B. E.

Eighth Semester Examination, May-2007

POWER PLANT ENGINEERING

Note : Attempt any five questions.

Q. 1. (a) Draw a pumped storage hydro-electric power plant. Discuss the functions of each components of the plant.

Ans. Pumped Storage Plants :

General Description :

A pumped storage plant is a special type of plant meant to supply peak loads. During peak load period, water is drawn from he head water pond through the penstock and generates power for supplying the peak load. During the off-peak period, the same water is pumped back from the tail water pond to the head water pond so that this water may be used to generate energy during the next peak load period. Thus, the same water is used again and again and extra water is needed only to take care of evaporation and seepage. Generally the pumping of water from the tail water pond to the head water pond is done at night when loads are low. The plant generates energy for supplying peak loads during day time. The off peak pumping maintains the firm capacity of the pumped storage plant. The reservoir capacity should be such that the plant can supply peak load for 4 to 11 hours. A general arrangement of pumped storage plant is shown in fig.

The earlier pumped storage installations used a separate pump for pumping the water back into the head water pond. A recent development is a reversible turbine pump. During peak loads, the turbine drives the alternator and the plant generates electrical energy. During low loads, the alternator runs as a motor and drives the turbine which now works as a pump for pumping the water into the head water pond. This arrangement reduces the capital cost of the plant. The power for driving the motor is taken from the system.

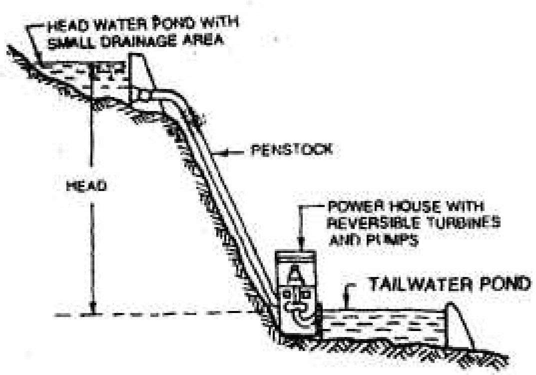


Fig. Pumped storage hydro electric plant

Q. 1. (b) Write advantages, disadvantages and applications of hydro-electric power plant.

Ans. Advantages of Hydro-Electric Plants :

Hydro-electric plants offer many distinct advantages over other means of power generation. These advantages can be summarised as under :

1. The useful life of a hydro-electric plant is around 50 years as compared to around 25-30 years for a steam station.
2. The hydro plants do not require any fuel. Their operating costs are, therefore, low. Since no fuel is required, there are no charges and problems of handling and storage of field and disposal of ash.
3. There are no standby losses in hydro plants. They can be run up and synchronised in a few minutes. The load can be adjusted rapidly.
4. Hydro plants are more robust as compared to steam plants.
5. The maintenance cost of hydro plants is very low as compared to that of steam and nuclear plants.
6. Efficiency of hydro plants does not reduce with age. On the other hand efficiency of steam plants decreases with age.
7. Generation of electric energy through hydro plants leads to conservation of coal and other fuels.
8. The operation of thermal plants is totally dependent on efficient and quick transport of coal. Transport bottle-necks are likely to render thermal plants idle for long periods. Hydro plants are free from such bottle-necks.
9. The operating personnel required for hydro plants are smaller in number as compared to those required for other plants.
10. Hydro projects are generally multipurpose projects. In addition to electric power generation, they are also useful for irrigation, flood control, navigation etc.
11. Hydro plants are free from air pollution due to smoke and exhaust gases.
12. Hydro plants are located in remote areas where land costs are low.

Disadvantages of Hydro-Electric Plants :

1. Due to high cost of civil engineering works, the capital cost per kW of hydro plants is considerably higher than that of steam plants.
2. Hydro power generation is dependent on availability of water. In a dry year, the power generation is very small.
3. The firm capacity of hydro plants is low and needs to be backed up by steam plants.
4. Since hydro plants entail huge civil engineering works, they take a considerably long time for completion.
5. Hydro plant reservoir submerges huge areas, uproots large population and creates social and other problems.

Q. 1. (c) Define run-off. How is it measured. List the factors. Which affect run off.

Ans. Run-Off : Only a small part of rainfall can be used for power generation. A significant part of rain water evaporates, another part seeps into soil and forms the underground storage and some portion is taken up by the vegetation. The remaining water flows on the ground surface of the catchment area to form the stream and is known as run-off. Investigations of run-off form the first phase in the planning of a hydro-project. The factors affecting run-off are—rainfall pattern, geology of the area, shape and size of catchment area, the topography and nature of soil in the catchment area, amount of vegetation and weather conditions in the catchment area.

Q. 2. (a) Draw a line diagram of hydraulic ash handling system for modern high capacity plants. Explain its working.

Ans. Ash handling system :

Boilers burning pulverized coal (PC) have dry bottom furnaces. The large ash particles are collected under the furnace in a water-filled ash hopper. Fly ash is collected in dust collector with either an electrostatic precipitator or a bag house. A PC boiler generates approximately 80% fly ash and 20% bottom ash. Ash must be collected and transported from various points of the plants as shown in fig. Pyrites, which are the rejects from the pulverizers are disposed with the bottom ash system. Three major factors should be considered for ash disposal systems.

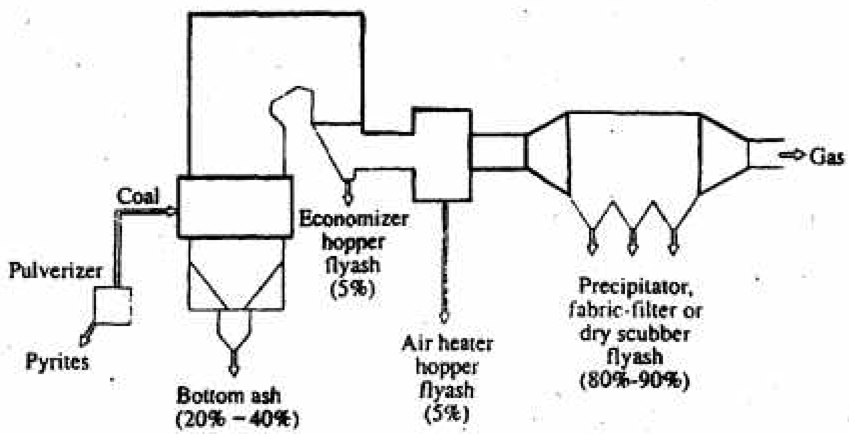


Fig. Ash collection and transportation

1. Plant site
2. Fuel source
3. Environmental regulation

Needs for water and land are important considerations for many ash handling systems. Ash quantities to be disposed depend on the kind of field source. Ash storage and disposal sites are guided by environmental regulations.

The sluice conveyor system (Fig. a) is most widely used for bottom ash handling, while the hydraulic vacuum conveyor (Fig. b) is the most frequently used for fly ash systems.

Bottom ash and slag may be used as filling material for road construction. Fly ash can partly replace cement for making concrete. Bricks can be made with fly ash. These are durable and strong.

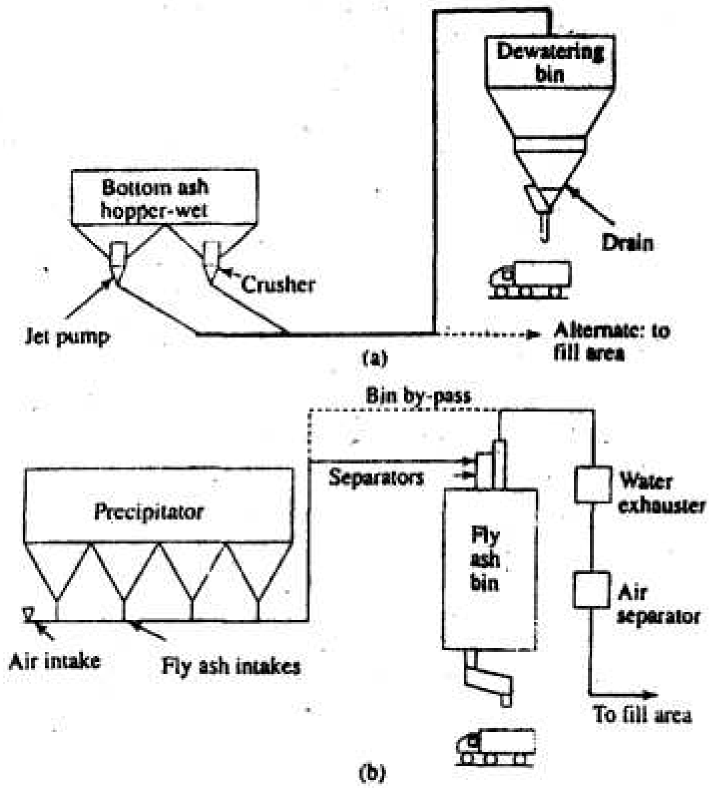


Fig. (a) Bottom ash sluice conveyor, (b) Fly ash hydraulic vacuum conveyor

Q. 2. (b) Draw a neat line diagram of implant coal handling system and explain the working with neat diagram of equipments used at different stages.

Ans. In small boilers, the grate is stationary and coal is fed manually by shovels. But for more uniform operating condition, higher burning rate and greater efficiency, moving grates or stokers are employed. Stokers may be of the following types :

(a) Travelling grate stoker

(b) Chain grate stoker

(c) Spreader stoker

(d) Vibrating grate stoker

(e) Underfeed stoker

(a) Travelling grate stoker : The grate surface is made up of a series of cast-iron bars joined together by links to form an endless belt running over two sets of sprocket wheels with a surface as wide as needed (Fig.). A coal gate at the rear of the coal hopper regulates the depth of the fuel bed. The gate can be raised or lowered as needed. Simultaneous adjustment of grate speed, fuel bed thickness and air flow controls the burning rate sot hat nothing but ash remains on the grate by the time it reaches the furnace rear. The ash falls into the ash pit as the grate turns on the rear sprocket to make the return trip.

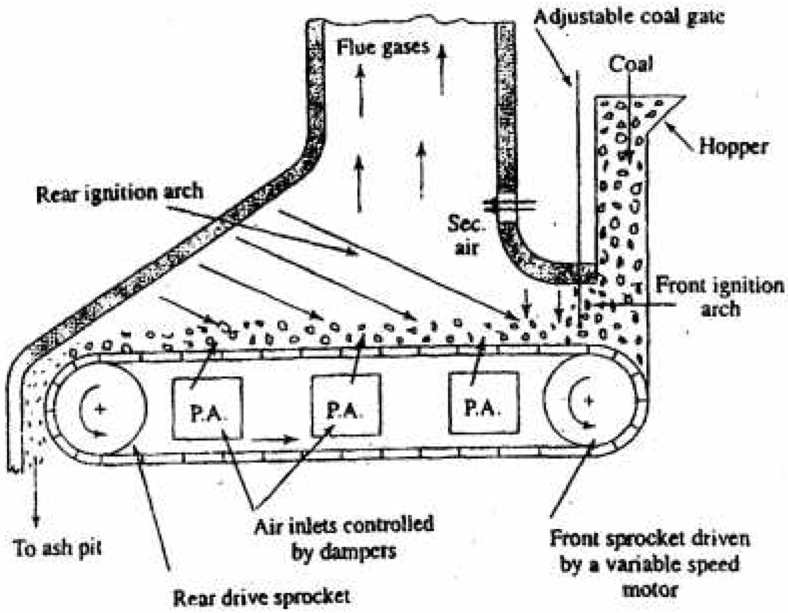
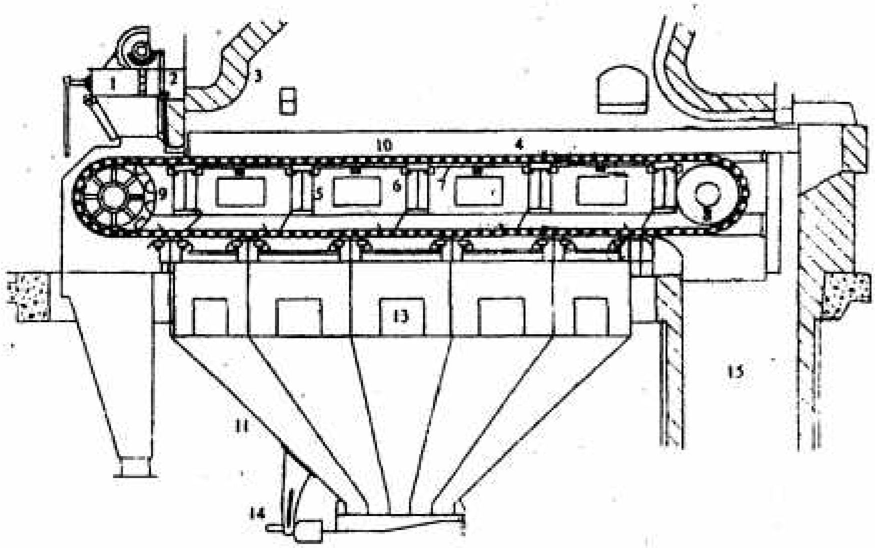


Fig. (a) Travelling grate stoker moving like an endless belt carrying the fuel bed from right to the left

As the raw or green coal on the grate enters the furnace, the surface coal gets ignited from heat of the furnace flame and from radiant heat rays reflected by the ignition arch. The field bed becomes thinner toward the furnace rear as the combustible matter burns off. Undergrate air pressures are varied by dampers from front to rear of the stoker to admit gradually reduced quantity of primary air fed by the FD fan. The secondary air aids in mixing the gases and supplies oxygen to complete combustion.



1. Hopper	**5. Cross-girders**	**9. Sprockets**	**13. Dampers**
2. Coal gate	**6. Caps**	**10. Water-wall boxes**	**14. Hopper gate**
3. Front arch	**7. Skid bars**	**11. Hoppers**	**15. Ash-pit**
4. Chain grate	**8. Rear drum**	**12. Drag seals**	

Fig. (b) A chain grate stoker

Chain grate stoker : It is similar to the travelling grate stoker except that it is made up of a series of CI links connected by bars or pins to form an endless chain, the principle of its operation being the same.

Overfeed stokers are suited for industrial power plants having steady demand. The grate heat release rate should be limited to a maximum of $1340\, kW/m^2$ of active grate area. A relatively wide range of coals can be burned on overfeed stokers, the size varying from 19 to 38 mm with the amount of fines limited to 50% passing through a 6 mm screen. Non-caking or free-burning coal is preferred. Coal having more than 20% ash is difficult to burn efficiently, incurring considerable unburnt carbon loss.

Spreader stoker :

Coal from the hopper is fed by a rotating feeder, a drum fitted with short blades on its surface, to the spreader or distributor below, which projects the coal particles in a continuous stream on to the grate holding an ignited fuel bed (Fig.). The finer particles burn in suspension and the coarser particles are consumed on the grate. The speed of the feeder varies directly with the steam output of the boiler.

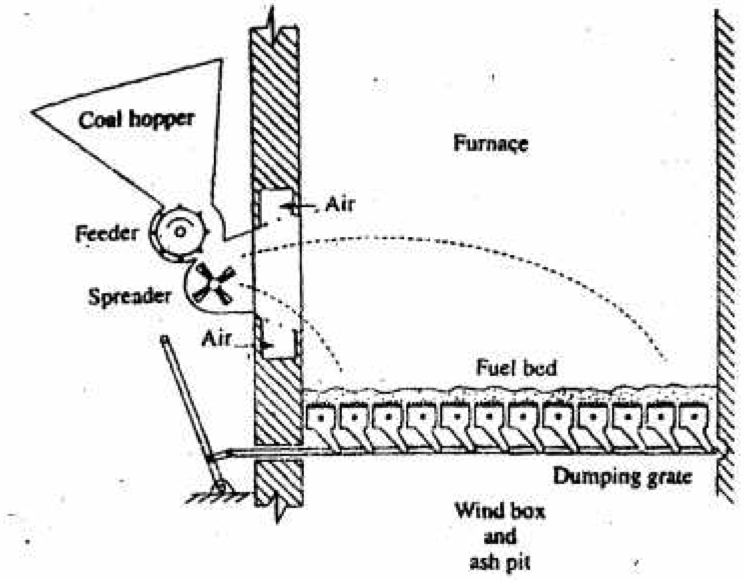


Fig. Spreader stoker hurling coal particles into furnace

Secondary or overfire air promotes turbulence and completes combustion. High capacity boiler may have a travelling grate in addition to the spreader.

The grate consists of CI bars. Link underneath the grate connect all the bars to a lever. Moving the lever back and forth makes the bars rock about their pivots, which makes the ash fall through to the ash pit below.

The solid fuels burned on spreader stokers include bituminous coal, subbituminous coal, lignite, wood waste from the forest products industry, bagasse from the sugar cane industry, peat from peat bogs, peanut shells, hydrocarbon from agricultural wastes and refuse-derived fuels (RDF) of municipal solid waste.

It is necessary to size the fuel properly for spreader stokers. Coal should have 95% less than 32 mm. Waste fuels can have top sizes up to 102mm. Spreader stokers can be applied to a wide range of boiler sizes which can go up to 155MW for coal and 264 MW for certain waste fuels with steaming rates of 50 kg/s and 75 kg/s respectively.

Vibrating Grate Stoker : The stoker shakes the field bed intermittently, the frequency and amplitude of vibration depending on boiler load. The fuel bed is inclined so that the fuel moves towards the rear of the boiler by gravity with the progress of combustion and then falls into the ash pit. The grate is water-cooled to prevent slagging.

Q. 3. (a) Describe with neat sketches the working of constant pressure. Open cycle gas turbine plant. Derive an expression for the efficiency of the cycle on which the plant works.

Ans. **Principle of operation of gas turbine plants :** A gas turbine plant consists of a compressor, combustion chamber, gas turbine and alternator. The compressor takes in atmospheric air, congresses it and supplies the pressurised air to the combustion chamber. Fuel is injected into the combustion chamber and burnt in the stream of air supplied by the compressor. The combustion raises the temperature of air and increases its volume under constant pressure. The hot pressurised gas expands in the turbine, produces mechanical power and turns the rotor of the turbine. Both the compressor and the alternator are coupled to the turbine shaft. Due to the high temperature of the products of combustion, the turbine output exceeds the input to the compressor. The turbine, therefore, drives the compressor and the surplus power drives the alternator. The products of combustion, after expansion through the turbine, are finally exhausted to the atmosphere. Such plants are known as open cycle gas turbine plants.

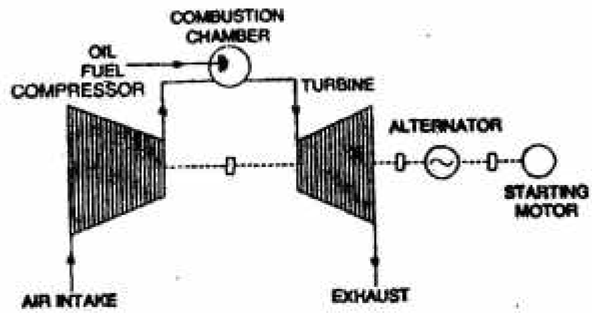


Fig. Open cycle gas turbine plant

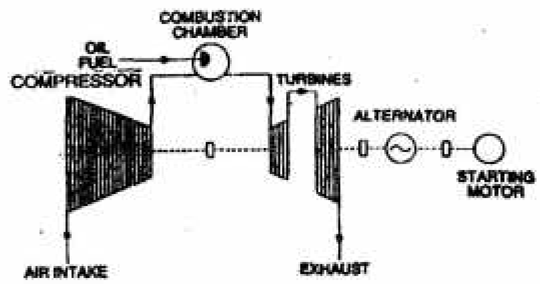


Fig. Open cycle gas turbine with LP and HP turbine

The gas turbine has to drive the compressor as well as the alternator. Some times two turbines are used for these two purpose. A high pressure turbine drives the compressor and a low pressure turbine drives the alternator (Fig.). This arrangement has the advantage that the speed of the power turbine (which drives the alternator) can be kept constant at synchronous speed while the speed of the turbine driving the compressor can be varied depending on the required output.

The pressure ratio in gas turbine plants is around 5 : 1. The compressor compresses the air to about 5 times the atmospheric pressure. The pressure at exhaust is nearly the atmospheric pressure. In the combustion chamber the temperature is around 1600°C. The hot gas at this high temperature cannot be allowed to enter the turbine directly because of a possible damage to the turbine blades. A part of the air (from compressor) is delivered directly to the turbine, ahead of the hot gas from combustion chamber, so that the hot gas may be cooled to a safe temperature of around 800°C. The temperature at exhaust is around 500°C.

The analysis of Brayton cycle has been given the salient features of the cycle are being given below. This is in with reference to fig.

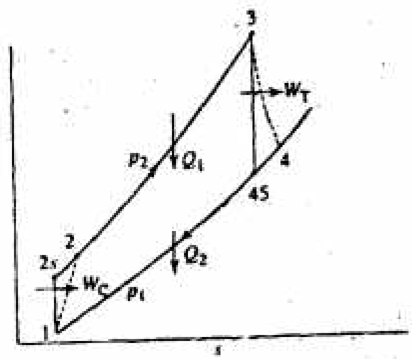


Fig. Brayton cycle

Heat supplied, $Q_1 = m_a c_p (T_3 - T_2)$

Heat rejected, $Q_2 = m_a c_p (T_4 - T_1)$

$$T_{2s} / T_1 = T_3 / T_{4s} = [p_2 / p_1]^{(\gamma-1)/\gamma} = r_p^{(\gamma-1)/\gamma}$$

Where m_a = mass of air and r_p is the pressure ratio, p_2 / p_1.

The compressor efficiency, $\eta_c = (T_{2s} - T_1)/(T_2 - T_1)$ and the turbine isentropic efficiency,

$$\eta_T = (T_3 - T_4)/(T_3 - T_{4s}).$$

For the ideal cycle $1 - 2s - 3 - 4s - 1$.

$$\eta_{cycle} = 1 - \frac{1}{r_p^{(\gamma-1)/\gamma}} = 1 - \frac{T_1}{T_{4s}} r_p(\gamma - 1)/\gamma.$$

Q. 3. (b) Explain the working of Repowering systems using steam turbine only and boiler only. Discuss the relative merits and demerits.

Ans. Repowering : The conversion of older power plants into combined cycle units—known as repowering—is one interesting way to continue using at least parts of older steam power plants which have become uneconomical. In this procedure, the boilers are normally replaced with high output modern gas turbines and waste heat boilers. Steam turbines of older power stations with relatively low steam inlet pressure and temperature are well adapted for combined cycle operation. These 20-25 years old steam turbines still have a considerable service lift left, but their boilers are often ready for scrapping.

Figures show the example of a conventional steam turbine plant, before and after such a conversion (r ,owering). It was possible to reuse the following components :

1. Building
2. Steam turbine and generator
3. Condenser
4. Main cooling system
5. Main transformer
6. High voltage equipment.

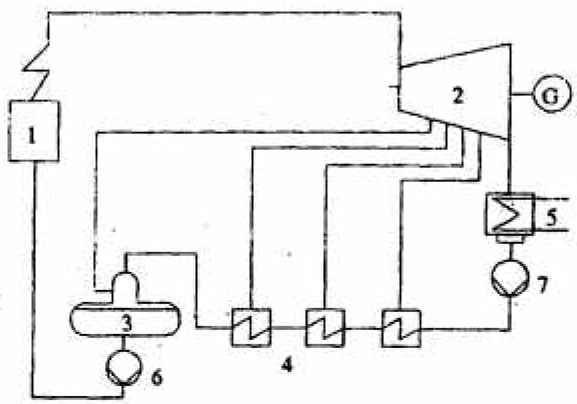


Fig. Steam power plant before conversion to a combined cycle plant

1. Steam generator
2. Steam turbine
3. Feed water tank, deaerator
4. Low pressure preheater
5. Condenser
6. Feed pump
7. Condensate pump

The following components were dismantled :

1. Boiler
2. Piping and fittings
3. Feedwater heaters
4. Condensate pumps
5. Boiler feed pumps
6. Control equipment

The list may vary from one case to another. Feed water preheating system for a CC plant is different in design from that for a conventional steam power plant because of thermodynamic considerations. In most cases, no extraction points are needed any more on the steam turbine (Fig.), which increases the power output from the turbine.

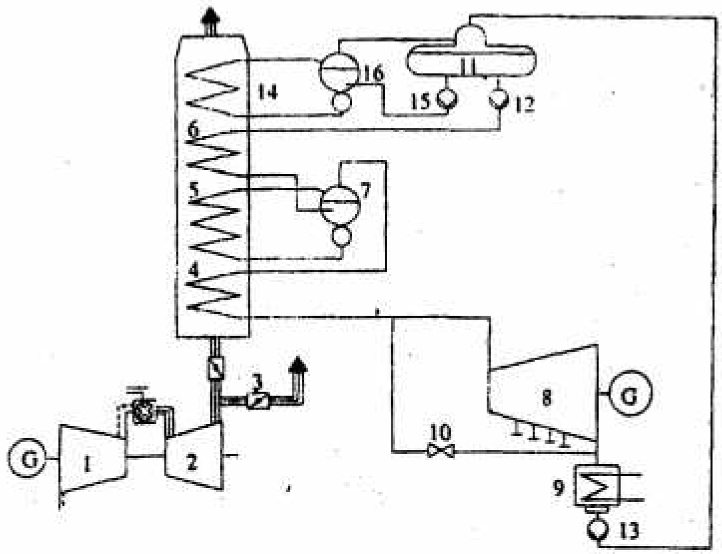


Fig. Combined-cycle plant with existing steam turbine

1. Gas Turbine
2. Compressor
3. Flue gas bypass
4. Superheater
5. Evaporator
6. Economizer
7. Drum
8. Steam turbine
9. Condenser
10. Steam bypass
11. Feedwater tank/deaerator
12. HP Feedwater pump
13. Condensate pump
14. LP evaporator
15. LP feedwater pump
16. LP drum

Q. 4. (a) What is a nuclear reactor? How are nuclear reactors classified?

Ans. Reactor Classification : Reactors can be classified in many ways—type of fission, fuel used, moderator material, distribution of fuel and moderator, purpose for which it is being used etc. Some of the possible ways in which classifications can be done are listed in table. The number of the possible combinations can be very large. However, only a few of the possible combinations are appropriate and practicable.

Table

Reactor classification

1. Purpose :

Research and development reactors : For testing new reactor designs and research.

Production : For converting fertile materials into fissile materials.

Power : For electric energy generation.

2. **Type of Fission :**

   Slow : Neutron kinetic energy less than 0.1eV.

   Intermediate : Neutron kinetic energy between 0.1eV and 0.1 meV.

   Fast : Neutron kinetic energy 1 MeV or so.

3. **Fuel used :**

   Natural uranium

   Enriched uranium

   Plutonium

4. **State of fuel :**

   Solid

   Liquid

5. **Fuel cycle :**

   Burner (Thermal) : Designed for producing heat only without any recovery of converted fertile material.

   Converter : Converts fertile material into a fissile material different from the one initially fed into the reactor, r is less than 1.

   Breeder : Converts fertile material into fissile material, which is the same as that initially fed into the reactor, r is more than 1.

6. **Arrangement of fissile and fertile material :**

   One region : Fissile and fertile material mixed.

   Two region : Fissile and fertile material separate.

7. **Arrangement of fuel and moderator :**

   Homogeneous : Fuel and moderator mixed.

   Heterogeneous : Fuel in discrete lumps in moderator.

8. **Moderator Material :**

   Heavy water

   Graphite

   Ordinary water

   Beryllium

   Organic

9. **Cooling System :**

   Direct : The liquid fuel circulated from the reactor to heat exchanger where steam is generated.

   Indirect : Coolant passed through the reactor and then through the heat exchanger for steam generation.

10. Coolant Used :

Gas, water, heavy water, liquid metal.

Q. 4. (b) What is a moderator? Name common moderators and discuss their advantages and limitation.

Ans. The purpose of moderator material is to slow down the fast neutrons. The fast neutrons collide with the nuclei of moderator material, loose their energy and get slowed down. The properties required for a good moderator material are :

1. It must not react with neutrons because neutrons captured in nuclear reactions are lost to the fission process and this leads to an inefficient reactor.
2. It should be inexpensive.
3. It should be chemically inert and should not corrode or erode.
4. It should not undergo harmful physical or chemical changes when bombarded by neutrons.
5. The average neutron-nucleus collision should lead to large neutron energy loss.

Only the elements at the top of periodic table or compounds with small molecular weight are suitable as moderator materials.

Out of the elements having small atomic mass, gases are unsuitable on account of their low density and the consequent small number of collisions. Helium and Beryllium are costly. Boron and lithium have high neutron absorption tendency. Heavy water is an ideal moderator material and is used in many reactors in spite of its high cost. Carbon is cheap and satisfactory and can be readily obtained in desired purity. It is used in many reactors.

The moderator and the fuel can either be intimately mixed or the fuel may be scattered throughout the moderator in discrete lumps. These two arrangements are known as homogenous and heterogenous arrangements respectively.

Q. 4. (c) Explain the working with neat diagram of a reactor in which moderator is not used.

Ans. A fast breeder reactor is different from the thermal reactors. A thermal reactor uses fissile nuclear fuel and produces heat. A fast breeder reactor produces heat and at the same time converts fertile material into fissile material. It is possible to make a fast reactor produce more fissile material than it consumes.

The advantage of using high energy neutrons, in a reactor, has been known since early days of nuclear science. In a fast breeder reactor the average neutron yield of a fission caused by a fast neutron is greater than in thermal reactors. The absorption cross-sections are low and conversion factor is high. $PuO_2 - UO_2$ is used as fuel, liquid metal as fuel and stainless steel as canning material. Evidently, no moderator is needed in this reactor.

The central portion of this reactor is a stainless steel pot in which a core of fissile material is kept. This core of fissile material is surrounded by a blanket of uranium. Two heat exchangers are used. The reactor core is cooled by liquid sodium/potassium. In the secondary heat exchanger the coolant is again liquid sodium/potassium which transfers heat to feed water. A neutron shield (made of graphite) separates the reactor core and primary heat exchanger.

The core of a fast reactor requires high enrichment (above 10% of fissile material). To reduce the effect of cost of fuel, it is necessary to use high ratings. The core consists of 30% fuel $(PuO_2 - UO_2)$, 50% coolant and 20% canning and structural material (by volume).

The development of fast reactor for power generation is mainly because it uses fuel very efficiently and in addition to producing power, it produces Pu^{239} from U^{238}. However, the possibility of core being over-heated and destroyed has to be taken into account. Thee heat transfer and control problems of these reactors need special attention. The primary heat exchanger, situated inside the concrete shield is a sodium-sodium heat exchanger. In the secondary heat exchanger, situated outside the shield, sodium delivers heat energy to feed water of the boiler. Some proposed developments for this reactor design are :

1. Only one tank containing the core and uranium blanket, primary pumps and primary heat exchanger. Proper shielding of core and blanket to reduce irradiation of the pumps and primary heat exchanger.
2. Use of centrifugal pumps for both heat exchanger circuits.
3. Use of fuel in the form of mixed oxides either sintered into pellets or vibro compacted.

Q. 5. (a) An electrical system experiences linear changes in load such that its daily load curve is defined as follows :

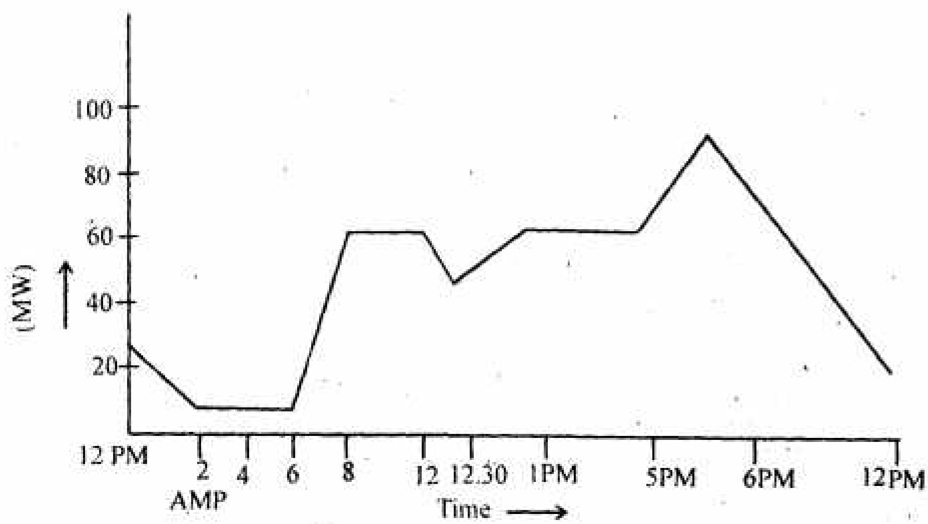
Time	**12 PM**	**2 AM**	**6 AM**	**8 AM**	**12 AM**	**12.30 PM**	**1 PM**	**5 PM**	**6 PM**	**12 PM**
Load (MW)	**24**	**12**	**12**	**60**	**60**	**48**	**60**	**60**	**84**	**24**

(i) Plot the chronological curve and load duration curve of the system.

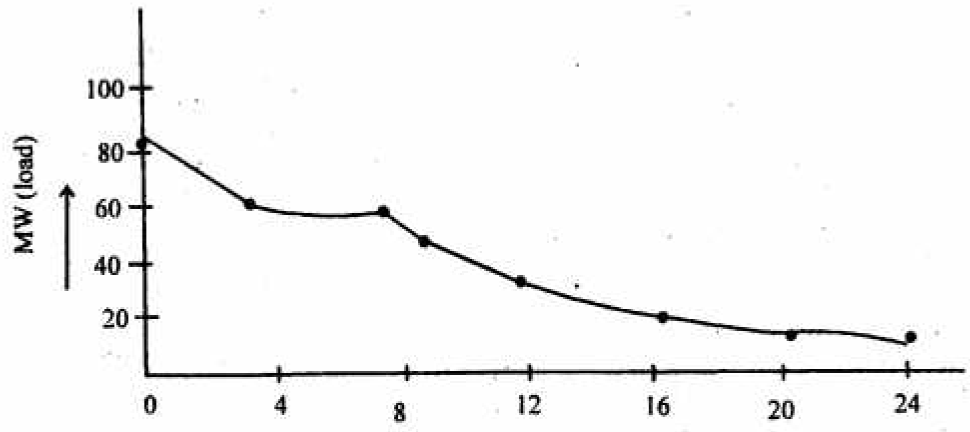
(ii) Find the load factor.

(iii) What is its utilization factor of the plant serving this load if its capacity is 120 MW.

Ans.



Chronological load curve



Load duration curve

Load Factor : The energy produced by the plant in 24 hours is,

$$= 2 \times 12 + 4 \times 12 + 2 \times 60 + 4 \times 60 + 0.5 \times 48 + 0.5 \times 60 + 4 \times 60$$
$$+ 1 \times 84 + 6 \times 24$$
$$= 24 + 48 + 120 + 240 + 24 + 30 + 240 + 84 + 144$$
$$= 954 \text{ mwh}$$

Load factor $= \dfrac{954}{84 \times 24} = 0.4732 = 47.32\%$

Utilization Factor :

Capacity $= 120$ MW

Utilization factor $= \dfrac{\text{Max. load}}{\text{Capacity}}$

$$= \frac{84}{120} = 0.7.$$

Q. 5. (b) The peak load on a 50 MW power station is 39 MW. It supplies power through four transformers whose connected loads are 17, 12, 9 and 10 MW. The maximum demands on these transformers are 15, 10, 8 and 9 MW respectively. If annual load factor is 50% and the plant is operating for 65% of the period in a year. Find :

(i) Average load on the station,

(ii) Energy supplied per year,

/

(iii) Demand factor,

(iv) Diversity factor and

(v) Power station use factor.

Ans. Power station rated capacity

= 50 MW

Maximum demand on the power station

= 39 MW

Sum of connected loads = 17 + 12 + 9 + 10 = 48 MW

Sum of maximum demands on transformers

$= 15 + 10 + 8 + 9 = 42\,MW$

Annual load factor = 50% or 0.5

Plant operating period $= 0.65 \times 8760 = 5694$ hours

(i) Average load on station $= M_D \times L_F = 39 \times 0.5 = 19.5\,MW$

(ii) Energy supplied per year = Average load × 8760 = 19.5 × 8760

= 170820 MWH

(iii) Demand factor $= \dfrac{\text{Maximum demand}}{\text{Sum of connected loads}} = \dfrac{39}{48}$

= 0.8125 or 81.25%

(iv) Diversity factor $= \dfrac{\text{Sum of Maximum demand}}{\text{Maximum demand}} = \dfrac{42}{39}$

= 1.077

(v) Use factor $= \dfrac{\text{Energy generated per year}}{\text{Rated capacity} \times \text{number of operating hours}}$

$= \dfrac{170820 \times 10^3}{50 \times 10^3 \times 5694}$

$= 0.6$ or 60%.

Q. 6. (a) What are the different sources of geothermal energy? Discuss any two systems used for generating the power using geothermal energy.

Ans. Geothermal Energy :

General : Geothermal energy means the heat energy of the interior of earth. Geothermal energy can be used for generation of electricity by extracting this heat convectionally from the rocks by natural or forced circulation of water and using this steam for running the turbine. The development of geothermal energy programmes has been rather restricted due to the fact that the low enthalpy water cannot be profitably used for power generation. However this energy can be profitably used for agricultural or domestic heating. Nevertheless the plant at Larderello in Italy has been generating geothermal electricity since 1904. At present the installed capacity of geothermal plants in Italy is more than 500 MW. Geothermal plants are also operating in New Zealand, USA, Japan, Mexico and some other countries.

The Geysers geothermal project, north of San Francisco (USA), was started with a 12 MW unit in 1960,. By this time units having a total generating capacity of around 4000 MW have been installed and put in operation in USA. Active exploration programmes have been undertaken in Chile, Ethiopia, Kenya, Yugoslavia, Hungary, Japan, USSR and other countries.

Earth's Energy : Earth is in a state of thermal equilibrium. Energy received from sun is lost at night. The small amount of energy generated by the decay of unstable isotopes of Uranium, Thorium etc. is dissipated from earth's interior to oceans and atmosphere.

Heat generation within earth in around 2700 GW. The temperature difference within the earth depends on :

1. The thermal properties of earth's interior and their radial and lateral variation.
2. Movements of fluids or solid rock materials occurring at rates of more than a few millimeters per year.

A potential geothermal source region should have high thermal gradient which is defined as :

$$\text{Thermal gradient} = \frac{\text{Heat flux}}{\text{Thermal Conductivity}}$$

Thermal gradient will be high if either heat flux is high or thermal conductivity is low.

The heat energy in earth's interior is due to radioactivity. Regions of higher radioactivity have higher heat flux and are potential geothermal sites.

The surface of the earth consists of about one dozen tectonic plates e.g. American plate, African plate, Arabian plate, Indian plate, Philippine plate, Pacific plate etc. Each of these plates has thickness around 100 km and thousands of kilo metres of area. Earth's interior is unable to lose heat, by conduction, as rapidly as it is generated by radioactivity. This leads to convective instabilities which means that these plates are continuously in motion with respect to each other. A variety of processes along the margins of the plates lead to partial melting at depths between 15 to 200 kms. The molten masses penetrate the surrounding rocks and rise towards earth at rates varying from a few cms per day to a few cms per year thus resulting in volcanic activity. The molten masses which do not reach earth's surface come to rest in the middle or upper part of earth's crust at depths less than 20 km. These liquid magmas may have temperatures around 1000°C. The crystallisation of these liquid magmas produces intrusive igneous bodies. The cooling and crystallisation of igneous bodies gives rise to local heat flux. This heat flux constitutes the geothermal energy which may be used for a variety of purposes including electricity generation. These local heat fluxes continue for thousands of years and form an inexhaustible source of energy. The majority of active geothermal areas tend to concentrate around the margins of major lithospheric plates.

Heat Extraction : The extraction of heat from the earth's interior needs a natural or artificial heat exchanger. In many geothermal areas natural sub-surface water circulating systems bring out this heat giving rise to hot springs.

A schematic representation of geothermal system is shown in fig. At a depth of 5 kilometres or so lies an impermeable magma. Above the magma are the impermeable crystalline rocks which are overlain by localised pockets of permeable rocks. One such localised pocket is shown in this figure. The localised pockets are bounded by fracture zones of faults along which some relative motion of rocks has occurred.

Water circulates along fault lines. As it goes down and moves in the earth's interior (path ABCDE) it is heated by the permeable layer which is in turn heated by conduction of heat from the magma. The hot water comes out through another fault and forms a hot spring.

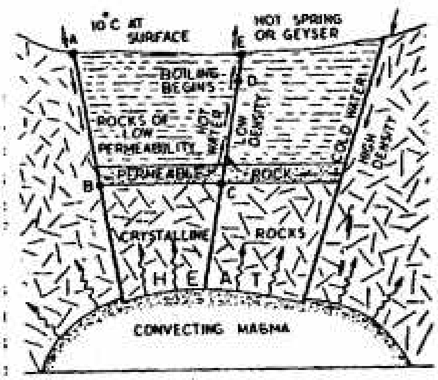


Fig. Schematic representation of a geothermal system

Depending on the temperature and depth of the permeable rock, the natural hydro thermal systems can be divided into three categories.

1. Dry steam system : The temperature of the permeable rocks is very high. The whole of water is converted into steam which gets superheated by the time it comes out of the surface. The Larderello (Italy) and Geysers (California) fields are dry steam systems.

2. Wet steam system : The temperature of permeably rock is not very high. By the time water comes out, only a part of it gets converted to steam. Therefore the eruption gives a water-steam mixture.

3. Hot water system : The temperature of the permeable rock is rather low. The surface eruption provides hot water.

For proper exploitation of geothermal energy for electricity generation, extensive surveys by geological and geophysical methods are necessary. When the areas have been located after these surveys, it is necessary to drill a number of holes at carefully selected sites. The cost of drilling the wells increases with the depth. The wells of Geysers field (California) are 2km deep, 51 cm diameter at top and 22 cm diameter at bottom.

The dry steam of the high temperature dry steam systems can be directly taken to the steam turbine and used for generating electricity.

The set steam fields in the world have been estimated to be about twenty times more abundant than the dry steam fields. The wet systems yield about 20 per cent (by weight) steam and the remaining quantity of hot water. It is necessary to separate the steam and water at the surface before the steam can be used to drive the turbine. Generally, in such systems, the steam is used for electricity generation and the hot water for other miscellaneous purposes. In New Zealand the hot water of a wet steam field is being used for industrial processes by a paper mill. In Iceland such water is used for industrial purposes and house hold heating. Similar is the case in Japan, USSR and Hungary. In chile a project is being developed for using the steam, from a wet steam geothermal field, for electricity generation and distillation of the hot water to yield fresh water and valuable minerals.

The utilisation of low temperature hot water fields has started receiving attention only recently. Such systems generally yield large quantities of water at temperatures ranging from 50 to 80°C. Such hot waters are used for domestic heating and industrial purposes and can go a long way in saving fuel. Rough estimates indicate that proper utilisation of such systems can save hundreds of million tonnes of fuel every year in the world. This aspect of geothermal energy utilisation is likely to find more avenues in future.

Vapour turbine cycle : In recent past plants using a heat exchanger and vapour turbine cycle have been proposed for generation of electricity.

The geothermal hot water is used to heat a low boiling fluid (i.e. propane of freon). This fluid is expanded in a turbine which drives the generator. The fluid is condensed and reused to form a closed circuit system.

In a vapour turbine cycle system the low enthalpy geothermal water can also be profitably used. Though such systems are yet in development stages, one small freon based system has been in operation in USSR for the past more than one decade. Fig. shows a vapour turbine cycle system.

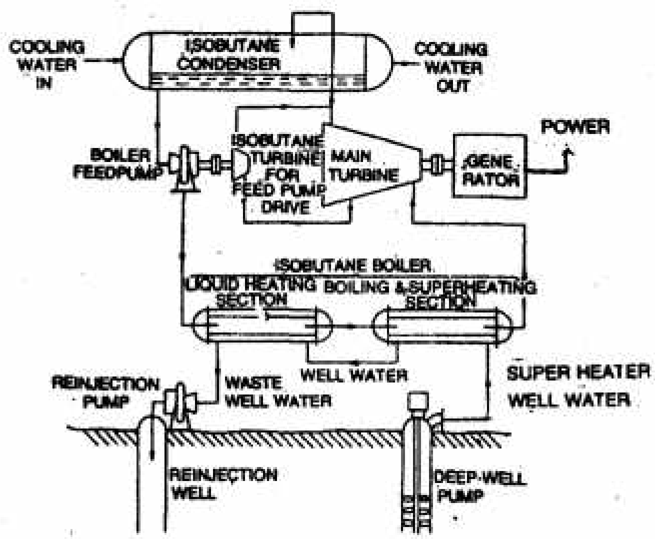


Fig. Vapour turbine cycle

Difficulties and Disadvantages :

The use of geothermal energy is beset with the following difficulties and disadvantages :

1. The geothermal water has been found to be highly corrosive and abrasive.

2. As more and more of heat extraction takes place the mean temperature of rocks is likely to fall. As such the capability of plant is likely to decrease over the years. However this aspect is governed wholly by local conditions. The Larderello plant has been operating for more than 90 years and at an increasing power output.

3. In low rain fall areas the sub-soil water depletion may occur. It may then be necessary to reinject water

into earth.

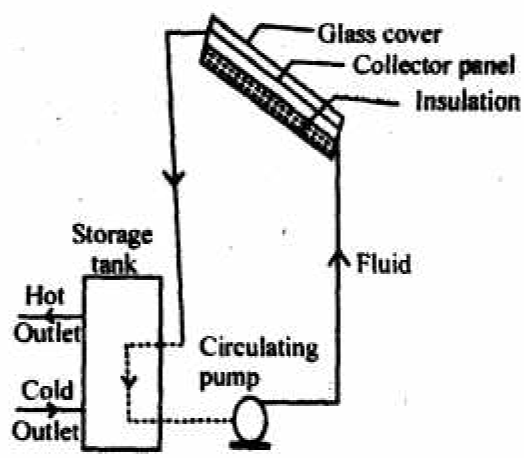
4. Transmission : In most of the case of geothermal power has to be utilised within a short distance from the site.

5. Environmental problems : The most serious environmental aspect is the disposal of high salinity water after its heat has been utilised. Dry steam plant are very noisy and emit hydrogen, nitrogen, ammonia and hydrogen sulphide. Some attempts have been made to extract salt from the saline water.

6. Seismic effects : If a balance between the rate of inflow and the rate of withdrawal of water is upset, the geothermal reservoirs would experience a change in porosity and fluid pressure with a danger of seismic effects. If underground nuclear explosions are done to increase the permeability of rocks, the seismic effects may become pronounced and dangerous.

Q. 6. (b) Explain the working of power generating systems illustrating the use of flat plate collector as a source of energy and R-113 as a working fluid of the system.

Ans. Solar radiation passes through the transparent cover and is absorbed by the collector plate. A fluid flowing in a passage in contact with the collector is heated and the heat from the fluid is extracted for use. The circulating pump keeps a continuous circulation of the fluid through the collector and the storage tank. In the storage tank, which is working as heat exchanger, the fluid heats water which is used for the desired purpose.



Flat plate collector

Q. 7. Discuss the following :

(a) Closed cycle MHD system

(b) Fuel Cell

(c) Thermo-electric power generation.

Ans. (a) Closed cycle MHD system : The closed cycle inert gas MHD system was conceived around 1965. It was thought that in this method all the advantages of the open cycle system would be retained and the main disadvantages of the open cycle system (viz. very high temperature requirements and a very chemically active flow) could be removed. As the name suggests, the working fluid, in a closed cycle, is circulated in a closed loop. The working fluid is helium or argon with cesium seeding.

The working fluid is a mixture of atomic gases, without rotational and vibrational modes, that interact readily with thermal electrons. Therefore it is possible in closed cycle systems to maintain the conduction electrons in the flow at a higher temperature than the bulk gas. Since electron density tends to be governed by electron temperature rather than gas temperature we can get substantially higher electron density and electrical conductivity than would exist at the same temperature in combustion gas flow.

The possibility of using a nuclear heat source with a closed cycle MHD system has also been investigated. However its feasibility has yet not been established.

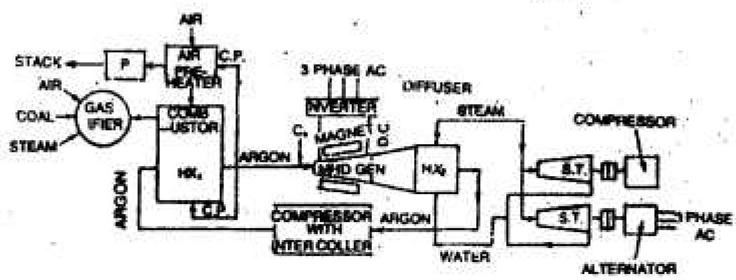


Fig. Closed cycle MHD system

(HX_1-heat exchanger 1, HX_2-heat exchanger 2, G-gas, C. P-combustion products, Cs-cesium injection, ST-steam turbine, MHD Gen.-MHD Generator, P-Removal of nitrogen and sulphur).

Fig. shows a closed cycle MHD system. The complete system has three distinct but interlocking loops. On the left is the external heating loop. Coal is gasified and the gas (having a high heat value of about 5.35 MJ/kg and at a temperature of about 520°C) is burnt in a combustor to produce heat. In the heat exchanger HX_1- this heat is transferred to argon, the working fluid of the MHD cycle. The combustion products after passing through the air preheater (to recover a part of the heat of combustion products) and purifiers (to remove harmful emissions) are discharged to atmosphere.

The loop in the centre is the MHD loop. The hot argon gas is seeded with cesium and passed through MHD generator. The d.c. power output of MHD generator is converted to a.c. by the inverter and is then fed into the grid.

The loop shown on the right hand side in fig. It is the steam loop for further recovering the heat of the working fluid and converting this heat into electrical energy. In the diffuser the working fluid is slowed down to a low subsonic speed. Then this fluid passes through the heat exchanger HX_2 where it imparts its heat to water which gets converted to steam. This steam is used partly for driving a turbine which runs the compressor and partly expanded in a turbine which drives an alternator. The output of the alternator is also fed to the grid. The working fluid goes back to the heat exchanger HX_1 after passing through compressor and intercooler.

A closed cycle system can provide more useful power conversion at lower temperatures (around 1900°K as compared to 2500°K for open cycle system). However its use is still a distant dream. The heat exchanger design is one of the difficulties because the heat exchanger works upto the highest temperature of the gas.

Moreover the working fluid must be kept absolutely pure. The electrical stability of the flow in the generator poses problems because the gas is subject to electric fields approaching breakdown conditions. General Electric Company (USA) and Westinghouse Electric Corporation (USA) have initiated extensive studies of MHD open and closed cycles.

(b) Fuel Cells :

Principle : A fuel cell is a device which directly converts chemically energy into electrical energy. The chemical energy is the free energy of the reactants.

In thermal generation the chemical energy of the fuel is converted to heat energy by burning the fuel. The heat energy is, then, converted into electrical energy. The efficiency of this conversion process is limited by the limitations of Carnot cycle. In fuel cells the chemical energy of the reactants is converted into electrical energy as an isothermal process. Thus heat is not involved in the conversion process and a high conversion efficiency is possible. Another reason for the interest in fuel cells is that their efficiency and cost per kilowatt of power are independent of the size (or rating) of he fuel cell. This advantage makes the prospects of fuel cells very attractive as portable power plants for spacecraft, locomotive etc. A fuel cell gives a few times more electrical energy per unit weight as compared to a turbo-generator or storage battery.

Hydrogen oxygen cell (Hydrox cell) : In this cell hydrogen and oxygen are used as the fuel and oxidant respectively, as these elements are most reactive with least complications. The electrolyte is Potassium Hydroxide (20% to 40% concentration) which has high electrical conductivity and is less corrosive than acids. Fig. shows the basic structure of a hydrox cell.

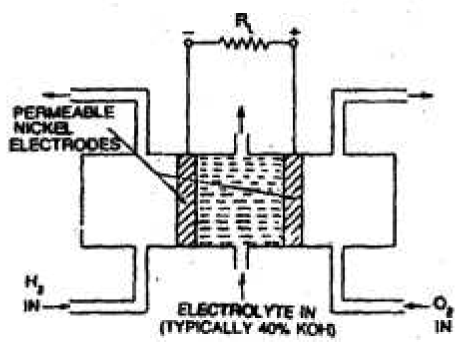


Fig. Hydrox cell

Two permeable nickel electrodes are immersed in the electrolyte. At one electrode, hydrogen is diffused through the permeable nickel in which is embedded a catalyst. The catalyst enables the hydrogen molecules to be absorbed on the electrode surface as hydrogen atoms. The hydrogen atoms react with hydroxyl ions in the electrolyte to form water which is the waste product of the cell. Thus the reaction at hydrogen electrode is,

$$H_2 \rightarrow 2H^+ + 2e^-$$

$$2H^+ + 2OH^- \rightarrow 2H_2O$$

At the other electrode oxygen diffuses through and is absorbed on the surface. Oxygen is reduced to

· hydroxyl ions which migrate to the hydrogen electrode

$$O_2 \longrightarrow 2O$$

$$O + H_2O + 2e^- \rightarrow 2HO^-$$

The action at the oxygen electrode is also aided by a catalyst. Thus the hydroxyl ions and electrons produced at one electrode are involved in the reaction at the other. The net overall reaction is

$$2H_2 + O_2 \longrightarrow 2H_2O$$

The reactants are stored outside the cell and the electrodes and he electrolyte are not consumed in the over process.

If the electrodes are on open circuit, negative charges accumulate at hydrogen electrode. These negative charges attract potassium ions K^+, of the electrolyte producing a double layer. The loss of electrons from the oxygen electrode results in a layer of positive charges which attract hydroxyl ions OH^-, from the electrolyte and form a double layer. These double layers build up until the potentials are so much that further reactions between the electrolyte and the fuel gases are inhibited. An open circuit voltage of 1.23 V at one atmospheric pressure and 25°C is developed.

If the circuit is closed through an external load resistance, the electrons flow from the hydrogen electrode, through the external circuit to the oxygen electrode and take part in the reaction at the oxygen electrode. This motion of electrons constitutes the load current. Thus electrical energy is obtained directly from chemical energy. The hydrogen electrode serves as cathode and the oxygen electrode as anode.

The Low-temperature cell and High-pressure cell are typical developments of the hydrox cell.

(c) Thermoelectric power generation : These power plants basically operates on ranline cycle coal is burnt in boiler which converts water into steam. The steam is expanded in a turbine, which produces mechanical power driving the alternator coupled to the turbine. The steam after expansion is prime mover is usually condensed in a condenser to be fed into the boiler again. In practice, however, a layer number of modifications and improvements have been made so as to affect economy and improve the thermal efficiency of the plant.

Q. 8. Write short notes on :

(a) Energy resources & their availability in India.

(b) Electrostatic precipitator.

(c) Tariffs methods of electrical energy.

Ans. (a) Energy resources & their availability in India : The main source of energy are the sun, wind, terrestrial heat, ocean tides and waves, water, fuels and radioactive substances. The last three sources are most dependable and are commonly used for generation of electricity :

(i) The sun : It is the primary source of energy. In our country conditions for utilization of solar energy are favourable since for nearly six months of the year.

(ii) The wind : The winds produced by the sun got sufficient energy which can be utilised in the wind mills to drive small generators. In our counter this source of generation will prove economical at a number of places.

(iii) Geothermal energy : The earth has a molten core. During volamic action the material that comes out from the bowls of earth to form volcanic eruptions also produces steam vents and hot springs. It is proposed to set up a cold storage and a power plant based on geothermal energy at Manikaran (HP). An experimental 5 MW plant is proposed in Pugga valley (Ladakh).

(iv) Ocean tides & waves : There is tremendous energy is oceantides and wave but it is very difficult harness this power for generation of electrical energy. In India the potential for tidal energy exists in gulf of kutch and in sunderbans of west bengal.

(b) Electrostatic precipitator : In 1905, Dr. F.G. Cotrtrell, Professor of Physical Chemistry at the University of California, conducted a series of laboratory experiments that resulted in the development of the first commercial electrostatic precipitator. It was an immediated success and the precipitation soon came to be widely used in power plants, smelters, steel plants, paper mills and many other industries.

The principal components of an electrostatic precipitator (ESP) are two sets of electrodes insulated from each other. The first set is composed of rows of electrically grounded vertical parallel plates, called the collection electrodes, between which the dust-laden gas flows. The second set of electrodes consists of wires, called the discharge or emitting electrodes that the centrally located between each pair of parallel plates (Fig.) The writes carry a unidirectional negatively charged high-voltage (between 20 and 100 kV) current from an external dc source. The applied high voltage generates a unidirectional, non-uniform electrical field whose magnitude is greatest near the discharge electrodes. When that voltage is high enough, a blue luminous glow, called a corona, is produced around them. Electrical forces in the corona accelerate the free electrons present in the gas so that they ionize the gas molecules, thus forming more electrons and positive gas ions. The new electrons create again more free electrons and ions, which result in a chain reaction.

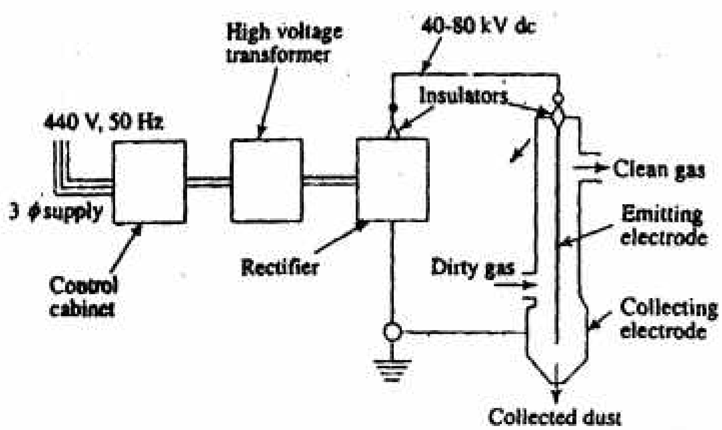
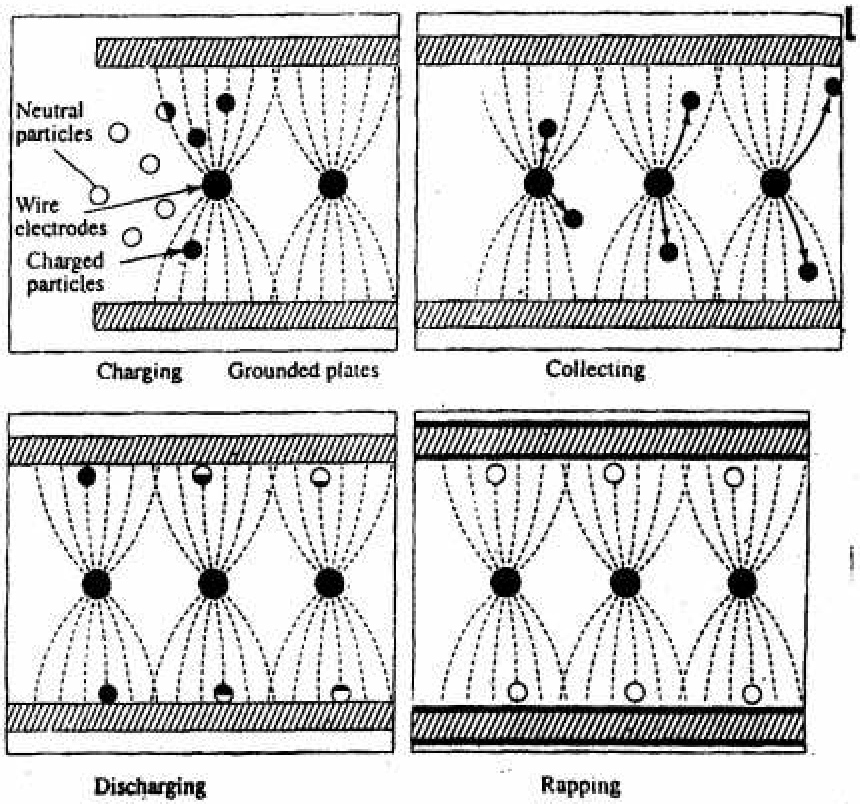


Fig. Basic elements of an electrostatic precipitator

The positive ions travel to the negatively charged wire electrodes. The electrons follow the electrical field toward the grounded electrodes, but their velocity decreases as they move away from the corona region around the wire electrodes toward the grounded plates. Gas molecules capture the low velocity electrons and become negative ions. As these ions move to the collecting electrode, they collide with the fly ash particles in the gas stream and give them negative charge. The negatively charged fly ash particles are driven to the collecting plate by the force which is proportional to the product of this charge and the strength of the electric field (Fig.).



Vertical electrodes and grounded plates in an ESP showing four basic operations

When the particles collect on the grounded plates, they lose their charge on the ground. The electrical resistivity of the particles, however, cause only partial discharging and the retained charge tends to hold the particles to the plates. High resistivity causes retention of most of the charge, which increases the forces holding the particles to the plates and makes removal more difficult. This can be rectified either by operating at high gas temperatures (before APH) or by superimposing a high voltage pulse on the base voltage to enhance ESP performance during operation under high-resistivity conditions.

Collected particulate matter must be removed from the collecting plates on a regular schedule to ensure efficient collector operation. Removal is usually accomplished by a mechanical hammer scrapping system. The vibration knocks the particulate matter off the collecting plates and into a hopper at the bottom of the precipitator. (Fig).

An electrostatic precipitator, like a cyclone separator, has an overall collection efficiency, η_0, defined by :

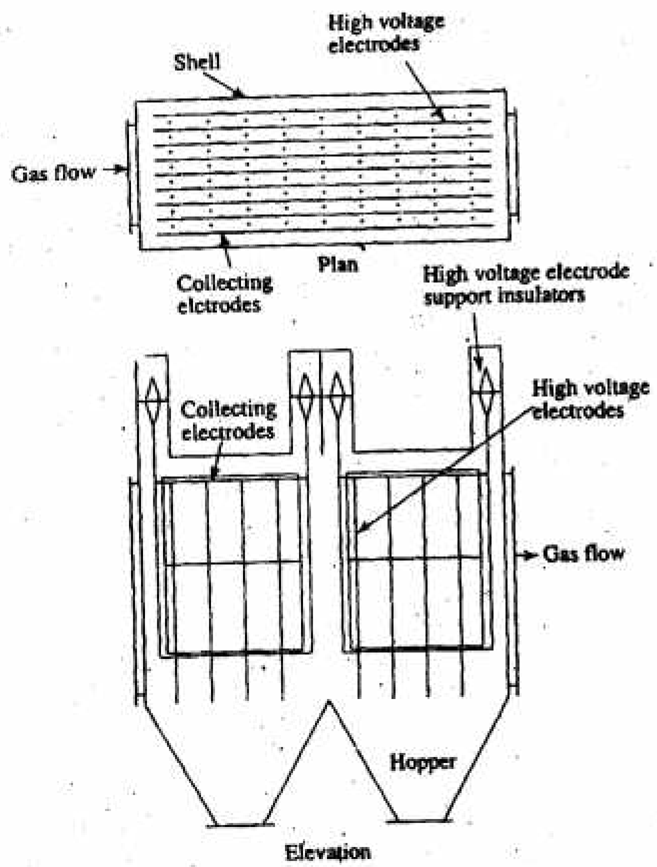


Fig. Arrangement of an electrostatic precipitator

(c) General tariff form : Quite a large number of tariffs have been proposed from time to time and are in use. They are all derived from the following equation :

$$A = cx + dy + f$$

Where A = Total amount of bill for a certain period (say one month)

x = Maximum demand during the period (kW or kVA)

y = Total energy consumed during the period (kWh)

c = Unit charge for maximum demand, Rs. per kW (or Rs. per kVA)

d = Unit cost of energy, Rs. pr kWh

f = Constant charge, Rs.

Thus the total bill consists of three parts, one depending on maximum power demand, the second depending on total energy consumed ad the third being a constant figure.

Flat demand rate : The flat demand rate can be expressed in the form, A = cx i.e. the bill depends only on the maximum demand irrespective of the amount of energy consumed.

This is the earliest form of tariff and the bill in those days was based on the total number of lamps installed in the premises, Now-a-days the use of this tariff is restricted to sign lighting, signal system, street lighting etc. where the number of hours are fixed and energy consumption can be easily predicted. Its use is very common for supplies to irrigation tube wells since the number of hours for which the tube well feeders are switched on are fixed. The charge is made according to the horse power of the motor installed. The cost of metering equipment and meter reading is eliminated by the use of this form of tariff.

Straight meter rate : This can be represented by the equation,

$$A = dy$$

The charges depend on the energy used. This tariff is sometimes used for residential and commercial customers. It has the advantage of simplicity. However the main disadvantage of this tariff is that a customer who does not use energy has zero bill though he has caused he has caused the utility to incur a definite expenditure due to its readiness to serve him. Another disadvantage is that this method does not encourage the use of electricity.

Block meter rate : To remove the inconsistency of straight meter rate, the block meter rate charges the customers on a sliding scale. A certain unit rate is for a certain block of energy and for each succeeding block of energy, the corresponding unit charge decreases.

$$A = d_1y_1 + d_2y_2 + \ldots\ldots + d_n\left[y - (y_1 + y_2 + \ldots\ldots + y_{n-1})\right]$$

Where d_1, d_2, d_3 are unit charges for energy blocks of magnitude y_1, y_2, y_3 etc. Generally the charge and energy consumption are divided into three blocks, a high rate for the initial certain number of energy units, a lower rate for the next certain number of energy units and a still lower rate for the remaining energy units. This tariff is very commonly used for residential and commercial customers.

In many states in India, a reverse form of this tariff is being used to restrict the energy consumption. In this reverse form, the unit energy charges increase with increase in energy consumption.

Hopkinson demand rate : This tariff, also known as two part tariff, can be expressed in the form

$$A = cx + dy$$

Thus the total bill includes a demand charge based on the maximum demand plus a charge based on energy consumed. The factors c and d may be constant or may vary as per sliding scale. This tariff is used for industrial customers. This tariff introduces the problem of measuring the maximum power demand of the customers. This maximum demand can either be taken as a certain fraction of the connected load or measured by a maximum demand meter. It is usual to specify a minimum demand that must be paid for. Sometimes, to discourage the customers from using low power factor devices, the demand charges are based on kVA of

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maximum demand.

Doherty rate : This rate, also known as three part tariff, extends the two part tariff by adding a constant term, the form being identical with equation. This tariff is suitable for and applied to industrial customers.

Wright demand rate : Hopkinson demand rate offers an inducement to a customer to keep his maximum demand at a low value. Wright demand rate intensifies this inducement by lowering both the demand charge and energy charge for a reduction in maximum demand i.e. an improvement in load factor. This tariff is generally specified for those industrial customers who have a control over their maximum demands.