B. E.

Eighth Semester Examination, Dec.-2006

POWER PLANT ENGINEERING

Note : Attempt five questions.

Part-A

Q. 1. Give layout repowering systems (combined power generation using gas turbine and steam turbine). Explain the functions of each component of repowering system and working of whole plant.

Ans. Repowering system : Before the advent of large capacity power stations, there were many built with steam turbine units of 30, 40 and 60 MW size throughout the world which are still in excellent conditions. For cycle efficiency reasons, they are operated as stand by units. It is possible to upgrade such situations by adding gas turbines and heat recovery boilers to substitute for the existing boilers and operate the plant in combined cycle. This has been done in America, Europe and Hong Kong.

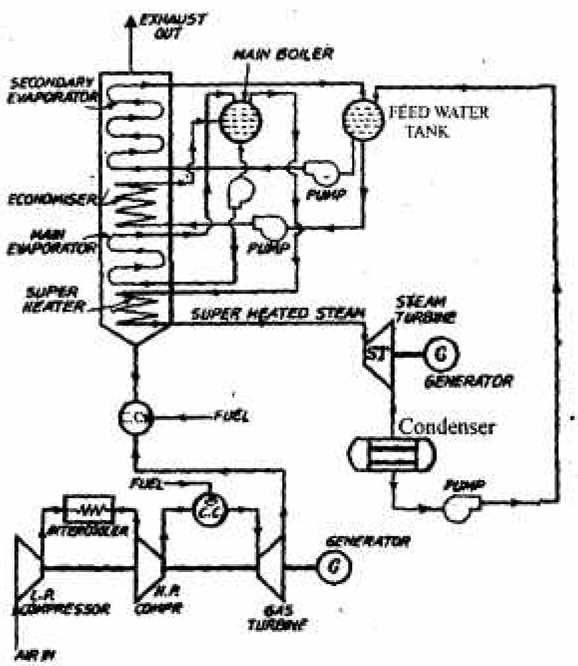


Fig. Combined cycle using liquid or solid fuel

Repowering of the existing small capacity steam plant conserves energy in the steam plants by adding gas turbine, heat recovery boilers and economisers in conjunction with existing steam equipments. Repowering significant in areas where utilities have been limited by environmental or economic considerations to using oil or gas in steam generators.

Both reheat and non-reheat plants are used for combined cycle repowering. The repowering cost can be as low as Rs. 800-1000/kW. The plant efficiency can be improved as much as 40% with a corresponding plant capacity to 100%.

These are mainly two repowering systems commonly used in practice.

1. Steam turbine repowering : In this systems, gas turbine generates power and new heat recovery steam generators replace the old steam generators. The steam output from the new boilers drives existing steam turbine. The arrangement of the system in shown in fig. 2.

2. Boiler repowering : In this arrangement gas turbine generates power and acts as a forced drought fan for the existing boiler, supply hot exhaust gases as combustion air. Increased thermal efficiency is achieved when an economiser is installed instead of regenerative feed heaters. The arrangement is shown in fig. 3.

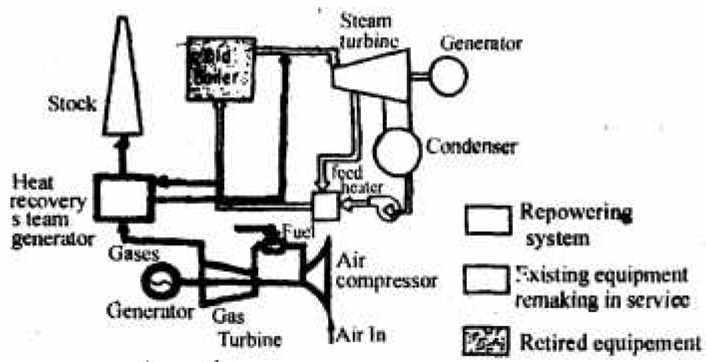


Fig. Steam turbine repowering

(Old steam generator is replaced by gas turbine plant and heat recovery steam generator)

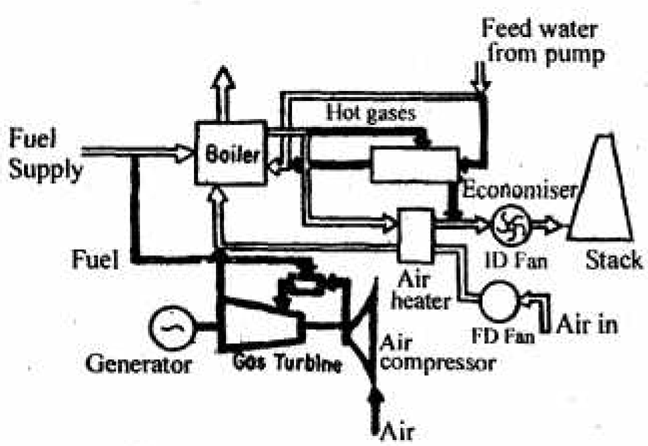


Fig. Boiler repowering

(Replacement of FD-fan and Air-heater and addition of Gas turbine plant and economiser)

In both the cases, substantial boiler modifications are necessary to accommodate the exhaust gases.

Repowering can also be used to pulverised coal-fired plants but it poses some other difficulties, when exhaust gases from gas turbine are used as a source of O_2 in the pulverised boiler, the flow (velocity) of exhaust gases through the boiler is increased. Pulverised coal boiler basically useless O_2 to reduce flyash erosion, therefore, increased exhaust gas flow through the existing boiler is not possible.

Advantages of repowering cycle : Repowering offers a means of increasing capacity and efficiency of the existing power stations in the cheapest possible way. Every 30 MW existing steam set can be upgraded to 111 MW by addition of gas turbine. There are 200 such sets of 10,000 MW capacity presently in U.K. It is thought by the Government to repower few of them instead of building new nuclear plants which the public does not want.

The advantages of repowering systemin addition to the above are listed below :

* Use is made of existing sites and civil works such as water-cooling channels, cooling towers, buildings and offices.
* The requirement of cooling water is changed little even though the output is trebled.
* The construction of the combined cycle can be completed just within a couple of years.
* Fuel used can be gas, distillate or blended residual. Extra handling of coal can be eliminated which reduces maintenance cost considerably.
* Automatic control of gas turbine helps for peak load requirement and operating staff can be reduced to one-third of requirements for a coal-fired station.
* The smoke and grit emissions are reduced considerably which maintain the environment more clean.

Belle Isle station (U.S.A.) is the first repowering installation in the power industry commissioned in 1949. A2 ×4 MW gas turbines were added as the boiler was unable to supply required quantity of steam to the existing steam turbine. Plant capacity was increased by 9 MW while the plant heat rate was improved by 2.5%

Another notable Station of Empire District Electricity Co., Riverbank station of Duke Power. Co., Long. Beach Generating Station of Southern California Edison Co., are some of the notable repowered combined cycle plants in U.S.A.

There are 44 combined cycle plants presently working in USA with total capacity of 6890 MW with a largest unit of 600 MW and smallest of 12 MW.

Q. 2. (a) Enumerate and explain briefly the factors which should be considered while selecting the site for hydro-electric plant.

Ans. Selection of Site for Hydro-electric Power Plant : While selecting a suitable site, if a good system of natural storage lakes at high altitudes and with large catchment areas can be located, the plant will be comparatively economical. The essential characteristics for a good site are large catchment area, steep gradient to the area, high average rain fall and favourable sites for impounding reservoir. For this purpose, the geological, geographical, and meteorological conditions of a site, need to be carefully investigated. The most important factors which have to be considered in this selection are:

1. Quantity of water available.
2. Storage of water,
3. Head of water which can be utilized,

4. Distance of power station site from power demand centres or load centre,

5. Accessibility of the site.

1. Quantity of water available : It is estimated on the basis of measurements of steam flow over as long a period as possible. Rain fall records taken at various locations in the catchment area for many years also serve as source of information for availability of water. The average water quantity available, maximum and minimum quantity available, the duration and intensity of flood will be known from hygrograph if the run-off data for sufficient long period is available. For dependable assessment of water potential, data recorded over a large number of years is desirable. Losses due to evaporation and percolation should be estimated to find the net volume of water available for power generation. These factors are necessary to decide the capacity of hydro electric power plant, setting up of peak load plant such as steam, diesel or gas turbine plant. Such conditions may also fix the capacity of the stand-by plant. The maximum or flood flows governs the size of the head-works and dam to be built with adequate spillway. Requisite quantity of water for the economic generation of power must be available at the site selected.

2. Storage of Water : Storage of water is necessary for maintaining its availability during all seasons of the year so that operation of the plant can be ensured at all times. Rain fall is usually varying from year to year and also during different months of year, with the result that flow of water in rivers and streams as

Never uniform storage of water helps to smoothen out this non-uniformity of flow. A strong reservoir is usually constructed for equalising the flow of water so that any excess quantity of water at a certain period of the year can be made available for maintaining output during times of very low or no flow. The storage capacity can be calculated with the help of mass curve or the minimum quantity of available water for the available storage capacity can also be calculated by mathematical approach to find the relation between the dam height and storage capacity which will give the least cot of construction. Maximum storage should be provided consistent with economic expenditure. There are two types of storage :

(i) Where it is intended to provide just sufficient storage (taking losses into account) for one year only so that there is no carry over water for the next season, this method of storage is called yearly used method.

(ii) Where it is intended to provide enough storage so as to be useful even during the worst dry periods, this is called safe yield method.

In the first method the reservoir is almost emptied by end of each water year and fills up at the beginning of the year. In the second method water within the calculated safe yield having been estimated from a study of previous dry periods.

3. Sedimentation : The capacity of storage reservoir is reduced due to gradual deposition of silt. Silt may also cause damage to turbine blades. Silting from forest covered areas is negligible. On the other hand the regions subject to violent storms and not protected by vegetation contribute lot of silt to the run off. In some cases this factor alone may render an otherwise suitable site unsuited.

4. Availability of head of water : Geographical and geological conditions of the area along with stream flow data may be used to estimate the head of water. Head of water has considerable effect on cost of a scheme and economy of power generation. Low falls on unregulated streams are subject to video variations which affect the net head, and some times reduce it to an abnormally low value resulting in reduced power generation. For a given power output an increase in effective head reduces the quantity of water required to be stored and to be passed through the turbine. In order to find out the most effective and economical head, it is necessary to consider all possible factors which may affect it.

5. Water Pollution : Polluted water may cause excessive corrosion and damage to metallic structures. This may render the operation of the plant unreliable and uneconomic. As such it is necessary to see that the water is of good quality and will not cause such troubles.

6. Distance From Load Centre : Most of time the electric power generated in a hydro electric power plant has to be used at some considerable distance from the site of plant. For this reason, to be economical on the transmission of electric power, the routes and the distances should be carefully considered since the cost of erection or transmission lines and their maintenance will depend upon the route selected. Usually hydro electric stations are located at the site where the requisite quantity and head of water is available.

7. Geological Investigations : Geological investigations are needed to see that the foundation rock for the dam and other structures is firm, stable, impervious and strong enough to withstand water thrust and other stresses. The area should also be free from earthquakes.

8. Access to Site : It is always a desirable factor to have a good access to the site of the plant. The site selected should have rail and road transportation facilities.

Q. 2. (b) Construct the mass curve from the following data collecting at a particular site and find

(i) the size of reservoir, and

(ii) maximum possible rate of flow that could be available.

Week	1–6	7–12	13–18	19–24	25–30	31–36	37–42	43–48
Weekly flow m^3/s	600	700	300	400	1700	900	600	300

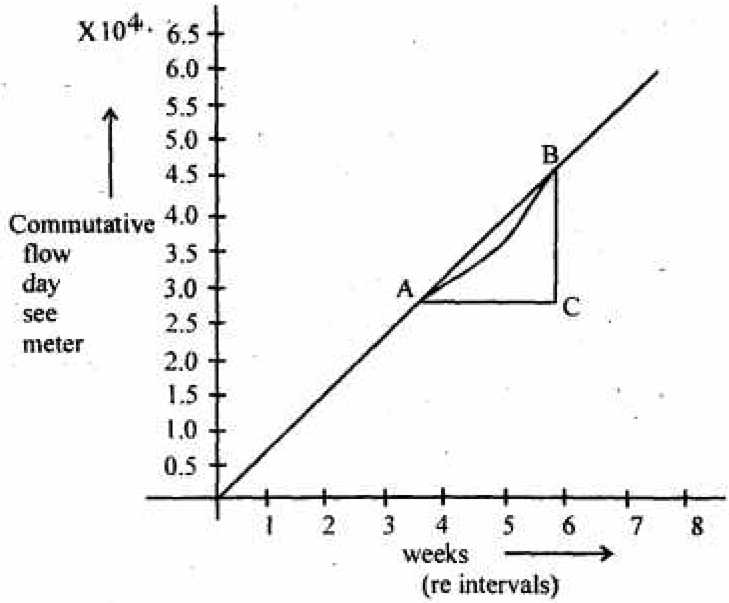
Ans.

Week internal in linearly	flow m^3/sec day-sec-metre	Weekly volume day-sec-meter	Cumulative flow
1–6 (1)	600	4200	4200
7–12 (2)	700	4900	4900
13–18 (3)	300	2100	11200
19–124 (4)	400	2800	14000
25–30 (5)	1700	11900	25900
31–36 (6)	900	6300	32200
37–42 (7)	600	4200	36400
43–48 (8)	300	2100	38500

One day second metre $= 1 \times 24 \times 60 \times 60$

$= 86400 m^3 / day$

Mass Curve :



Reservoir capacity $= 5500\,MW^3$ from graph.

Regulated flow = Slope of the mass curve corresponding to AB = BC.

Q. 3. Give description with neat sketches :

(i) Preparation of coal

(ii) Belt conveyor

(iii) Pneumatic Ash Handling System

(iv) Principle of Pulverized fuel firing system.

Ans. (i) Preparation : The preparation of coal before feeding to the combustion chamber include sizing of the coal (if brought unsized), drying and removing the iron particles.

A coal preparation plant includes the following equipments :

(a) Crushers,

(b) Breakers,

(c) Sizers,

(d) Dryers and

(e) Magnetic separators.

Fig. 3 shows a coal preparation plant. Many types of coal crushers are in the use for reducing the coal to required size. Part of the coal obtained from coal fields does not require sizing, crushing plant may be by-passed. The capacity of the crushers in large central stations is as high as 600 tons per hour. Sizers are used along with crushers and breakers. The coal driers are used in order to remove the excess free moisture from coal if it is wetted during transport. Hot flue gases are passed through the coal storage.

The iron particles which may be brought with coal from the coal fields, are removed with the help of magnetic separators. These iron particles may choke the burners and may increase the wear of handling equipment. The iron particles cling to the belt, where the coals falls off sooner, and dropped into a reject chute. The iron particles may be coal cutter teeth particles, bolts, nuts, wire fish plates etc. A small amount of bolts and nuts may enter the coal from the feeders, conveyors and elevators, and it is therefore desirable that the separator be placed as close as possible to the coal preparation plant, and in any case before passing on the storage bunkers. Magnetic separation is more desirable with pulverised fuel than stoker fired plant. The latter will pass trapped iron without any risk of damage, but the feeders and milling plant associated with the former may be damaged.

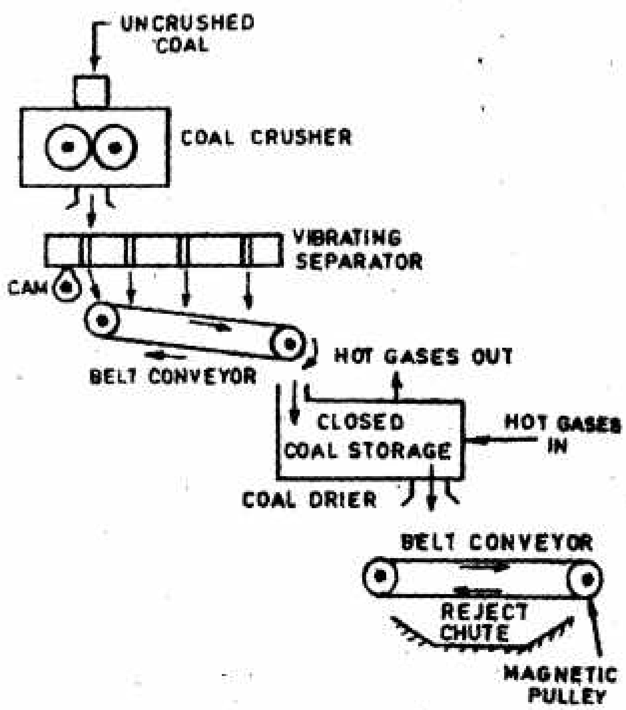
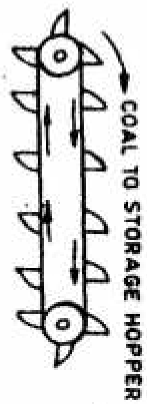
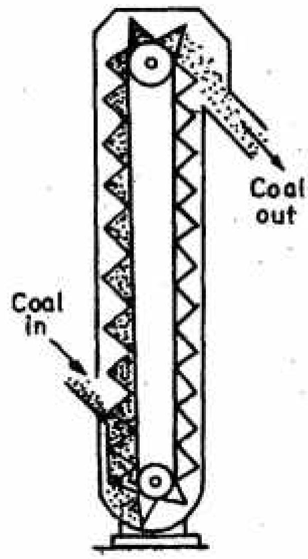


Fig. Schematic diagram of a coal preparation plant

(ii) Belt Conveyor : This device is used for hoisting and conveying. It is successfully used on inclinations upto 20° to the horizontal. The average speed ranges from 60 to 100 m/mm, with load carrying capacity of about 50 to 100 tonnes per hour, which can easily be transferred through 400 metres. Thus these can be used in large stations. In its simplest form the belt conveyor consists of a belt of a suitable material as rubber, convas etc., running over a pair of end drums of pulleys and supported at intervals by a series of rollers called idlers these in turn being supported on a conveyor frame. The carrying idlers, which support the located side of the belt are usually toughened to provide a sag in the belt section. These prevents loose materials from falling down the belt at the sides.



(a) Bucket elevator
(Centrifugal)



(b) Bucket conveyor
(Continuous type)

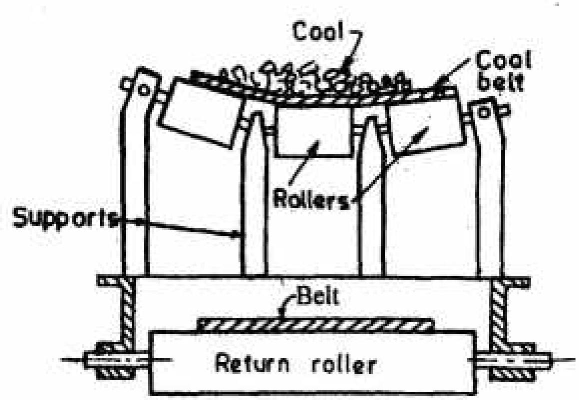


Fig. Section through belt conveyor

The advantages and disadvantages of belt conveyor is listed below :

Advantages :

(i) Continuous disc charge of coal is achieved.

(ii) Operation is smooth and clean.

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(iii) The coal over the belt can be easily protected from wind and rain by providing over head covers.

(iv) Power consumption is less as compared with other types of transport systems.

(v) Large quantity of coal can be transferred.

(vi) The repair and maintenance costs are minimum.

Disadvantages :

(i) It is not suitable for short distances and greater heights.

(ii) As the maximum inclination at which coal can be transported is limited (20°), moreover length of the conveyor becomes excessive if coal is transferred at considerable height.

(iii) Pneumatic ash handling system : This system has been specifically developed for the handling of both abrasive and very fine, dusty materials such as ashes, flyash, and soot (and fine coal). It is particularly well adopted to boiler plants from which the ashes and fly ash must be transported some considerable distance for final disposal, that is, plants which are located in more or less congested districts or in connection with which there are not available large areas of flow land for direct fill.

In general there are six main units in a pneumatic conveyer system :

1. Conveyer pipe line with feed inlets.
2. Air tight receiver combined with an efficient separator.
3. Air tight discharger gates for the receiver and separator.
4. Air washer or filter.
5. Air exhauster.
6. Storage bin with discharge gate and chute (or with conditioning unloader units).

A schematic arrangement is shown in fig. 6. This consists of a suction pipe from the boiler ash outlets to a crusher, then to a bunker outside the boiler house and continued on to the exhauster via filter. The air velocity accelerates, floats and maintains in suspension the largest particle has of material taken into the suction system. The asches accumulate until they are passed through a crusher to ensure being carried off to the storage bunker valves and connections are provided on the hoppers and suction pipe. Large ash particles are generally crushed to smaller size through mobile crushing unit. The cursher is mounted or narrow-gauge rails above the suction pipe and evacuation is affected by placing it between the corresponding hopper valve and the connection below. The pipe connections, when not in use, are closed by cover plates so that the hopper undergoing evacuation obtains full benefit of the suction.

The inlet of the suction pipe which is open to atmosphere, has a slide valve and vacuum gauge fitted.

The separator working on the cyclone principle removes dust and ash which pass out into the ash hopper at the bottom while clean air is discharged from the top. When the conveyer is in operation, air is exhausted from the receiver and separator by the air exhauster. With a mechanical exhauster it is usually necessary to use a filter or washer to ensure that the exhauster handles clean air. Such as exhauster may be used in a large station as its power requirements are not much. Small and Medium sized stations may use the steam exhauster. In a steam exhauster, the air passes through the exhauster and into an air washer, in which any remaining dust is removed from the air. Where a mechanical exhauster is used, such as a positive displacement vacuum pump, the air first passes through an air washer or filter and then through a vacuum pump. At regular, predetermined intervals, a timer mechanisms acts to break the vacuum in the pipe line and the receiver, the discharge gets then automatically swing open, allowing the material to discharge from the receiver and separator to the storage bin.

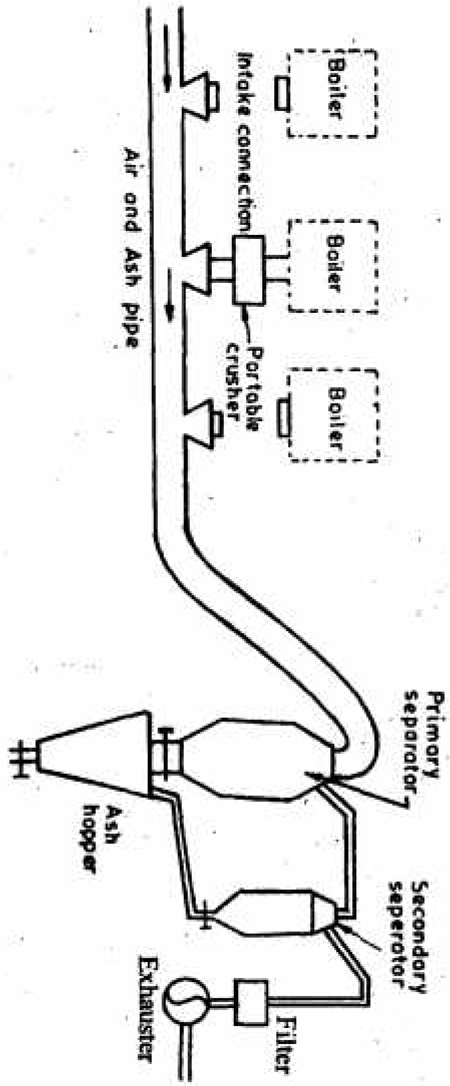


Fig. Arrangement for pheumatic handling of ash

The water jet exhauster is used where special plant conditions prevail and where large quantities of water are available at a low cost. Water requirements vary considerably with size and length of pipe line, number of bends vertical lifts, and hourly handling capacity required. Therefore, no dependable average figures can be given.

A good installation of pneumatic conveyer should avoid sharp bends and the lifts should be provided through a gradual sloping of the conveyer pipe. The pneumatic type of conveyor is particularly well adopted for handling ashes fly ash, and soot in age industrial and public-utility stations. It has capacity of 5 to 10 tons/hr depending upon the size of pipe-line used and the physical layout of the conveyer system.

The advantages of this system are :

1. With the pneumatic system, all dust nuisance is eliminated in the handling of ashes, fly dust. Dustless operation is accompanied because the materials are handled in a totally enclosed conveyor conduit from ash pit or dust hopper to ash storage bin.
2. In many installations a rotary type dust less unloader is used to eliminate all dust nuisance when discharging the materials from the storage bins to rail road cars and trucks, so there is no spillage and no rehandling.
3. The materials are conveyed in a dry and delivered to the storage bin in the same condition. Therefore, there can be no chance of the ash freezing, packing, or sticking in the storage bin, the material discharging freely by gravity.
4. The entire conveyer layout is quite flexible and can thus made to fit varying physical plant conditions.
5. Furthermore, the conveyer pipe line requires little space in the boiler plant and, therefore, costs are often reduced where this system is installed.

The disadvantages of this methods are :

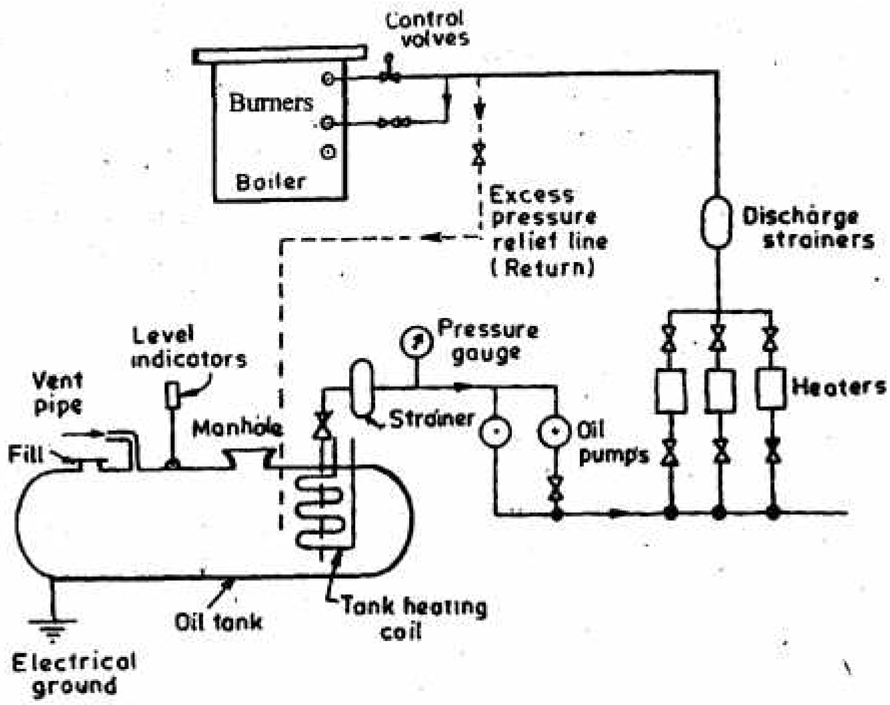
1. Large amount of wear on pipe work.
2. Labour and maintenance charges are high, and
3. It is rather dirty and noisy.

(iv) Principle-oil Handling : For storing a large quantity (several hundred thousand gallons) of oil near the plant, tanks of concrete or steel are used near the plant. Oil tanks must be completely surrounded by a dike that can hold at the oil contents if the tank should rupture. The steel tanks may be inside or outside the plant. Cylindrical tanks may be installed above ground or below ground or as esmiburied tanks. Underground tanks are usually preferred. Oil arrives at a plant by ship, barge, tank car, or truck and is usually stored closed to the unloading point. Storage tanks usually are fitted with fill pipe, vent pipe, oil gauge, steam smothering line, sludge pump out, manhole, low and high suction taps, suction heating coil, return line and electrical ground.

In order to allow the tank to breathe, as it is filled for emptied, a vent pipe open to atmosphere is provided. To see the level of oil in tank, a level indicator is also provided. Oil pumped from the tank is passed through the strainers and then may be passed through heaters in order to bring it to the conditions necessary for the burners.

Fuel-gas Handling : Pipe line system is provided for the availability of natural gas. For best economy these pipe lines should be kept flowing at full capacity. Many power plants use natural gas on a cut-off basis. The plant buys the gas at a low rate but agrees to stop taking fuel when the pipe lines run at peak-flows other customers. These plants then burn oil or coal as an alternate fuel.

Plants cannot justify storing gas on their premises, but the underground storage proves feasible in some areas by using depleted gas and oil fields. Natural gas usually needs conditioning after withdrawl from the ground in the form of removing dirt, water, hydrogen sulphide, liquid hydrocarbons, and inert gases, odorant is often added. Long distances lines use pressures upto $70\,kg/cm^2$ and distribution pressures of about $14\,kg/cm^2$ or less.



Liquid fuel handling arrangement

A typical handling system at a plant taps off from a distribution line to a gas metering house. The line divides into two parallel lines, each with meters, regulators, and stop valves. The lines reunit into a single line from the metering house to the plant boiler room. In the boiler room, branch lines feed gas through meters and regulating valves to the gas burners in the furnaces.

Q. 4. Air is drawn in a gas turbine unit at 15°C and 1.01 bar and pressure ratio is 7 : 1. The compressor is driven by the H.P. turbine and L.P. turbine drives a separate power shaft. The isentropic efficient of compressor, the H. P. and L. P. turbines are 0.82, 0.85 and 0.85, respectively. If the maximum cycle temperature is 610°C, calculate pressure and temperature of the gases entering the power turbine, the net power developed by the unit per kg/s mass flow, the work ratio, the thermal efficiency of the unit. Neglect the mass of fuel and assume $C_{pa} = 1.005\,kJ/kg\,K$ and $\gamma = 1.4$ for compression process and $C_{pg} = 1.15\,kJ/kg\,K$ and $\gamma = 1.333$ for combustion and expansion process.

Ans. The arrangement is shown in fig.

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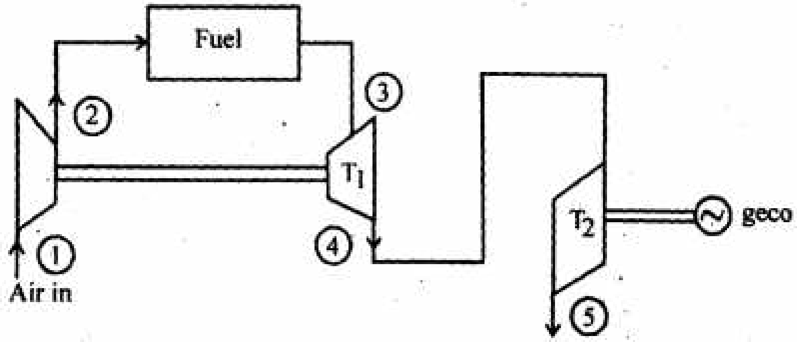

$T_1 = 288\,K$ and $T_3 = 610 + 273 = 883\,K$

$$\frac{T_2^1}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{r-1}{r}} = 7^{.285} = 1.74$$

$$T_2^1 = 288 \times 1.74 = 501.4\,K$$

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

$$.82 = \frac{501.4 - 288}{T_2 - 288}$$

$$.82T_2 - 236.16 = 501.4 - 288$$

$$T_2 = 548.24\,K.$$

Work input to the compressed per kg of air

$$= 1 \times C_{pa} \times (T_2 - T_1) = 1.005 \times (548 - 288) = 261.3\,kJ/kg$$

The power to be developed by H.P. turbine must be equal to the power input both compressor.

$$\omega_{t_1} = C_{pg}(T_5 - T_4) = 261.3$$

$$= 1.15(883 - T_4) = 261.3$$

$$T_4 = 883 - \frac{261.3}{1.15}$$

$$= 883 - 227.2$$

$$= 883 - 227.2$$

$$\eta_{t_1} = .85 = \frac{T_3 - T_4}{T_3 - T_4^1}$$

$$T_4^1 = T_3 - \frac{T_3 - T_4}{.85}$$

$$= 923 - \frac{(923 - 655.78)}{.85}$$

$$= 923 - 314.37$$

$$= 608.62\,k$$

From the process 3–4' we write

$$\frac{P_2}{P_3} = \left(\frac{T_3}{T_4^1}\right)^{\frac{r}{r-1}} = \left(\frac{923}{608}\right)^{\frac{1.33}{.33}} = 4.9$$

$$P_3 = \frac{P_2}{4.9} = \frac{7 \times 1.01}{4.9} = 1.44 \text{ bar}$$

The condition of the gas entering flue gas into the power turbine or L-P turbine is.

$$P_3 = 1.44 \text{ bar} \quad T_4 = 655 - 273$$

$$= 382^\circ C$$

$$\eta_{t_2} = \frac{T_4 - T_5}{T_4 - T_5^1} = .85$$

$$\Rightarrow \quad T_4 - T_5 = .83(655 - 588) = 64.8\,k$$

Let t_2 (work developed by power turbine

$$\omega_{t_2} = c_{pg}(T_4 - T_5)\,kJ/kg$$

$$= 1.15 \times 64.8 = 74.5\,kJ/kg$$

The network (ω_{t_2}) per of air :

$$= 74.5 \text{ kJ/kg}$$

Total work per kg of air

$$\omega_t = \omega_{t_1} + \omega_{t_2} = 261.3 + 74.5$$

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$$= 335.8\,kJ/kg$$

$$W.R. = \frac{\omega_{t_2}}{\omega_t} = \frac{74.5}{335.8} = 22$$

Power capacity of plant

$$= \omega_{t_2} \times m_a = 74.5 \times 1$$

$$= 74.5\,kJ/sec = 74.5\,kg.$$

Part-B

Q. 5. (a) Give the construction and working of a Gas cooled reactor. What are its advantages and disadvantages.

Ans. Gas Cooled Reactor (GCR) : The circuit for gas cooled reactor is similar to pressurized water reactor with the following differences. The reactor core would include a graphite moderator. The coolant would be a gas and the pump a blower or gas compressor. There would no need for a pressurizer. The vessels and piping would be considerably larger because of the lighter density of the coolant. The tubes of the boiler would have extended surfaces such as fins to improve heat-transfer rates. Gas pressures would be less than $7\,kg/cm^2$, so that vessel wall thickness would not be a problem. The gas could be air, hydrogen, helium or CO_2.

There are two principal classes of gas cooled reactors developed for central power station service and these are :

1. The gas cooled graphite moderated reactor (GCGM), and
2. The high temperature gas cooled reactor (HTGC).

In first type CO_2 is used as a coolant which was first developed in Britain. While the second adopted in U.S.A., uses helium as coolant. Both types are graphite moderated. The CGGM uses natural uranium fuel while the HTGC reactor employs highly enriched uranium carbide mixed with thorium carbide and cold with graphite.

Q. 5. (b) Write notes on Radioactive waste disposal and safety features in connection with nuclear power plant.

Ans. Radioactive Waste Disposal : Used fuel in a nuclear power station is highly radioactive and can contaminate air or water, and if absorbed by a living organism, it can cause biological damage. In nuclear power stations, it is very important to take care to dispose of the waste which is likely to have radioactivity. The main sources of gaseous discharge and any liquid effluent are sampled and records are kept of the radio-activity discharged from such sources. Gaseous wastes require no treatment other than filtration before being discharged at high level to assist in dispersion. The gas should be passed through a clean up-plant to remove radioactive iodine which constitute the major gaseous hazard. Various methods used for the disposal of radio-active waste are briefly described here.

1. Dilution of Liquid and Gases : The loss of CO_2 from a reactor is monitored and should not exceed

1 or $1\frac{1}{2}$ tons a day. The concentration of the coolant gas in the atmosphere in the working areas is checked and precautions are taken against toxic and radiological hazards. This is particularly required when the blowing down operation of the station is planned.

At several nuclear stations, liquid wastes can be discharged following filtration by adjustment of pH value and by diluting and mixing with the station cooling water discharge. If the conditions in some stations demand this, some or most of the soluble radio-activity in the liquid effluent must be removed by the ion exchange process. All potentially radio-active liquids discharged from stations are monitored and the quantities discharged are noted in a register. These should be kept within permissible limits as authorised for particular stations and locations.

2. Storage in Sealed Containers : Special care is taken to prevent leakage of liquids containing radioactive substances into the ground in the area around the stations. This is effected by providing double containment of drains and by designing concrete storage tanks as water retaining structures. These sealed containers are then disposed of at sea where they are quickly and completely covered with mud in the bottom. Radioactivity can only get into the sea by slow diffusion through the mud.

Solid wastes such as those arising from discarded control rods, pieces of fuel cans etc., are stored in a shielded concrete vaults. Care is taken to segregate materials which are chemically incompatible or combustible. Combustible waste of low specific radioactivity is burnt in an incinerator which incorporates a high standard of filtration of the flue gases. The irradiated fuel elements comprise the most highly radioactive wastes. These are stored in a water or air cooled shielded area to allow the activity to decay. These are th·· returned to the Atomic Energy Authority for processing.

3. Underground Burial : Another alternative is the burial of radioactive waste directly in the ground taking percussions that buried ground is isolated from the public and under ground water must not be able to seep through as it may cause radioactive contamination of drinking water supplies. Such disposal is permissible mostly in areas of low rainfall at points which are highly above the ground water level.

Safety Features : The radioactivity of the fission products which accumulate in the fuel during reactor operation has an important influence on the design of nuclear reactors of all types. Because radioactive material in the air or water constitutes a potential health hazard, special precautions are taken to ensure that any unavoidable releases to environmental during normal operation or at the lowest reasonably achievable levels. In addition so called "engineered safety features" are provided to minimize the escape of radioactivity in the event of a severe malfunction.

The engineered safety features are designed to prevent or minimize the escape of radioactive fission products to the environment as the result of a severe transient that persists or develops after a reactor trip. Among the more important of these features are the emergency core cooling system and the containment structure.

After a reactor is shutdown, either deliberately or as the result of an emergency, heat continues to be generated by radioactive decay of the fission products present in the fuel. For a reactor which has been operating for some time, the rate of decay heat generation after shutdown in initially about 7 percent of the full reactor heat power. This decreases with time but is still significant after several days. Consequently, to avoid damage to the fuel by over heating, with the accompanying release of fission products, adequate cooling must be maintained for some time after the reactor is shutdown.

Safety considerations also dictate that the neutron detection and electronic gear be provided in duplicate such that, if one circuit fails, control can still be maintained. During normal operation the reactor control system must be able to maintain the power level at a constant value, change power levels as load demand changes, and be able to handle short and long-term transients.

A variety of signals are used during steady-state operation to actuate control devices. Load demand, temperature, pressure, flow rate, and neutron flux signals are fed to appropriate discriminating and integrating circuits to provide the signals which adjust control rods, change moderator level, change fuel concentration, close or open valves, change motor speeds, etc. Either manual or automatic control can be used with a tendency toward greater reliance on automatic systems.

The use of safety devices, such as fuses to prevent over heating and relief valves to prevent over pressures, is common in industry. Safety devices on reactor differ in two important aspects–speed of action and range of operation.

Q. 6. (a) The annual consumption of a customer is 15×10^5 units and the annual load factor is 40%. If the load factor improves to 100% what will be the saving in the average unit cost. The two part tariff is Rs. 110/kW + 10 paise/kWh.

Ans. Consumption $= 15 \times 10^5$ units

Load factor $= .4$

Load factor improves to 100%

So the max demand is

$$.4 \times 1000^5 = 4000\,\text{kwl}$$

So the cost of energy according to the tariff.

Rs 110/kms + 10 paise/kwh

$$-110 \times 4000 + .10 \times 15 \times 10^5$$

$$= 440000 + 1.5 \times 10^5$$

$$= (4.4 + 1.5) \times 10^5$$

$$= 5.9 \times 10^5 \text{ Rs}$$

Saving $= (15 - 6 - 9) \times 10^5$

$$= 9.1 \times 10^5 \text{ Rs.}$$

Q. 6. (b) The input-output curve of a 25 MW capacity generating power plant is given by

$$\mathbf{I = 10^6.\left[7 + 0.2L + 0.1L^2\right]}$$

where I is in kCal/h and L is in MW.

Find the average heat rate when the plant is operating at 25 MW load for 10 hours in a day and it

was kept hot at zero load for the remaining period of 14 hours. Also find the saving in the heat rate if the same energy is produced for the whole day at constant load.

Ans. At $L = 0$

$$I_0 = (7.56 + 0.2016 \times 0 + 0.126 \times 0)10^6$$

At $L = 25$

$$I_{25} = \left(7.56 + 0.2016 \times 25 + 0.126 \times 25^5\right)10^6$$

$$= (7.56 + 5.04 + 78.75)10^6$$

$$= 91.35 \times 10^6 \text{ kcal / hr}$$

Total energy generated,

$$= 25 \times 10 + 0 \times 14$$

$$= 250 \text{ MW hr.}$$

Total input $= (7.56 \times 14 + 91.35 \times 10)10^6 \text{ kcal}$

$$= (105.84 + 913.50)10^6 \text{ kcal}$$

$$= 1019.34 \times 10^6 \text{ kcal}$$

∴ Average heat rate

$$= \frac{\text{Total input}}{\text{Total output}} \text{ for a given time.}$$

$$= \frac{1019.34 \times 10^6}{250} \text{ kcal / MW hr}$$

$$= 4.-7736 \times 10^6 \text{ kcal / MW hr}.$$

In the second case when same energy is produced at constant load in 24 hrs.

Average load $= \frac{250}{24} = 10.41 \text{ MW}$

Also at $L = 10.41$

$$I = \left[7.56 + 0.2016 \times 10.14 + 0.126 \times 10.41^2\right]10^6$$

$$= 23.3129 \times 10^6 \text{ kcal / hr}$$

Now heat rate

$$HR = \frac{1}{L}$$

$$= \frac{23.3129}{10.41} 10^6$$

$$= 2.23948 \times 10^6 \text{ kcal / MW hr}$$

∴ The saving is

$$= (4.07736 - 2.23948) 10^6$$

$$= 1.83788 \times 10^6 \text{ kcal / MW hr}$$

$$= 1837.88 \text{ kcal / k Whr}.$$

Q. 7. (a) Describe with the help of neat sketch, the working of a solar power plant. What are its salient features?

Ans. Solar thermal power generation (or Thermal Electric Conversion) : Solar thermal power generation employs power cycles which are broadly classified as low, medium and high temperature cycles. Low temperature cycles generally use flat-plate collectors so that maximum temperatures are limited to about 100°C. Medium temperature cycles work at maximum temperature ranging from 150 to 300°C, while high temperature cycles work at temperatures above 300°C. For the low and medium temperature ranges, the thermodynamic cycles preferred is the Rankine cycle. For the high temperature range apart from the Rankine cycle, the Brayton and the Stirling cycles are also being considered.

In a solar thermal power production system the energy is first collected by using a solar pond, a flat plate collector or a focusing collector. The energy is used to increase the internal energy or temperature of a fluid. This fluid may be directly used in any of the common or known cycles such as Rankine, Brayton or Stirling or passes through a hat exchanger to heat a secondary fluid (working fluid) which is being used in the cycle to produce mechanical power from which electrical power can be produced easily.

The following three systems are discussed in the following section.

1. Low temperature cycles using flat plate collector or solar pond.
2. Contracting collectors for medium and high temperature cycle.
3. Power tower concept.

Low temperature systems : (Rankine Cycle Solar Thermal Power Generation System). These are basic low temperature systems which use flat-plate collectors or solar ponds with which Rankine cycle solar thermal power production system is employed. Since the temperature of the fluid (water) is usually below 100°C (with solar pond, the maximum temperature is limited approximately 80°C), and it is not possible to generate steam with flat-plate collectors or solar point, so this can not be used directly to run the prime mover. Therefore, some other organic fluid is used (Freon group etc.) which evaporates at low temperature and high pressure by absorbing the heat from the heated water. The vapour formed can be used to run a turbine or engine which may generate power, which will be sufficient to light the group of house for rural areas and for irrigation purposes.

To convert solar energy into electricity through thermal conversion, researches in the world have done a considerable work in varying capacity power system. Organic fluid Rankine cycle has bene extensively used in these studies. The development work in the generation of solar thermal power in higher range 10 kW and above upto megawatts, is in line in various parts of the worlds. The systems have been developed by using a solar pond, flat plate collector, focusing collector (distribution type) or a heliostat. The heliostat systems are used normally in a very high range of solar thermal power production (around megwatts). It will be described later.

A low temperature thermal electric power production scheme using solar pond is shown schematically in fig. 1. Thermal energy from a solar pond is used to derive a Rankine cycle heat engine. Hot water from the bottom of the point is pumped to the evaporator where the organic working fluid is vaporized. The vapour flows under high pressure to the turbine and thereby expanding through the turbine wheel and the electric generator linked to it. The vapour then travels to the condenser where cold water from the cooling tower condenses the vapour back it to a liquid. The liquid is pumped back to the evaporator where the cycle is repeated.

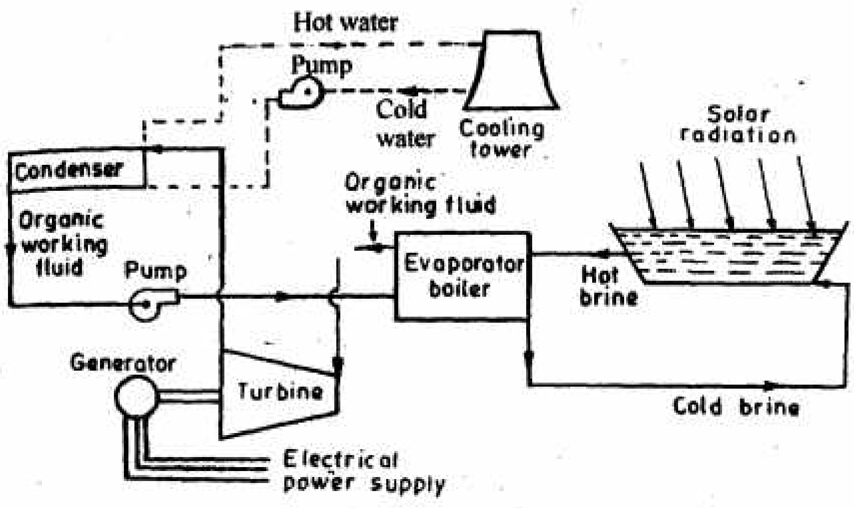


Fig. Flow diagram of solar pond electric power plant

Another low temperature solar engine, using heated water from flat-plate collector and butane as the working fluid is shown fluid is shown in fig. 2, which is developed in France for lift irrigation. The system has an array of flat plate collectors to heat water upto nearly 70°C and in the heat exchanger, the heat of water is used for building butane. The high pressure butane vapour runs a butane turbine which operates a hydraulic pump which pump the water from well and used for irrigation. The exhaust butane vapour from butane turbine is condensed with the help of water which is pumped by the pump. This condensate is fed to the heat exchanger or butane boiler.

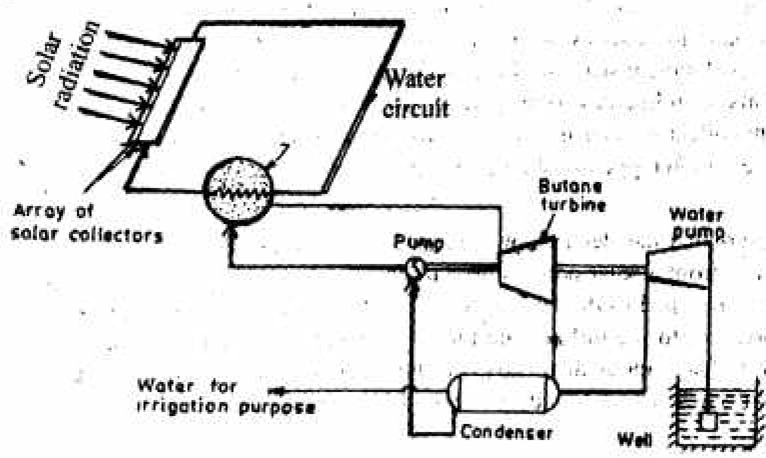
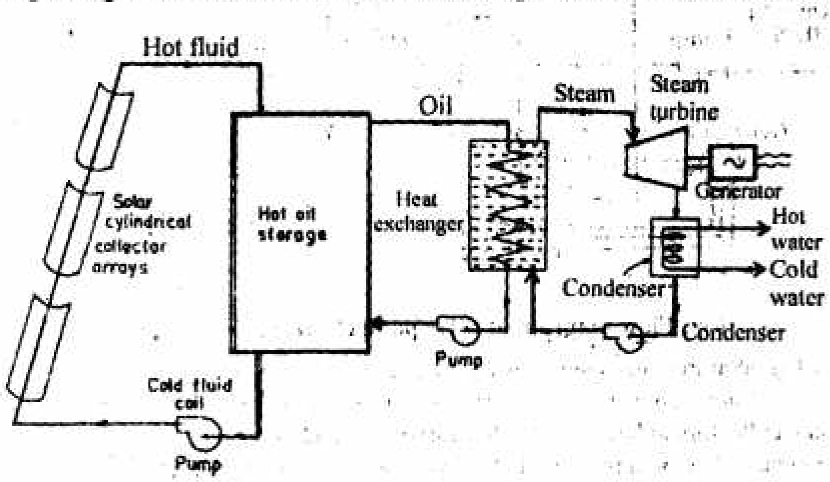


Fig. Schematic of a low temperature solar power plant

Medium temperature systems with concentrating collectors : These systems generally employ an array of parabolic through concentrating collectors, which give temperature above 100°C. As described before, a simple parabolic cylindrical concentrate for medium temperature system is shown in fig. (1, 2, 3). It consists of a parabolic cylindrical reflector to concentrate sunlight on to a collecting pipe within a pyrex of glass envelope. A selective coating of suitable material is applied to pipe to minimize infra-red emission. Proper suntracking arrangement is made so that maximum sunlight of succeed on the reflector.



High temperature systems : For the efficient conversion of heat energy into mechanical energy and hence into electricity, the working fluid should be supplied to the turbine at high temperature. To obtain such temperatures, above 175°C, from solar energy requires the use of focusing concentrating collectors. Since these collectors concentrate direct solar predation, they would be most effective in locations where there is ample sunshine (e.g., in the western region of India). Two basic arrangements have been proposed for converting solar radiation into electrical energy :

1. The central receiver system, and
2. The distributed collector system or solar farms.

In the central receiver system, commonly known as 'power tower' design, an array of sun tracking mirrors (hesitates) reflect solar radiation on to receiver mounted on top of a central tower. Solar energy absorbed in the central receiver is removed as heat by means of a heat transport fluid and converted into electrical energy in a turbine generator.

The distributed collector system or solar farms may consists of a number of parabolic though type (line focusing) collectors or of paraboloid dish type (point focusing) collectors. The absorber pipes (or receivers) of the individual collectors are connected so that all the heated fluid is carried to a single location where the electricity is generated. The basic difference between the central receiver and distributed collector systems is that in the former the solar energy falling on a large area is transmitted to a central point as radiation, but in the latter, the energy is carried as heat in a fluid.

Q. 7. (b) How the power can be obtained from tides? Discuss a tidal plant (single basic concept), mentioning the limitations of the plant.

Ans. Tidal Power :

Introduction : The large scale up and down movement of sea water represents an unlimited source of energy, if some part of this vast energy can be converted into electrical energy, it would be an importance source of hydropower. The main feature of the tidal cycle is the difference in water surface elevations at the high tide and at the low tide. If thus 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. In principle, this is not very difficult as water, at the time of high tide, is at a high level, and can be let into a basin to be stored at a high level three. The same water can be let back into the sea during the low tide through the turbines, thus producing power. Since the basin water levels is high and sea level is low, there is a different head comparable to the tidal range, that can be utilized for the running of the turbines. Basically, it appears to be simple proposition, the problems involved in it are many.

The first tidal power plant was commissioned by General De-Gaule at La Rance (France) in 1966, used a single basin and submerged reversible propeller type turbine generators that could generate power with the water flowing in either direction through the turbine runner. This plant of 240 MW capacity (24 Nos. of 10 MW pump turbine sets) is located near Saint Malo on the N.W. french channel coast, in an area in which maximum tide range is not less than 13.5 m. Bulb turbines have been provided in this project. They are operating satisfactorily.

In 1968 an experimental tiny tidal plant was started at Kisalaya Guba in USSR. Nearly for 17 years there was a dull period in the tidal power development due to the problems involved in it. The main disadvantage of tidal power plant is that the production of power from tidal station occurs at times and in magnitudes which are dependent on the relative positions of earth, moon, and sun to one-other and net on the electrical demand of consumers.

The pioneering project in Nova Scotia, Canada at Annapolis Royal was commissioned in 1983. For the first time conventional bulb turbines were replaced by large rim generator units or straflo turbines with runner diameter of 7.6 m and capacity of 10 MW.

In India, there are possible tidal project in the Gulf of Kutch combay, and on a smaller scale, in the Sunderbans regions of the Bay of Bengal.

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Basic principle of tidal power : Tides are provided mainly by the gravitational attraction of the moon and the sun on the water of solid earth and the oceans.

About 70 percent of the tide producing force is due to the moon and 30 percent by the sun. The moon is thus the major factor in tide formation.

Surface water is pulled away from the earth on the side facing the moon, and at the same time, the solid earth is pulled away from the water on the opposite side. Thus high tides occur in these two areas with low tides at intermediate points. As the earth rotates, the position of a given area relative to the moon changes, and so also do the tides. There are thus a periodic succession of high and low tides.

Although there are exceptions, two tidal cycles (i.e. two high tides and two low tides) occur during a lunar day of 24 hours and 50 min. (The lunar day is the apparent time or revolution of the moon about the earth). That is to day, the time between high tide and low tide at any given location is little over 6 hours. A high tide will be experienced at a point which is directly under the moon. At the same time, a diametrically opposite point on the earths surface also experiences a high tide due to dynamic balancing. Thus a full moon as well as a no moon produce a high tide. In a period of 24 has 50 min; there are therefore, two high tides and two low tides. These are called semidiurnal tides. The rise and fall of the water level follows a sinusoidal curve shown in fig. 1. 2, with point A indicating the high tide point, and point B indicating the low tide point. The average time for the water level to fall from A to B and then rise again to C is approximate 6 hours $12\frac{1}{2}$ minutes.

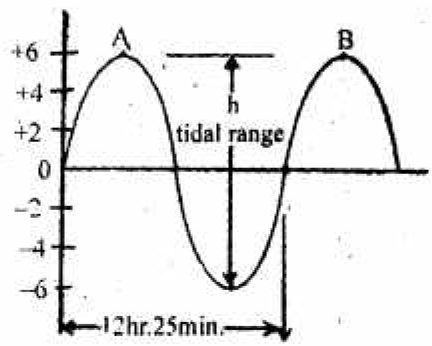

Fig. The tides of the sea

The difference between successive high and low water levels is called the range of the tide. Because of the changing positions of the moon and sun relative to the earth, the range varies continuously. There are however, some characteristic features of this variation.

At times near full or new moon, when sun, moon and earth are approximately in a line, the gravitional forces of sun and moon enhance each other. The tidal range is then exceptionally large; the high tides are higher and low tides are lower than average. These high tides are called spring-tides. On the other hand, near the first and third quarters of the moon, when the sun and moon are at right angles with respect to the earth, neap-tides occur. The tidal range is then exceptionally small; the high tides are lower and the low tides higher than the average.

Components of tidal power plants : There are three main components of a tidal power plant these are :

1. The power house.

2. The dyke to from basin or basins.

3. Sluice-ways from the basins to the sea and vice-versa.

The power house, houses the turbines, generators and other auxiliary equipments. The sluice ways, which are gate controlled are used either to fill the basin during the high tide or employ the basin during the low tide as per operational requirement. The dyke forms a barrier between the sea and the basin or between one basin and the other in case of multiple basins.

It is generally convenient to have the power hours as well as the sluice-ways in alignment with the dyke.

The design cycle may also provide for pumping between the basin and the sea in either direction. If the turbines provided are reversible pump turbines, the pumping operation can be taken over at any time by the same machine. As a matter of fact, the modern tubular turbines are so versatile that they can be used either as turbines or as pumps in either direction of flow. Besides, the turbular passages can also be used as additional sluice-ways by locking the machine to a stand still. This, however imposes a great number of operation in tidal power plants are compared to conventional plants. For instance, the periodic opening and closing of the sluice-ways of a tidal plant are approximately 730 times in one year.

Advantages and Limitations of Tidal Power Generation

Advantages :

1. The biggest advantages of the tidal power is that besides being inexhaustible, it is completely independent of the precipitation (rain) and its uncertainty. Even a continuous dry spell of any number of years can have no effect what-so-ever on the tidal power generation.
2. Tidal power generation is pollution free as it does not use any fuel and also does not produce any unearthly waste like gases, ash atomic refuse.
3. These power plants do not demand large area of valuable land because they are on the bays (i.e. sea shore).

Limitation of the Tidal Power Station :

1. The fundamental drawback to all methods of generating power is the variability in output caused by the variations in the tidal range.
2. Tidal power generation, is an intermittent operation of power supply.
3. The tidal range is limited to a new metres. Thus till the bulb turbine technology was not well developed, use of conventional Kaplan runners was the only alternative. This was found to be unsuitable. Now with the development of reversible bulb turbines, this difficulty is overcome.
4. The tidal range is highly variable and thus the turbines have to work on a wide range of head variation. This affects the efficiency of the plant.
5. Sea water is corrosive and so machinery may get corroded.

   Stainless steel with a high chromium content and a small amount of molybdenum and the aluminum bronzes proved to be good corrosion resistant.
6. Cost is not favourable comapred to the other sources of energy.
7. Construction in sea or in estruaries is found difficult.

Q. 8. Write notes on :

(a) Fuel cell

(b) Thermionic power generation.

Ans. Fuel Cell :

Introduction : A cell (or combination of cells) capable of generating an electric current by converting the chemical energy of a fuel directly into electrical energy. The fuel cell is similar to other electric cells in the respect that it consists of positive and negative electrodes with an electrolyte between them. Fuel in a suitable form is supplied to the negative electrode and oxygen, often from air, to the positive electrode. When the cell operates, the fuel is oxidized and the chemical reaction provides the energy that is converted into electricity. Fuel cells differ from conventional electric cells in the respect that the active material (i.e. fuel and oxygen) are not generally contained within the cell but are supplied from outside.

But for its cost pure (or fairly pure) hydrogen gas would be the preferred fuel for fuel cells. Alternatively impure hydrogen obtained from hydrocarbon fuels, such as natural gas or substitute natural gas (methane), liquidied petroleum gases (propane and butane) or liquid petroleium products, and be used in fuel cells. Efforts are being made to develop cells that can use carbon monoxide as the fuel; it they are successful, it should be possible to utilize coal as the primary energy source.

Main uses of fuel cells are in power production, automobile vehicles and in special military use.

Design and Principle of Operation of a Fuel Cell : As stated these are electro-chemical devices in which the chemical energy of fuel is converted directly into electric energy. The chemical energy is the free energy of the reactants used. This conversion takes place at constant temperature and pressure. The basic features of the fuel cell is that the fuel and its oxidant are combined in the forms of ions rather than neutral molecules.

The first practical fuel cell was demonstrated by Frances T Bacin and J.C. Frost of Cambridge University in 1959. As per the fuel used the main types of fuel cell are :

(i) Hydrogen (H_2) fuel cell.

(ii) Hydrazine (N_2H_4) fuel cell.

(iii) Hydrocarbon fuel cell.

(iv) Alcohol (Methanol) fuel cell.

The operation of the fuel cell can best be described with reference to a specific device. Fuel cells can be adopted to a variety of fuels by charging the catalyst. Here principle and operation of Hydrogen-oxygen (Hydrox) cell is described. These types are the most efficient and the most highly developed.

The main components of a fuel cell are :

1. A fuel electrode.
2. An oxidant or air electrode, and
3. An electrolyte.

In most fuel cells, hydrogen (pure or impure) is the active material at the negative electrode, and oxygen (from the oxygen or air) is active at the positive electrode. Since hydrogen and oxygen are gases, a fuel cell requires a solid electrode conductor to serve as a current collector and to provide a terminal at each electrode. The solid electrode material is generally used in field cells for commercial applications. Platinum and other precious metals are being used in certain fuel cells which have potential utility in military and space applications. The porous electrode has a large number of sites, where the gas electrolyte, and electrode are in contact;

the electro chemical reactions occur at these sites. The reactions are normally very slow, and catalyst is included in the electrode to expedite them. The best electrochemical catalysts are finely divided platinum or platinum like metal deposited on or incorporated with the porous electrode material. Since the platinum metals are expensive, other catalysts, such as nickle (for hydrogen) and silver (for oxygen), are used where possible. The very small catalyst particles provide a large number of active sites at which the electro-chemical reactions can take place at a fairly rapid rate.

Although practical fuel cells differ in design details, the essential principles are the same, as indicated by the schematic illustration in fig. 1. Hydrogen gas is supplied to one electrode and oxygen gas (or air) to the other. Between the electrodes is a layer of electrolyte. Most existing fuel cells operate at temperature below about 200°C; the electrolyte is then usually an aqueous solution of an alkali or acid. The liquid electrolyte is generally restained in a porous membrane, but it may be free flowing in some cells. Direct electric current is drawn from the cell in the usual manner by connecting a load between the electrode terminals.

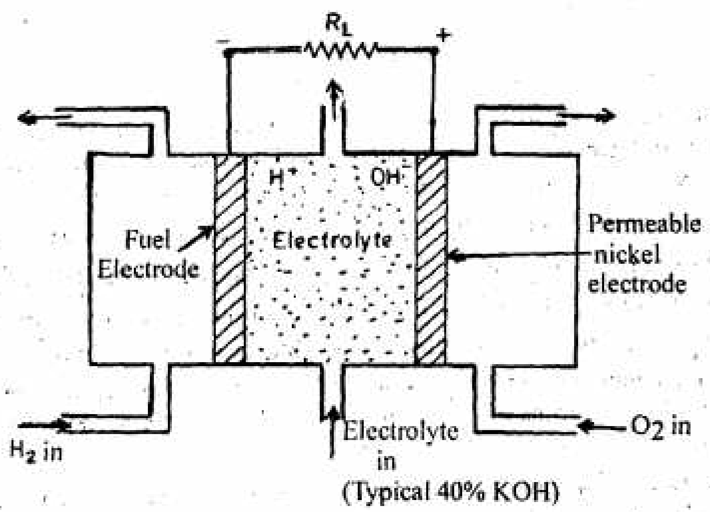

Fig. A Hydrox cell

The electro chemical reactions occurring at the electrodes of a hydrogen-oxygen cell may vary with the nature of the electrolyte, but basically they are as follows. At the negative electrode, hydrogen gas (H_2) is converted into hydrogen ions (H^+), i.e. hydrogen with a positive electric charge, plus an equivalent number of electrons (i.e. $\bar{e}$); thus

$$H_2 \rightarrow 2H^+ + 2\bar{e}$$

At this electrode, hydrogen is diffused through the permeable nickel in which is embedded a catalyst. This catalyst enables the hydrogen molecules, H_2 to be absorbed, on the electrode surface as hydrogen atoms, which react with the hydroxyl ions (OH) in the electrolyte to form water. When the cell is operating and producing current, the electrons flow through the external load to the positive electrode; here they interact with oxygen (O_2) and water (H_2O) from the electrolyte to form negatively charged hydroxyl ions (OH); thus

$$\frac{1}{2}O_2 + H_2O + 2\bar{e} \rightarrow 2O\bar{H}$$

The hydrogen and hydroxyl ions then combine in the electrolyte to produce water. The electrolyte is typically 40% KOH because of its high electrical conductivity and it is less corrosive than acids.

$$H^+ + O\bar{H} \rightarrow H_2O$$

These equations show that hydroxyl ions produced at one electrode are involved in the reaction at the other. Also electrons are absorbed from the oxygen electrode and released to the hydrogen electrode. Addition of the three foregoing reactions shows that when the cell is operating, the overall process is the chemical combination of hydrogen and oxygen (gases) to form water that is,

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$$

The oxygen and hydrogen are converted to water, which is the waste product of the cell. The reactants are stored outside the cell (note difference from storage battery), and the electrodes and electrolyte are not consumed in the overall process. These properties lead to the design of convenient small size long life power units.

If the electrodes are on open circuit the hydrogen electrode accumulates a surface layer of negative charges. These attract potassium ions, K^+, of the electrolyte, providing an electrical double layer. Similarly, the loss of electrons from the oxygen electrode results in a layer of positive charges, which in turn attracts hydroxyl ions, $O\bar{H}$, from the electrolyte. These electrical double layer at the electrodes build up until the potentials are such that they inhibit any further reactions, between the electrolyte and the fuel gases. This situation is illustrated in the figure showing that an open circuit voltage is developed between the electrodes. The magnitude of this e.m.f. is 1.23 volt at 1 atm. and 25°C.

If the circuit is closed the electrons can now leave the electrode, pass through the connecting circuit to the oxygen electrode and take part in the reaction of equation (15.6.2) above. This movement of electrons constitutes a current passing through an external load. In this way useful electrical work is obtained directly from the chemical process. Note that the electron flow is from the hydrogen to the oxygen electrode. The oxygen electrode is thus the anode.

Advantages and Disadvantages of Fuel Cells

Advantages :

1. It has very high conversion efficiencies (as high as 70 per cent have been observed). Since it is a direct conversion process and does not involve a thermal process.
2. Fuel cells can be installed near the use point, thus reducing electrical transmission requirements and accompanying losses. Consequently considerably higher efficiencies are possible.
3. They have few mechanical components; hence, they operate fairly, quietly and require little attention and less maintenance.
4. Atmospheric pollution is less, if the primary energy source is hydrogen, the only waste product is water; if the source is a hydrocarbon, carbondioxide is also produced. Nitrogen oxides, such as a

company combustion of fossil fuels in the air, are not formed in the fuel cells. Some heat is generated by a fuel cell, but it can be dissipated to the atmosphere or possibly used locally.

5. There is no requirement for large volumes of cooling water such as are necessary to condense exhaust steam from a turbine in a conventional power plant.
6. As fuel cells do not make noise, they can be readily accepted in residential areas.
7. The fuel cell takes little time to go into operation.
8. The space requirements for fuel cell power plant is considerably less as comapred to conventional power plants.

Ans. (b) Thermionic Conversion :

Principle and Working of Thermionic Generator : An other form of direct conversion of heat energy to electrical energy has been achieved in the thermionic converter. It utilizes the thermionic emission effect, that is, the emission of electrons from heated metal (and some oxide) surfaces. The energy required to extract an electron from the metal is an important parameter, known as the work function of the metal. Typical values are of the order of a few electron volts. The value of the work function varies with the nature of the metal and its surface condition. In principle, a thermionic converter consists of two metals (or electrodes) with different work functions sealed into an evacuated vessel. The electrodes with the large work function is a maintained at a higher temperature than the one with the smaller work-function.

System consists of two electrodes held in a container filled with ionized cesium vapour. Heating one electrode, electrons are emitted, that travel to the opposite, colder electrode. The hotter electrode (or emitter) emits electrons (i.e. negative charges and so acquires a positive charge. Whereas the colder electrode (or collector) collects, electrons and become negatively charged. A voltage (or electromotive force) thus develops between the two electrodes and a direct electric current will flow in an external circuit (or load) connecting them Fig. The voltage, which may be 1 volt (or so), is determined primarily by the difference in the work function of the electrode materials.

The emission of electrons from the hotter electrode is inhibited by a space charge resulting from the accumulation of electrons in its vicinity. To reduce the space charge, as mentioned, small quantity of cesium metal is introduced into the evacuated vessel containing the electrodes.

Thermionic power generation is the form of heat engine as principle. It generate power as long as heat is supplied to the emission and a temperature different is maintained between it and the collector.