-energy technologies.

APPLICATIONS OF SOLAR ENERGY

The actual and proposed applications of solar energy may be considered in three general categories.

Direct thermal application: It makes direct use of heat, resulting from the absorption of solar radiation, for space heating, supply heat for agricultural, industrial, and other processes that require only moderate temperatures.

Solar electric applications: Solar energy is converted directly or indirectly into electrical energy.

a. **Solar thermal methods** involve production of high temperatures, required to boil water or other working fluid for operating turbines which drive electric generators. These are considered under solar thermal-electric conversion.
b. **Photovoltaic:** Used to convert solar energy directly into electric energy without machinery.
c. **Thermo electric conversion:** Conversion of solar energy into electrical energy without use of machinery by utilizing thermo electric effect.
d. **Wind energy:** A form of solar energy that can be converted into mechanical energy and hence into electrical energy by means of a generator.

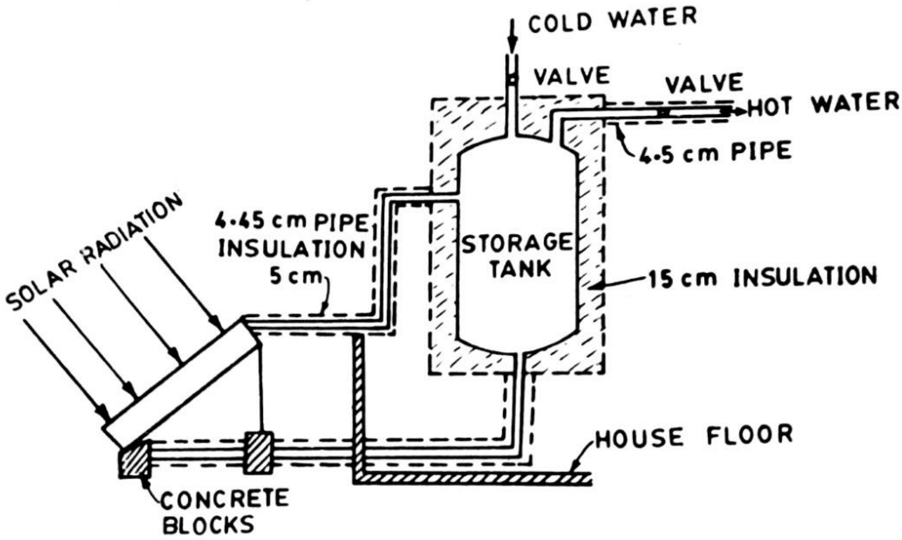
Energy from Biomass and Bio-gas: The conversion of Biomass and Bio-gas into clean fuels or other energy related product of organic matter derived directly or indirectly from plants which use solar energy to grow. Biomass materials include agricultural, forest, and animal, residues, as well as terrestrial and aquatic plants grown especially for the purpose.

Solar Thermal Applications

Solar Water Heating Systems

In a Solar water heating system water is heated by the use of solar energy. These generally comprise of solar thermal collectors, a fluid system to absorb the heat from the collector toughened glass shield, insulated storage tank, cold water supply tank and insulated piping.

These systems use the solar energy to heat either water or a heat-transfer fluid, such as a water-glycol antifreeze mixture, in collectors generally mounted on a roof. The sun rays penetrate through the glass and fall on the absorber. The heat of the sunrays is absorbed by the cold water inside the absorber thereby increasing its temperature. The storage is either through the thermosyphon or the forced flow system. In the thermosyphon system up to 3000 liters per day can be installed; however, for higher capacities it is necessary to use forced flow system. The water temperature can be raised up to 85^{0}C. Atypical schematic diagram of solar water heating system is shown in the Figure.



Schematic of Solar Water Heating system

The solar water heating system can be used for bathing, washing, boiler feed water pre heating and other similar purposes. The cost of solar water heating system range from Rs.140/- to Rs.220/- per litre. The investment made can be recovered in 4 to 6 years time. The life of the system is around 10-15 years, if maintained properly. The operation and maintenance cost is negligible.

Solar Photovoltaic Applications

Three most important and widely used applications of Solar PV have been considered here. These are

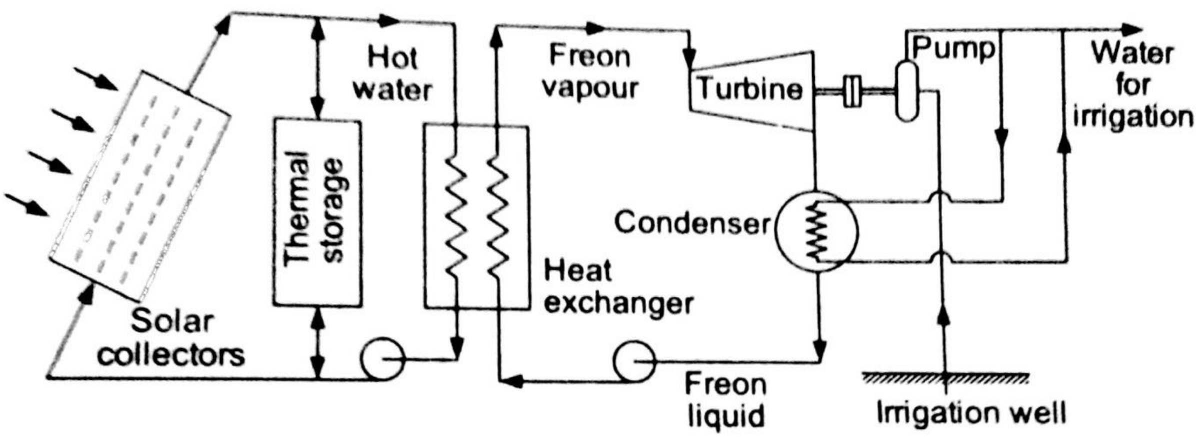
- Solar home lighting systems
- Solar water pumping systems
- Solar power plants

Solar home lighting system

Home lighting systems are powered by solar energy using solar modules. The generated electricity is stored in batteries and used for the purpose of lighting whenever required. These systems are most widely used in non-electrified rural areas and as reliable emergency lighting system for important domestic, commercial and industrial applications. The Solar Home Lighting system is a fixed installation designed for domestic application. The system comprises of Solar PV Module (Solar Cells), charge controller, battery and lighting system (lamps & fans). The schematic of the Home lighting system is shown in Figure 18 below. The solar module is installed in the open on roof/terrace - exposed to sunlight and the charge controller and battery are kept inside a protected place in the house. The solar module requires periodic dusting for effective performance.

Solar water pumping system

These water pumping systems are powered by solar energy. It is a stand-alone system. The power generated by solar module is used for operating DC surface centrifugal mono-block pump set for lifting water from bore / open well or water reservoir for minor irrigation and drinking water purpose. The system schematic is shown in the Figure 19. The system requires a shadow-free area for installation of the Solar Panel

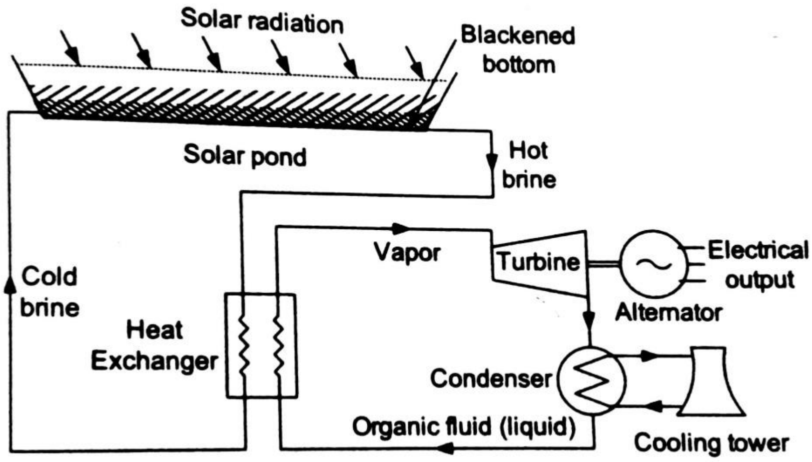


Schematic of Solar Water pumping System

Solar pond Power Plants

Power supply in most of the cities and towns is unreliable, which has forced the people to use small generators. These generators are operated with fossil fuels like kerosene, petrol or diesel cause pollution. It also leads to increase dependence on oil imports.

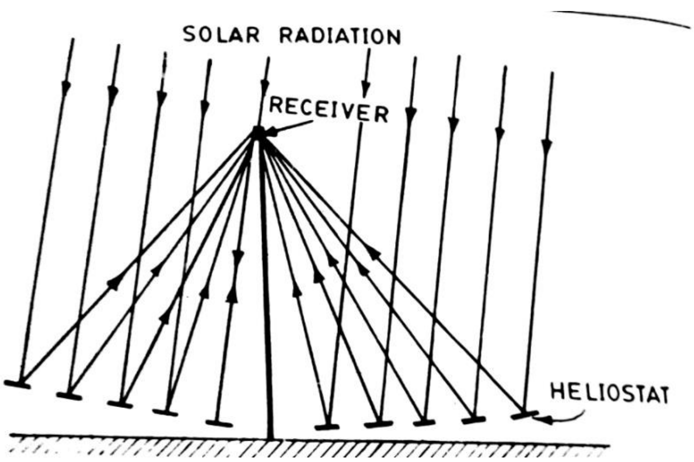
A solar power plant is a good option for electrification in areas that are located away from the grid line or where other sources are neither available nor can be harnessed in a techno economically viable manner. A solar power plant of the size 10–100 kW (kilowatt), depending



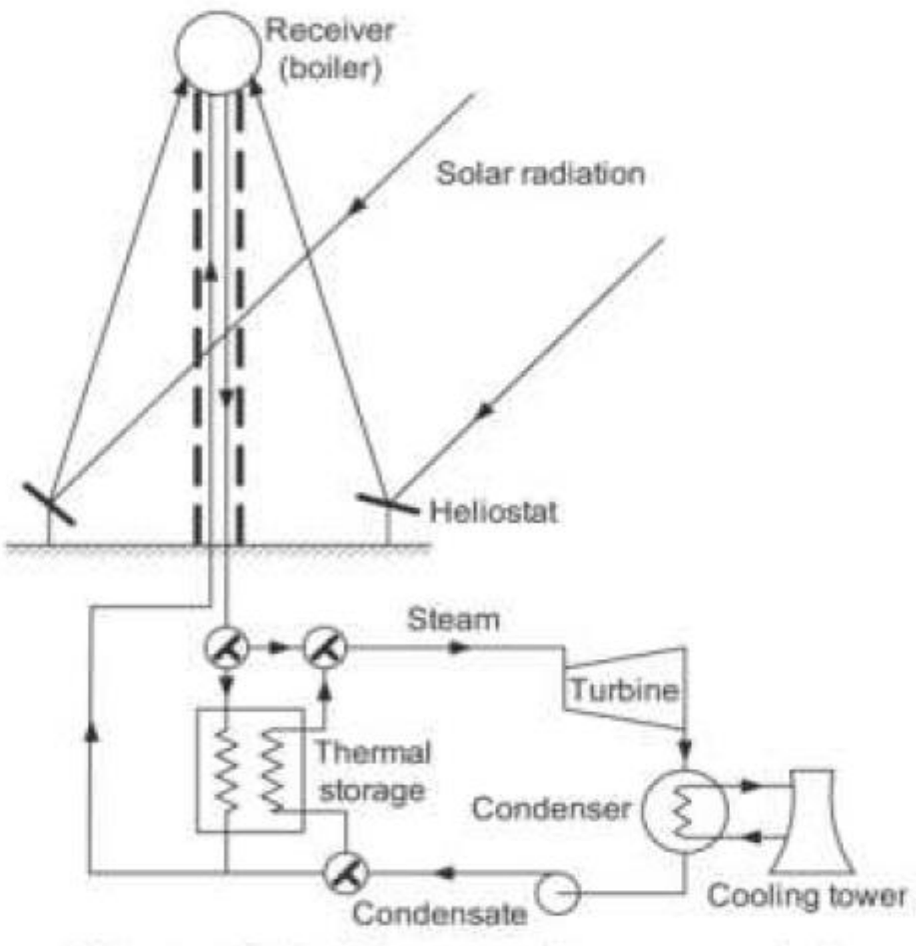
on the load demand, is preferable particularly with a liberal subsidy and low-interest soft loan from financial institutions. The idea is to raise the quality of life of the people subjected to poverty in these areas. This coupled with low-gestation remote areas of many states that need electrification. Typical Stand alone solar power plant for the power generation comprises of Solar PV module array, Module mounting structures, Charge controller, Battery bank, Inverter and Load circuitry. A typical stand alone Solar PV power plant is shown in the Figure 20. The control panel (inset of photograph) with all the peripheral components is housed as shown below.

Solar Power Tower

In this system as already stated, the incoming solar radiation is focused to central receiver or a boiler mounting on tall tower using thousands of plane reflectors, which are steerable about two axes and are known by heliostats.

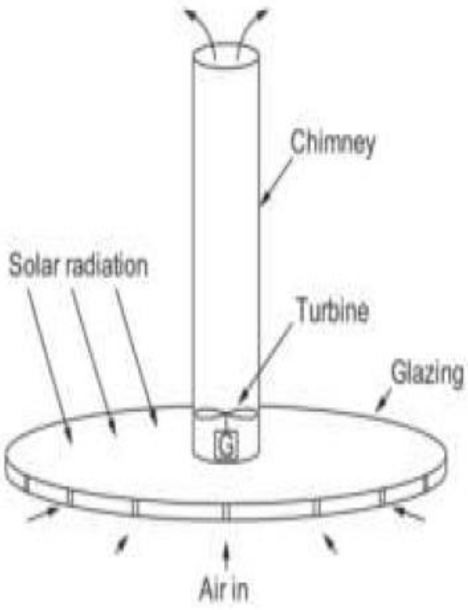


A schematic view of an electric power plant using gas turbine power plant working on Bray ton gas power cycle is shown in the figure. The mirrors are installed on the ground and are oriented so as to reflect the direct beam radiation into an absorber or receiver which is mounted on the top of the tower located near the centre of the field of mirrors to produce high temperature. This makes it possible to position the boiler in the field of view of all mirrors, at all hours of the day. Beam radiation incident on the boiler absorbed by black pipes in which working fluid circulates and is heated. The working fluid is allowed to drive the turbine and produce mechanical energy. The turbine which is coupled to an alternator produces electrical energy.



Solar Chimney

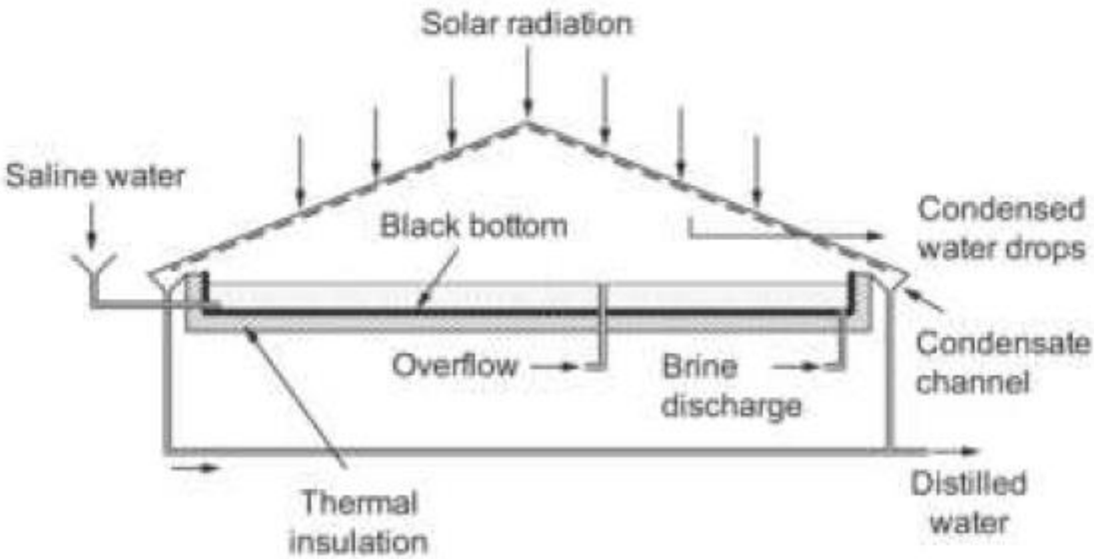
A solar chimney consists of a transparent large room (usually made of glass) which is sloped gently up to a central hollow tower or chimney. The sun heats the air in this greenhouse-type structure which then rises up the chimney, thereby driving an air turbine as it rises. This air turbine then creates electricity.



Solar chimneys are very simple in design and could therefore be a viable option for projects in the developing world.

Solar distillation

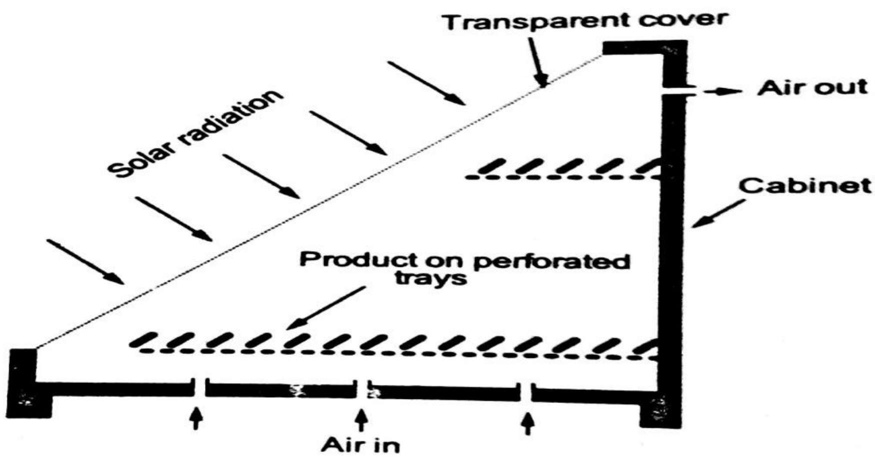
Fresh water is necessary for the sustenance of life and also the key to man's prosperity. It is generally observed that in many places people are bringing water from the long distance, in such areas solar energy is plentiful and can be used for converting saline water into distilled water. The pure water can be obtained by distillation in the simplest solar still, generally known as the "basin type solar still".



It consists of blackened basin containing saline water at a shallow depth, over which transparent air tight cover is that encloses completely the space above the basin. It has a roof like space. The cover which is usually glass,, may be of plastic, is sloped towards a collection trough. Solar radiation is passes through the cover and is absorbed and converted into heat in the black surface. Impure water in the basin or tray is heated and the vapor produced is condensed to purified water on the cooler interior of the roof. The transparent roof material transmits nearly all radiation falling on it and absorbs very little hence it remains cool enough to condense the water vapor. The condensed water flows down the sloping roof and is collected in troughs at bottom.

Solar dryer

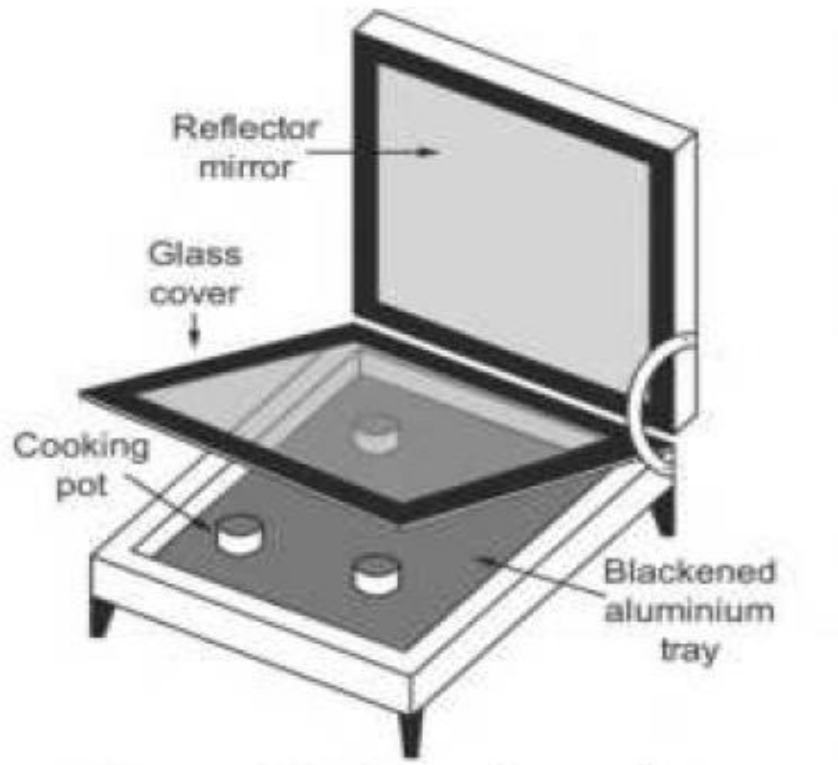
The drying process removes moisture and helps in the preservation of any product. Solar crop drying is perhaps the most ancient and widespread direct use of solar energy. The customary way is to spread the material to be dried in a thin layer on the ground. The disadvantages associated with this method are (i) the process is slow (ii) the product is vulnerable to attack by insects, and (iii) dust gets mixed with the product. The use of solar dryer helps eliminate these disadvantages. Also the drying can be a faster and controlled process, and a better quality product can be produced.



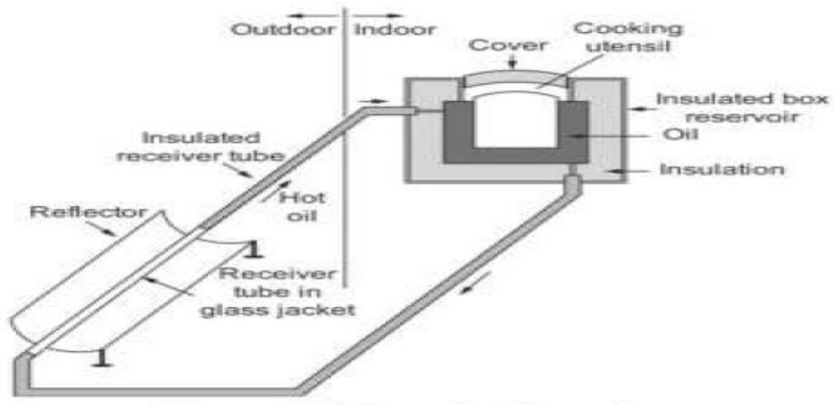
A simple cabinet type solar dryer is shown in the figure. It is an enclosure with a transparent cover. The material to be dried to be placed on perforated trays. Solar radiation enters the enclosure and is absorbed by the product as well as the surrounding internal surfaces of the enclosure, increasing its temperature. The inside air heats up to a temperature range of 50 to 80^0 C, and rises above. Natural circulation of air is ensured by providing suitable openings at the top and bottom. The circulating air removes the moisture from the product. For large scale drying forced circulation of air maybe used by employing a blower.

SOLAR COOKER

This is a box type solar cooker with external dimensions of a typical family size (4 dishes) box type cooker are 60x60x20 cm. the cooker is simple in construction and operation. An insulated box of blackened aluminum contains the utensils with food material. The box receives direct radiation and also reflected radiation from reflector mirror fixed on inner side of the box cover hinged to one side of the box. The angle of reflector can be adjusted as required. A glass cover consisting of two layers of clear window glass sheets serves as the box door.



solar box type cooker



Advanced solar cooker

History of Wind-Mills

The wind is a by-product of solar energy. Approximately 2% of the sun's energy reaching the earth is converted into wind energy. The surface of the earth heats and cools unevenly, creating atmospheric pressure zones that make air flow from high- to low-pressure areas.

The wind has played an important role in the history of human civilization. The first known use of wind dates back 5,000 years to Egypt, where boats used sails to travel from shore to shore. The first true windmill, a machine with vanes attached to an axis to produce circular motion, may have been built as early as 2000 B.C. in ancient Babylon.

By the 10th century A.D., windmills with wind-catching surfaces having 16 feet length and 30 feet height were grinding grain in the areas in eastern Iran and Afghanistan.
The earliest written references to working wind machines in western world date from the 12th century. These too were used for milling grain. It was not until a few hundred years later that windmills were modified to pump water and reclaim much of Holland from the sea.
The multi-vane "farm windmill" of the American Midwest and West was invented in the United States during the latter half of the l9th century. In 1889 there were 77 windmill factories in the United States, and by the turn of the century, windmills had become a major American export. Until the diesel engine came along, many transcontinental rail routes in the U.S. depended on large multi-vane windmills to pump water for steam locomotives.

Farm windmills are still being produced and used, though in reduced numbers. They are best suited for pumping ground water in small quantities to livestock water tanks. In the 1930s and 1940s, hundreds of thousands of electricity producing wind turbines were built in the U.S. They had two or three thin blades which rotated at high speeds to drive electrical generators. These wind turbines provided electricity to farms beyond the reach of power lines and were typically used to charge storage batteries, operate radio receivers and power a light bulb. By the early 1950s, however, the extension of the central power grid to nearly every American household, via the Rural Electrification Administration, eliminated the market for these machines. Wind turbine development lay nearly dormant for the next 20 years.

A typical modern windmill looks as shown in the following figure. The wind-mill contains three blades about a horizontal axis installed on a tower. A turbine connected to a generator is fixed about the horizontal axis.

Like the weather in general, the wind can be unpredictable. It varies from place to place, and from moment to moment. Because it is invisible, it is not easily measured without special instruments. Wind velocity is affected by the trees, buildings, hills and valleys around us. Wind is a diffuse energy source that cannot be contained or stored for use elsewhere or at another time.

Working principle of wind mill : The kinetic energy of the air is converted in to mechanical energy

Eq-(i) $kinetic\ energy = \frac{1}{2}\dot{m}v^2$

Eq-(ii) $The\ mass\ flow\ rate\ of\ the\ fluid\ crossing\ the\ blade => \dot{m} = \rho AV$

By substituting eq-(ii) in (i)

$$kinetic\ energy = \frac{1}{2}\rho AV^3$$

$$For\ an\ horizontal\ axis\ wind\ turbine\ A = \frac{\Pi}{4}D^2$$

$$The\ available\ wind\ power(\mathrm{P_a}) = \frac{1}{8}\rho\Pi D^2V^3 wats$$

Site selection considerations of wind Turbine

- The power availability in the wind increase rapidly with the speed
- Wind energy conversion mechanism should be located preferable in areas where the winds are persistent
- The technical, environmental, social and other parameters are considered before plant construction.

The average velocity of air is calculated by using anemometer at 10m above the ground

1. **High annual wind average wind speed**

- The uniform wind velocity
- survey of historical wind data
- contour maps of terrain and wind are consulted
- potential sites are visited
- Best sites are instrumented for approximately one year
- choose optimal site

2.Availability of anemometry Data:

- The anemometer data is very much useful for calculation of available wind energy
- Icing of wind(water molecules of the wind)
- Temperature of the wind

This data collected by anemometer over a time period

3.Availability of wind V(t) curve at the proposed site

- The average wind velocity V>=12-16 km/hr (3.5 to 4.5m/s)
- The V(t) curve is draw over a 5 yr time period

4. Wind structure at the proposed site

- it is depends on the V(t) curve the smooth and steady (curve)wind is blows all the time .(ideal case)
- A typical site selection always less than the ideal case
- wind near the ground is always high turbulence and rapid motion (in different direction)

A homogenous flow referred to a site construction

5. Altitude of the proposed site

- The wind have high velocity at high altitudes
- altitudes are considered from the ground level except from the sea level

6**. Terrain and its aerodynamic**

- the aero turbine always perpendicular to the actual wind flow

7. Local Ecology

- If the surface is bare rock it may mean lower hub height hence lower structure cost
- The tree or grass are disturb the wind direction to avoid such a kind of site selection otherwise the structure height is to high and cost

8.Distance to roads and Railways

9.Nearness of site to local/users

- To reduce the transmission losses of power by decreasing the line.

10.Nature of the ground

- weak soil is completely destroy the whole system to avoid such a kind of site

11. Favorable Land Cost

- Low and waste land referred for construction

12.Other problems such as icing ,spray and blowing

- These are effected in material(ex: blades are eroded)

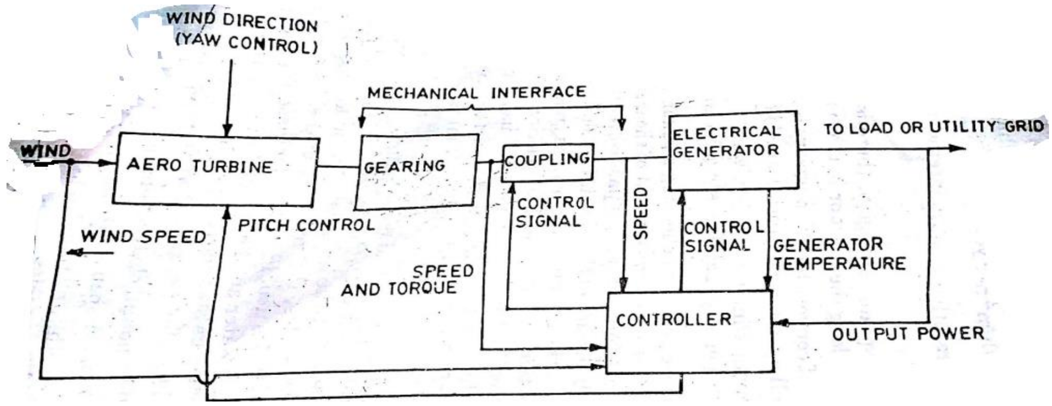
2. Classification of Wind-mills

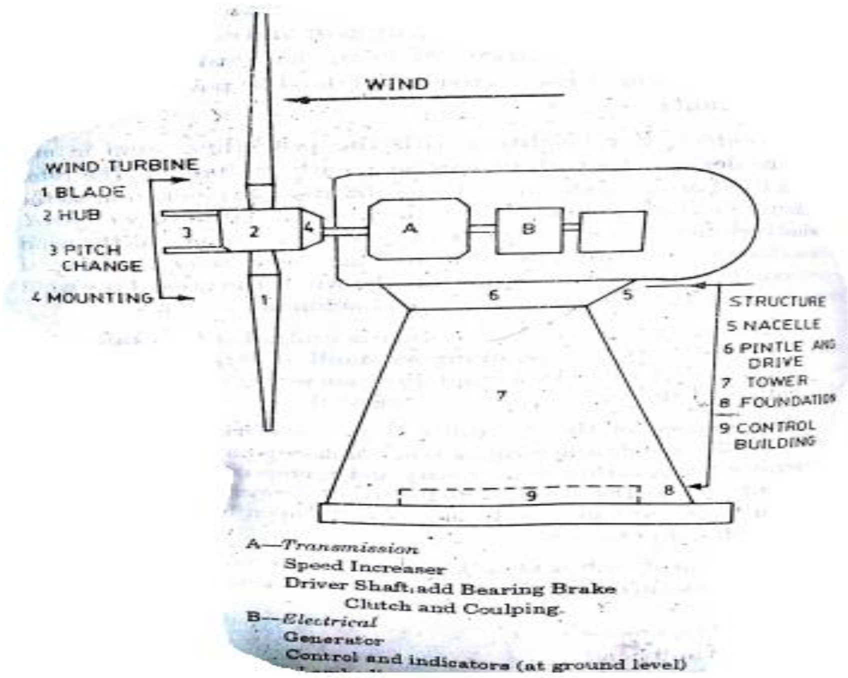
Wind turbines are classified into two general types: Horizontal axis and Vertical axis. A horizontal axis machine has its blades rotating on an axis parallel to the ground as shown in the above figure. A vertical axis machine has its blades rotating on an axis perpendicular to the ground. There are a number of available designs for both and each type has certain advantages and disadvantages. However, compared with the horizontal axis type, very few vertical axis machines are available commercially.

Horizontal Axis

This is the most common wind turbine design. In addition to being parallel to the ground, the axis of blade rotation is parallel to the wind flow. Some machines are designed to operate in an upwind mode, with the blades upwind of the tower. In this case, a tail vane is usually used to keep the blades facing into the wind. Other designs operate in a downwind mode so that the wind passes the tower before striking the blades. Without a tail vane, the machine rotor naturally tracks the wind in a downwind mode. Some very large wind turbines use a motor-driven mechanism that turns the machine in response to a wind direction sensor mounted on the tower. Commonly found horizontal axis wind mills are aero-turbine mill with 35% efficiency and farm mills with 15% efficiency.

BASIC COMPONENTS OF WINDENERGY





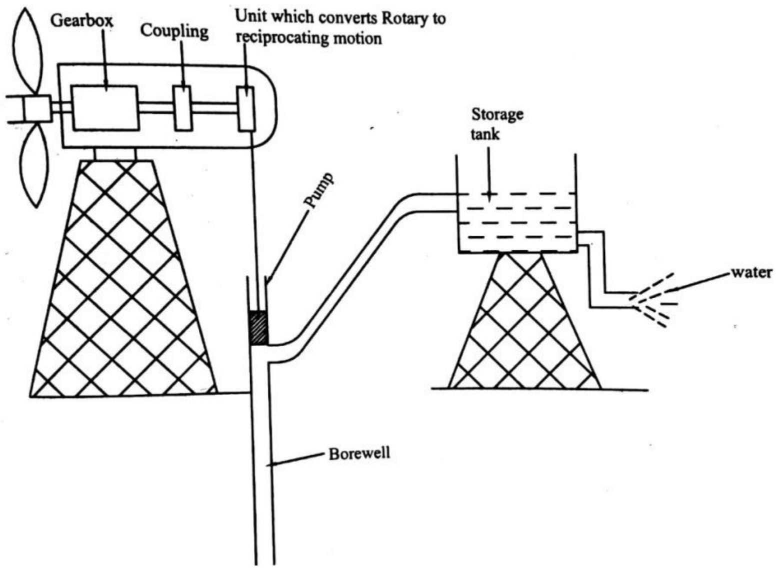
Horizontal axis Wind Turbine

- Axial Thrust is present
- Cut-in speed >4 m/s solidity ratio is low 0.5 need a straight device.

- Lift force e are predominant high Rotational speeds Tip speed ratio >4(equal to 4)
- Need yawing mechanism
- robust construction
- Suitable site are cost line , elevated places
- Use :

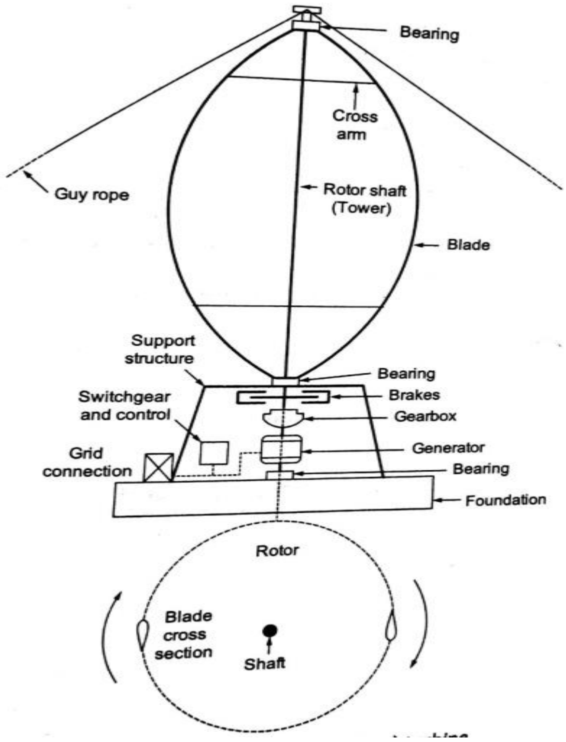
Electric power, water pumping

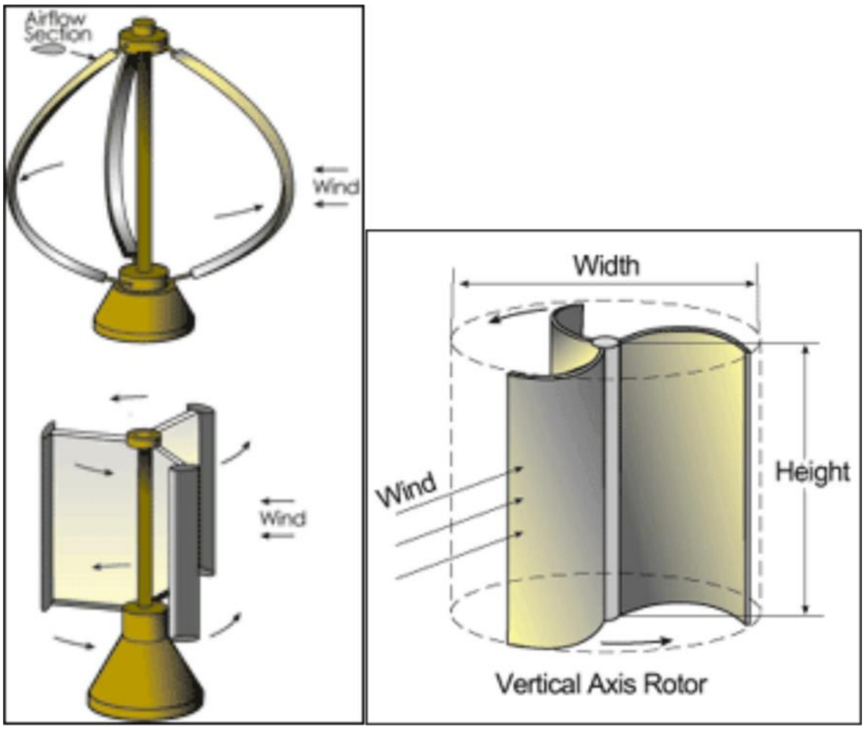
- **HAWT Water pumping Application**



Vertical Axis

Although vertical axis wind turbines have existed for centuries, they are not as common as their horizontal counterparts. The main reason for this is that they do not take advantage of the higher wind speeds at higher elevations above the ground as well as horizontal axis turbines. The basic vertical axis designs are the Darrieus, which has curved blades and efficiency of 35%, the Giromill, which has straight blades, and efficiency of 35%, and the Savonius, which uses scoops to catch the wind and the efficiency of 30%. A vertical axis machine need not be oriented with respect to wind direction. Because the easier servicing and a lighter weight, lower cost tower. Although vertical axis wind turbines have these advantages, their designs are not as efficient at collecting energy from the wind as are the horizontal machine designs. The following figures show all the above mentioned mills.





Vertical axis Wind Turbine

- Axial thrust is absent
- Cut in speed <2 m/s (equal to 2 m/s) solidity ratio <1(equal to 1)
- Drag forces predominant low spe and good starting torque Tip speed ratio<3 (equal to 3)
- coefficient of power <_0.36

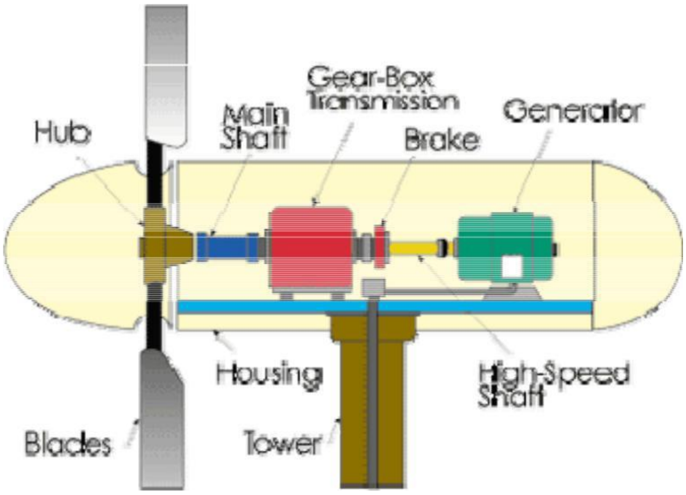
  Even low wind speeds =10m/s
- No need of yaw mechanism
- Construction is simple and low cost
- Use Battery charging, water pump

- VAWT Water pumping Application

There is one more type of wind-mill called Cyclo-gyro wind-mill with very high efficiency of about 60%. However, it is not very stable and is very sensitive to wind direction. It is also very complex to build.

Main Components of a wind-mill

Following figure shows typical components of a horizontal axis wind mill.



Rotor

The portion of the wind turbine that collects energy from the wind is called the rotor. The rotor usually consists of two or more wooden, fiberglass or metal blades which rotate about an axis (horizontal or vertical) at a rate determined by the wind speed and the shape of the blades. The blades are attached to the hub, which in turn is attached to the main shaft.

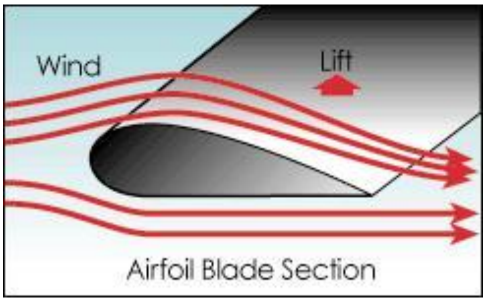
Drag Design

Blade designs operate on either the principle of drag or lift. For the drag design, the wind literally pushes the blades out of the way. Drag powered wind turbines are characterized by slower rotational speeds and high torque capabilities. They are useful for the pumping, sawing or grinding work. For example, a farm-type windmill must develop high torque at start-up in order to pump, or lift, water from a deep well.

Lift Design

The lift blade design employs the same principle that enables airplanes, kites and birds to fly. The blade is essentially an airfoil, or wing. When air flows past the blade, a wind speed and pressure differential is created between the upper and lower blade surfaces. The pressure at the lower surface is greater and thus acts to "lift" the blade. When blades are attached to a central axis, like a wind turbine rotor, the lift is translated into rotational motion. Lift-powered wind turbines have much higher rotational speeds than drag types and therefore well suited for electricity generation.

Following figure gives an idea about the drag and lift principle.



Tip Speed Ratio

The tip-speed is the ratio of the rotational speed of the blade to the wind speed. The larger this ratio, the faster the rotation of the wind turbine rotor at a given wind speed. Electricity generation requires high rotational speeds. Lift-type wind turbines have maximum tip-speed ratios of around 10, while drag-type ratios are approximately 1. Given the high rotational speed requirements of electrical generators, it is clear that the lift-type wind turbine is most practical for this application.

The number of blades that make up a rotor and the total area they cover affect wind turbine performance. For a lift-type rotor to function effectively, the wind must flow smoothly over the blades. To avoid turbulence, spacing between blades should be great enough so that one blade will not encounter the disturbed, weaker air flow caused by the blade which passed before it. It is because of this requirement that most wind turbines have only two or three blades on their rotors.

Generator

The generator is what converts the turning motion of a wind turbine's blades into electricity. Inside this component, coils of wire are rotated in a magnetic field to produce electricity. Different generator designs produce either alternating current (AC) or direct current (DC), and they are available in a large range of output power ratings. The generator's rating, or size, is dependent on the length of the wind turbine's blades because more energy is captured by longer blades.

It is important to select the right type of generator to match intended use. Most home and office appliances operate on 240 volt, 50 cycles AC. Some appliances can operate on either AC or DC, such as light bulbs and resistance heaters, and many others can be adapted to run on DC. Storage systems using batteries store DC and usually are configured at voltages of between 12 volts and 120 volts.

Generators that produce AC are generally equipped with features to produce the correct voltage of 240 V and constant frequency 50 cycles of electricity, even when the wind speed is fluctuating.

DC generators are normally used in battery charging applications and for operating DC appliances and machinery. They also can be used to produce AC electricity with the use of an inverter, which converts DC to AC.

Transmission

The number of revolutions per minute (rpm) of a wind turbine rotor can range between 40 rpm and 400 rpm, depending on the model and the wind speed. Generators typically require rpm's of 1,200 to 1,800. As a result, most wind turbines require a gear- box transmission to increase the rotation of the generator to the speeds necessary for efficient electricity production. Some DC-type wind turbines do not use transmissions. Instead, they have a direct link between the rotor and generator. These are known as direct drive systems. Without a transmission, wind turbine complexity and maintenance requirements are reduced, but a much larger generator is required to deliver the same power output as the AC-type wind turbines.

Tower

The tower on which a wind turbine is mounted is not just a support structure. It also raises the wind turbine so that its blades safely clear the ground and so it can reach the stronger winds at higher elevations. Maximum tower height is optional in most cases, except where zoning restrictions apply. The decision of what height tower to use will be based on the cost of taller towers versus the value of the increase in energy production resulting from their use. Studies have shown that the added cost of increasing tower height is often justified by the added power generated from the stronger winds. Larger wind turbines are usually mounted on towers ranging from 40 to 70 meters tall.

Towers for small wind systems are generally "guyed" designs. This means that there are guy wires anchored to the ground on three or four sides of the tower to hold it erect. These towers cost less than freestanding towers, but require more land area to anchor the guy wires. Some of these guyed towers are erected by tilting them up. This operation can be quickly accomplished using only a winch, with the turbine already mounted to the tower top. This simplifies not only installation, but maintenance as well. Towers can be constructed of a simple tube, a wooden pole or a lattice of tubes, rods, and angle iron. Large wind turbines may be mounted on lattice towers, tube towers or guyed tilt-up towers.

Towers must be strong enough to support the wind turbine and to sustain vibration, wind loading and the overall weather elements for the lifetime of the wind turbine. Their costs will vary widely as a function of design and height.

- **Wind Power**
  - Wind power is the use of air flow through wind turbines to mechanically power generators for electricity.
  - Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, uses no water, and uses little land.
  - The net effects on the environment are far less problematic than those of nonrenewable power sources.
  - Wind power gives variable power which is very consistent from year to year but which has significant variation over shorter time scales.
  - It is therefore used in conjunction with other electric power sources to give a reliable supply. As the proportion of wind power in a region increases, a need to upgrade the grid, and a lowered ability to supplant conventional production can occur

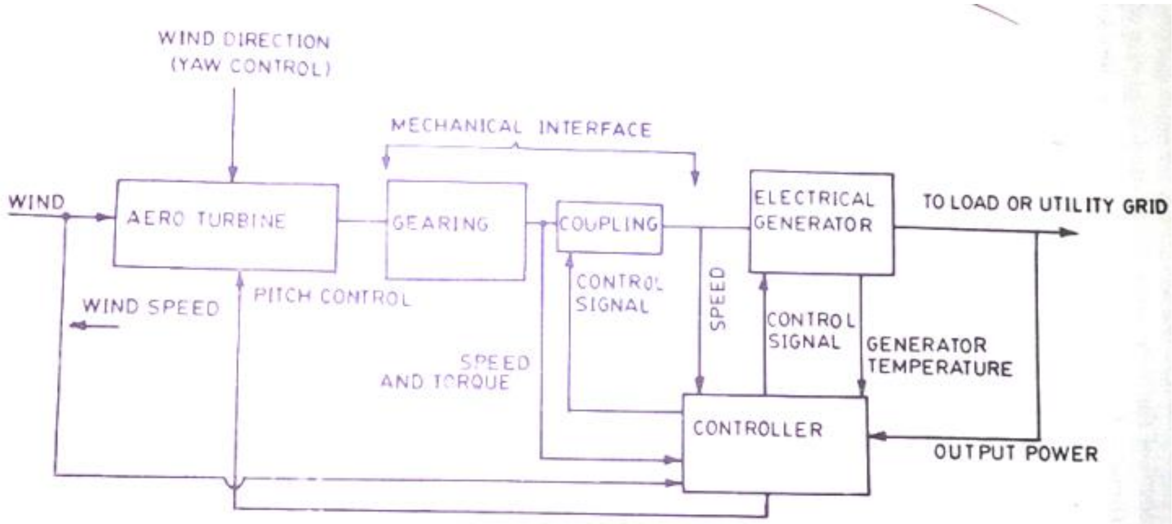


Fig 1. Wind Energy Generation

- **Classifications of Wind Mills according to axis based**
  i. **Horizontal axis**
  ii. **Vertical axis**

Features	**Small**		**Medium**			**Large**			**Very large**		
Rated Power, KW	**10**	**25**	**50**	**100**	**150**	**250**	**500**	**1000**	**200**	**3000**	**4000**
Rotor Diameter, KW	**6.4**	**10**	**14**	**20**	**25**	**32**	**49**	**64**	**90**	**110**	**130**
Rotor RPM	**200**	**150**	**100**	**67**	**55**	**43**	**29**	**19**	**15**	**13**	**11**

Table 1: Types of wind turbine characteristics

- **Horizontal axis Wind Turbine**
  - In the wind turbine business there are basically two types of turbines to choose from, vertical axis wind turbines and horizontal axis wind turbines.
  - Horizontal axis wind turbine dominates the majority of the wind industry. Horizontal axis means the rotating axis of the wind turbine is horizontal, or parallel with the ground. In big wind application, horizontal axis wind turbines are almost all you will ever see.
  - However, in small wind and residential wind applications, vertical axis turbines have their place. The advantage of horizontal wind is that it is able to produce more electricity from a given amount of wind. So if you are trying to produce as much wind as possible at

all times, horizontal axis is likely the choice for you. The disadvantage of horizontal axis however is that it is generally heavier and it does not produce well in turbulent winds.

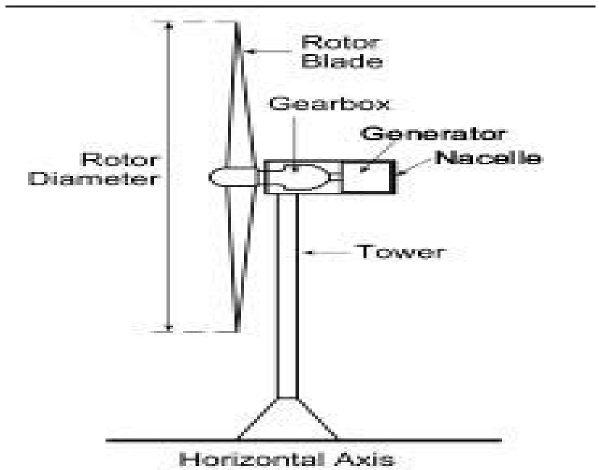
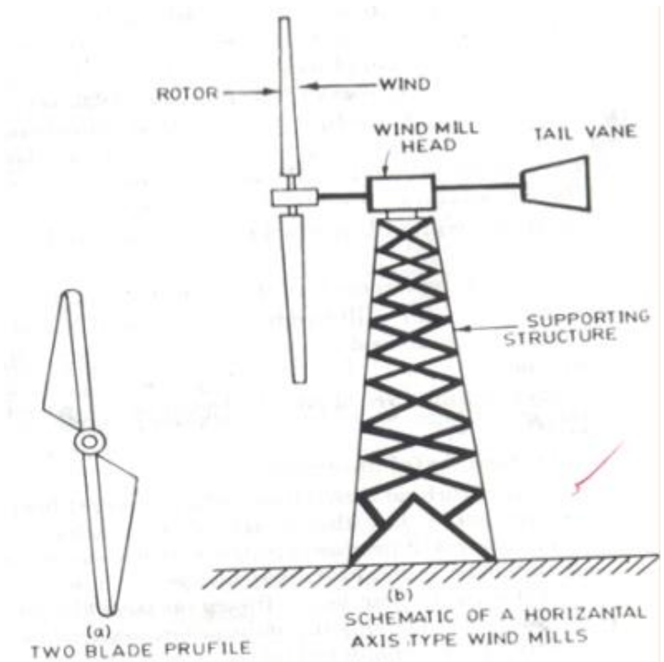


Fig :2 Horizontal axis Wind Turbine



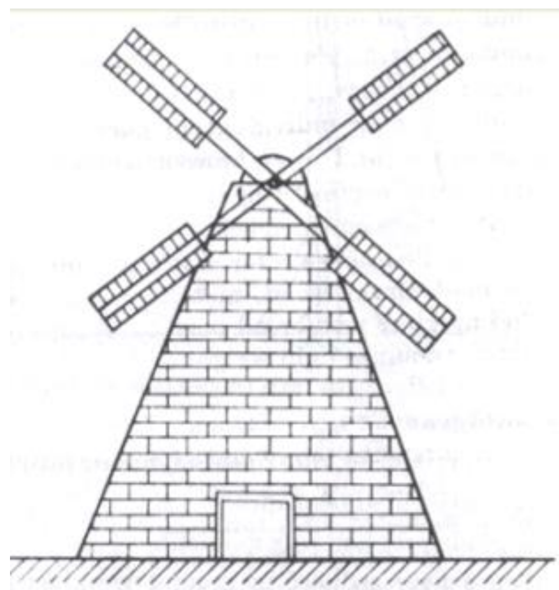
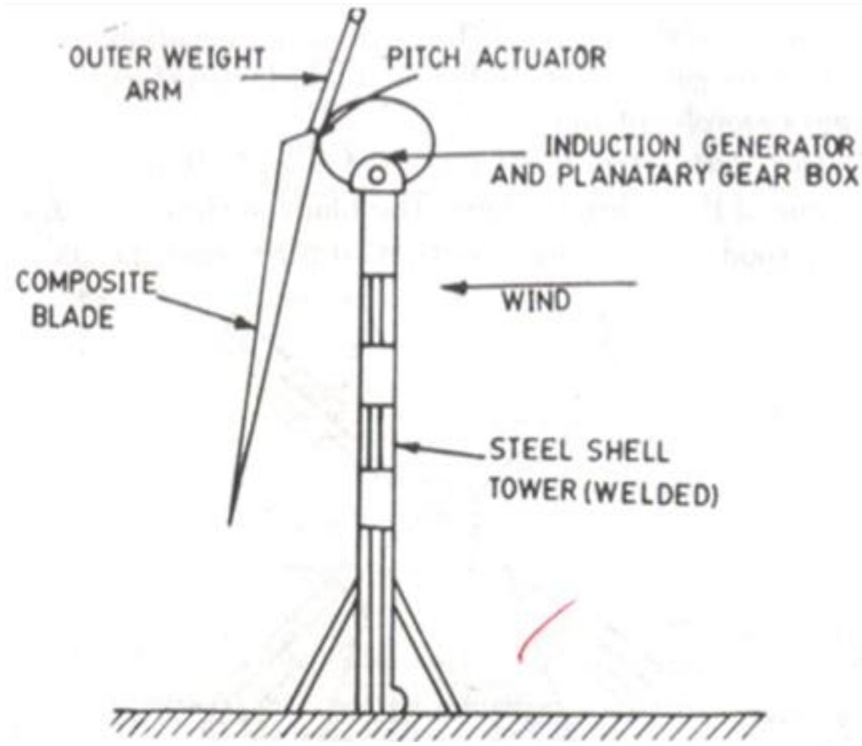


Fig: 2 b Horizontal axis Wind Turbine
With a single blade

Fig: 2. c Horizontal axis Wind Turbine
Dutch type



➢ **Vertical axis Wind Turbine**

- With vertical axis wind turbines the rotational axis of the turbine stands vertical or perpendicular to the ground. As mentioned above, vertical axis turbines are primarily used in small wind projects and residential applications. Vertical Axis Wind-Turbine This niche comes from the OEM's claims of a vertical axis turbines ability to produce well in tumultuous wind conditions.
- Vertical axis turbines are powered by wind coming from all 360 degrees, and even some turbines are powered when the wind blows from top to bottom.
- Because of this versatility, vertical axis wind turbines are thought to be ideal for installations where wind conditions are not consistent, or due to public ordinances the turbine cannot be placed high enough to benefit from steady wind.

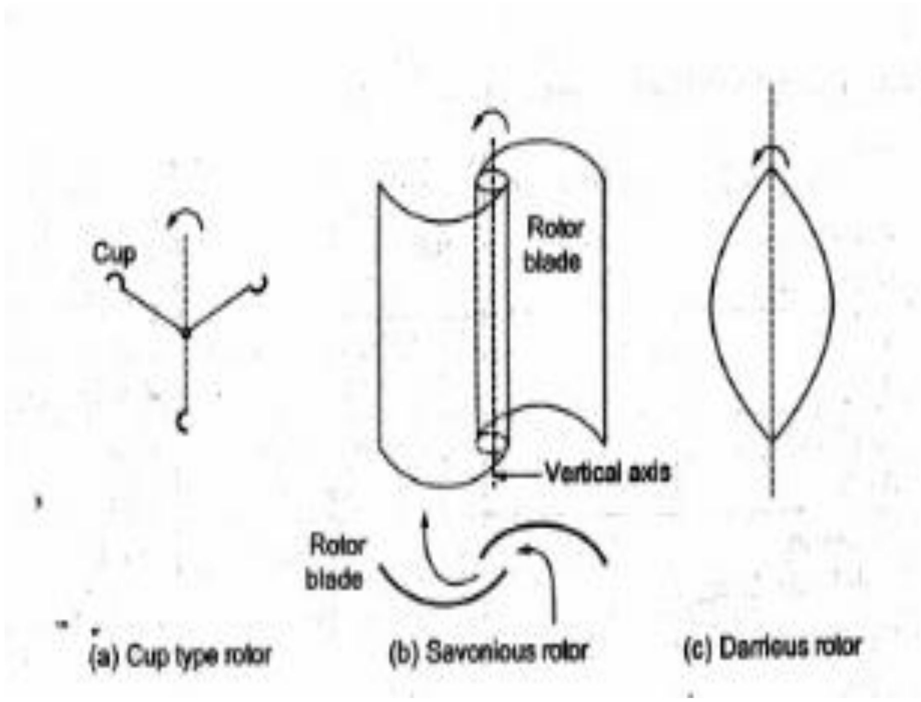


Fig 3 vertical axis rotor

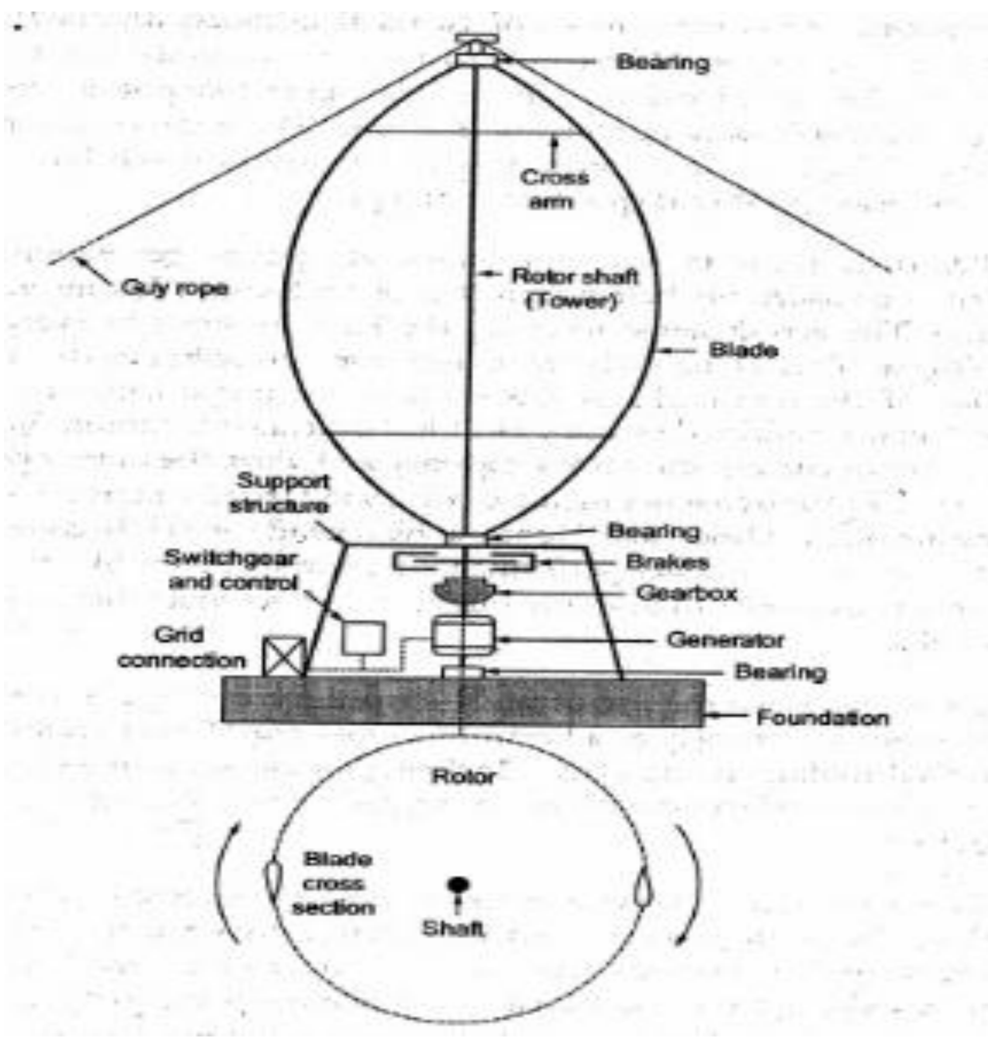


Fig 4 Vertical axis Wind Turbine

- **Betz criteria:**
  - **Betz's law** indicates the maximum power that can be extracted from the wind, independent of the design of a wind turbine in open flow. It was published in 1919, by the German physicist Albert Betz.
  - The law is derived from the principles of conservation of mass and momentum of the air stream flowing through an idealized "actuator disk" that extracts energy from the wind stream.
  - According to Betz's law, no turbine can capture more than 16/27 (59.3%) of the kinetic energy in wind.
  - The factor 16/27 (0.593) is known as Betz's coefficient.
  - Practical utility-scale wind turbines achieve at peak 75% to 80% of the Betz limit.
  - The Betz limit is based on an open disk actuator. If a diffuser is used to collect additional wind flow and direct it through the turbine, more energy can be extracted, but the limit still applies to the cross-section of the entire structure

- **Bio Mass**

The material of plants and animals, including their wastes and residues, is called ***biomass***

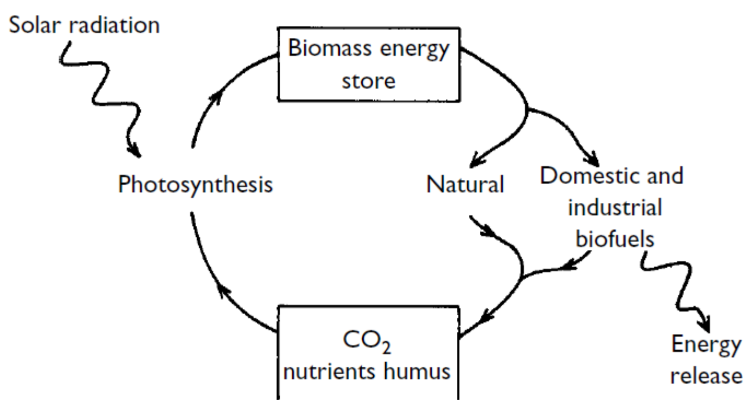


Fig: 5 Biomass cycle

- **BIOFUELS**

An organic carbon-based, material that reacts with oxygen in combustion and natural metabolic processes to release heat. Such heat, especially if at temperatures >400° C, may be used to generate work and electricity. The initial material may be transformed by

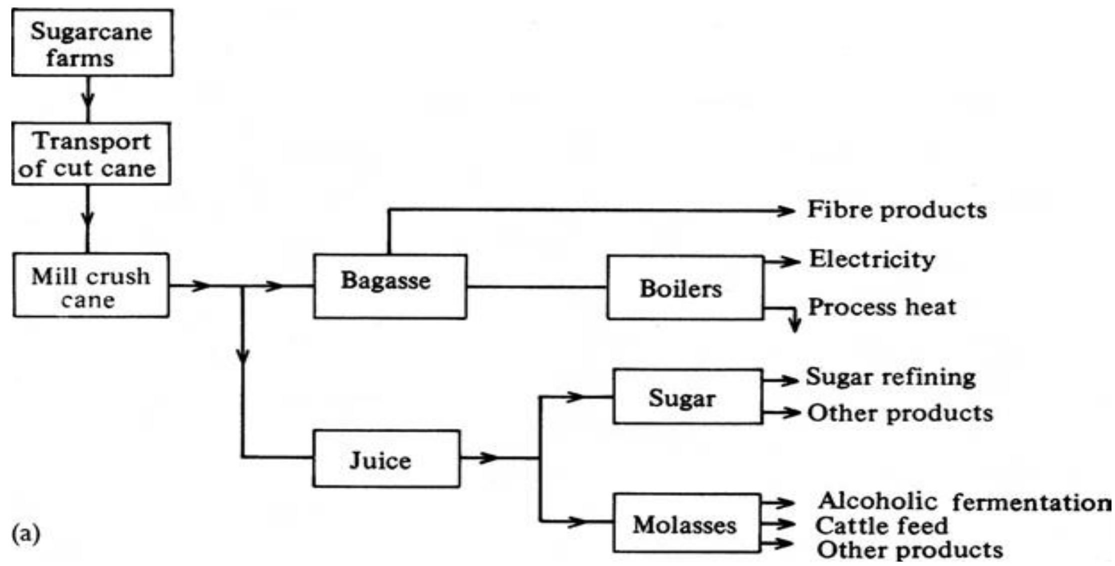


Fig 6: Methods for obtaining energy from biomass

- **Anaerobic digester**
  - **Anaerobic digestion** is a collection of processes by which microorganisms break down biodegradable material in the absence of oxygen.
  - The process is used for industrial or domestic purposes to manage waste and/or to produce fuels. Much of the fermentation used industrially to produce food and drink products, as well as home fermentation, uses anaerobic digestion.
  - Anaerobic reactors are generally used for the production of methane rich biogas from manure (human and animal) and crop residues.
  - They utilize mixed methanogenic bacterial cultures which are characterized by defined optimal temperature ranges for growth.
  - These mixed cultures allow digesters to be operated over a wide temperature range i.e. above 0°C up to 60°C.
- **Aerobic digester**
  - Aerobic digestion is a biological wastewater treatment. Once sediments and substances such as oil are removed from wastewater in the primary treatment stage, aerobic treatments are used to break down organic matter through the use of oxygen.
  - Aerobic biological processes use natural microbial colonies and molecular oxygen to decompose organic substances in the wastewater.
  - The microbes feed on undesired biological substances in the water, creating aggregates or "flocks" of organic substances and microorganisms that settle to the bottom of the container. This sludge is stable and usually can be disposed of easily.
- **Bio fuel classification**

- Biomass is largely composed of organic material and water. However, significant quantities of soil, shell or other extraneous material may be present in commercial supplies.
- It is essential that biomass is clearly assessed as either wet or dry matter mass, and the exact moisture content should be given.

➢ Bio mass conversion classifications

(i) Direct combustion

(ii) Thermo chemical

(iii) Bio chemical

And nine general types of biomass energy process. These are as follows

❖ **Thermochemical, heat**

1 Direct *combustion* for immediate heat. Dry homogeneous input is preferred.

2 *Pyrolysis*.

- Biomass is heated either in the absence of air or by the partial combustion of some of the biomass in a restricted air or oxygen supply.
- The products are extremely varied, consisting of gases, vapours, liquids and oils, and solid char and ash.
- The output depends on temperature, type of input material and treatment process.
- In some processes the presence of water is necessary and therefore the material need not be dry. If output of combustible gas is the main product, the process is called ***gasification*.**

3. Other ***thermo chemical processes***.

- A wide range of pre-treatment and process operations are possible.
- These normally involve sophisticated chemical control and industrial scale of manufacture; methanol production is such a process, e.g. for **liquid fuel**. Of particular importance are processes that break down cellulose and starches into sugars, for subsequent fermentation.

❖ **Biochemical**

1. ***Aerobic digestion*.**

- In the presence of air, microbial aerobic metabolism of biomass generates heat with the emission of CO_2, but not methane. This process is of great significance for the biological carbon cycle, e.g. decay of forest litter, but is not used significantly for commercial bioenergy.

2.Anaerobic digestion.

- In the absence of free oxygen, certain micro-organisms can obtain their own energy supply by reacting with carbon compounds of medium reduction level to produce both CO_2 and fully reduced carbon as CH_4.
- The process (the oldest biological 'decay' mechanism) may also be called 'fermentation', but is usually called 'digestion' because of the similar process that occurs in the digestive tracts of ruminant animals.
- The evolved mix of CO_2 CH_4 and trace gases is called ***biogas*** as a general term, but may be named ***sewage gas*** **or** ***landfill-gas*** as appropriate.

3 Alcoholic fermentation.

- Ethanol is a volatile liquid fuel that may be used in place of refined petroleum.
- It is manufactured by the action of micro-organisms and is therefore a fermentation process. Conventional fermentation has sugars as feedstock.

4. Biophotolysis.

- Photolysis is the splitting of water into hydrogen and oxygen by the action of light. Recombination occurs when hydrogen is burnt or exploded as a fuel in air. Certain biological organisms produce, or can be made to produce, hydrogen in biophotolysis. Similar results can be obtained chemically, without living organisms, under laboratory conditions.

❖ **Agrochemical**

- *Fuel extraction*. Occasionally, liquid or solid fuels may be obtained directly from living or freshly cut plants. The materials are called exu-dates and are obtained by cutting into (tapping) the stems or trunks of the living plants or by crushing freshly harvested material. A well-known similar process is the production of natural rubber latex. Related plants to the rubber plant ***Herea,*** such as species of ***Euphorbia,*** produce hydrocarbons of less molecular weight than rubber, which may be used as petroleum substitutes and turpentine.
- ***Biodiesel and esterification***.
- Concentrated vegetable oils from plants may be used directly as fuel in diesel engines; indeed Rudolph Diesel designed his original 1892 engine to run on a variety of fuels, including natural plant oils.
- However, difficulties arise with direct use of plant oil due to the high viscosity and combustion deposits as compared with standard diesel-fuel mineral oil, especially at low ambient temperature $\leq 5\ C$.

- Both difficulties are overcome by converting the vegetable oil to the corresponding ester, which is arguably a fuel better suited to diesel engines than conventional (petroleum-based) diesel oil.

Advantages and dangers of energy farming	
Advantages	Dangers and difficulties
Large potential supply	May lead to soil infertility and erosion
Variety of crops Variety of uses (including transport fuel and electricity generation)	May compete with food production
Efficient use of by-products, residues, Wastes	Bulky biomass material handicaps transport to the processing factory
Link with established agriculture and Forestry Encourages integrated farming practice Establishes agro-industry that may include full range of technical processes, with the need for skilled and trained personnel	May encourage genetic engineering of uncontrollable organisms
Environmental improvement by utilizing wastes	Pollutant emissions from poorly controlled processes
Fully integrated and efficient systems need have little water and air pollution (e.g. sulphur content low)	Poorly designed and incompletely integrated systems may pollute water and air
Encourages rural development	Large-scale agro-industry may be socially disruptive

- **Types of Small-Scale Digesters**
  - ✓ **Fixed Dom**

- A **fixed-dome** plant comprises of a closed, dome-shaped digester with an immovable, rigid gas-holder and a displacement pit, also named 'compensation tank'.
- The gas is stored in the upper part of the digester.
- When gas production commences, the slurry is displaced into the compensating tank.

- Gas pressure increases with the volume of gas stored, i.e. with the height difference between the two slurry levels. If there is little gas in the gas-holder, the gas pressure is low.

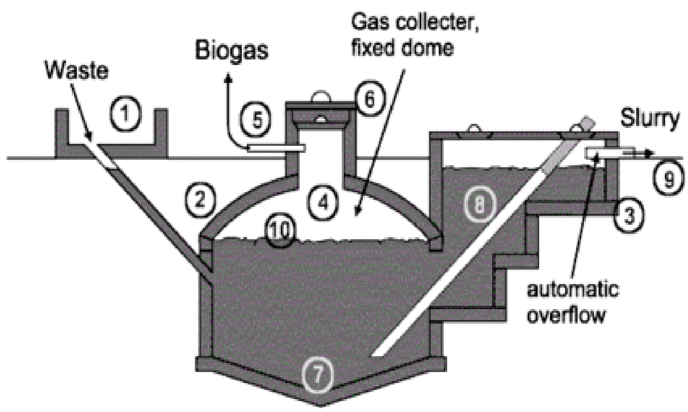


Fig 7: Fixed dome plant Nicarao design: 1.Mixing tank with inlet pipe and sand trap. 2.Digester. 3.Compensation and removal tank. 4.Gasholder. 5.Gaspipe. 6.Entry hatch, with gastight seal. 7.Accumulation of thick sludge. 8.Outlet pipe. 9.Reference level. 10.Supernatant scum, broken up by varying level.

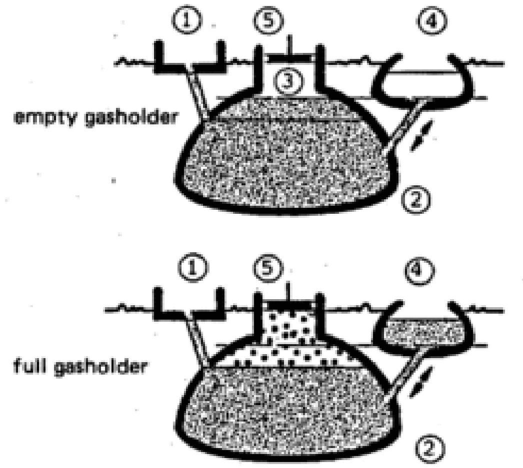


Fig 8: Basic function of a fixed-dome biogas plant: 1.Mixing pit, 2.Digester, 3.Gasholder, 4.Displacement pit, 5.Gas pipe

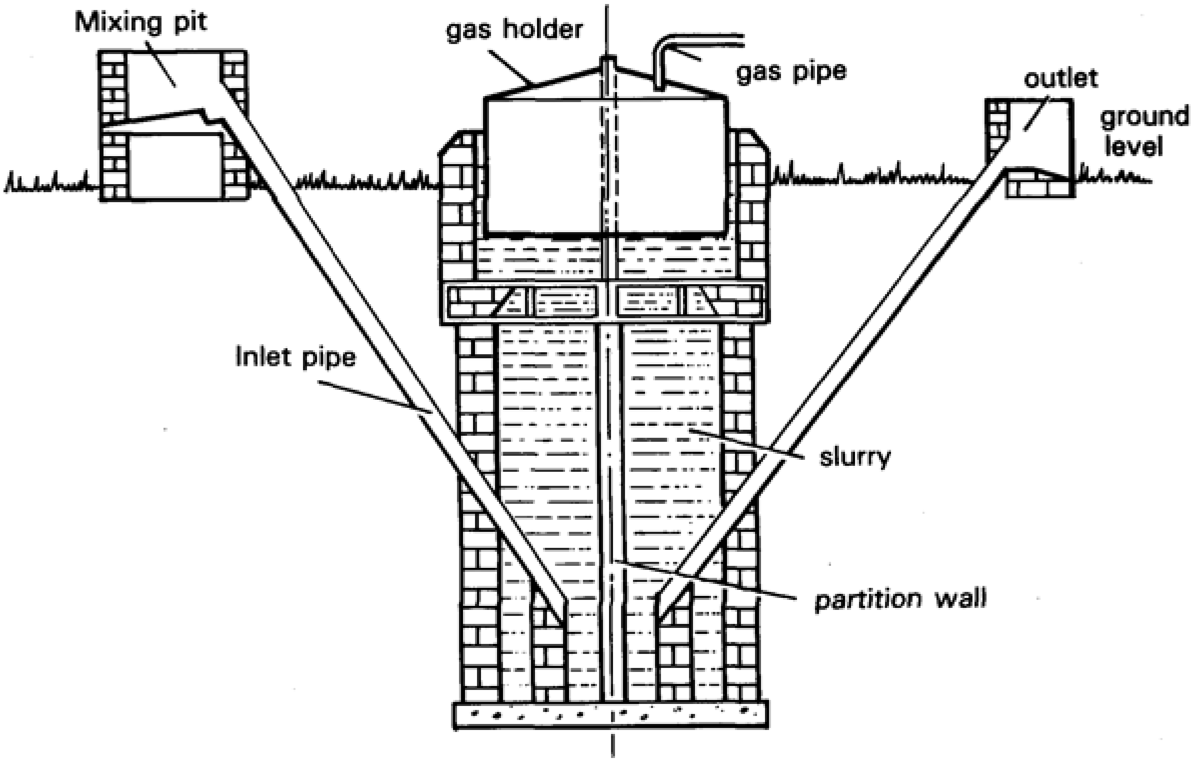


Fig 9: KVIC digester

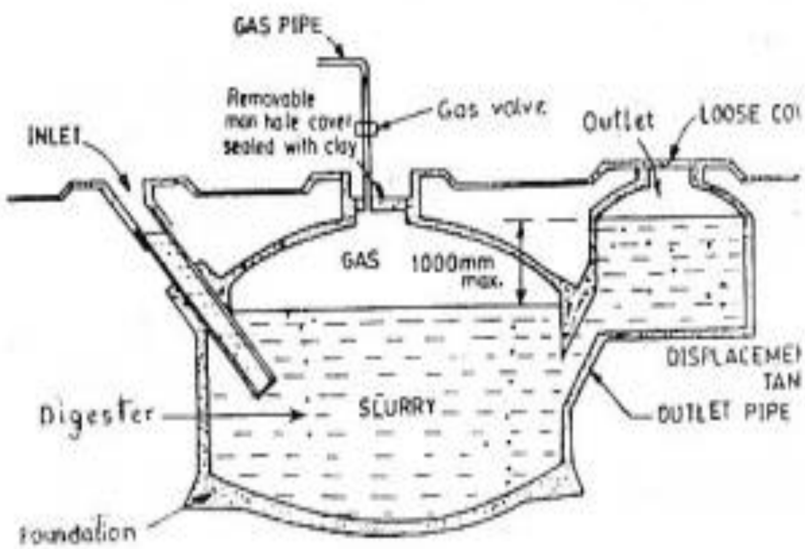


Fig 10: common circulated fixed dome (china)

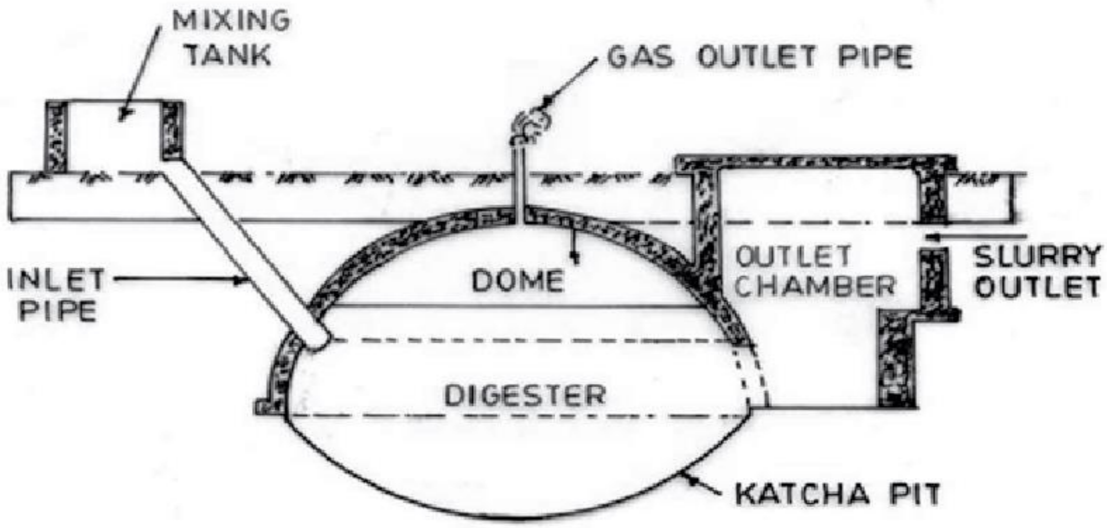


Fig 11: Deenbhandu bio gas plant

- **Floating Drum Plants**
  - Floating-drum plants consist of an underground digester and a moving gas-holder.
  - The gas-holder floats either directly on the fermentation slurry or in a water jacket of its own.
  - The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored.

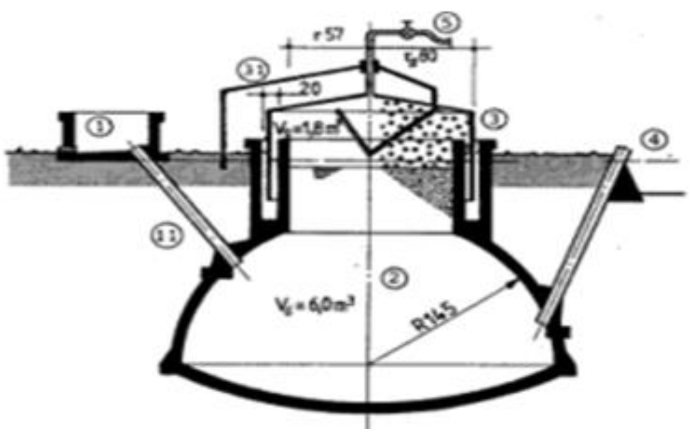


Fig 12: Water-jacket plant with external guide frame: 1 Mixing pit, 11 Fill pipe, 2 Digester, 3 Gasholder, 31 Guide frame, 4 Slurry store, 5 Gas pipe

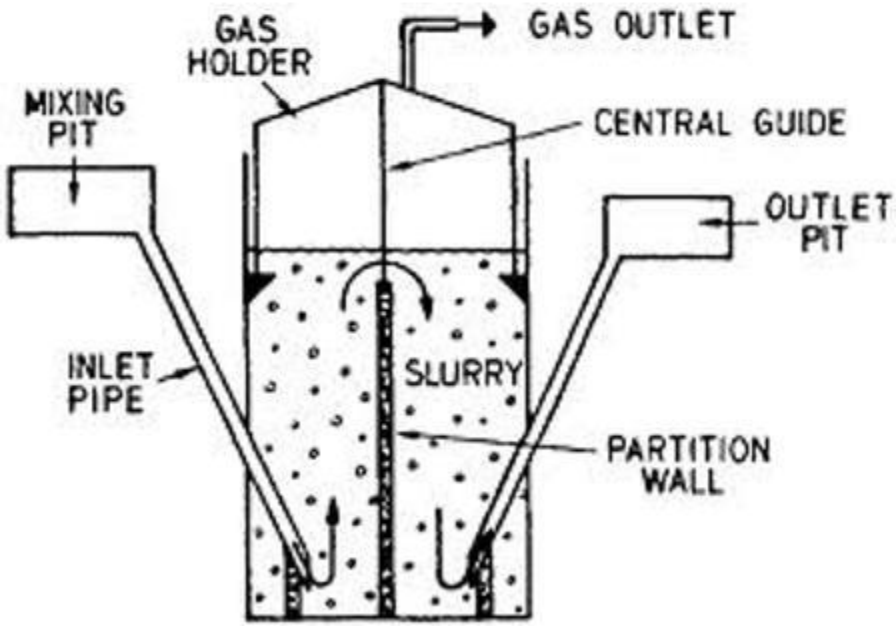


Fig 13: Taper digester with floating gas holder

- **Low-Cost Polyethylene Tube Digester**
  - The Low-Cost Polyethylene Tube Digester model consist of tubular polyethylene film (two coats of 300 microns) bent at each end around a 6 inch PVC drainpipe and is wound with rubber strap of recycled tire-tubes.

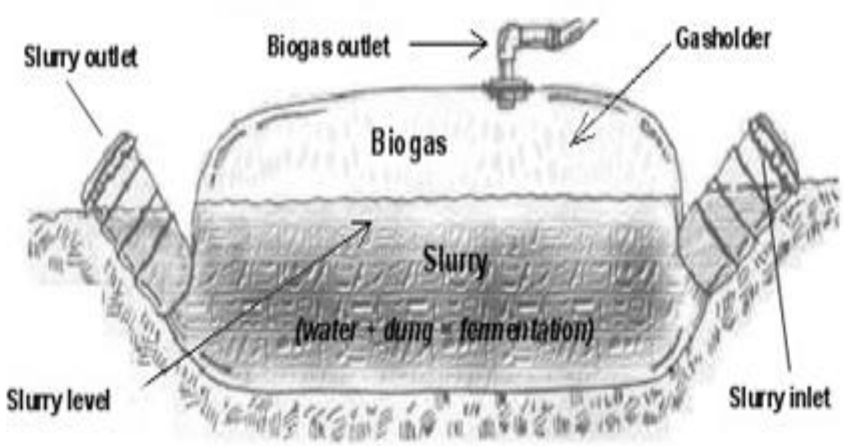


Fig 14: Scheme of Low-cost Polyethylene Tube Digester

- **Balloon Plants**
  - A balloon plant consists of a heat-sealed plastic or rubber bag (balloon), combining digester and gas-holder. The gas is stored in the upper part of the balloon. The inlet and outlet are attached directly to the skin of the balloon

- A balloon plant consists of a heat-sealed plastic or rubber bag (balloon), combining digester and gas-holder.
- The gas is stored in the upper part of the balloon. The inlet and outlet are attached directly to the skin of the balloon.
- Gas pressure can be increased by placing weights on the balloon. If the gas pressure exceeds a limit that the balloon can withstand, it may damage the skin. Therefore, safety valves are required. If higher gas pressures are needed, a gas pump is required.
- Since the material has to be weather- and UV resistant, specially stabilized, reinforced plastic is given preference. Other materials which have been used successfully include RMP (red mud plastic), Trevira and butyl. The useful life-span does usually not exceed 2-5 years.

➢ **Advantages**:

- Standardized prefabrication at low cost,
- low construction sophistication,
- ease of transportation,
- shallow installation suitable for use in areas with a high groundwater table;
- high temperature digesters in warm climates;
- uncomplicated cleaning,
- emptying and maintenance;
- difficult substrates like water hyacinths can be used

Balloon biogas plants are recommended, if local repair is or can be made possible and the cost advantage is substantial.

➢ **Disadvantages**:

- Low gas pressure may require gas pumps;
- scum cannot be removed during operation;
- The plastic balloon has a relatively short useful life-span and is susceptible to mechanical damage and usually not available locally. In addition, local craftsmen are rarely in a position to repair a damaged balloon. There is only little scope for the creation of local employment and, therefore, limited self-help potential.

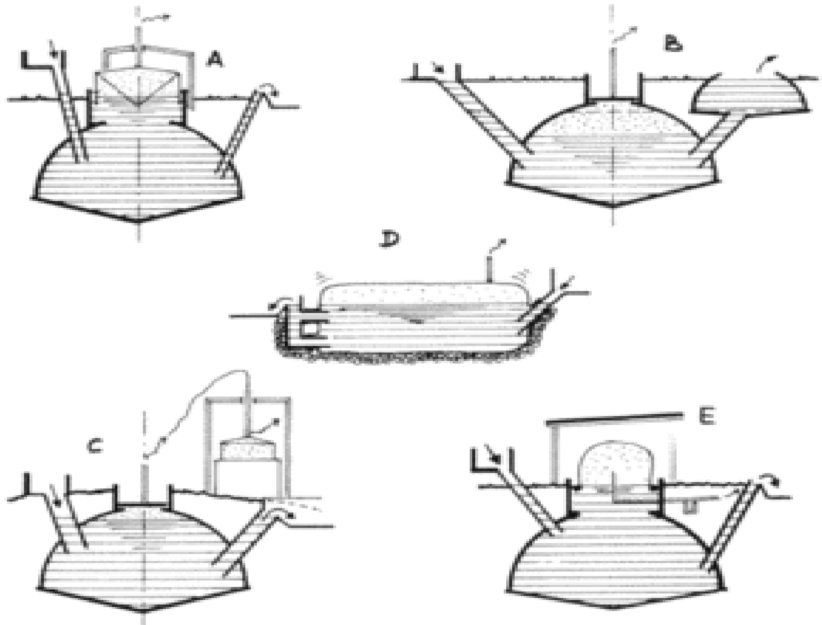


Fig 15: Bloom Type Plant

- **Combustion characteristics of bio gas**

1. Destructive carbonization of woody biomass to charcoal
2. Gasification of biomass to gaseous products
3. Pyrolysis of biomass and solid wastes to liquid, solid and gaseous products
4. Supercritical fluid extractions of biomass to liquid products
5. Liquefaction of biomass to liquid products
6. Hydrolysis of biomass to sugars and ethanol
7. Anaerobic digestion of biomass to gaseous products
8. Biomass power for generating electricity by direct combustion or gasification and Pyrolysis
9. Co firing of biomass with coal
10. Biological conversion of biomass and waste (biogas production, wastewater treatment)
11. Biomass densification (briquetting, pelleting)
12. Domestic cook stoves and heating appliances of fuel wood
13. Biomass energy conservation in households and industry
14. Solar photovoltaic and biomass based rural electrification
15. Conversion of biomass to pyrolytic oil (biofuel) for vehicle fuel
16. Conversion of biomass to methanol and ethanol for internal combustion engines

- **Bio Gas utilization for cooking**

Fig 16: Bio gas cooking arrangement

- **Economic Parameters Bio mass energy**
  - Price of biogas plant cum ancillaries.
  - Price of engine cum modification.
  - Price of driven machine and energy distribution system (electrical wiring, water system, etc.) unless already existing.
  - Operational cost of biogas system, i.e plant, engine and driven machine.
  - Cost of the system's service and maintenance.
  - Capital costs (interest rates, pay back periods, etc.).
  - Expected revenue from provision of selling energy or services, including the use of the engine's waste heat.
  - Savings by the omission of cost for other fuels or forms of energy.
  - Anticipated development of economic parameters (inflation, laws, regulations, fuel taxes, etc.).

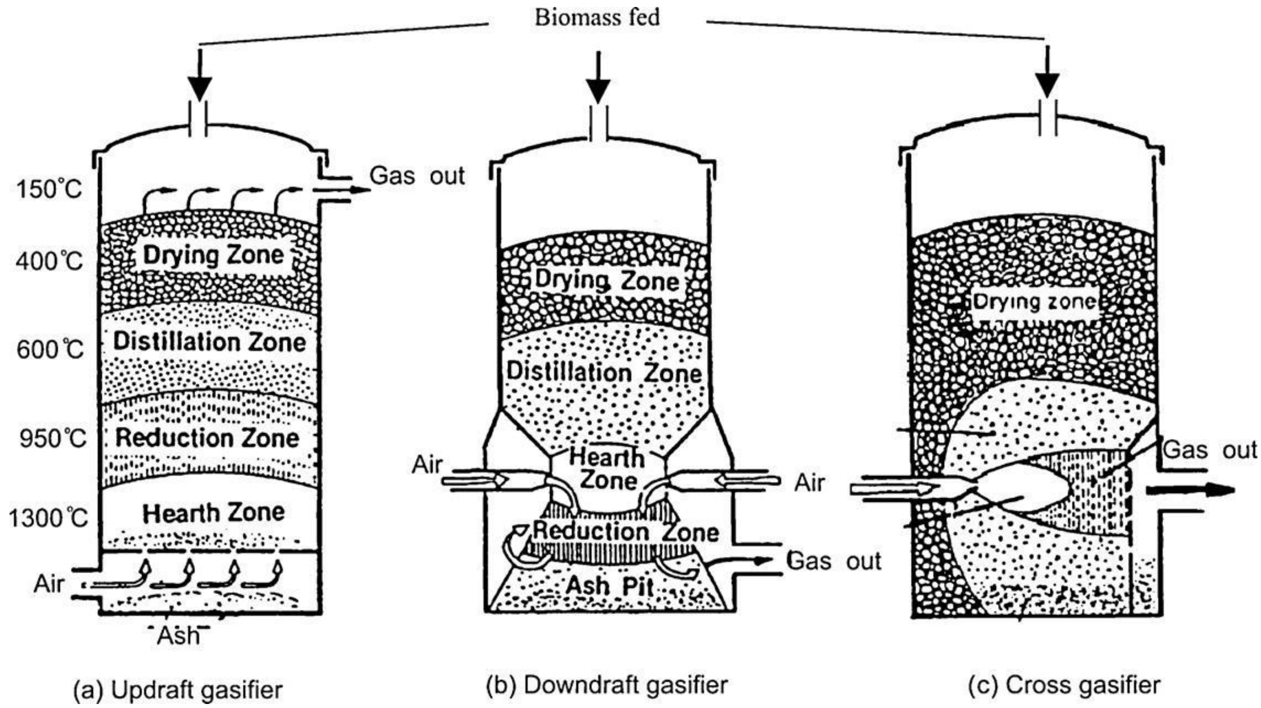


Fig 17: Thermal gasification

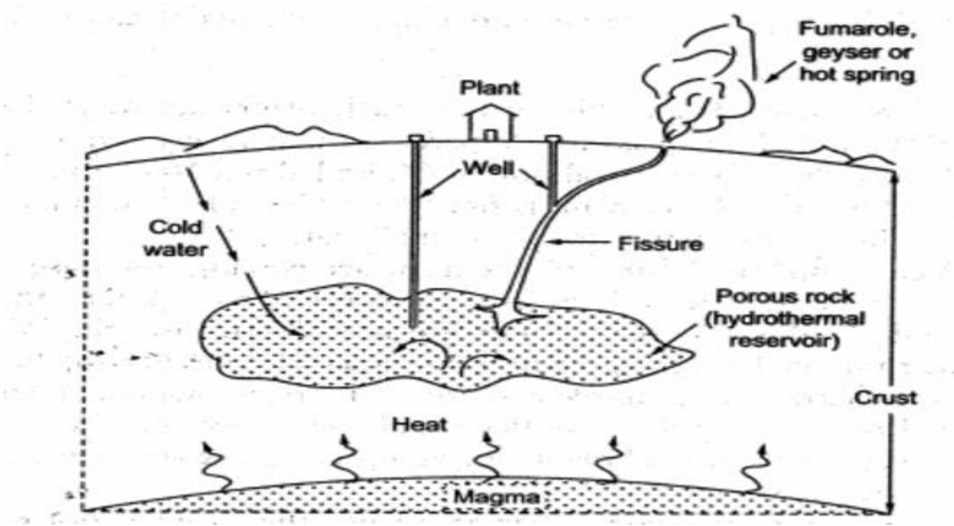
- Biomass gasification is a process of converting solid biomass fuel into a gaseous combustible gas (called producer gas) through a sequence of thermo-chemical reactions.
- The gas is a low-heating value fuel, with a calorific value between 1000- 1200 kcal/Nm3 (kilo calorie per normal cubic meter). Almost 2.5-3.0 Nm3 of gas can be obtained through gasification of about 1 kg of air-dried biomass.
- Since the 1980's the research in biomass gasification has significantly increased in developing countries, as they aim to achieve energy security.
- TERI independently began research work in gasifier technology in the mid-1980s. Since, the gasifier technology has been customized for a range of direct-heat application and tested successfully in the field. Silk processing, large-cardamom drying and gasifier-based crematoria are a few examples of the applications worked on at TERI. This technology is slowly replacing both traditional biomass use and gas-powered systems, as it provides an excellent de-centralized source of energy at an affordable cost. Apart from rural households, biomass fuels are the main source of energy to a large number of small, rural and cottage industries.

Geothermal Energy:

Geothermal energy originates from the earth's interior in the form of heat. Volcanoes, geysers, hot springs and boiling mud pots are visible evidence of the great reservoirs of heat that lie beneath the earth.

Geothermal field:

The following figure shows the geothermal filed or structure of earth



Structure of the earth

The above figure shows a typical geo thermal field.

- The hot magma (molten mass) near the surface solidifies into igneous rock.
- The heat of the magma is conducted upward to this igneous rock.
- Ground water that finds its way down to this rock through fissures in it will be heated by the heat of the rock or by mixing with hot gases and steam emanating from the magma.
- The heated water will then rise convectively upward and then into a porous and permeable reservoir above the igneous rock.
- The reservoir is capped by a layer of impermeable solid rock that traps the hot water in the reservoir.
- The solid rock however, has fissures that act as vents of the giant underground boiler.
- The vents show up at the surface as the geysers fumaroles or hot spring.
- A well taps the steam from the fissures for use in geo thermal power plant.

Classification of geothermal fields:

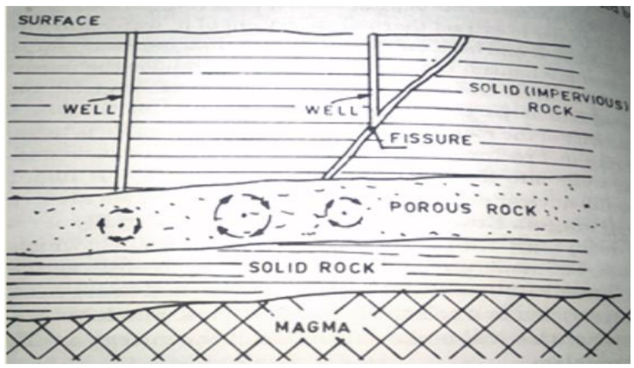
1. Non thermal geo fields
    a) Hot dry vapour
    b) Wet vapour
2. Semi thermal geo fields
3. Hydro thermal geo fields
    a) Vapour dominated
    b) Liquid dominated
4. Geo pressured resources

5. Hot dry rocks (HDR)
6. Magma fields
    a) Magmatic steam
    b) Meteoritic steam
    c) Hot aquifer

Hydro thermal resources:

- These are wet reservoirs at moderate depths containing steam and or hot water under pressure at temperatures up to about 350^0C.
- Most hydro thermal wells range in depth from about 600 to 1200m, although there are some shallower and deeper production wells.

The following figure shows the hydro thermal convective region

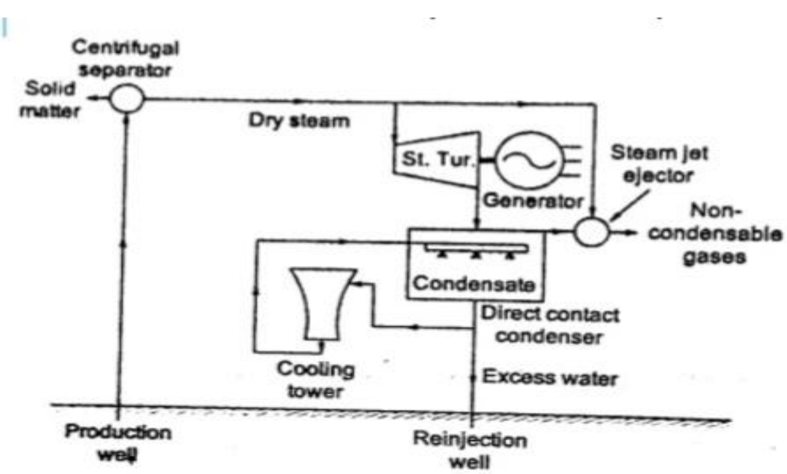


Hydro thermal convective region

Hydro thermal sources are sub divided as follows

a) Vapour dominated systems:

The following figure shows the schematic diagram of a vapour dominated power plant



Vapour dominated hydro thermal power plant

Working procedure:

- Dry steam is extracted from the well, cleaned in a centrifugal separator to remove solid matter and then piped directly to a turbine.
- The exhaust steam of the turbine is condensed in a direct contact condenser, in which the steam is condensed by direct contact with cooling water.
- The resulting warm water is circulated and cooled in a cooling tower returned to the condenser.
- The condensation of steam continuously increases the volume of cooling water.
- Excess water is re injected at some distance deep into the ground for disposal.
- The non-condensable gases are removed from the condenser by steam jet ejection.

b) Liquid dominated systems:

Liquid dominated systems are classified as follows

i. The flashed steam system
   a. Single flash steam system   b. Double flash steam system
ii. Binary fluid system
iii. Total flow concept system

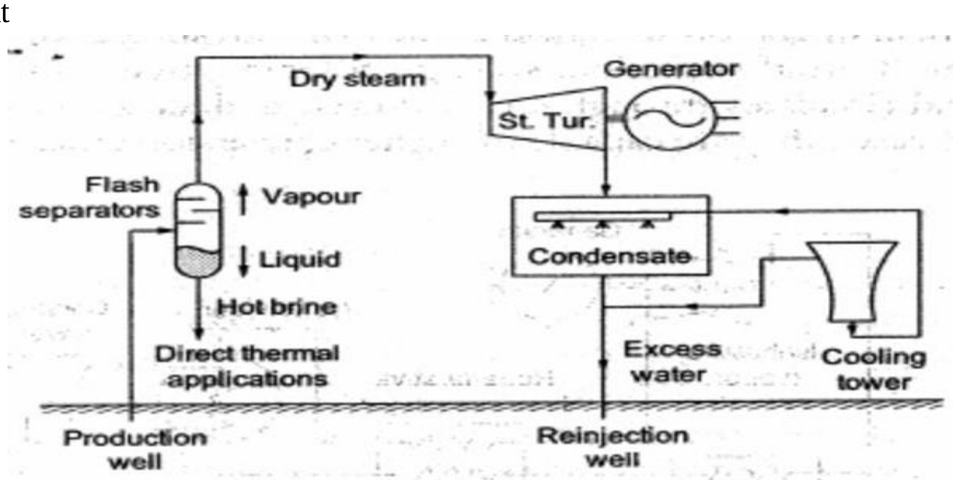
Single flash steam system:

- ✓ Single flash and double flash systems are belongs to high temperature systems because the operating temperature is above 175^0c

Working procedure:

- In single flash system wet steam is extracted from the well and that steam is separated from water particles with the help of flash separator.
- The exhaust steam of the turbine is condensed in a direct contact condenser, in which the steam is condensed by direct contact with cooling water.
- The resulting warm water is circulated and cooled in a cooling tower returned to the condenser.
- The condensation of steam continuously increases the volume of cooling water.
- Excess water is re injected at some distance deep into the ground for disposal.
- The non-condensable gases are removed from the condenser by steam jet ejection.

The following figure shows the schematic diagram of a liquid dominated single flash steam power plant



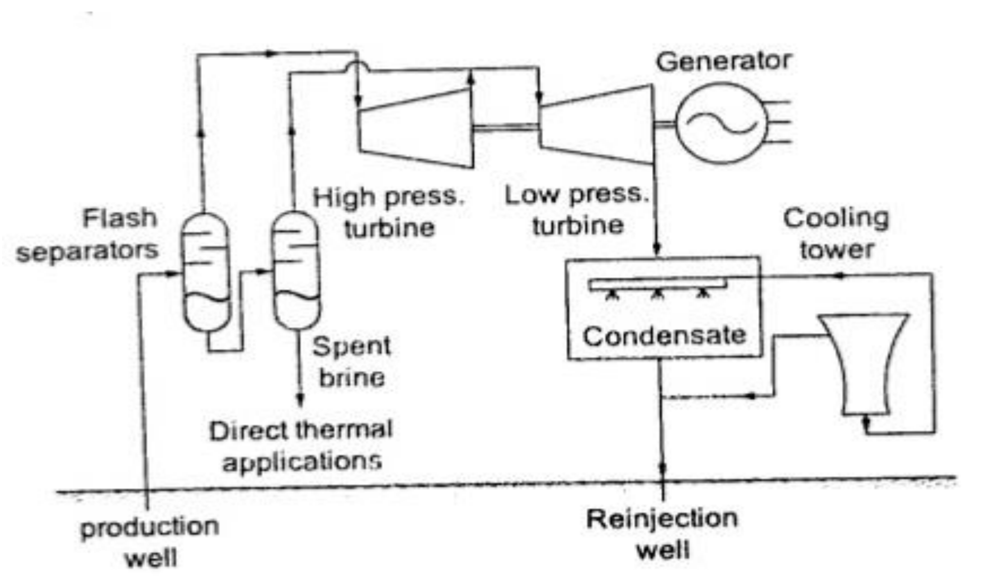
Liquid dominated single flash steam power plant

Double flash steam system:

Working procedure:

- In this two flash systems are used
- In double flash system wet steam is extracted from the well and that steam is separated from water particles with the help of first flash separator.
- The exhaust steam of the turbine is condensed in a direct contact condenser, in which the steam is condensed by direct contact with cooling water.
- The resulting warm water is circulated and cooled in a cooling tower returned to the condenser.
- From the second flash chamber the water particles are flows for condensation.
- The condensation of steam continuously increases the volume of cooling water.
- Excess water is re injected at some distance deep into the ground for disposal.
- The non-condensable gases are removed from the condenser by steam jet ejection.

The following figure shows the schematic diagram of a liquid dominated double flash steam power plant



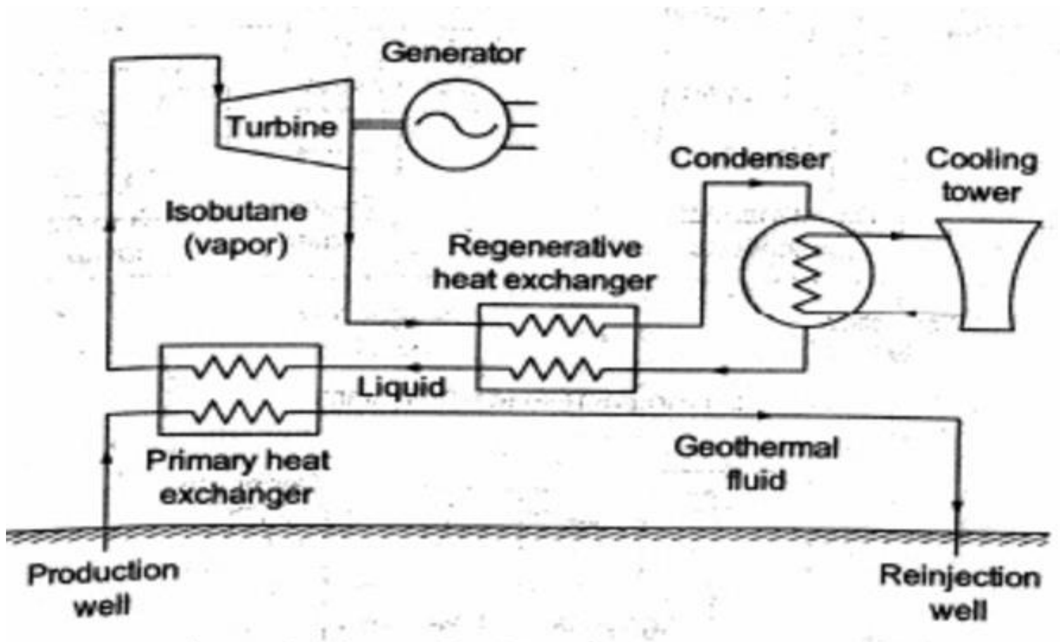
Liquid dominated double flash system

Binary fluid system:

- ✓ The operating temperature of the binary fluid system is below 175^0c so it is belongs to low temperature system.
- ✓ In binary fluid system two heat exchangers are used in place of two flash separators.
- ✓ In those heat exchangers for the vaporization of steam organic fluid is used as a binary fluid.
- ✓ Two different fluids are flows in this system that's why this system is called as binary fluid system.
- ✓ In most of the cases Isobutene is used a binary fluid.
- ✓ The exhaust steam of the turbine is condensed in a direct contact condenser, in which the steam is condensed by direct contact with cooling water.
- ✓ The resulting warm water is circulated and cooled in a cooling tower returned to the condenser.
- ✓ The condensation of steam continuously increases the volume of cooling water.
- ✓ Excess water is re injected at some distance deep into the ground for disposal.

- ✓ The non-condensable gases are removed from the condenser by steam jet ejection.

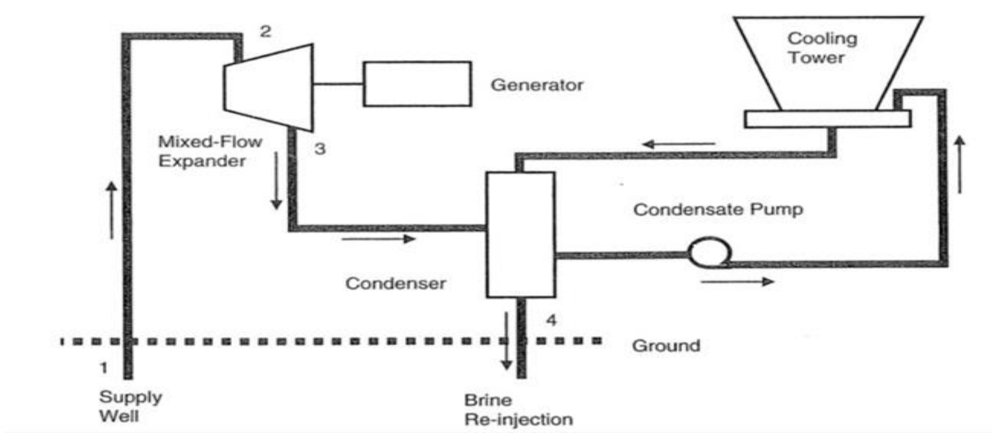
The following figure shows the schematic diagram of a Binary fluid geothermal power system



Binary fluid geothermal power system

Total flow concept system:

The following figure shows the schematic diagram of a liquid dominated total flow concept



Liquid dominated total flow concept

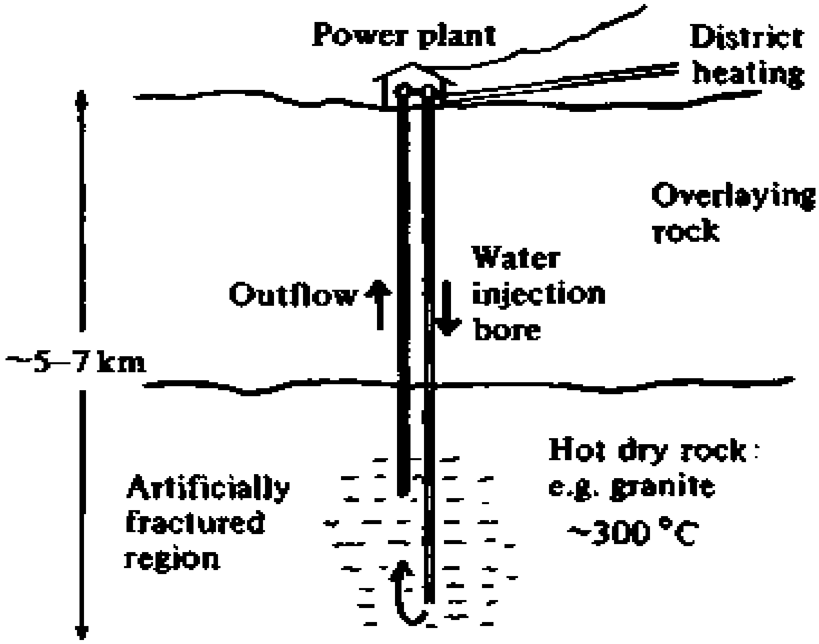
Geo pressured resources:

- ➢ Drilling for oil and gas has revealed the existence of reservoirs containing salt water at moderately high temperatures and very high pressures in a belt some 1200 Km in length.
- ➢ Because of the abnormally high pressure of the water, up to 1350 atm. In the deepest layers, the reservoirs are referred to as geo pressured.

- The geo pressured hot water reservoirs were apparently formed by accumulation of geothermal heat stored over several million years, in water trapped in a porous sedimentary medium by the overlying impervious layers.
- The upward loss of heat is relatively small and there are no obvious surface indications of the deep, high temperature reservoirs.
- Higher pressure and temperatures have been measured at greater depths. The amount of dissolved salt in the water varies with location and depth of the reservoir, ranging from very small to about three times that in sea water.
- A special feature of geo pressured water (or brines) is their content of methane (natural gas).
- The energy value of the brines thus depends on their temperature.
- The solubility of methane in water at normal pressure is quite low, but is increased at high pressures of the geo thermal reservoirs.
- When the water is brought to the surface and its pressure reduced, the methane gas is released from solution
- The gas content of geo pressured brine is usually about 1.9 to 3.8 m^3 gas per m^3 of water but higher values have been reported in brief tests.
- However the amount of natural gas recoverable economically from geo pressured reservoirs is presently unknown.

Hot dry rock resources (HDR):

- ✓ There are regions underground at temperatures exceeding 200^0c, with little or no water.
- ✓ The rocks are impermeable and/or there is no surface water in the vicinity.
- ✓ Such resources up to a depth of 5km are estimated to be significant and worthy of development as a source of energy.
- ✓ Hot dry rocks are much more common than hydro thermal reservoirs and more accessible. So their potential is quite high.
- ✓ The recovery of heat from HDR involves forming a man-made reservoir by drilling deep in to the hot rocks and then cracking it to form cavity or fractures.
- ✓ Such a system is known as an Enhanced Geothermal System(EGS), sometimes also called Engineered Geothermal Systems.
- ✓ EGS can be achieved by
    a. Detonating high explosives at the bottom of the well.
    b. Nuclear explosion.
    c. Hydraulic fracturing.
- ✓ Hydraulic fracturing, which is performed by pumping of water at high pressure into the rock formation, is commonly used in oil and gas fields to improve the flow.
- ✓ It appears that the quantity of conventional explosives required would be uneconomically large.
- ✓ Nuclear explosives are associated with environmental and safety issues and therefore, hydraulic fracturing seems to be more promising.



Heat extraction from hot dry rocks

Magma resources:

- ❖ At some places, molten or partially molten rock (magma chamber), at temperatures of 650^0c to 1200^0c occurs at depths of 5 km – 10 km.
- ❖ These resources are located especially in the vicinity of recent volcanic activity.
- ❖ Very high temperature and large volume make magma huge potential energy source, the largest of all geo thermal resources.
- ❖ However, successful magma drilling technology has not been established yet.
- ❖ Extracting magma energy is expected to be most difficult of all types of resource utilization.
- ❖ Magma technology will require special drilling technology to deal with interaction of the drill bit with molten rock, the effects of dissolved gases, and mechanisms of heat transport in molten magma.
- ❖ This technology has not been developed as yet.

OCEAN THERMAL ENERGY CONVERSION

OTEC, or Ocean Thermal Energy Conversion, is an energy technology that converts solar radiation to electric power. OTEC systems use the ocean's natural thermal gradient the fact that the ocean's layers of water have different temperatures to drive a power-producing cycle. As long as the temperature between the warm surface water and the cold deep water differs by about 20°C, an OTEC system can produce a significant amount of power, with little impact on the surrounding environment.

The distinctive feature of OTEC energy systems is that the end products include not only energy in the form of electricity, but several other synergistic products. The principle design objective was to minimize plan cost by minimizing plant mass, and taking maximum advantage of minimal warm and cold water flows. Power is converted to high voltage DC, and is cabled to shore for conversion to AC and integration into the local power distribution network.

The oceans are thus a vast renewable resource, with the potential to help us produce billions of watts of electric power.

OCEAN THERMAL ENERGY CONVERSION

- Oceans cover more than 70% of Earth's surface, making them the world's largest solar collectors. The sun's heat warms the surface water a lot more than the deep ocean water, and this temperature difference creates thermal energy.
- Just a small portion of the heat trapped in the ocean could power the world.
- OTEC or Ocean Thermal Energy Conversion (OTEC) is a process which utilizes the heat energy stored in the tropical ocean.
- The world's oceans serve as a huge collector of heat energy. OTEC plants utilize the difference in temperature between warm surface sea water and cold deep sea water to produce electricity.
- Thermal energy conversion is an energy technology that converts solar radiation to electric power.
- OTEC systems use the ocean's natural thermal gradient—the fact that the ocean's layers of water have different temperatures to drive a power-producing cycle.
- As long as the temperature between the warm surface water and the cold deep water differs by about 20°C, an OTEC system can produce a significant amount of power.
- The oceans are thus a vast renewable resource, with the potential to help us produce billions of watts of electric power.
- This potential is estimated to be about 1013 watts of base load power generation, according to some experts.
- The cold, deep seawater used in the OTEC process is also rich in nutrients, and it can be used to culture both marine organisms and plant life near the shore or on land.
- OTEC produce steady, base-load electricity, fresh water, and air-conditioning options.

OTEC requires a temperature difference of about 36 deg F (20 deg C). This temperature difference exists between the surface and deep seawater year round throughout the tropical regions of the world.

To produce electricity, we either use a working fluid with a low boiling point (e.g. ammonia) or warm surface sea water, or turn it to vapour by heating it up with warm sea water (ammonia) or de-pressurizing warm seawater.

The pressure of the expanding vapour turns a turbine and produces electricity.

Commercial OTEC facilities can be built on

- Land or near the shore
- Platforms attached to the shelf
- Moorings or free-floating facilities in deep ocean water

Land-based and near-shore are more advantageous than the other two. OTEC plants can be mounted to the continental shelf at depths up to 100 meters, however may make shelf-mounted facilities less desirable and more expensive than their land-based counterparts. Floating OTEC facilities with a large power capacity, but has the difficulty of stabilizing and of mooring it in very deep water may create problems with power delivery.

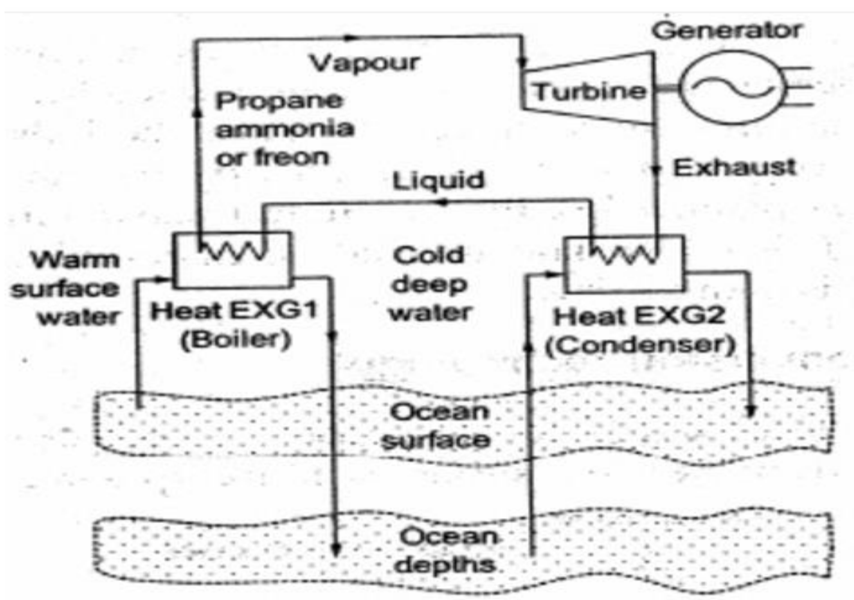
Commercial ocean thermal energy conversion (OTEC) plants must be located in an environment that is stable enough for efficient system operation. The temperature of the warm surface seawater must differ about 20°C (36°F) from that of the cold deep water that is no more than about 1000 meters (3280 feet) below the surface. The natural ocean thermal gradient necessary for OTEC operation is generally found between latitudes 20 deg N and 20 deg S.

TYPES OF ELECTRICITY CONVERSION SYSTEMS

There are three types of electricity conversion systems: closed-cycle, open-cycle, and hybrid. Closed-cycle systems use the ocean's warm surface water to vaporize a working fluid, which has a low-boiling point, such as ammonia. The vapour expands and turns a turbine. The turbine then activates a generator to produce electricity. Open-cycle systems actually boil the seawater by operating at low pressures. This produces steam that passes through a turbine/generator. And hybrid systems combine both closed-cycle and open-cycle systems.

CLOSED-CYCLE OTEC

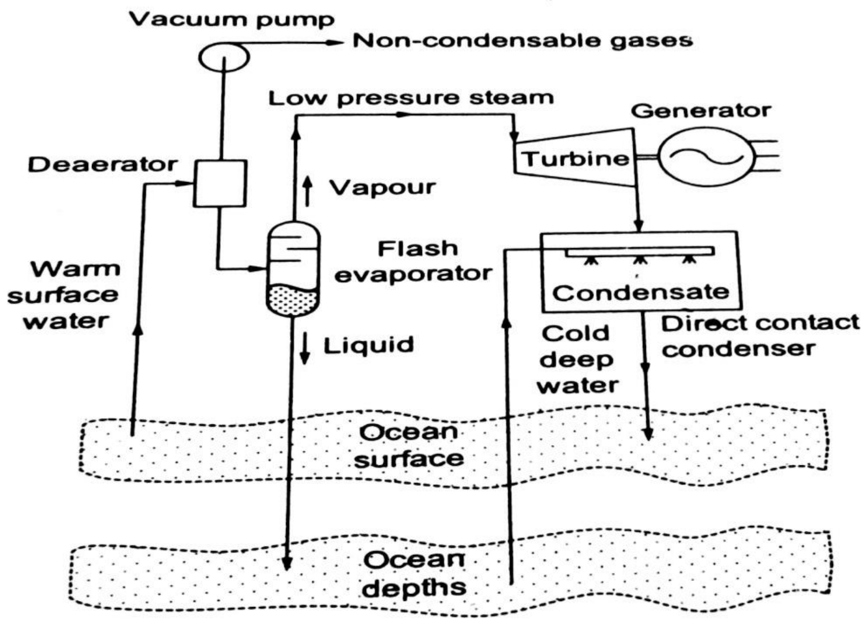
In the closed-cycle OTEC system, warm sea water vaporizes a working fluid, such as ammonia, flowing through a heat exchanger (evaporator). The vapor expands at moderate pressures and turns a turbine coupled to a generator that produces electricity. The vapor is then condensed in heat exchanger (condenser) using cold seawater pumped from the ocean's depths through a cold-water pipe. The condensed working fluid is pumped back to the evaporator to repeat the cycle. The working fluid remains in a closed system and circulates continuously.



The heat exchangers (evaporator and condenser) are a large and crucial component of the closed-cycle power plant, both in terms of actual size and capital cost. Much of the work has been performed on alternative materials for OTEC heat exchangers, leading to the recent conclusion that inexpensive aluminium alloys may work as well as much more expensive titanium for this purpose.

OPEN-CYCLE OTEC

The open cycle consists of the following steps: (i) flash evaporation of a fraction of the warm seawater by reduction of pressure below the saturation value corresponding to its temperature (ii) expansion of the vapor through a turbine to generate power; (iii) heat transfer to the cold seawater thermal sink resulting in condensation of the working fluid; and (iv) compression of the non-condensable gases (air released from the seawater streams at the low operating pressure) to pressures required to discharge them from the system.



Hybrid OTEC System

Another option is to combine the two processes together into an open-cycle/closed-cycle hybrid, which might produce both electricity and desalinated water more efficiently. In a hybrid OTEC system, warm seawater might enter a vacuum where it would be flash-evaporated into steam, in a similar fashion to the open-cycle evaporation process.

The steam or the warm water might then pass through an evaporator to vaporize the working fluid of a closed-cycle loop. The vaporized fluid would then drive a turbine to produce electricity, while the steam would be condensed within the condenser to produced desalinated water

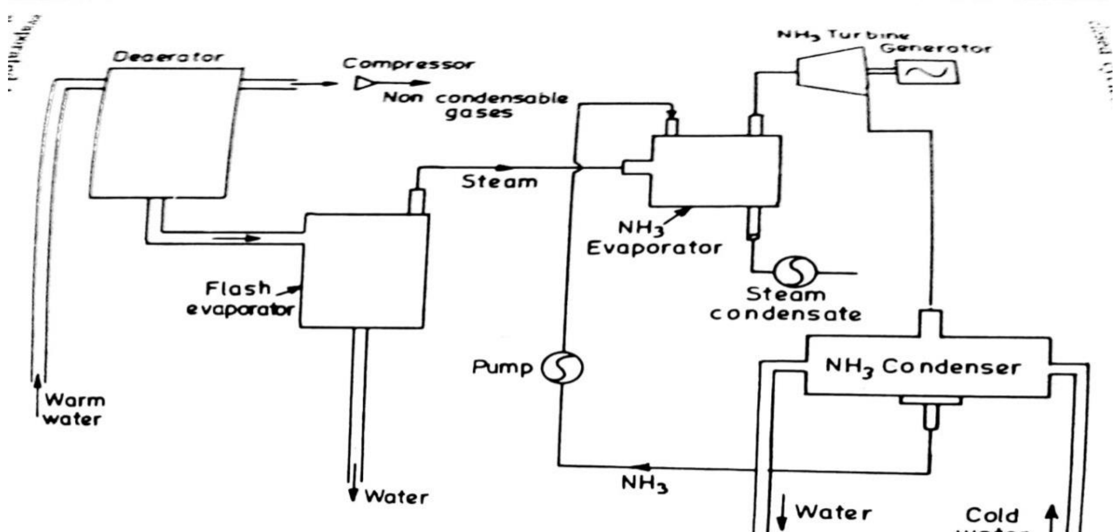


Fig. 9.2.5.1. Hybrid Cycle.

BENEFITS OF OTEC

We can measure the value of an ocean thermal energy conversion (OTEC) plant and continued OTEC development by both its economic and no economic benefits. OTEC's economic benefits include the:

- Helps produce fuels such as hydrogen, ammonia, and methanol
- Produces base load electrical energy
- Produces desalinated water for industrial, agricultural, and residential uses
- Is a resource for on-shore and near-shore Mari culture operations
- Provides air-conditioning for buildings
- Provides moderate-temperature refrigeration
- Has significant potential to provide clean, cost-effective electricity for the future.
- Fresh Water up to 5 litres for every 1000 litres of cold seawater.
- Food Aquaculture products can be cultivated in discharge water.

OTEC's no economic benefits, which help us achieve global environmental goals, include these:

- Promotes competitiveness and international trade
- Enhances energy independence and energy security
- Promotes international socio-political stability

DISADVANTAGES

- OTEC plant construction and operation may affect commercial and recreational fishing.
- Fish will be attracted to the plant, potentially increasing fishing in the area.
- Enhanced productivity due to redistribution of nutrients may improve fishing.
- Other risks associated with the OTEC power system are the safety issues associated with steam electric power generation plants: electrical hazards, rotating machinery, use of compressed gases, heavy material-handling equipment, and shop and maintenance hazards.

APPLICATIONS

Ocean thermal energy conversion (OTEC) systems have many applications or uses. OTEC can be used to generate electricity, desalinate water, support deep-water Mari culture, and provide refrigeration and air-conditioning as well as aid in crop growth and mineral extraction. These complementary products make OTEC systems attractive to industry and island communities even if the price of oil remains low.

TIDAL ENERGY

The periodic rise and fall of water level of sea which are carried by the action of the sun and moon on water of the earth is called "tide". The large scale up and down movement of sea water represents an unlimited source of energy.

The main feature of the tidal cycle is the difference in water surface elevations at the high tide and at the low tide. If the differential head could be utilized in operating a hydraulic turbine, the tidal energy could be converted into electrical energy by means of an attached generator.

Physical principle of tidal energy

A tide is a regular rise and fall of the surface of the ocean due to the gravitational force of the sun and moon on the earth and the centrifugal force produced by the rotation of the earth and moon about each other. It is known that the gravitational force that mutually attracts any two bodies is directly proportional to the product of their masses and is inversely proportional to the square of the distance that separates the masses. The attractive force exerted by the sun or moon on a molecule of water can be calculated as:

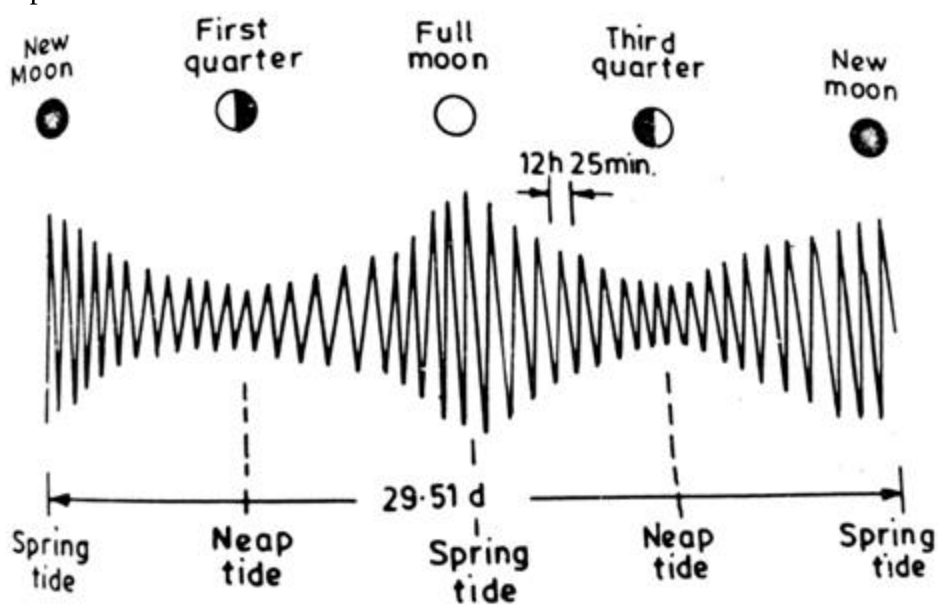
$$F = \frac{K \times M \times m}{d^2}$$

F: attraction force

K: universal constant of gravitation
M: mass of the moon or sun
m: mass of a water molecule
d: the distance from a water molecule to the moon/sun

The effect of the gravitational force exerted by the moon on the earth is about 2.17 times larger than the exerted by the sun, due to the smaller distance between the earth and the moon. A bulge of water is created being greater on the earth side nearest to the moon due to the gravitational force. Simultaneously, another bulge of water is created due to the centrifugal pull due to the rotation of the earth-moon system, but in this case the water bulge is created on the side of the earth furthest away of the moon. As a result of the two forces, a resultant bulge is created around the earth.

- When sun and moon are in line whether pulling on the same side or on the opposite side (full or new moons) the gravitational attraction combine together causes high tides, known as spring tides.
- Conversely, when sun and moon are orthogonal, their gravitational forces pulls water in different directions causing the bulges to cancel each other, giving place to neap tides.
- The maximum power is produced during spring tide while the minimum is during the neap tide.



Tidal phenomenon is periodic. The periodicity varies according to the lunar and solar gravitational effects, respective movements of the moon and sun, and other geographical peculiarities. The mean interval between conjunctions of the sun and moon (new moon to new moon) has a cycle of 29.53 days, which is known as Synodic month or lunation. There are three different types of tidal phenomena at different locations of the earth.

- Semidiurnal tides with monthly variation.
- Diurnal tides with monthly variation
- Mixed tides

POTENTIAL

Worldwide, the technically harvestable tidal energy resource from those areas close to the coast is estimated by several sources at 1 terawatts (TW).

- The potential for tidal current technologies is larger than for tidal range.

- Total tidal range deployment in 2012 was around 514 MW, and around 6 MW for tidal current (of which 5 MW is deployed in the UK).
- Extensive plans exist for tidal barrage projects in India, Korea, the Philip-pines and Russia adding up to around 115 giga watts (GW).
- Deployment projections for tidal current up to 2020 are in the range of 200 MW.

An advantage of both tidal range and tidal current energy is that they are relatively predictable with daily, bi-weekly, biannual and even annual cycles over a longer time span of a number of years. Energy can be generated both day and night. Furthermore, tidal range is hardly influenced by weather conditions.

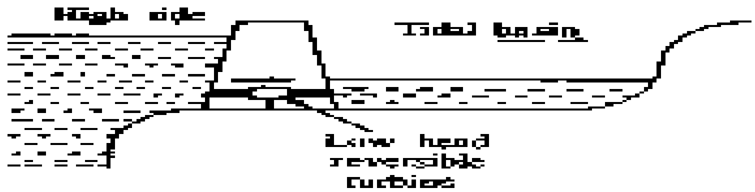
TIDAL POWER PLANT

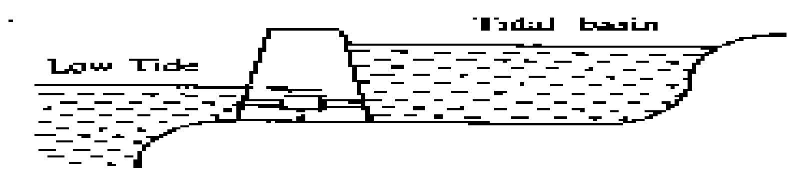
A Tidal power plant mainly consists of the following:

1. A barrage with gates and sluices
2. One or more basins
3. A power house

A barrage is a barrier constructed across the sea to create a basin for storing water. The barrage has to withstand the pressure exerted by the water head and also should resist the shock of the waves.

A basin is the area where water is retained by the barrage. Low head reversible water turbine are installed in the barrage separating the sea from the basin.-





During high tide, water will flow from sea to tidal basin through turbine, thus producing electricity. During low tide, water will flow from tidal basin to sea through turbine producing electricity.

TIDAL ENERGY CONVERSION SYSTEMS

Single basin tidal barrage

This system consists of one basin and requires a barrage across an estuary or a bay. There are three main operation patterns in which power can be generated within a single basin: ebb generation, single tide cycle system, double cycle system.

Ebb generation

This method is the simplest mode of operation for a tidal plant, in which the basin is filled with water through the sluices gates during flood tide. At high tide, the sluice gates are closed, keeping the water in the basing. During periods of low demand, extra water can be pumped to raise the level further.

The sluices are kept closed until the current has ebbed sufficiently to develop substantial hydrostatic head across the barrage. Consequently, the water is let flow through the turbines, generating electricity for several hours, until the hydrostatic head drops to the minimum level in which turbines can efficiently operate. Once this point is reached, the sluices are opened, turbines disconnected and the basin is filled again, starting a new cycle. Ebbs generation takes this name because generation occurs as the tide ebbs.

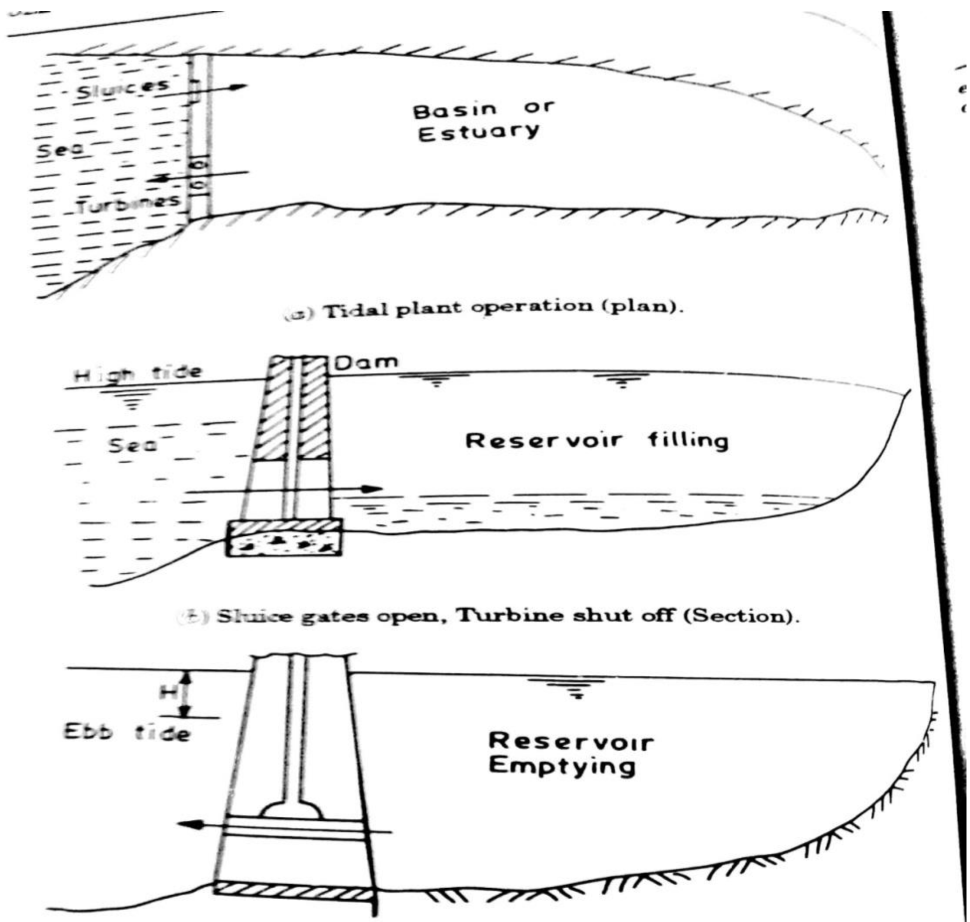


Fig. Ebb generation mode

Following typical day fluctuations are summarized:

- Every day there are two burst of generation activity beginning approximately three hours after high tide and lasting 4 to 6 hours.
- For each tidal cycle production levels rapidly increase with tidal range. Therefore, the output characteristic displays a 14 days cycle.
- High water times shift by about 1 hour per day.
- For each 14 day, energy production will not be evenly distributed throughout the 24h of the day.
- Output levels will only show slight variation from one fortnightly period to the next.
- Annual production levels show fluctuations of around ±5% and follow a cycle of 18 2/3

years.

Single tide cycle system:

The flood generation method uses incoming tide to generate power. During the flood tide turbines and sluices gates are kept closed until a substantial hydrostatic head is developed across the barrage. Once the sufficient head is achieved the turbine gates are opened allowing the water to flow through them into the basin.

Generally, flood generation is less efficient than ebb generation because the volume of water stored on the upper half of the basin (which is where ebb generation operates) is greater than the volume stored on the lower half (filled first during flood generation).Therefore, the water head between the basin and the sea, reduces more quickly than it would be with ebb generation, thus, less energy is produced.

Moreover, as in average the system it creates a decrease in sea level within the basin, it can have a negative effect on shipping and the environment; as the level of the reservoir is subjected to continuous changes in water level, whereas in ebb generation, the greater changes in water level are suffered by the basin.

Double cycle system:

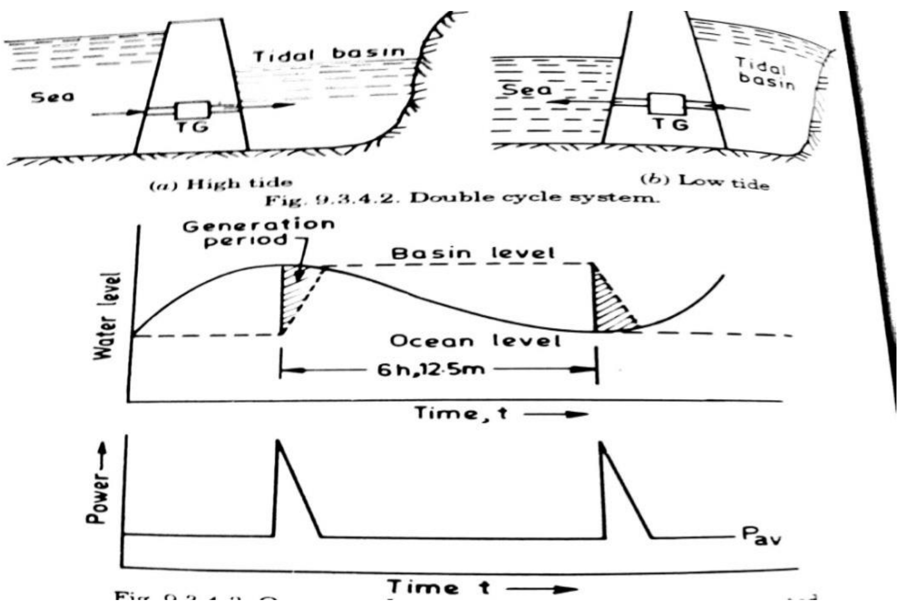
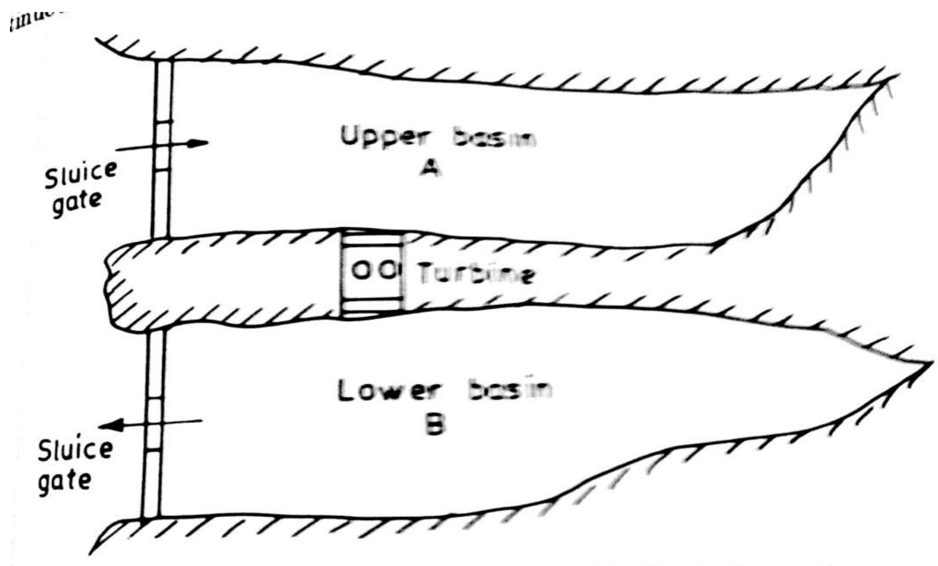


Fig. 9.3.4.2. Double cycle system.

This method combines ebb generation and flood generation. Generation occurs in both, as the tide ebbs and floods in every cycle. The sluices gates are kept close until near the end of the flood cycle. When the minimum hydrostatic head for electricity generation is reached, the sluices gates are opened. At high tide, the sluices gates are closed and water is trapped until sufficient hydrostatic head is reached again. Water is then allowed to flow through the turbines to generate in the ebb mode. This method has an advantage respect to the other two; it has a reduced period of non-generation and a reduction in generators costs due to lower peak power. Blocks of energy are produced in approximately 6 hours cycle, with smaller output and greater plant utilization factor. However, it presents a smaller power output than for simple ebb generation, due to the reduce range within the basin. Moreover, turbines are designed to operate in both directions are more costly.

DOUBLE BASIN-TIDAL BARRAGE

This system requires the construction of two barrages, the main one and the inner one, giving place to two basins. The main basin is essentially the same as ebb generation in a single-basin system. The only difference is that in this case, part of the energy produced by it is used to pump water into the second basin [4]. For this reason, the second barrage acts as a storage element, extending the time period in which the barrage can produce electricity, therefore this system can adjust the delivery of electricity to match consumer demands. The system major advantage is the ability to delivery electricity at periods of high demand. However, double-basin systems are unlikely to become feasible for both, inefficiencies of low-head turbines and high construction costs.



ADVANTAGES

1. It is inexhaustible source of energy
2. No problem of pollution
3. The cost of power generation is quite low
4. High output can be obtained compared to solar or wind energy

DISADVANTAGES

1. Capital cost is very high
2. As the head is not constant, variable output is obtained
3. As the head is low, large amount of water is necessary for the turbine
4. It will not operate when the available head is less than 0.5m

Energy conversion

- ➢ Most of these energy converters, sometimes called **static energy-conversion devices**, use electrons as their “working fluid” in place of the vapor or gas employed by such dynamic heat engines as the external-combustion and internal-combustion engines.
- ➢ In recent years, direct energy-conversion devices have received much attention because of the necessity to develop more efficient ways of transforming available forms of primary energy into electric power.
- ➢ In NASA space-power-generation work, considerable emphasis has been placed on direct energy conversion. This is an advanced technology which is of interest though not necessarily of immediate usefulness to industry.

There are four types of direct-conversion processes:

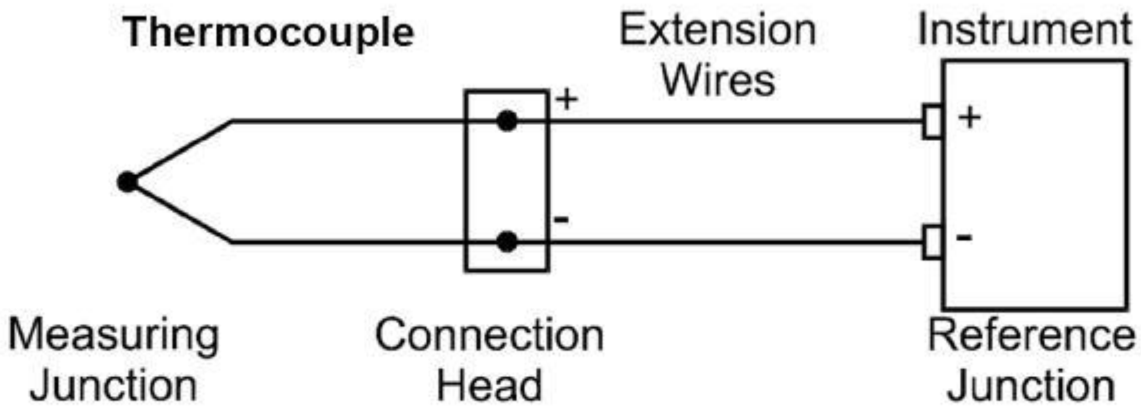
- Electrochemistry
- Thermoelectric
- Thermionic, and
- Magneto hydrodynamics, more commonly called MHD.

THERMOELECTRICS:

- Like the battery and the fuel cell, the origins of thermoelectricity date back to the early 1800's.
- In **1820,** See beck was working with an electrical circuit made of dissimilar materials and found that a voltage was developed in the circuit when one of the junctions was heated.

Seebeck effect

- The See beck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances.
- When heat is applied to one of the two conductors or semiconductors, heatedelectrons flow toward the cooler one. If the pair is connected through an electrical circuit, direct current (DC) flows through that circuit.
- The voltages produced by Seebeck effect are small, usually only a few microvolts (millionths of a volt) per kelvin of temperature difference at the junction.

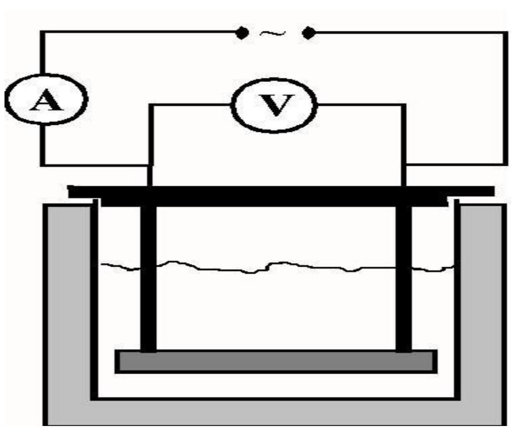


- If the temperature difference is large enough, some Seebeck-effect devices can produce a few milli-volts (thousandths of a volt).
- Numerous such devices can be connected in series to increase the output voltage or in parallel to increase the maximum deliverable current. Large arrays of Seebeck-effect devices can provide useful, small-scale electrical power if a large temperature difference is maintained across the junctions.
- Thomas Johann Seebeck discovered the phenomenon in the 1800s. More recently, in 2008, physicists discovered what they are calling the spin Seebeck effect. The spin Seebeck effect is seen when heat is applied to a magnetized metal. As a result, electrons rearrange themselves according to their spin. Unlike ordinary electron movement, this rearrangement does not create heat as a waste product. The spin Seebeck effect could lead to the development of smaller, faster and more energy-efficient microchips as well as spintronics devices.
- The Seebeck effect is responsible for the behavior of thermocouples, which are used to approximately measure temperature differences or to actuate electronic switches that can turn large systems on and off. This capability is employed in thermoelectric cooling technology. Commonly used thermocouple metal combinations include constantan/copper, constantan/iron, constantan/chromel and constantan/alumel.
- The Seebeck coefficient may range in value from −100 μV/K to +1,000 μV/K

Joule Effect:

- James Prescott Joule first published in December 1840 an abstract in the *Proceedings of the Royal Society*, suggesting that heat could be generated by an electrical current. Joule immersed a length of wire in a fixed mass of water and measured the temperature rise due to a known current flowing through the wire for a 30 minute period. By varying the current and the length of the wire he deduced that the heat produced was proportional to the square of the current multiplied by the electrical resistance of the immersed wire.

- This refers to the irreversible conversion of electrical energy into heat when a current I flows through a resistance R, an amount of heat equal to I^2R is generated per unit time. This heat is called Joulean heat.
- **Joule heating**, also known as **ohmic heating** and **resistive heating**, is the process by which the passage of an electric current through a conductor releases heat.
- **Joule's first law**, also known as the **Joule–Lenz law**, states that the power of heating generated by an electrical conductor is proportional to the product of its resistance and the square of the current. $P \propto I^2 \cdot R$
- Joule heating is caused by interactions between the moving particles that form the current (usually, but not always, electrons) and the atomic ions that make up the body of the conductor. Charged particles in an electric circuit are accelerated by an electric field and have electrostatic potential energy. When the charged particles collide with ions in the conductor, the particles are scattered and so their motion becomes random and therefore thermal, increasing the temperature of the system as they continue to move through the circuit. Some kinetic energy is lost in these collisions however the drift velocities of these particles is of the order of mm/h and so kinetic energy loss is negligible and almost all kinetic energy comes from thermal motion.



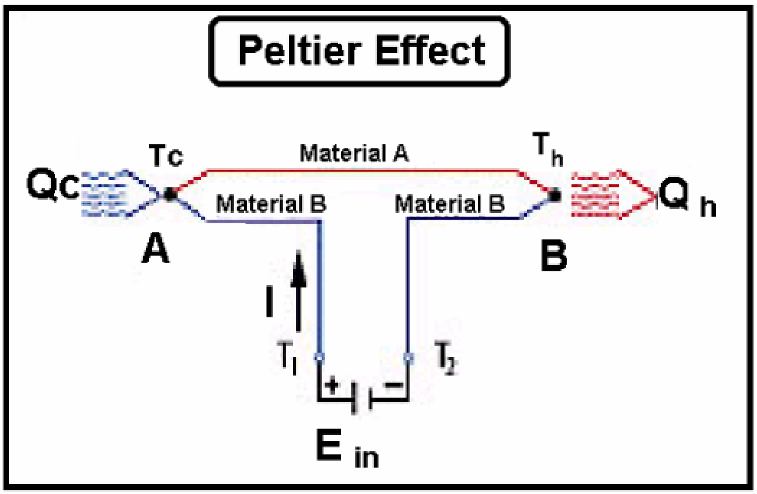
Peltier Effect:

- The **Peltier effect** is the presence of heating or cooling at an electrified junction of two different conductors and is named after French physicist Jean Charles Athanase Peltier, who discovered it in 1834.

- When a current is made to flow through a junction between two conductors, A and B, heat may be generated or removed at the junction. The Peltier heat generated at the junction per unit time, Q, is equal to:

$$\dot{Q} = (\Pi_A - \Pi_B) I$$

- Where Π_A (Π_B) is the Peltier coefficient of conductor A (B), and I is the electric current (from A to B). The total heat generated is not determined by the Peltier effect alone, as it may also be influenced by Joule heating and thermal gradient effects.
- The Peltier effect can be considered as the back-action counterpart to the Seebeck effect (analogous to the back-emf in magnetic induction): if a simple thermoelectric circuit is closed then the Seebeck effect will drive a current, which in turn (via the Peltier effect) will always transfer heat from the hot to the cold junction.

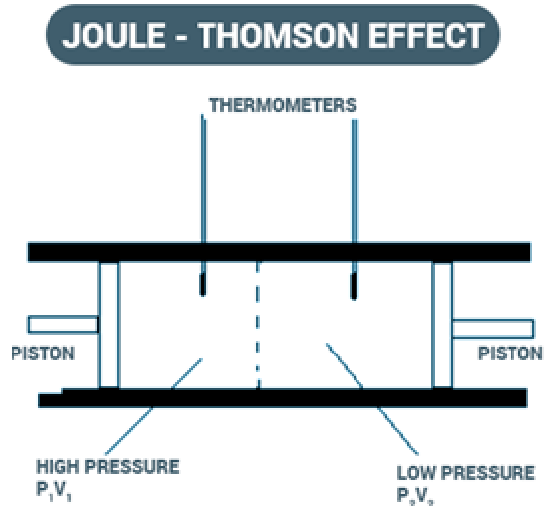


- **Peltier effect,** the cooling of one junction and the heating of the other when electric current is maintained in a circuit of material consisting of two dissimilar conductors; the effect is even stronger in circuits containing dissimilar semiconductors.
- In a circuit consisting of a battery joined by two pieces of copper wire to a length of bismuth wire, a temperature rise occurs at the junction where the current passes from copper to bismuth, and a temperature drop occurs at the junction where the current passes from bismuth to copper.

Thomson effect*:*

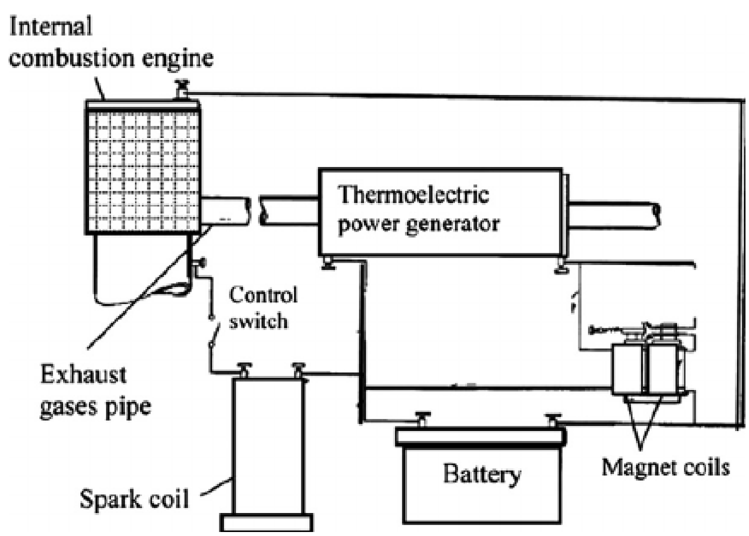
- **Thomson effect,** the evolution or absorption of heat when electric current passes through a circuit composed of a single material that has a temperature difference along its length.
- This transfer of heat is superimposed on the common production of heat associated with the electrical resistance to currents in conductors.
- If a copper wire carrying a steady electric current is subjected to external heating at a short section while the rest remains cooler, heat is absorbed from the copper as the conventional current approaches the hot point, and heat is transferred to the copper just beyond the hot point.

- This effect was discovered (1854) by the British physicist William Thomson (Lord Kelvin).



Thermoelectric power generators

- ➢ It is a system i.e.. Solid-state device that either convert heat directly into electricity or transform electrical energy into thermal power for heating or cooling.
- ➢ Such devices are based on thermoelectric effects involving interactions between the flow of heat and of electricity through solid bodies. All thermoelectric power generators have the same basic configuration, as shown in the figure.



- ➢ A heat source provides the high temperature, and the heat flows through a thermoelectric converter to a heat sink, which is maintained at a temperature below that of the source. The temperature differential across the converter produces direct current (DC) to a load (*RL*) having a terminal voltage (*V*) and a terminal current (*I*). There is no intermediate energy conversion process. For this reason, thermoelectric power generation is classified as direct power conversion. The amount of electrical power generated is given by I^2RL, or VI.
- ➢ A unique aspect of thermoelectric energy conversion is that the direction of energy flow is reversible. So, for instance, if the load resistor is removed and a DC power supply is

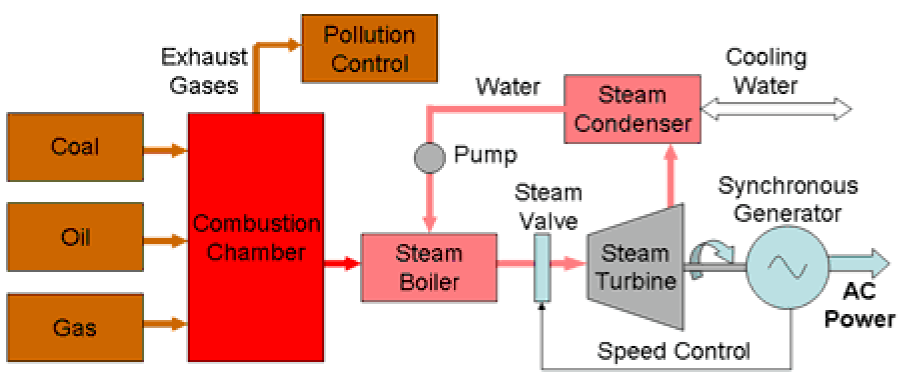
substituted, the thermoelectric device can be used to draw heat from the “heat source” element and lower its temperature. In this configuration, the reversed energy-conversion process of thermoelectric devices is invoked, using electrical power to pump heat and produce refrigeration.

MAJOR TYPES OF THERMOELECTRIC GENERATORS:

- Thermoelectric power generators vary in geometry, depending on the type of heat source and heat sink, the power requirement, and the intended use. During World War II, some thermoelectric generators were used to power portable communications transmitters. Substantial improvements were made in semiconductor materials and in electrical contacts between 1955 and 1965 that expanded the practical range of application. In practice, many units require a power conditioner to convert the generator output to a usable voltage.

Fossil-fuel generators

- Generators have been constructed to use natural gas, propane, butane, kerosene, jet fuels, and wood, to name but a few heat sources.
- Commercial units are usually in the 10- to 100-watt output power range.
- These are for use in remote areas in applications such as navigational aids, data collection and communications systems, and cathodic protection, which prevents electrolysis from corroding metallic pipelines and marine structures.



Fossil Fuel Powered Steam Turbine Electricity Generation

Conventional Electrical Energy Generation

Over 65% of the world's electrical energy used today is generated by steam turbine generators burning fossil fuels as their source of energy and large scale fossil fuelled plants provide most of the world's base load generating capacity. The electricity generation process is described in detail in the section about steam turbines. This page considers issues concerning the fuel.

Fossil fuelled plants use either coal (60%), oil (10%)or gas (30%) in purpose designed combustion chambers to raise steam. These are all non-renewable resources whose supply will ultimately be exhausted. The energy content of these fuels and their variants is shown on the Energy Resources page

Oil is probably the most convenient fuel and thirty years ago it accounted for 30% of the consumption but it has mostly been replaced by coal as oil prices have risen faster than the price of coal due to insecurities of supply. At the same time, the premium value of oil for transportation and chemical uses, rather than for just burning it to extract its calorific value, has also been recognized.

Coal is the least convenient. Its calorific content, on average, is less than half that of the other two fuels. Handling and transporting it is more difficult and it produces large quantities of residues, ash and greenhouse gases, some of which are toxic, depending on the quality of the coal.

Electricity Generating Plant

Drax Power Station

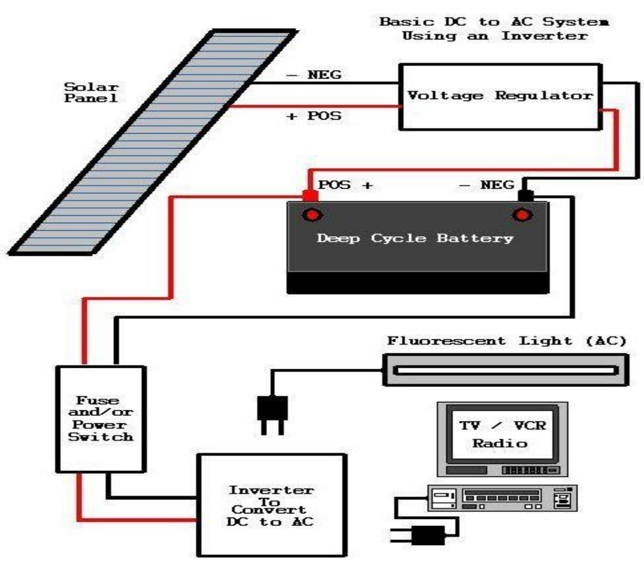
As a benchmark for comparison, in the UK, one power station, Drax, produces 7% of of all the country's electricity.

- It burns 13 million tons of coal a year in 6 X 660 MW coal fired generators providing a total of 4000 MW capacity.
- Plans were in place to use 10% biomass co-firing with coal. This would require 400,000 hectares (1,000,000 acres) of elephant grass, rapeseed or 750,000 hectares of short-rotation willow to produce the 1.5 million tons required. Recently however the target utilisation has been cut back to 1% since the total costs of the biomass fuel including transportation and processing is about three time the cost of coal.See also the footprint of equivalent Wind Farms
- About The 100% efficiency of the produced power
- Taking into consideration the three conversion processes, thermal, mechanical and electrical, used to extract the energy from fossil fuels the overall efficiency of a modern fossil fuelled electrical power generating plant will be about 40%.
- This means that 60% of the energy input to the system is wasted. Efficiencies may be as low as 30% in some older plants.

Solar-source generators

- Solar thermoelectric generators have been used with some success to power small irrigation pumps in remote areas and underdeveloped regions of the world.
- An experimental system has been described in which warm surface ocean water is used as the heat source and cooler deep ocean water as the heat sink.
- Solar thermoelectric generators have been designed to supply electric power in orbiting spacecraft, though they have not been able to compete with silicon solar cells, which have better efficiency and lower unit weight.
- However, consideration has been given to systems featuring both heat pumping and power generation for thermal control of orbiting spacecraft. Utilizing solar heat from the Sun-oriented side of the spacecraft, thermoelectric devices can generate electrical power for use by other thermoelectric devices in dark areas of the spacecraft and to dissipate heat from the vehicle.

  Ex : battery storage Devices



Nuclear-fueled generators:

The decay products of radioactive isotopes can be used to provide a high-temperature heat source for thermoelectric generators. Because thermoelectric device materials are relatively immune to nuclear radiation and because the source can be made to last for a long period of time, such generators provide a useful source of power for many unattended and remote applications. For example, radioisotope thermoelectric generators provide electric power for isolated weather monitoring stations, for deep-ocean data collection, for various warning and communications systems, and for spacecraft. In addition, a low-power radioisotope thermoelectric generator was developed as early as 1970 and used to power cardiac pacemakers. The power range of radioisotope thermoelectric generators is generally between 10^{-6} and 100 watts.

FIGURE OF MERIT FOR THERMOELECTRIC MATERIALS:

	Materials	Z (˚K^{-1})
1	Bismuth telluride (dopped with Sb or Se)	4×10^{-8}
2	Lead telluride	1.5×10^{-3}
3	Germanium telluride (with Bismuth)	1.5×10^{-3}
4	Zinc antimonide (doped with Silver)	1.5×10^{-3}
5	Cesium Sulfide	1.0×10^{-3}

SELECTION OF MATERIALS:

The usefulness of a material in thermoelectric systems is determined by the two factors device

1.Efficiency

2. Power factor.

These are determined by the material's electrical conductivity, thermal conductivity, Seebeck coefficient and behavior under changing temperatures.

The efficiency of a thermoelectric device for electricity generation is given by

$$\eta = \frac{\text{energy provided to the load}}{\text{heat energy absorbed at hot junction}}.$$

The ability of a given material to efficiently produce thermoelectric power is related to its dimensionless figure of merit given by:

$$ZT = \frac{\sigma S^2 T}{\lambda}$$

Which depends on the Seebeck coefficient *S*, thermal conductivity *λ*, electrical conductivity *σ*, and temperature *T*.

Power factor

In order to determine the usefulness of a material in a thermoelectric generator or a thermoelectric cooler the power factor is calculated by its Seebeck coefficient and its electrical conductivity under a given temperature difference:

$$\text{Power factor} = \sigma S^2$$

where S is the See -beck coefficient, and σ is the electrical conductivity.

Materials with a high power factor are able to 'generate' more energy (move more heat or extract more energy from that temperature difference) in a space-constrained application, but are not necessarily more efficient in generating this energy.

Module-IV
(Nuclear Power Plant)

NUCLEAR REACTOR:

A nuclear reactor is an apparatus in which heat is produced due to nuclear fission chain reaction. Fig. 1 shows the various parts of reactor, which are as follows:

1. Nuclear Fuel
2. Moderator
3. Control Rods
4. Reflector
5. Reactors Vessel
6. Biological Shielding
7. Coolant.

Fig. 1 shows a schematic diagram of nuclear reactor.

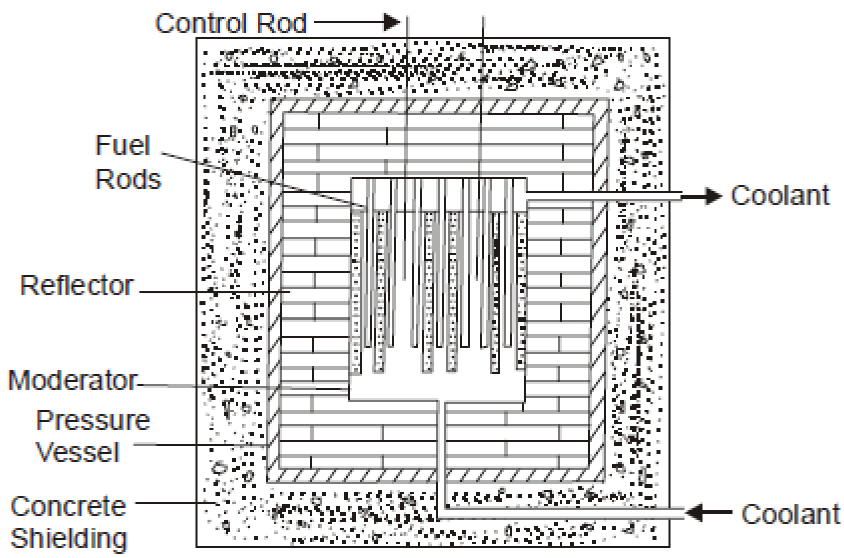


Fig. 1 Nuclear Reactor.

NUCLEAR FUEL

Fuel of a nuclear reactor should be fissionable material which can be defined as an element or isotope whose nuclei can be caused to undergo nuclear fission by nuclear bombardment and to produce a fission chain reaction. It can be one or all of the following

U233, U235 and Pu239.

Natural uranium found in earth crust contains three isotopes namely U234, U235 and U238 and their average percentage is as follows :

U238 — 99.3%

U235 — 0.7%

U234 — Trace

Out of these U235 is most unstable and is capable of sustaining chain reaction and has been given the name as primary fuel. U233 arid Pu239 are artificially produced from Th232 and U238 respectively and are called secondary fuel.

Pu239 and U233 so produced can be fissioned by thermal neutrons. Nuclear fuel should not be expensive to fabricate. It should be able to operate at high temperatures and should be resistant to radiation damage.
Uranium deposits are found in various countries such as Congo, Canada, U.S.A., U.S.S.R., Australia.
The fuel should be protected from corrosion and erosion of the coolant and for this it is encased in metal cladding generally stainless steel or aluminum. Adequate arrangements should be made for fuel supply, charging or discharging and storing of the fuel.
For economical operation of a nuclear power plant special attention should be paid to reprocess the spent: up (burnt) fuel elements and the unconsumed fuel. The spent up fuel elements are intensively radioactive and emits some neutron and gamma rays and should be handled carefully.
In order to prevent the contamination of the coolant by fission products, a protective coating or cladding must separate the fuel from the coolant stream. Fuel element cladding should possess the following properties:

1. It should be able to withstand high temperature within the reactor.
2. It should have high corrosion resistance.
3. It should have high thermal conductivity.
4. It should not have a tendency to absorb neutrons.
5. It should have sufficient strength to withstand the effect of radiations to which it is subjected.

Uranium oxide (UO2) is another important fuel element. Uranium oxide has the following advantages over natural uranium:

1. It is more stable than natural uranium.
2. There is no problem or phase change in case of uranium oxide and therefore it can be used for higher temperatures.
3. It does not corrode as easily as natural uranium.
4. It is more compatible with most of the coolants and is not attacked by H2, Nz.
5. There is greater dimensional stability during use.

Uranium oxide possesses following disadvantages:

1. It has low thermal conductivity.
2. It is more brittle than natural uranium and therefore it can break due to thermal stresses.
3. Its enrichment is essential.

Uranium oxide is a brittle ceramic produced as a powder and then sintered to form fuel pellets.
Another fuel used in the nuclear reactor is uranium carbide (UC). It is a black ceramic used in the form of pellets.

Table indicates some of the physical properties of nuclear fuels.

Fuel	Thermal con-ductivity K-cal/m. hr°C	Specific heat kcal/kg °C	Density kg/m^3	Melting point (°C)
Natural uranium	26.3	0.037	19000	1130
Uranium oxide	1.8	0.078	11000	2750
Uranium carbide	20.6	—	13600	2350

MODERATOR

In the chain reaction the neutrons produced are fast moving neutrons. These fast moving neutrons are far less effective in causing the fission of U235 and try to escape from the reactor. To improve the utilization of these neutrons their speed is reduced. It is done by colliding them with the nuclei of other material which is lighter, does not capture the neutrons but scatters them. Each such collision causes loss of energy, and the speed of the fast moving neutrons is reduced. Such material is called Moderator. The slow neutrons (Thermal Neutrons) so produced are easily captured by the nuclear fuel and the chain reaction proceeds smoothly. Graphite, heavy water and beryllium are generally used as moderator.

Reactors using enriched uranium do not require moderator. But enriched uranium is costly due to processing needed.

A moderator should process the following properties:

1. It should have high thermal conductivity.
2. It should be available in large quantities in pure form.
3. It should have high melting point in case of solid moderators and low melting point in case of liquid moderators. Solid moderators should also possess good strength and machinability.
4. It should provide good resistance to corrosion.
5. It should be stable under heat and radiation.
6. It should be able to slow down neutrons.

Control Rods. The Control and operation of a nuclear reactor is quite different frorn a fossil and fuelled (coal or oil fired) furnace. The furnace is fed continuously and the heat energy in the furnace is controlled by regulating the fuel feed, and the combustion air whereas a nuclear reactor contains as much fuel as is sufficient to operate a large power plant for some months. The consumption of this fuel and the power level of the reactor depends upon its neutron flux in the reactor core. The energy produced in the reactor due to fission of nuclear fuel during chain reaction is so much that if it is not controlled properly the entire core and surrounding structure may melt and radioactive fission products may come out of the reactor thus making it uninhabitable. This implies that we should have some means to control the power of reactor. This is done by means of control rods.

Control rods in the cylindrical or sheet form are made of boron or cadmium. These rods can be moved in and out of the holes in the reactor core assembly. Their insertion absorbs more neutrons and damps down the reaction and their withdrawal absorbs less neutrons. Thus power of reaction is controlled by shifting control rods which may be done manually or automatically.

Control rods should possess the following properties:

1. They should have adequate heat transfer properties.
2. They should be stable under heat and radiation.
3. They should be corrosion resistant.
4. They should be sufficient strong and should be able to shut down the reactor almost instantly under all conditions.
5. They should have sufficient cross-sectional area for the absorption.

REFLECTOR

The neutrons produced during the fission process will be partly absorbed by the fuel rods, moderator, coolant or structural material etc. Neutrons left unabsorbed will try to leave the reactor core never to return to it and will be lost. Such losses should be minimized. It is done by surrounding the reactor core by a material called reflector which will send the neutrons back into the core. The returned neutrons can then cause more fission and improve the neutrons economy of' the reactor. Generally the reflector is made up of graphite and beryllium.

REACTOR VESSEL

It is a strong walled container housing the cure of the power reactor. It contains moderator, reflector, and thermal shielding and control rods.

BIOLOGICAL SHIELDING

Shielding the radioactive zones in the reactor roan possible radiation hazard is essential to protect, the operating men from the harmful effects. During fission of nuclear fuel, alpha particles, beta particles, deadly gamma rays and neutrons are produced. Out oil these nc-1utroxrs and gamma rays are of main significance. A protection must be provided against them. Thick layers of lead or concrete are provided round the reactor for stopping the gamma rays. Thick layers of metals or plastics are sufficient to stop the alpha and beta particles.

COOLANT

Coolant flows through and around the reactor core. It is used to transfer the large amount of heat produced in the reactor due to fission of the nuclear fuel during chain reaction. The coolant either transfers its heat to another medium or if the coolant used is water it takes up the heat and gets converted into steam in the reactor which is directly sent to the turbine.

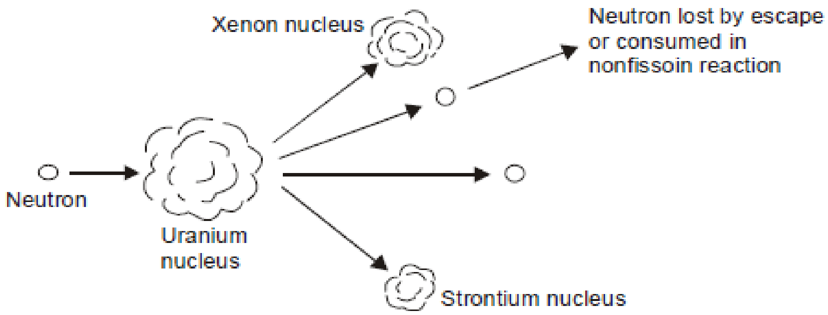
Coolant used should be stable under thermal condition. It should have a low melting point and high boiling point. It should not corrode the material with which it comes in contact. The coolant should have high heat transfer coefficient. The radioactivity induced in coolant by the neutrons bombardment should be nil. The various fluids used as coolant are water (light water or heavy water), gas (Air, CO2, Hydrogen, Helium) and liquid metals such as sodium or mixture of sodium and potassium and inorganic and organic fluids. Power required to pump the coolant should be minimum. A coolant of greater density and higher specific heat demands less pumping power and water satisfies this condition to a great extent. Water is a good coolant as it is available in large qualities can be easily handled, provides some lubrication also and offers no unusual corrosion problems. But due to its low boiling point (212 F at atmospheric pressure) it is to be kept under high pressure to keep it in the liquid state to achieve a high that transfer efficiency. Water when used as coolant should be free from impurities otherwise the impurities may become radioactive and handling of water will be difficult.

REACTOR CORE

Reactor core consists of fuel rods, moderator and space through which the coolant flows.

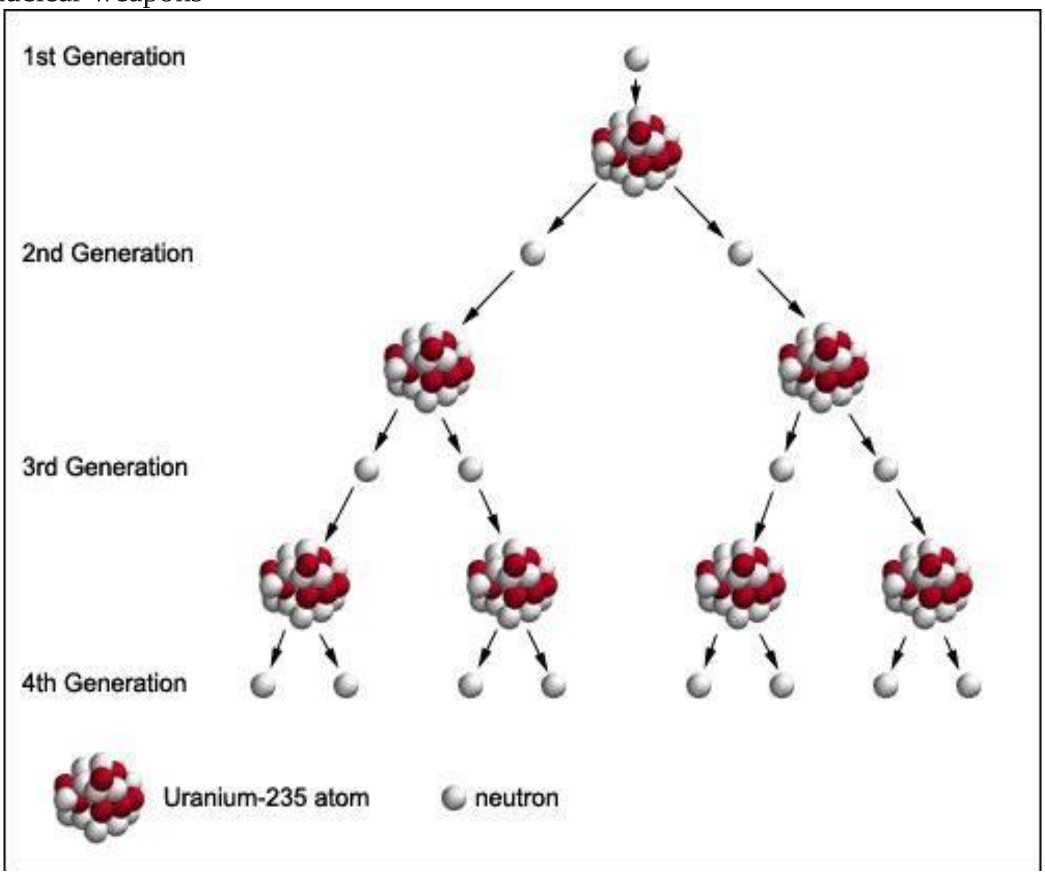
Fission

Which involves nuclei of similar electric charge and therefore requires high kinetic energies, fission can be caused by the neutron, which, being electrically neutral, can strike and fission the positively charged nucleus at high, moderate, or low speeds without being repulsed. Fission can be caused by other particles, but neutrons are the only practical ones that result in a sustained reaction because two or three neutrons are usually released for each one absorbed in fission. These keep the reaction going. There are only a few fissionable isotopes U235, Pu239 and U233 are fissionable by neutrons of all energies. The immediate (prompt) products of a fission reaction, such as Xe° and Sr^{y4} above, are called fission fragments. They, and their decay products are called fission products.



Nuclear Chain Reaction

- A chain reaction refers to a process in which neutrons released in fission produce an additional fission in at least one further nucleus.
- This nucleus in turn produces neutrons, and the process repeats.
- If the process is controlled it is used for nuclear power or if uncontrolled it is used for nuclear weapons



- $U_{235} + n \rightarrow$ fission + 2 or 3 n + 200 MeV
  (1 **MeV**, 1 megaelectronvolt = 1,000,000 eV)
- If each neutron releases two more neutrons, then the number of fissions doubles each generation.
- In that case, in 10 generations there are 1,024 fissions and in 80 generations about 6 x 10^{23} (a mole) fissions.

Naturally occurring fertile materials:

Naturally occurring fertile materials that can be converted into a fissile material by irradiation in a reactor include:

- thorium-232 which converts into uranium-233
- uranium-234 which converts into uranium-235
- uranium-238 which converts into plutonium-239

Artificial isotopes formed in the reactor which can be converted into fissile material by one neutron capture include:

- plutonium-238 which converts into plutonium-239
- plutonium-240 which converts into plutonium-241

Some other actinides need more than one neutron capture before arriving at an isotope which is both fissile and long-lived enough to probably be able to capture another neutron and fission instead of decaying.

- plutonium-242 to americium-243 to curium-244 to curium-245
- uranium-236 to neptunium-237 to plutonium-238 to plutonium-239
- americium-241 to curium-242 to curium-243 (or, more likely, curium-242 decays to plutonium-238, which also requires one additional neutron to reach a fissile nuclide)

Since these require a total of 3 or 4 thermal neutrons to eventually fission, and a thermal neutron fission generates only about 2 to 3 neutrons, these nuclides represent a net loss of neutrons. In a fast reactor, they may require fewer neutrons to achieve fission, as well as producing more neutrons when they do fission.

CLASSIFICATION OF REACTORS

The nuclear reactors can be classified as follows:

1. Neutron Energy. Depending upon the energy of the neutrons at the time they are captured by the fuel to induce fissions, the reactors can be named as follows:

(a) *Fast Reactors.* In such reactors fission is brought about by fast (non moderated) neutrons.

(b) *Thermal Reactors or Slow Reactors.* In these reactors the fast moving neutrons are slowed down by passing them through the moderator. These slow moving neutrons are then captured by the fuel material to bring about the fission of fundamental research.

On the basis of fuel used

1. Natural uranium fuel reactors
2. Enriched uranium fuel reactor

On the basis of coolant used

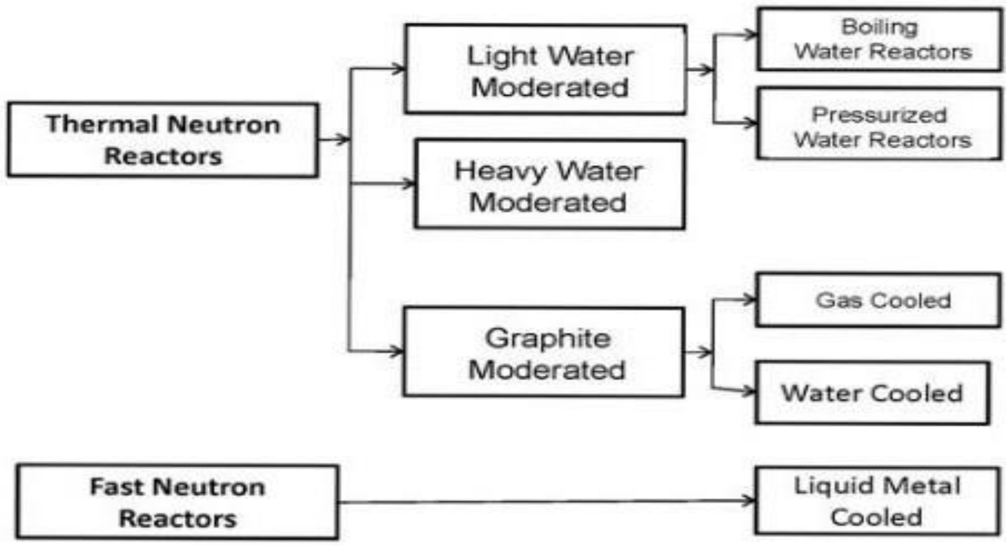
1. Water /heavy water cooled reactors
2. Liquid metal /organic liquid cooled reactors
3. Gas cooled reactors

On the basis of moderator:

1. Water moderated
2. Graphite moderated
3. Heavy water moderated
4. Beryllium moderated

On the basis of reactor core used

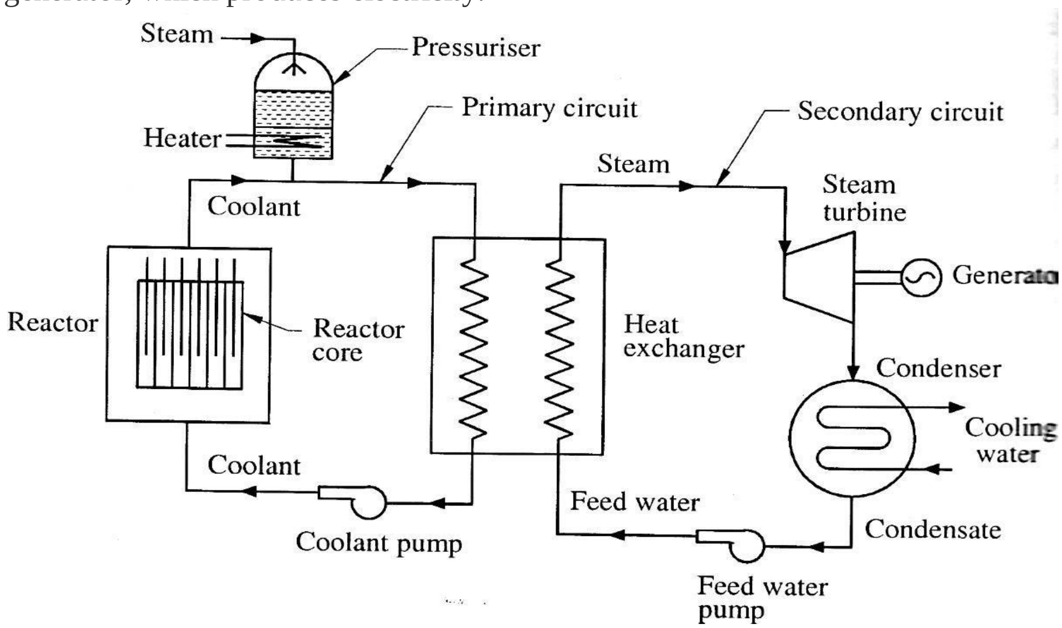
1. Homogeneous reactor
2. Heterogeneous reactor



Pressurized Water Reactor (PWR):

In a typical design concept of a commercial PWR, the following process occurs:

1. The core inside the reactor vessel creates heat.
2. Pressurized water in the primary coolant loop carries the heat to the steam generator.
3. Inside the steam generator, heat from the primary coolant loop vaporizes the water in a secondary loop, producing steam.
4. The steam line directs the steam to the main turbine, causing it to turn the turbine generator, which produces electricity.



In a PWR the primary coolant (water) is pumped under high pressure to the reactor core where it is heated by the energy generated by the fission of atoms. The heated water then flows to a steam generator where it transfers its thermal energy to a secondary system where steam is generated and flows to turbines which, in turn, spins an electric generator.
Nuclear fuel in the reactor vessel is engaged in a fission chain reaction, which produces heat, heating the water in the primary coolant loop by thermal conduction through the fuel cladding. The hot primary coolant is pumped into a heat exchanger called the steam generator, where it flows through hundreds or thousands of tubes (usually 3/4 inch in diameter).

Heat is transferred through the walls of these tubes to the lower pressure secondary coolant located on the sheet side of the exchanger where it evaporates to pressurized steam. The transfer of heat is accomplished without mixing the two fluids, which is desirable since the primary coolant might become radioactive. Some common steam generator arrangements are u-tubes or single pass heat exchangers. In a nuclear power station, the pressurized steam is fed through a steam turbine which drives an electrical generator connected to the electric grid for distribution.

After passing through the turbine the secondary coolant (water-steam mixture) is cooled down and condensed in a condenser. The condenser converts the steam to a liquid so that it can be pumped back into the steam generator, and maintains a vacuum at the turbine outlet so that the pressure drop across the turbine, and hence the energy extracted from the steam, is maximized.

Before being fed into the steam generator, the condensed steam (referred to as feed water) is sometimes preheated in order to minimize thermal shock.

Advantages

- PWR reactors are very stable due to their tendency to produce less power as temperatures increase; this makes the reactor easier to operate from a stability standpoint.
- It uses ordinary water as a coolant, moderator and reflector since water is available near the plant location this is great savings in cost.
- Reactor is compact and high power density.
- As steam is not affected by radiation so the inspection and maintenance of the turbine condenser and feed pump is possible.
- Small numbers of control road are required.
- PWR turbine cycle loop is separate from the primary loop, so the water in the secondary loop is not contaminated by radioactive materials.

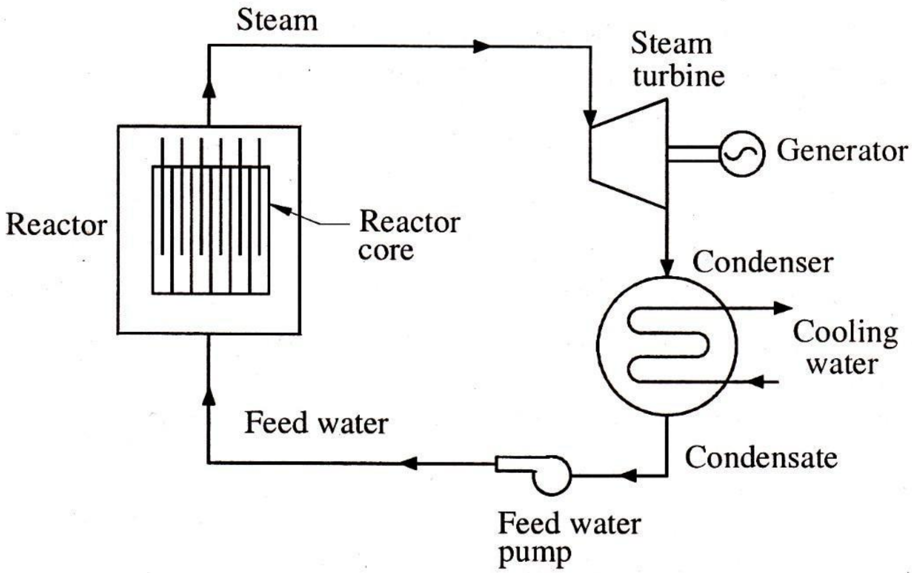
Disadvantages

- Its capital cost is high due to heavy and strong pressure vessel is required in the primary circuit.
- Thermodynamic efficiency is less 20% due to low pressure in secondary circuit.
- Its required enriched uranium fuel cost of enriched uranium is high.
- It is necessary to shut down the reactor for fuel charging.
- Because water acts as a neutron moderator, it is not possible to build a fast neutron reactor with a PWR design.

Boiling Water Reactor (BWR):

In a typical design concept of a commercial BWR, the following process occurs:

1. The core inside the reactor vessel creates heat.
2. A steam-water mixture is produced when very pure water (reactor coolant) moves upward through the core, absorbing heat.
3. The steam-water mixture leaves the top of the core and enters the two stages of moisture separation where water droplets are removed before the steam is allowed to enter the steam line.
4. The steam line directs the steam to the main turbine, causing it to turn the turbine generator, which produces electricity.



The BWR uses dematerialized water as a coolant and neutron moderator. Heat is produced by nuclear fission in the reactor core, and this causes the cooling water to boil, producing steam. The steam is directly used to drive a turbine, after which it is cooled in a condenser and converted back to liquid water. This water is then returned to the reactor core, completing the loop.

Advantages

- The pressure inside the reactor is less than PWR as water is allowed to boil inside the reactor. Therefore the reactor vessel can be much lighter than PWR and reduce the cost of pressure vessel considerably.
- It eliminates the use of heat exchanger pressure equalizer circulating pump and piping therefore the cost of further reduced.
- The thermal efficiency of this reactor is 30% is considerably higher than PWR plant.
- The metal temperature remains low for given output conditions.

Disadvantages

- The steam leaving the reactor is slightly radioactive. Therefore light shielding of turbine and piping is necessary.
- It cannot meet the sudden changes in load the plant.
- The size of vessel is comparatively large as compare to PWR.
- It required enriched uranium as a fuel.

The salient differences between PWR and BWR are:

• The operating pressure of BWR is lower than that of a PWR

• Separate steam generators are not required for BWR as the steam is generated in the core itself

• There is only one coolant loop in BWR as against two in PWR

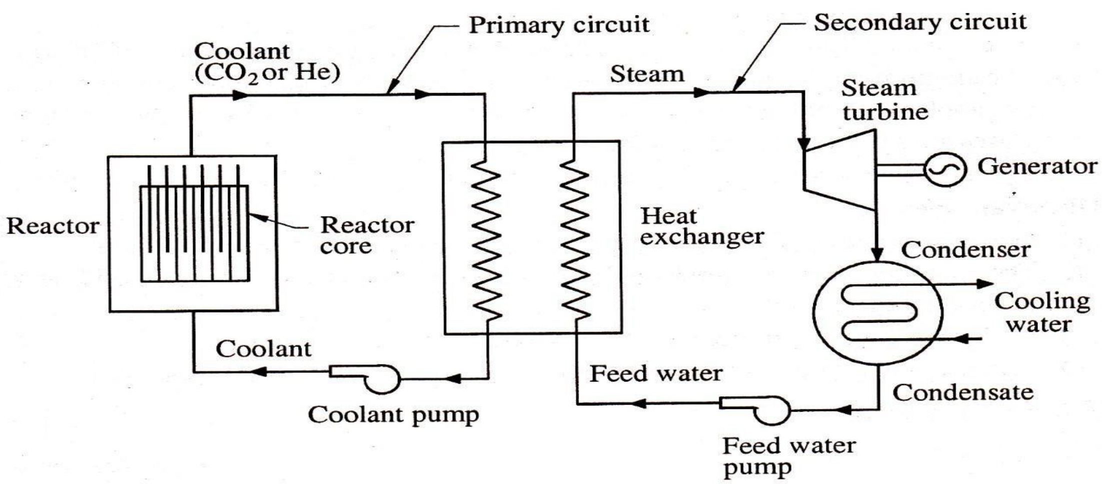
(iv) There is no requirement for pressurizer in BWR as against the requirement of a pressurizer in PWR

(v) Control rods are inserted from the bottom in BWR as against their insertion from top in a PWR. The moderating capability of water is higher at lower temperatures. At increased coolant temperatures near the top of the core, appreciable boiling results in the formation of steam, leading to reduced moderation. Hence to control the reactor power, control rods must be inserted from the bottom where the flux of thermal neutrons is high.

(vi) BWR plant is a simpler one due to lack of steam generator, pressurizer and the associated pipelines. The lower operating pressure in BWR leads to lower structural problems compared to that of a PWR. BWR plant has good response to operational transient where in higher temperature results in boiling of water resulting in steam and hence a reduction in moderation and heat generation.

Gas-Cooled Reactor (GCR):

A schematic diagram of a gas-cooled reactor is shown in Figure. This is a type of nuclear reactor that uses a gas as the coolant. Mostly CO_2 is used. Graphite blocks are used as moderator, within which channels are made for housing fuel rods. Control rods are inserted into the graphite blocks. Channels are established between the graphite blocks for the flow of coolant. Natural uranium is used as the fuel while cladding is made of a magnesium alloy called magnox. This reactor derives its name from the alloy used for cladding, ‘magnox’. The coolant gas is supplied by a gas circulator and enters the core from bottom. Gas flows through the coolant channels between the graphite blocks. As the gas moves up through the core, it gets heated up and leaves the top of the core at high temperature


Primary circuit
Secondary circuit
Coolant
(CO_2 or He)
Steam
Steam
turbine
Generator
Reactor
Reactor
core
Heat
exchanger
Condenser
Cooling
water
Coolant
Feed water
Condensate
Coolant pump
Feed water
pump

This high temperature gas exchanges heat with water in a heat exchanger, resulting in the production of steam, which runs the turbine. The spent steam is condensed and returned back to the heat exchanger, while the gas returns to the reactor. The heat exchanger is located outside the pressure vessel and the containment.

Advantages of gas cooled reactor:

1. Processing of fuel is simpler.
2. No corrosion problem.
3. Graphite remains stable under irradiation at high temperature.
4. Use of CO_2 as coolant completely eliminates the possibility of explosion in the reactor which is always present in water cooled plants.
5. Uranium carbide and graphite are able to resist high temperatures.

Disadvantages of gas cooled reactor:

1. Fuel loading is costly.

2. Due to high critical mass large amount of fuel loading is initially required.

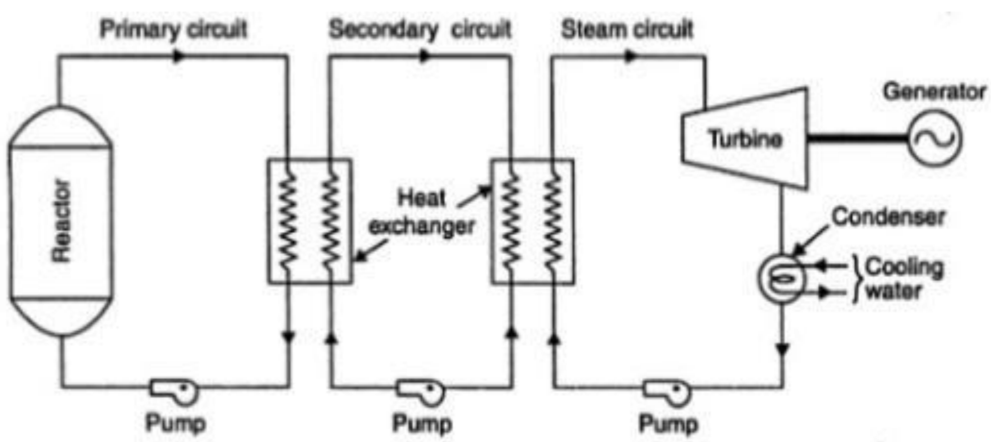
3. If helium is used instead of CO_2 then leakage may occur.

4. Controlling these reactors is a complicated task

Sodium Graphite Reactor (SGA):

The reactor shown in figure uses two liquid metal coolants. Liquid sodium (Na) serves as the primary coolant and an alloy of sodium potassium (NaK) as the secondary coolant.

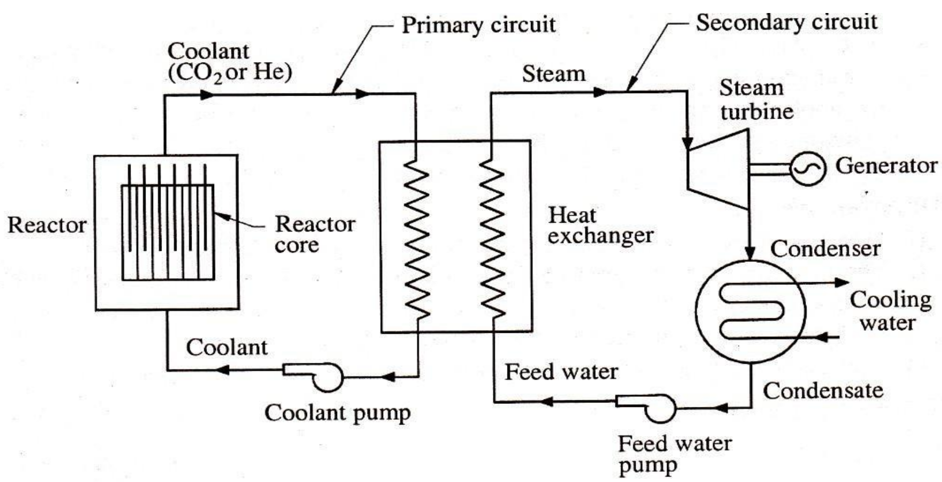
Sodium melts at 208°C and boils at 885°C. This enables to achieve high outlet coolant temperature in the reactor at moderate pressure nearly atmospheric which can be utilized in producing steam of high temperature, thereby increasing the efficiency of the plant. Steam at temperature as high as 540°C has been obtained by this system. This shows that by using liquid sodium as coolant more electrical power can be generated for a given quantity of the fuel burn up.



Secondly low pressure in the primary and secondary coolant circuits, permits the use of less expensive pressure vessel and pipes etc. Further sodium can transfer its heat very easily. The only disadvantage in this system is that sodium becomes radioactive while passing through the core and reacts chemically with water. So it is not used directly to transfer its heat to the feed water, but a secondary coolant is used. Primary coolant while passing through the tubes of intermediate heat exchanges (I.H.X) transfers its heat to the secondary coolant. The secondary coolant then flows through the tubes of steam generator and passes on its heat to the feed water. Graphite is used as heat transfer media have certain advantages of using liquids used for heat transfer purposes. The various advantages of using liquid metals as heat transfer media are that they have relatively low melting points and combine high densities with low vapour pressure at high temperatures as well as with large thermal conductivities.

Fast Breeder Reactor (FBR)

The process of converting more fertile material into fissile material in a reactor is called breeding. In fast breeder reactor the core containing U235 is surrounded by a blanket of fertile material U238. In this reactor no moderator is used the fast moving neutrons liberated due to fission of U235 are absorbed by U238 which gets converted in to Pu239 a fissile material. This reactor also uses two liquid metal coolants in which sodium is used as primary coolant and sodium potassium as secondary coolant (sodium boils at 850^{O} C under atmospheric pressure and freeze at 95^{O} C). The reactor also used two liquid metal coolants in which sodium is used as primary coolants and sodium potassium as secondary coolants. Liquid sodium is circulated through the reactor to carry the heat produced. The heat produced by the sodium is transferred to secondary coolant sodium potassium in the primary heat exchanger which in turn transfers the heat in secondary heat exchanger called steam generator.



Advantages

- It gives high power density than any other reactor therefore small core is sufficient.
- Moderator is not required.
- Secondary fusible materials by breeding are obtained.
- Absorption of neutrons is slow.

Disadvantages

- It require highly enriched uranium fuel.
- Safety must be provided against melt down.
- Neutron flux is high at the center of the core.
- Thick shielding is necessary.

Coolants are used for Fast Breeder Reactors

The commonly used coolants for fast breeder reactors are as follows:

i) Liquid metal (Na or NaK).
ii) Helium (He)
iii) Carbon dioxide.

Sodium has the following advantages:

i) It has very low absorption cross-sectional area.
ii) It possesses good heat transfer properties at high temperature and low pressure.
iii) It does not react on any of the structural materials used in primary circuits.

Homogeneous reactor:

A nuclear reactor in which the active core consists of a homogeneous mixture of nuclear fuel and a moderator.The distinguishing feature of the homogeneous reactor is the absence of fuel eleme nts; the nuclear fuel and the raw materialfor breeding (uranium, thorium, or plutonium) may be placed into the active core as a salt solution with ordinary or heavywater, or as a dispersion in a solid moderator (for example, graphite). Possible modifications of the homogeneous reactor contain the fuel in gaseous formsuch as gaseous compounds of uranium or a suspension of uranium dust in a gas. Heat released in the core may be conducted away by a heat transfer agent (water, gas, or other materials), which iscirculated through pipelines that pass through the core, or else the homogeneous mixture of fuel and moderator is conducted out of the core directly.

Because of considerable difficulties of engineering and design, homogeneous reactors are not widely used and are appliedonly for experimental purposes. There are only isolated examples of projects using homogeneous reactors as heat sourcesin the industrial production of electrical power

Nuclear Waste and its Disposal

The radioactive emission during the operation of the plant is negligible but the emission intensity is very high which comes out from the waste. Therefore, safe nuclear waste disposal is major problem before the nuclear industry. It is estimated that the radioactive products of 400 MW power plants would be equivalent to 100 tons of radium daily and the radioactive effect of this plants products if exposed to atmosphere would kill all the living organism with in the area about 160 square kilometers. The waste produced in a nuclear power plant may be in the form of liquid, gas and solid and each is treated in different water.

Solid waste

It will arise used filters, sludge from the cooling ponds, pieces from discarded fuel element cans, splitters control rods etc. The combustible solid waste is burnt and flue gases formed are filtered and then exposed to the high level of atmosphere. Active solid wastes are stored in water for about 100 or more days to allow radioactivity to decay then these are disposed to deep salt mines or an ocean floor or in deep wells drilled in stable geological strata.

Liquid waste

Radioactive effluents will arise from the laundry, personal decontamination etc. together with activity accumulating from the corrosion of the irradiated fuel elements in the storage ponds. The disposal of liquid waste has done in two ways.

1. Dilution

   The liquid waste are diluted with large quantity of water and then released in to the ground. The major drawback of this method there is a chance of contamination of underground water if dilution factor is not adequate.
2. Concentration to small volumes and storage

   If the dilution of water in not possible then liquid will store in leakage proof and high strength material storage can or tank and then stored in deep drilled salt mines.

Gaseous Waste

Gaseous wastes are generally diluted with air passed through filters and then released to the atmosphere through large chimneys. Krypton is removed by cryogenic treatment of dissolved off gas stream and packed in gas cylinder under pressure. Generally gaseous waste filtered in filter and then allows escaping to the atmosphere or stored in pressure tanks and then stored in deep drilled salt mines.

• Geological Disposal

The process of geological disposal centers on burrowing nuclear waste into the ground to the point where it is out of human reach. The waste needs to be properly protected to stop any material from leaking out. Seepage from the waste could contaminate the water table if the burial location is above or below the water level. Furthermore, the waste needs to be properly fastened to the burial site and also structurally supported in the event of a major seismic event, which could result in immediate contamination.

• Reprocessing

Reprocessing has also emerged as a viable long term method for dealing with waste. As the name implies, the process involves taking waste and separating the useful components from those that aren’t as useful. Specifically, it involves taking the fissionable material out from the irradiated nuclear fuel.

• Transmutation

Transmutation also poses a solution for long term disposal. It specifically involves converting a chemical element into another less harmful one. Common conversions include going from Chlorine to Argon or from Potassium to Argon. The driving force behind transmutation is chemical reactions that are caused from an outside stimulus, such as a proton hitting the reaction materials. Natural transmutation can also occur over a long period of time. Natural transmutation also serves as the principle force behind geological storage on the assumption that giving the waste enough isolated time will allow it to become a non-fissionable material that poses little or no risk

Module-V

Power plant Economics and Environmental Consideration

Types of Loads:

1. **Residential load:** This type of load includes domestic lights, power needed for domestic appliances like radios, television, water heaters, refrigerators, electrical cookers, and small motors for pumping water.
2. **Commerical load**: It includes lighting for shops, advertisements and electrical appliances used in shops and restaurants, etc.,
3. **Industrial load**: It includes load demand of various industries.
4. **Municipal load**: It consists of street lighting, power required for water supply and drainage purposes.
5. **Irrigation load**: It includes the power required for pumps driven by electrical motor to supply water to fields.
6. **Traction load**: It includes trams, cars, trolley, buses and railways.

Terms and Definitions:

1. **Connected load:** It is the combined continuous rating of all appliances in the consumer premises, which is connected to the system under consideration.
2. **Demand**: It is the load that is drawn from the source of supply over a suitable and specified period of time.
3. **Maximum demand or peak load**: It is the greatest of all the demands that have occurred during a given period.
4. **Demand factor:** It is the ratio of maximum demand of the system to the total connected load of the system under consideration.

$$Demand\ factor = \frac{Maximum\ demand}{Total\ connected\ load}$$

5. **Load factor**: It is the ratio of average power to the maximum demand.

$$Load\ factor = \frac{Average\ load}{Maximum\ demand}$$

6. **Diversity factor**: It is the ratio of the sum of the maximum demands of the individual parts of the system to the maximum demand of the whole system, under consideration.

$$Diversity\ factor = \frac{Sum\ of\ individual\ Maximum\ demand}{Maximum\ demand\ of\ whole\ system}$$

7. **Utilization factor**: It is defined as the ratio of the maximum generator demand to the generator capacity.

8. **Plant capacity factor**: It is defined as the ratio of actual energy produced in kwh to the maximum power that could have been produced during the same period.

$$Plant\ capacity\ factor = \frac{E}{C \times t}$$

9. **Plant use factor:** It is defined as the ratio of energy produced in a given time to the maximum power that could have been produced during the actual number of hours, the plant was in operation.

$$Plant\ use\ factor = \frac{E}{C \times t^1}$$

11. **Load Curve:** 10.

It is a graphic record showing the power demands for every instant during a certain time interval. If it is for 1 hour, it is called hourly load curve; for 24 hours, it is called daily load curve; for 30 days it is called monthly load curve; for 8760 hours it is called yearly load curve.

- Area under the load curve gives the total energy generated in the period considered.
- Area under the curve divided by the total number of hours gives the average load on the power station.
- The peak indicated on the load curve represents the maximum demand of the power station.

12. **Load Duration Curve:**

It represents the rearrangement of all the load elements of chronological load curve in the order of descending magnitude.

Firm power: It is the power which should be always available even under emergency conditions.

Cold reserve: It is that reserve generating capacity which is not in operation but can be made available for service.

Hot reserve: It is that reserve generating capacity which is in operation but not in service.

Spinning reserve: It is that reserve generating capacity which is connected to the bus and ready to take the load.

13. **Economic Analysis**

The cost of a power system, depends on whether

a. an entire new power system has to be setup or
b. an existing system has to be replaced or
c. an extension has to be provided to the existing system.

The cost criteria includes:

1. Capital cost or fixed cost: It includes the following:

   (a) Initial cost

   - ✓ It includes land cost, building cost, equipment cost, installation cost, overhead charges and primary distribution system.
   - ✓ To reduce the initial cost,
     - Construction of superstructure above the boiler and turbo-generator should be avoided.
     - Equipment cost can be reduced by adopting the unit system i.e. one boiler for one turbo-generator.

   (ii) Interest

   - ✓ All the enterprises need investment as money which may be obtained as loan, bonds and shares from owners of personal funds.
   - ✓ Interest is the difference between money borrowed and money returned.
   - ✓ Interest may be charged at a simple rate expressed as % per annum or may compounded.
   - ✓ Amortization is the periodic repayment of principle as a uniform annual expense.

   (iii) Depreciation cost –

   - ✓ It accounts for the deterioration and decrease in the value of the equipment due to corrosion, weathering and wear and tear with use.
   - ✓ It also covers the decrease in the value of equipment due to obsolescence.
   - ✓ Following are the methods used to calculate the depreciation cost.

     i. Straight line method:

     Let the initial investment is I.

     Life of the equipment is assessed, say (N years).

     Salvage value (S) of the equipment after N years is estimated.

     Salvage value is deducted from the initial investment and the balance amount when divided with the life of the equipment gives the depreciation cost of the equipment.

$$D = \frac{I - S}{N}$$

ii. ***Sinking fund method:***

Concept is the annual uniform deduction from income for depreciation will accumulate to the capital value of the plant at the end of life of the plant or equipment. In this method, amount set aside per year consists of annual installments and the interest earned on all installments.

A – Amount set aside at the end of each year for 'n' years

n – Life of the plant in years

S – Salvage value of the equipment at the end of plant life

I – Initial investment

i – Annual rate of compound interest on the invested capital

Amount to be set aside is given as $A = \left[\frac{i}{(i+1)^n - 1}\right](P-S)$

(iv) Insurance

2. Operational cost: It includes the following:

(i) Fuel cost

Better quality fuel should be chosen to achieve higher thermal efficiency.

Cost of fuel varies with the following:

- Unit price of fuel
- Amount of energy produced
- Efficiency of the plant

(ii) Operating labour cost

(iii) Maintenance cost

- It includes periodic cleaning, greasing, adjustments and overhauling of equipment.
- The material for maintenance is also charged under this head.

(iv) Supplies

- The items of consumable stores other than fuel include such as lubricating oil and greases, cotton waste, small tools, chemicals, paints etc.,

(v) Supervision

- Salaries of supervision staff will be included.

(vi) Operating taxes

- They include income tax, sales tax, social and employee's security etc.,

Pollution and Its Control

- Different power plants releases different waste products into the atmosphere in the form of gases, ash, radioactivity etc.,
- These affect the ecology balance creating harmful effects to the living beings as well as flora and fauna.
- Major power plant pollutants of concern are:
  - From Fossil fuel power plants (Gas and Coal based)
    - Sulphur oxide, Nitrogen oxide, Carbon oxide, Thermal pollution, Particulate matter
  - From Nuclear Power plants
    - Radioactivity release
    - Radioactivity wastes
    - Thermal pollution
- Thermal power plants release the products of combustion as well as waste heat to surroundings. Hence the total emission can be classified as follows:
  - Gaseous emission
  - Particulate emission
  - Solid waste emission
  - Thermal pollution or waste heat

Gaseous Emissions and their effects:

S. No	Pollutant	Effects		
		On Man	On Vegetation	On Materials/ Animals
1	SO_2	Suffocation, Irritation of throat and eyes, respiration system	Destruction of sensitive crops and reduced yield	Corrosion

2	NO_2	Irritation, Bronchitis, Oedema of lungs	---	---
3	H_2S	Bare disease, Respiratory diseases	Destruction of crops	Fluorosis in cattle grazing
4	CO	Poisoning, increased accident-liability	---	---

Methods to reduce the emission of SOx from Thermal & Gas Turbine plants,

- Usage of wet and dry scrubbers reduces the emissions of Sox to the surroundings through flue gases.

Methods to reduce the emission of NOx from Thermal & Gas Turbine plants,

- Reduction of temperature in combustion zone
- Reduction of residence period in combustion zone
- Increase of equivalence ratio in the combustion zone

Particulate Emissions and Control: Various particulate emissions are

- Smoke
  - Diameter less than 10 microns and are visible only in the aggregate
- Fumes
  - Very small particles resulting from chemical reactions
  - Normally composed of metals and metallic oxides
- Fly-Ash
  - Particles of diameters 100 microns or less
- Cinders
  - Particles of diameters 100 microns or more
- Systems used: Bag house filters, Cinder catchers, Electrostatic precipitator
- Collection Efficiency:

$$Collector\ efficiency = \frac{mass\ of\ dust\ removed}{mass\ of\ dust\ present} \times 100$$

For Bag house filters and Cinder catchers, collection efficiency caries from 50 – 90% whereas for Electrostatic precipitator, it is as high as 99.9%.

Thermal Pollution

- Large quantity of hot water is discharged into rivers or lakes from the condenser.

- ***Effects***:
  - This increases the temperature of water bodies.
  - It the temperature is greater than 35^0C, the dissolved oxygen levels decreases leading to the death of aquatic living beings.
- One regulation stipulated on the water temperature is the limitation on the maximum outlet temperature as 1^0C above the atmospheric temperature.
- ***<u>Thermal Discharge Index (TDI):</u>***
- It is the number of thermal energy units discharged to the environment for every unit of electric energy generated.

$$TDI = \frac{Thermal\ power\ Disch\arg ed\ to\ environment(MW)}{Electrical\ power\ output\ in\ MW} \times 100$$

- <u>Methods</u>: Construction of cooling ponds, cooling towers, and separate lakes.

Pollution from Nuclear Power Plants

- Radioactive Pollution
  - Radiation released from the reaction during chain reaction
  - Can be reduced by the construction of radiation shield around the reactor
- Waste from reactor
  - Solid waste - contains isotopes of with various half lives
  - Liquid
  - Gas
- Nuclear Waste Disposal
  - **Storage tanks** – radioactive waste can be stored in tanks and buried under earth surface in corrosion resistance tanks
  - **Dilution** – low energy wastes are diluted either in liquid or gaseous materials
  - **Sea disposal**
  - **Atmospheric dilution** – used for the gaseous radioactive wastes.
  - **Burying in sea** – solid waste is stored in concrete blocks which are buried in sea.