EEC560 Electric Power Plants

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Topics to be covered:

- Types of power stations:
  - Thermal power stations
  - hydro power stations
  - Diesel power stations
  - Nuclear power stations
  - Gas Turbine Power Plant
  - Hydrothermal coordination
- New energy sources
  - solar
  - wind
- Major electrical equipment in power plants
  - generator and exciters
  - Parallel operation of alternators
  - Circuit breakers
  - Protective equipment's
  - Control board equipment

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INTRODUCTION TO THE SOURCES OF ENERGY: CONVENTIONAL AND NON-CONVENTIONAL PRINCIPLE OF POWER GENERATION

A variety of energy sources are available to supply to expanding needs in each country around the world. These sources are broadly classified as commercial or conventional energy sources and noncommercial or nonconventional energy sources.

Energy sources may be mainly classified into two categories: renewable and non-renewable energy sources.

1. Renewable energy sources

These are produced by nature and are inexhaustible. Renewable energy sources include both direct solar radiation utilized by solar collectors and cells and indirect solar energy in the form of wind, hydropower, ocean energy and sustainable biomass resources.

2. Non-renewable energy sources

These are either available in nature or produced by man artificially. They are exhaustible and non-renewable. Conventional energy sources such as nuclear power and fossil fuels are nonrenewable.

Advantages and disadvantages of renewable energy sources are as follows:

Advantages

(i) They are produced by nature and considered as inexhaustible.
(ii) They are pollution free, and hence eco-friendly.
(iii) If utilized properly in developing countries, they can save a lot of foreign exchange and generate employment opportunities.
(iv) Deployment is easy and rapid due to flexibility in their utilization.
(v) They are economical when considered over a longer period of time.

Disadvantages

(i) Their availability is intermittent (e.g. solar, wind, tidal, hydro, etc.) and hence need the assistance of nonrenewable energy.
(ii) Complete commercialization is difficult on a larger scale.
(iii) Initial cost is high due to the newer technologies used, which are still at preliminary stages.
(iv) Sources are not evenly spread across the globe.

Conventional power plants

- Steam Power Station (Thermal Station)
- Schematic Arrangement of Steam Power Station
- Choice of Site for Steam Power Stations
- Efficiency of Steam Power Station
- Equipment of Steam Power Station
- Hydro-electric Power Station
- Schematic Arrangement of Hydroelectric Power Station
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- Constituents of Hydro-electric Plant
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- Nuclear Power Station
- Schematic Arrangement of Nuclear Power Station
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- Gas Turbine Power Plant
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- Comparison of the Various Power Plants

Introduction

- The ever increasing use of electric power for domestic, commercial and industrial purposes necessitates to provide bulk electric power economically.

- This is achieved with the help of suitable power producing units, known as *Power plants or Electric power generating stations.*

- The design of a power plant should incorporate two important aspects:

- Firstly, the selection and placing of necessary power-generating equipment should be such so that a maximum of return will result from a minimum of expenditure over the working life of the plant.

- Secondly, the operation of the plant should be such so as to provide cheap, reliable and continuous service.

Generating Stations

- *Bulk electric power is produced by special plants known as* **generating stations** *or* **power plants.**
- A generating station essentially employs a prime mover coupled to an alternator for the production of electric power.
- The prime mover (*e.g.*, steam turbine, water turbine etc.) converts energy from some other form into mechanical energy.
- The alternator converts mechanical energy of the prime mover into electrical energy.
- The electrical energy produced by the generating station is transmitted and distributed with the help of conductors to various consumers.
- It may be emphasized here that apart from prime mover-alternator combination, a modern generating station employs several auxiliary equipment and instruments to ensure cheap, reliable and continuous service.

Depending upon the form of energy converted into electrical energy, the **conventional** generating stations are classified as under :

(*i*) Steam power stations (*ii*) Hydroelectric power stations
(*iii*) Diesel power stations (*iv*) Nuclear power stations

Steam Power Station (Thermal Station)

A generating station which converts heat energy of coal combustion into electrical energy is known as a **steam power station.**

- A steam power station basically works on the Rankine cycle. Steam is produced in the boiler by utilizing the heat of coal combustion.

- The steam is then expanded in the prime mover (*i.e.*, steam turbine) and is condensed in a condenser to be fed into the boiler again.

- The steam turbine drives the alternator which converts mechanical energy of the turbine into electrical energy.

- This type of power station is suitable where coal and water are available in abundance and a large amount of electric power is to be generated.

Advantages

(i) The fuel (*i.e.,* coal) used is quite cheap.

(*ii*) Less initial cost as compared to other generating stations.

(*iii*) It can be installed at any place irrespective of the existence of coal. The coal can be transported to the site of the plant by rail or road.

(*iv*) It requires less space as compared to the hydroelectric power station.

(*v*) The cost of generation is lesser than that of the diesel power station.

Disadvantages

(i) It pollutes the atmosphere due to the production of large amount of smoke and fumes.

(*ii*) It is costlier in running cost as compared to hydroelectric plant.

Schematic Arrangement of Steam Power Station

The schematic arrangement of a modern steam power station is shown in Fig. 2.1.

The whole arrangement can be divided into the following stages for the sake of simplicity :

1. Coal and ash handling arrangement **2.** Steam generating plant **3.** Steam turbine

4. Alternator **5.** Feed water **6.** Cooling arrangement

1. Coal and ash handling plant.

- The coal is transported to the power station by road or rail and is stored in the coal storage plant.
- Storage of coal is primarily a matter of protection against coal strikes, failure of transportation system and general coal shortages.
- The coal is burnt in the boiler and the ash produced after the complete combustion of coal is removed to the ash handling plant and then delivered to the ash storage plant for disposal.
- The removal of the ash from the boiler furnace is necessary for proper burning of coal.
- In fact, in a thermal station, about 50% to 60% of the total operating cost consists of fuel purchasing and its handling.

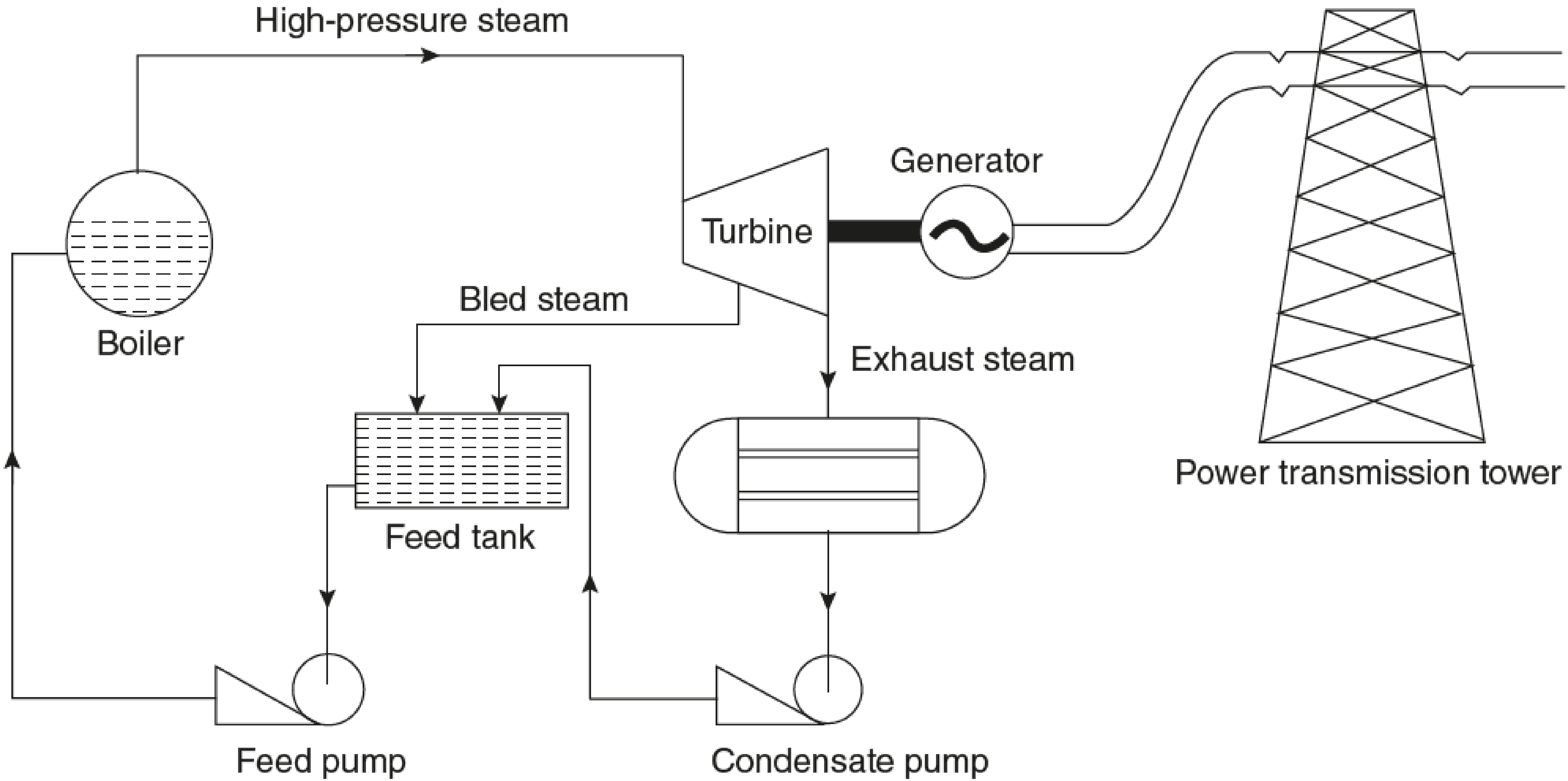
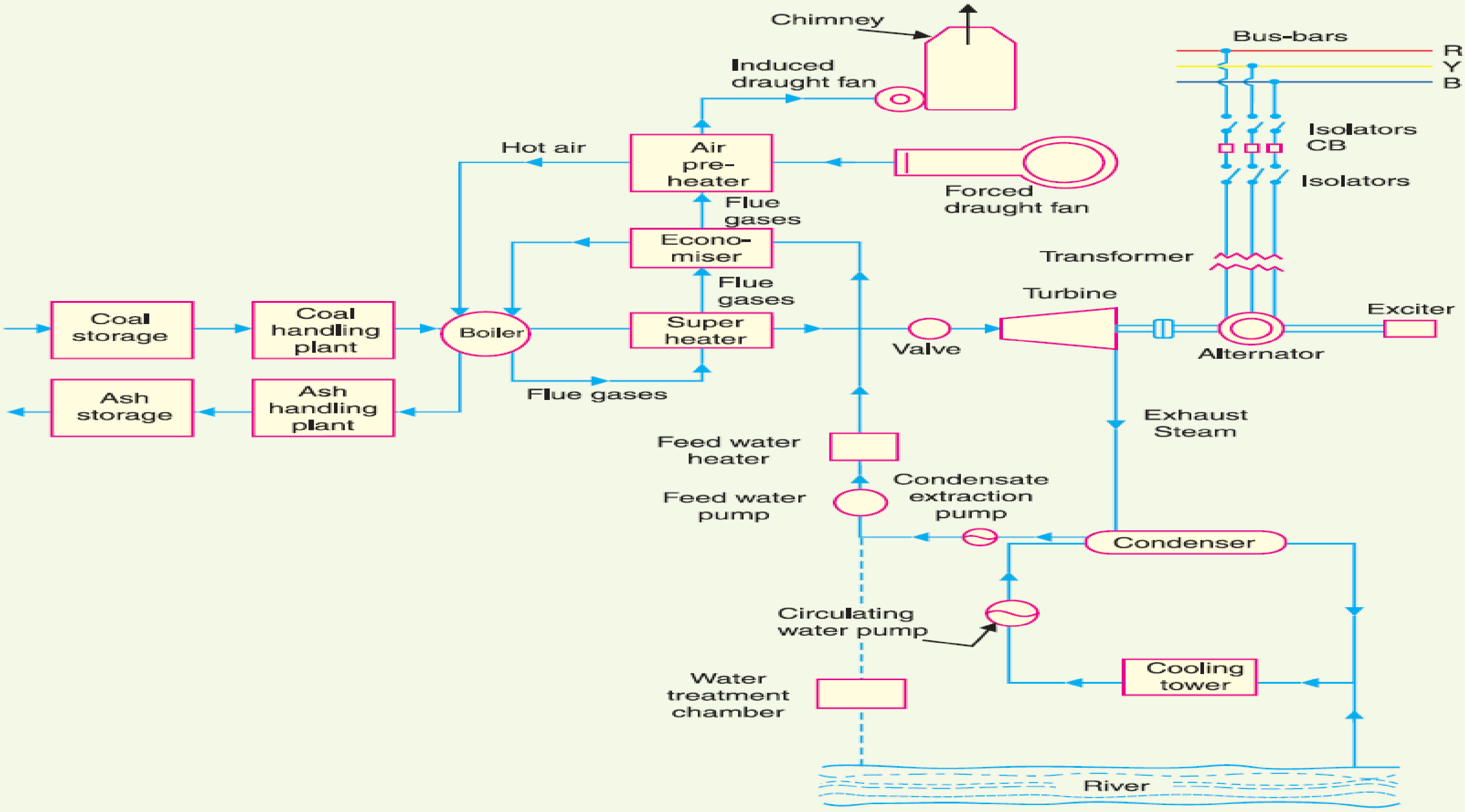


Fig. 1.1 *A Typical Thermal Power Plant*



Schematic arrangement of Steam Power Station
Fig. 2.1

2. Steam generating plant. The steam generating plant consists of a boiler for the production of steam and other auxiliary equipment for the utilization of flue gases.

(*i*) *Boiler.* The heat of combustion of coal in the boiler is utilized to convert water into steam at high temperature and pressure. **The flue gases from the boiler make their journey through superheater, economizer, air pre-heater and are finally exhausted to atmosphere.**

(*ii*) *Superheater.* The steam produced in the boiler is wet and is passed through a superheater where it is dried and superheated (*i.e.*, steam temperature increased above that of boiling point of water) by the flue gases on their way to chimney.

Superheating provides two principal benefits. **Firstly**, the overall efficiency is increased. **Secondly**, too much condensation in the last stages of turbine (which would cause blade corrosion) is avoided. The superheated steam from the superheater is fed to steam turbine through the main valve.

(*iii*) *Economizer.* An economizer is essentially a feed water heater and derives heat from the flue gases for this purpose.

(*iv*) *Air preheater.* An air preheater increases the temperature of the air supplied for coal burning by deriving heat from flue gases.

3. Steam turbine. The dry and superheated steam from the superheater is fed to the steam turbine through main valve. The heat energy of steam when passing over the blades of turbine is converted into mechanical energy. After giving heat energy to the turbine, the steam is exhausted to the *condenser* which condenses the exhausted steam by means of cold water circulation.

4. Alternator. The steam turbine is coupled to an alternator. The alternator converts mechanical energy of turbine into electrical energy. The electrical output from the alternator is delivered to the bus bars through transformer, circuit breakers and isolators.

5. Feed water. The condensate from the condenser is used as feed water to the boiler. Some water may be lost in the cycle which is suitably made up from external source. The feed water on its way to the boiler is heated by water heaters and economizer. This helps in raising the overall efficiency of the plant.

6. Cooling arrangement.

- In order to improve the efficiency of the plant, the steam exhausted from the turbine is condensed by means of a condenser.
- Water is drawn from a natural source of supply such as a river, canal or lake and is circulated through the condenser.
- The circulating water takes up the heat of the exhausted steam and itself becomes hot.
- This hot water coming out from the condenser is discharged at a suitable location down the river. In case the availability of water from the source of supply is not assured throughout the year, *cooling towers* are used.
- During the scarcity of water in the river, hot water from the condenser is passed on to the cooling towers where it is cooled. The cold water from the cooling tower is reused in the condenser.

Choice of Site for Steam Power Stations

In order to achieve overall economy, the following points should be considered while selecting a site for a steam power station :

(*i*) *Supply of fuel.* The steam power station should be located near the coal mines so that transportation cost of fuel is minimum. However, if such a plant is to be installed at a place where coal is not available, then care should be taken that adequate facilities exist for the transportation of coal.

(*ii*) *Availability of water.* As huge amount of water is required for the condenser, therefore, such a plant should be located at the bank of a river or near a canal to ensure the continuous supply of water.

(*iii*) *Transportation facilities.* A modern steam power station often requires the transportation of material and machinery. Therefore, adequate transportation facilities must exist *i.e.*, the plant should be well connected to other parts of the country by rail, road. etc.

(*iv*) *Cost and type of land.* The steam power station should be located at a place where land is cheap and further extension, if necessary, is possible. Moreover, the bearing capacity of the ground should be adequate so that heavy equipment could be installed.

Choice of Site for Steam Power Stations

(*v*) *Nearness to load centers.* In order to reduce the transmission cost, the plant should be located near the center of the load. This is particularly important if *d.c.* supply system is adopted. However, if *a.c.* supply system is adopted, this factor becomes relatively less important. It is because *a.c.* power can be transmitted at high voltages with consequent reduced transmission cost. Therefore, it is possible to install the plant away from the load centers, provided other conditions are favorable.

(*vi*) *Distance from populated area.* As huge amount of coal is burnt in a steam power station, therefore, smoke and fumes pollute the surrounding area. This necessitates that the plant should be located at a considerable distance from the populated areas.

Conclusion. It is clear that all the above factors cannot be favorable at one place. However, keeping in view the fact that nowadays the supply system is *a.c.* and more importance is being given to generation than transmission, a site away from the towns may be selected. In particular, a site by river side where sufficient water is available, no pollution of atmosphere occurs and fuel can be transported economically, may perhaps be an ideal choice.

Efficiency of Steam Power Station

The overall efficiency of a steam power station is quite low (about 29%) due mainly to two reasons.

- Firstly, a huge amount of heat is lost in the condenser and
- secondly heat losses occur at various stages of the plant. The heat lost in the condenser cannot be avoided.
- It is because heat energy cannot be converted into mechanical energy without temperature difference.
- The greater the temperature difference, the greater is the heat energy converted into mechanical energy.
- This necessitates to keep the steam in the condenser at the lowest temperature.
- But we know that greater the temperature difference, greater is the amount of heat lost.
- This explains for the low efficiency of such plants.

(*i*) **Thermal efficiency.** *The ratio of heat equivalent of mechanical energy transmitted to the turbine shaft to the heat of combustion of coal is known as* **thermal efficiency** *of steam power station.*

$$\text{Thermal efficiency, } \eta_{thermal} = \frac{\text{Heat equivalent of mech. energy transmitted to turbine shaft}}{\text{Heat of coal combustion}}$$

The thermal efficiency of a modern steam power station is about 30%. It means that if 100 calories of heat is supplied by coal combustion, then mechanical energy equivalent of 30 calories will be available at the turbine shaft and rest is lost. It may be important to note that more than 50% of total heat of combustion is lost in the condenser. The other heat losses occur in flue gases, radiation, ash etc.

(*ii*) **Overall efficiency.** *The ratio of heat equivalent of electrical output to the heat of combustion of coal is known as* **overall efficiency** *of steam power station i.e.*

$$\text{Overall efficiency, } \eta_{overall} = \frac{\text{Heat equivalent of electrical ouput}}{\text{Heat of combustion of coal}}$$

The overall efficiency of a steam power station is about 29%. It may be seen that overall efficiency is less than the thermal efficiency. This is expected since some losses (about 1%) occur in the alternator. The following relation exists among the various efficiencies.

Overall efficiency = Thermal efficiency * Electrical efficiency

Equipment of Steam Power Station

A modern steam power station is highly complex and has numerous equipment and auxiliaries. However, the most important constituents of a steam power station are :

1. Steam generating equipment **2.** Condenser **3.** Prime mover

4. Water treatment plant **5.** Electrical equipment.

1. Steam generating equipment. This is an important part of steam power station. It is concerned with the generation of superheated steam and includes such items as boiler, boiler furnace, superheater, economizer, air pre-heater and other heat reclaiming devices.

(*i*) *Boiler.* A boiler is closed vessel in which water is converted into steam by utilizing the heat of coal combustion. Steam boilers are broadly classified into the following two types :

(*a*) Water tube boilers **(*b*)** Fire tube boilers

In a water tube boiler, water flows through the tubes and the hot gases of combustion flow over these tubes. On the other hand, in a fire tube boiler, the hot products of combustion pass through the tubes surrounded by water.

(*ii*) *Boiler furnace.* A boiler furnace is a chamber in which fuel is burnt to liberate the heat energy.

(*iii*) *Superheater.* A superheater is a device which superheats the steam *i.e.*, it raises the temperature of steam above boiling point of water. This increases the overall efficiency of the plant. A superheater consists of a group of tubes made of special alloy steels. These tubes are heated by the heat of flue gases during their journey from the furnace to the chimney.

(***iv***) *Economizer.* It is a device which heats the feed water on its way to boiler by deriving heat from the flue gases. This results in raising boiler efficiency, saving in fuel and reduced stresses in the boiler due to higher temperature of feed water.

(***v***) *Air Pre-heater.* Superheaters and economizers generally cannot fully extract the heat from flue gases. Therefore, pre-heaters are employed which recover some of the heat in the escaping gases. The function of an air pre-heater is to extract heat from the flue gases and give it to the air being supplied to furnace for coal combustion. This raises the furnace temperature and increases the thermal efficiency of the plant.

2. Condensers. A condenser is a device which condenses the steam at the exhaust of turbine. It serves two important functions.

Firstly, it creates a very low pressure at the exhaust of turbine, thus permitting expansion of the steam in the prime mover to a very low pressure. This helps in converting heat energy of steam into mechanical energy in the prime mover.

Secondly, the condensed steam can be used as feed water to the boiler.

There are two types of condensers, namely : **(*i*)** Jet condenser **(*ii*)** Surface condenser

In a jet condenser, cooling water and exhausted steam are mixed together. Therefore, the temperature of cooling water and condensate is the same when leaving the condenser. Advantages of this type of condenser are : low initial cost, less floor area required, less cooling water required and low maintenance charges. However, its disadvantages are : condensate is wasted and high power is required for pumping water.

In a surface condenser, there is no direct contact between cooling water and exhausted steam. It consists of a bank of horizontal tubes enclosed in a cast iron shell. The cooling water flows through the tubes and exhausted steam over the surface of the tubes. The steam gives up its heat to water and is itself condensed. Advantages of this type of condenser are : condensate can be used as feed water, less pumping power required and creation of better vacuum at the turbine exhaust. However, disadvantages of this type of condenser are : high initial cost, requires large floor area and high maintenance charges.

3. Prime movers. The prime mover converts steam energy into mechanical energy. There are two types of steam prime movers *viz.*, steam engines and steam turbines. A steam turbine has several advantages over a steam engine as a prime mover *viz.*, high efficiency, simple construction, higher speed, less floor area requirement and low maintenance cost. Therefore, all modern steam power stations employ steam turbines as prime movers.

Steam turbines are generally classified into two types according to the action of steam on moving blades *viz.*

(*i*) Impulse turbines

(*ii*) Reactions turbines

In an impulse turbine, the steam expands completely in the stationary nozzles (or fixed blades), the pressure over the moving blades remaining constant. In doing so, the steam attains a high velocity and impinges against the moving blades. This results in the impulsive force on the moving blades which sets the rotor rotating. In a reaction turbine, the steam is partially expanded in the stationary nozzles, the remaining expansion takes place during its flow over the moving blades. The result is that the momentum of the steam causes a reaction force on the moving blades which sets the rotor in motion.

S. No.	Particulars	Impulse turbine	Reaction turbine
1.	*Pressure drop*	Only in nozzles and not in moving blades.	In fixed blades (nozzles) as well as in moving blades.
2.	*Area of blade channels*	Constant.	Varying (converging type).
3.	*Blades*	Profile type.	Aerofoil type.
4.	*Admission of steam*	Not all round or complete.	All round or complete.
5.	*Nozzles/fixed blades*	Diaphram contains the nozzle.	Fixed blades similar to moving blades attached to the casing serve as nozzles and guide the steam.
6.	*Power*	Not much power can be developed.	Much power can be developed.
7.	*Space*	Requires less space for same power.	Requires more space for same power.
8.	*Efficiency*	Low.	High.
9.	*Suitability*	Suitable for small power requirements.	Suitable for medium and higher power requirements.
10.	*Blade manufacture*	Not difficult.	Difficult.

4. Water treatment plant. Boilers require clean and soft water for longer life and better efficiency. However, the source of boiler feed water is generally a river or lake which may contain suspended and dissolved impurities, dissolved gases etc. Therefore, it is very important that water is first purified and softened by chemical treatment and then delivered to the boiler.

The water from the source of supply is stored in storage tanks. The pure and soft water thus available is fed to the boiler for steam generation.

5. Electrical equipment. A modern power station contains numerous electrical equipment. However, the most important items are :

(*i*) *Alternators.* Each alternator is coupled to a steam turbine and converts mechanical energy of the turbine into electrical energy. The necessary excitation is provided by means of main and pilot exciters directly coupled to the alternator shaft.

(*ii*) *Transformers.* A generating station has different types of transformers, *viz.*,

- **(*a*)** main step-up transformers which step-up the generation voltage for transmission of power.
- **(*b*)** station transformers which are used for general service (*e.g.*, lighting) in the power station.
- **(*c*)** auxiliary transformers which supply to individual unit-auxiliaries.

(*iii*) *Switchgear.* It houses such equipment which locates the fault on the system and isolate the faulty part from the healthy section. It contains circuit breakers, relays, switches and other control devices.

Example 2.1. *A steam power station has an overall efficiency of 20% and 0·6 kg of coal is burnt per kWh of electrical energy generated. Calculate the calorific value of fuel.*

Solution.

Let x kcal/kg be the calorific value of fuel.

Heat produced by 0·6 kg of coal = 0·6 x kcal

Heat equivalent of 1 kWh = 860 kcal

$$\text{Now,} \quad \eta_{overall} = \frac{\text{Electrical output in heat units}}{\text{Heat of combustion}}$$

$$\text{or} \quad 0{\cdot}2 = \frac{860}{0 \cdot 6x}$$

$$\therefore \quad x = \frac{860}{0 \cdot 6 \times 0 \cdot 2} = \mathbf{7166{\cdot}67\ kcal/kg}$$

Example 2.2. *A thermal station has the following data :*

Max. demand	=	*20,000 kW*	;	*Load factor*	=	*40%*
Boiler efficiency	=	*85%*	;	*Turbine efficiency*	=	*90%*
Coal consumption	=	*0·9 kg/kWh*	;	*Cost of 1 ton of coal*	=	*Rs. 300*

Determine (i) thermal efficiency and (ii) coal bill per annum.

Solution.

(*i*) Thermal efficiency $= \eta_{boiler} \times \eta_{turbine} = 0{\cdot}85 \times {\cdot}9 =$ **0·765** or **76·5 %**

(*ii*) Units generated/annum = Max. demand × L.F. × Hours in a year

$= 20{,}000 \times 0{\cdot}4 \times 8760 = 7008 \times 10^4$ kWh

$$\text{Coal consumption/annum} = \frac{(0\cdot9)\left(7008 \times 10^4\right)}{1000} = 63{,}072 \text{ tons}$$

∴ Annual coal bill = Rs 300 × 63072 = **Rs 1,89,21,600**

Example 2.3. *A steam power station spends Rs. 30 lakhs per annum for coal used in the station. The coal has a calorific value of 5000 kcal/kg and costs Rs. 300 per ton. If the station has thermal efficiency of 33% and electrical efficiency of 90%, find the average load on the station.*

Solution.

$$\text{Overall efficiency, } \eta_{overall} = 0{\cdot}33 \times 0{\cdot}9 = 0{\cdot}297$$

$$\text{Coal used/annum} = 30 \times 10^5/300 = 10^4 \text{ tons} = 10^7 \text{ kg}$$

$$\text{Heat of combustion} = \text{Coal used/annum} \times \text{Calorific value}$$

$$= 10^7 \times 5000 = 5 \times 10^{10} \text{ kcal}$$

$$\text{Heat output} = \eta_{overall} \times \text{Heat of combustion}$$

$$= (0{\cdot}297) \times (5 \times 10^{10}) = 1485 \times 10^7 \text{ kcal}$$

$$\text{Units generated/annum} = 1485 \times 10^7/860 \text{ kWh}$$

$$\therefore \quad \text{Average load on station} = \frac{\text{Units generated / annum}}{\text{Hours in a year}} = \frac{1485 \times 10^7}{860 \times 8760} = \mathbf{1971\ kW}$$

Example 2.4. *The relation between water evaporated (W kg), coal consumption (C kg) and kWh generated per 8-hour shift for a steam generating station is as follows :*

$$W = 13500 + 7{\cdot}5 \text{ kWh} \quad \text{....(i)}$$

$$C = 5000 + 2{\cdot}9 \text{ kWh} \quad \text{....(ii)}$$

(i) To what limiting value does the water evaporating per kg of coal consumed approach as the station output increases ? (ii) How much coal per hour would be required to keep the station running on no load ?

Solution.

(*i*) For an 8-hour shift, weight of water evaporated per kg of coal consumed is

$$\frac{W}{C} = \frac{13500 + 7 \cdot 5 \text{ kWh}}{5000 + 2 \cdot 9 \text{ kWh}}$$

As the station output (*i.e.*, kWh) increases towards infinity, the limiting value of W/C approaches $7{\cdot}5/2{\cdot}9 = 2{\cdot}6$. Therefore, the weight of water evaporated per kg of coal consumed approaches a limiting value of **2·6 kg** as the kWh output increases.

(*ii*) At no load, the station output is zero *i.e.*, kWh = 0. Therefore, from expression (*ii*), we get, coal consumption at no load

$$= 5000 + 2{\cdot}9 \times 0 = 5000 \text{ kg}$$

$$\therefore \quad \text{Coal consumption/hour} = 5000/8 = \mathbf{625\ kg}$$

Example 2.5. *A 100 MW steam station uses coal of calorific value 6400 kcal/kg. Thermal efficiency of the station is 30% and electrical efficiency is 92%. Calculate the coal consumption per hour when the station is delivering its full rated output.*

Solution.

Overall efficiency of the power station is

$$\eta_{overall} = \eta_{thermal} \times \eta_{elect} = 0{\cdot}30 \times 0{\cdot}92 = 0{\cdot}276$$

$$\text{Units generated/hour} = (100 \times 10^3) \times 1 = 10^5 \text{ kWh}$$

$$\text{Heat produced/hour, } H = \frac{\text{Electrical output in heat units}}{\eta_{overall}}$$

$$= \frac{10^5 \times 860}{0 \cdot 276} = 311 \cdot 6 \times 10^6 \text{ kcal} \qquad (\because \ 1 \text{ kWh} = 860 \text{ kcal})$$

$$\therefore \quad \text{Coal consumption/hour} = \frac{H}{\text{Calorific value}} = \frac{311 \cdot 6 \times 10^6}{6400} = \mathbf{48687 \ kg}$$