2

Thermal Power Station

2.1 INTRODUCTION

Energy is an important input in all the sectors of any country's economy. The standard of living of a given country can be directly related to per capita energy consumption. Energy crisis is due to two reasons : firstly, that the population of the world has increased rapidly and secondly the standard of living of human beings has improved.

In this modern world, the dependence on electricity is so much that it has become a part and parcel of our life. The ever-increasing use of electric power for domestic, commercial and industrial purpose 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 that a maximum of return is obtained from a minimum of expenditure over the working life of the plant. Secondly, the operation of the plant should be such as to provide cheap, reliable and continuous service. In India, there is still a large scope of development of industry and hence large scope of increase of electric power too. Thermal electric power generation is one of the major methods. The design of steam power station requires wide experience as the subsequent operation and maintenance are greatly affected by its design. The satisfactory design consists of the following steps : (*i*) selection of the site, (*ii*) capacity of the power station, (*iii*) selection of boilers and its auxiliaries, (*iv*) selection of turbine, (*v*) selection of condensing units, (*vi*) design of cooling system, (*vii*) selection of electric generator, and (*viii*) design of control and instrumentation. In this chapter concise and relevant points are undertaken.

2.2 CONCEPT OF HEAT AND WORK

The fundamental forms of energy with which thermal power stations are mainly concerned are heat and work. Heat produces work and then work is further converted into electrical energy through some form or energy conversion cycle.

The term heat and work designates two fundamental forms of energy flow. Heat flow involves a quantity aspect and the temperature available. A heat cycle receives a heat flow at a given temperature pattern, to convert part to work and discard the remainder to the receiver. A cycle which uses heat in an ideal or reversible manner to produce work from the available energy, is called an ideal cycle.

The First Law and the Closed System

The open system is one in which mass crosses the boundaries. A closed system is one in which only energy and not mass crosses the boundaries. A third system of some interest is the isolated system, a special instance of the closed system. It is one in which neither mass nor energy crosses the boundaries but energy transformations may take place within the boundaries.

Because mass does not cross the boundaries in a closed system, the potential, kinetic, and flow energy terms drop out in the first law equation.

The Cycle

In order to convert forms of energy, particularly heat is to work on an extended or continuous basis, one needs to operate on a cycle. The process begins at one state of the working fluid and ends at another. A cycle, on the other hand, is a series of processes that begins and ends at the same state and thus can repeat indefinitely, or as long as needed. An example is the ideal diesel cycle, shown as the P-T and T-s in Fig. 2.2.

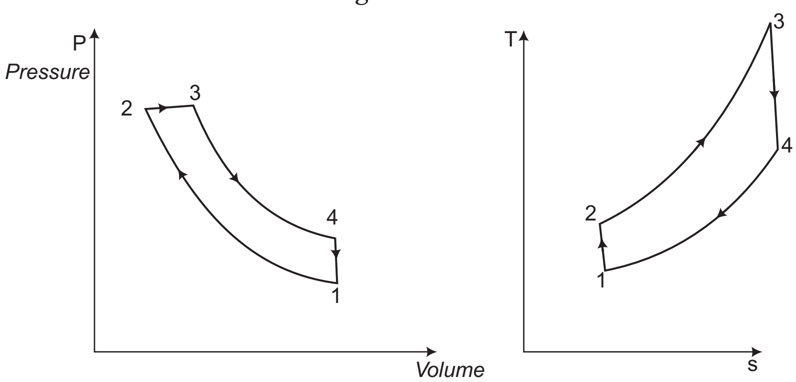

Fig. 2.2 Pressure-volume and temperature enthalpy diagram of an ideal diesel cycle

It is composed of an ideal and adiabatic compression process 1-2, a constant-pressure heat addition process 2-3, an ideal and adiabatic expansion process 3-4 and a constant volume heat rejection process 4-1 which returns the cycle back to 1. Because the beginning and the end of the cycle is 1, thermodynamic cycle is a closed loop system where, $\Delta U = U_1 - U_1 = 0$ and first law for this and all other cycles becomes

$$\Delta Q_{\text{net}} = Q_A - |Q_R| = \Delta W_{\text{net}} \text{ (for a cycle)}$$

The Second Law of Thermodynamics

The first law of thermodynamics was one of conservation of energy, declaring that all forms of energy are convertible to another, the second law puts a limitation on the conservation of same forms of energy to others. Second law does not negate the equivalence of conversion of these two, only the extent. Work is a more valuable commodity. It can be completely and continuously converted to heat. The opposite is not true. Heat cannot be completely and continuously converted to work. The portion of heat that cannot thus be converted to work, called unavailable energy, has to be rejected as low grade heat after the work has been done. Thus, while energy is conserved, availability is not.

2.4 POWER PLANT CYCLES

A thermal power station works on the principle that heat is released by burning fuel which produces (working fluid) (steam) from water. The steam so produced runs the turbine coupled to generator which produces electrical energy.

A working fluid goes through a repetitive cycle change and this cyclic change involving heat and work is known as thermodynamic cycle. Thus, a thermodynamic cycle is a series of operations, involving a heat source, a heat receiver, a machine and working substance.

Types of Power Plant Cycles

Thermal power plants, in general, may work on

(a) Vapour power cycles (b) Gas power cycles

Vapour Power cycles can be classified as:

(i) Rankine cycle
(ii) Reheat cycle
(iii) Regenerative cycle
(iv) Binary vapour cycle

Gas Power Cycle can be classified as follows:

(i) Otto cycle
(ii) Diesel cycle
(iii) Dual combustion cycle
(iv) Gas turbine cycle

Rankine Cycle

Rankine cycle is the theoretical cycle on which steam power plant works. Rankine cycle is a vapour-liquid cycle, it is most convenient to draw it on both the P-V and T-s diagrams with respect to the saturated-liquid and vapour lines of the working fluid, which usually but not alway, is H_2O.

Figure 2.3 shows a simplified flow diagram of a Rankine cycle.

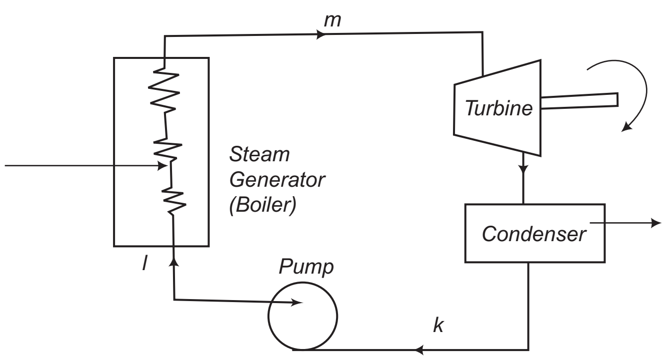

Fig. 2.3 Rankine cycle

P-V diagram is shown in Fig. 2.4.

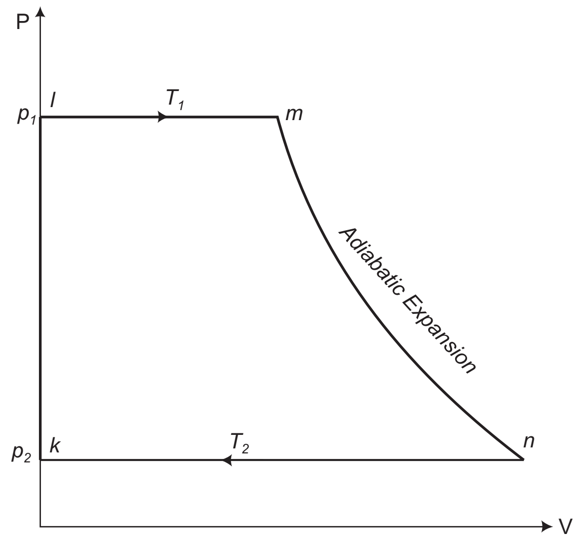

Fig. 2.4 P-V DIAGRAM OF RANKINE CYCLE

1. **Operation (*k-l*):** Condensed steam is at pressure p_2 and temperature T_2 which is pumped into the boiler by means of feed pump at pressure p_1 and there it is called temperature T_1.
2. **Operation (*l-m*):** The hot water at a saturation temperature T_1 is evaporated to steam at pressure p_1.
3. **Operation (*m-n*):** After coming out of the boiler, the steam enters the turbine and expands adiabatically to a pressure p_2.
4. **Operation (*n-k*):** The steam expands and condenses to water in the condenser at the same temperature and is pressure at point *k*. Thus, the cycle is completed. This condensed water is again pumped to the boiler and then the next cycle starts.

Reheat cycle: An additional improvement in cycle efficiency with gaseous primary fluids as in fossil fuel and gas-cooled power plants is achieved.

The improvement in thermal efficiency due to reheat greatly depends on the *reheat pressure* with respect to the original pressure of steam.

Figure 2.5 shows a schematic diagram of a theoretical single stage reheat cycle. The corresponding representation of ideal reheating process on T-s is shown in Fig. 2.6.

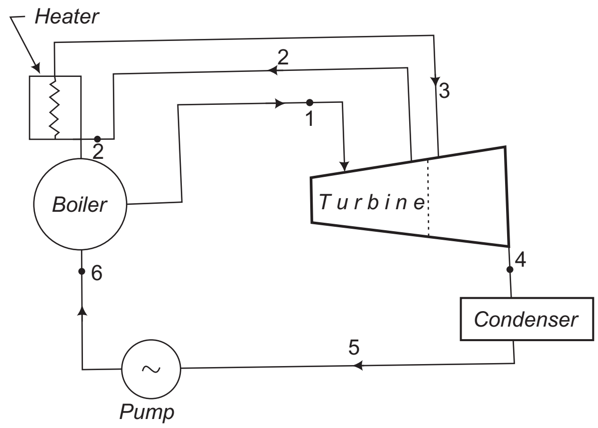

Fig. 2.5 Reheat cycle.

Figure 2.6. 5-1 shows the formation of steam in the boiler. The steam at state point 1 (i.e., pressure p_1 and temperature T_1) enters the turbine an expands isentropically to a certain pressure p_2 and temperature T_2. From this state point 2 the whole of steam is drawn out of the turbine and is reheated in a reheater to a temperature T_3.

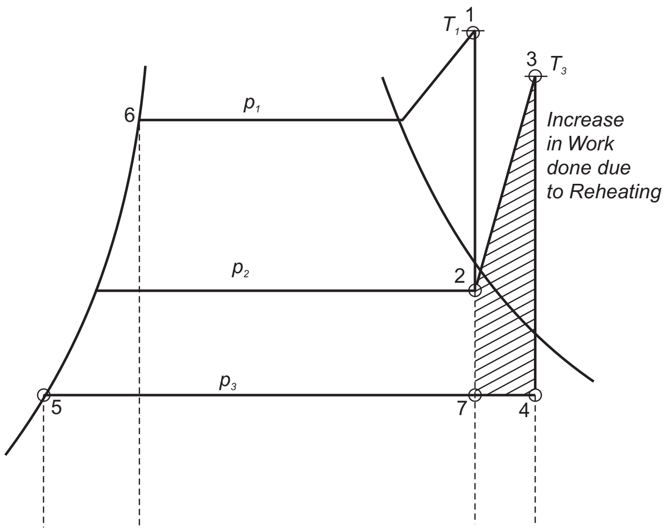

Fig. 2.6 Ideal reheating process on

This reheated steam is then readmitted to the turbine where it is expanded to condenser pressure isentropically. Reheat allows heat addition twice. It results in increasing the average temperature at which heat is added and keeps the boiler hot, which results in improvement in cycle efficiency. Reheating also results in drier steam at turbine exhaust which is beneficial for real cycles.

Advantages of Reheating

1. There is an increased output of the turbine.
2. The thermal efficiency of the turbines increases.

3. Efficiencies of nozzle and blade increase.
4. Corrosion problems are minimised in steam turbines.
5. Dryness factor of steam improved.

Disadvantages of Reheating

1. Reheating requires maintenance.
2. Reheating increases the expenditure.

2.5 REGENERATIVE CYCLE

In the Rankine cycle it is observed that the condensate which is fairly at low temperature has an irreversible mixing with hot boiler water and this results in the decrease of cycle efficiency. Methods are, therefore, adopted to heat the feed water from the hot well of condenser irreversibly by interchange of heat within the system and thus improving the cycle efficiency. This heating method is called regenerative feed heat and the cycle is called *regenerative cycle*.

The principle of generation can be practically utilised by extracting steam from the turbine at several locations and supplying it to the regenerative heaters. The resulting cycle is known as regenerative or bleeding cycle. The heating arrangement comprises; (i) for medium capacity turbine — not more than 3 heaters; (ii) for high pressure high capacity turbines — not more than 5 to 7 heaters; and (iii) for turbines of supercritical parameters—8 to 9 heaters. The most advantageous condensate heating temperature is selected depending on the turbine throttle conditions and this determines the number of heaters to be used.

Figure 2.7 shows a diagrammatic layout of a condensing steam power plant in which a surface condenser is used to condense all the steam that is not extracted by feed water heating. The turbine is double extracting and the boiler is equipped with a superheater. This arrangement constitutes a regenerative cycle.

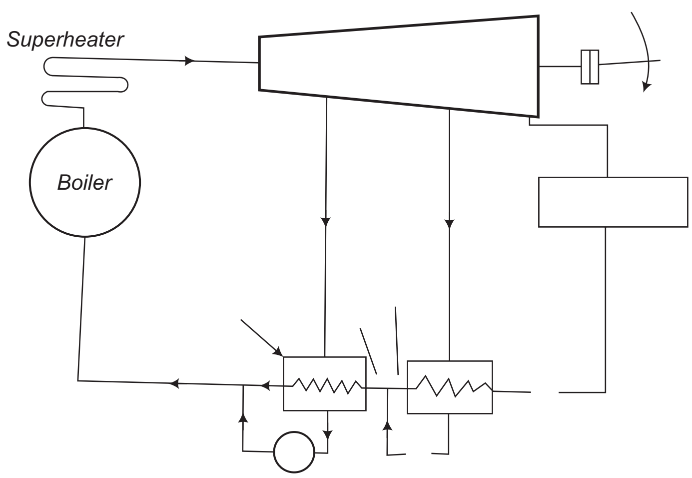

Fig. 2.7 Regenerator cycle.

The condensate from the bled steam is added to feed water.

Advantages of Regenerative Cycle Over Simple Rankine Cycle

1. The heating process in the boiler tends to become reversible.
2. The thermal stresses set up in the boiler are minimised. This is due to the fact that temperature ranges in the boiler are reduced.
3. The thermal efficiency is improved because the average temperature of heat addition to the cycle is increased.
4. Heat rate is reduced.
5. The blade height is less due to the reduced amount of steam passed through the low pressure stages.
6. Due to many extractions there is an improvement in the turbine drainage and it reduces erosion due to moisture.
7. A small size condenser is required.

Disadvantages of Regenerative Cycle Over Simple Rankine Cycle

1. The plant becomes more complicated.
2. Maintenance cost is more.
3. A large capacity boiler is needed for a given power rating.
4. The heaters are costly and the gain in thermal efficiency is not much in comparison to the costs.

2.6 BINARY VAPOUR CYCLE

Carnot cycle gives the highest thermal efficiency which is given by $\left(\frac{T_1 - T_2}{T_1}\right)$. To approach this cycle in an actual engine it is necessary that whole of heat must be supplied at constant temperature T_1 and rejected at T_2. This can be achieved only by using a vapour in the wet field but not in the superheated field. The efficiency depends on temperature T_1 since T_2 is fixed by the natural sink to which heat is rejected. This means that T_1 should be as large as possible, consistent with the vapour being saturated.

If we use steam as the working medium the temperature rise is accompanied by rise in pressure and at critical temperature of 374.15°C the pressure is as high as 225.65 kgf/cm^2 which will create many difficulties in design, operation and control. It would be desirable to use some fluid other than steam which has more desirable thermodynamic properties than water. An ideal fluid for this purpose should have a very high critical temperature combined with low pressure. Mercury, diphenyloxide and similar compound, aluminium bromide and zinc ammonium chloride are fluids which have the required properties in varying degrees. Mercury is the only working fluid which has been successfully used. It has high critical temperature (588.4°C) and correspondingly low critical pressure (21 kgf/cm^2 abs.). The mercury alone cannot be used as its saturation temperature at atmospheric pressure is high (357°C). Hence, binary vapour cycle is generally used to increase the overall efficiency of the plant. Two fluids (mercury and water) are used in cascade in the binary cycle for production of power.

Characteristics of ideal working fluid for vapour power cycle are:

(i) It should have high critical temperature at reasonably low pressure.
(ii) It should have high heat of vaporisation to keep the weight of fluid in the cycle minimum.
(iii) Freezing temperature should be below the room temperature.
(iv) It should have chemical stability through the working cycle.
(v) It must be non-corrosive to the metals normally used in power plants.
(vi) It must have the ability to wet the metal surfaces to promote the heat transfer.
(vii) The vapour pressure at a desirable condensation temperature should be nearly atmoshpheric which will eliminate requirement of power for maintenance of vacuum in the condesner.
(viii) After expansion through the prime mover the vapour should be nearly saturated so that a desirable heat transfer coefficient can be obtained which will reduce the size of the condenser required.
(ix) It must be available in large quantities at reasonable cost.
(x) It should not be toxic and, therefore, dangerous to human life.

Figure 2.8 shows the schematic line diagram of mercury vapour use mercury and water as working fluids.

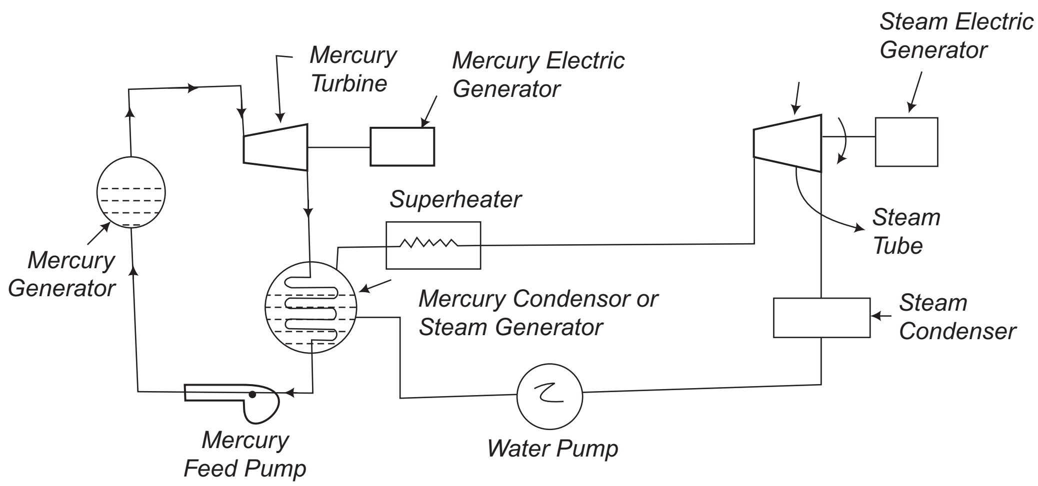

Fig. 2.8 Diagram of binary vapour cycle.

2.7 THERMAL STATION

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

A thermal power station basically works on the Rankine cycle. Steam is produced in the boiler by utilising 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*) Less initial cost as compared to other generating stations.

(*ii*) The fuel, which is generally coal, is quite cheap.

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

(*iv*) 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.

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

Disadvantages

(*i*) Running cost is more as compared to hydroelectric plant.

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

The schematic line diagram of a modern steam power station is shown in Fig. 2.9. The whole arrangement can be divided into the following stages for the sake of simplicity :

(*i*) Coal and Dust Handling Arrangement

(*ii*) Steam Generating Plant

(*iii*) Steam Turbine

(*iv*) Alternator Generator

(*v*) Feed Water

(*vi*) Cooling Arrangement

Coal and Dust Handling Arrangement : The coal is transported to the power station by road or rail and is stored in the coal storage plant. From the coal storage plant, coal is delivered to the coal handling plant where it is crushed into small pieces in order to increase its surface exposure, thus promoting rapid combustion without using large quantity of excess air. The crushed coal is fed to the boiler by belt conveyors. 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.

Steam Generating Plant : The steam generating plant consists of a boiler for the production of steam and other auxiliary equipment for the utilisation of flue gases.

Boiler : The heat of combustion of coal in the boiler is utilised to convert water into steam at high temperature and pressure. The flue gases from the boiler make their path through superheater, economiser, air preheater and are finally exhausted to atmosphere through the chimney.

Superheater : The steam produced in the boiler is generally wet and is passed through a superheater where it is dried and superheated. 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.

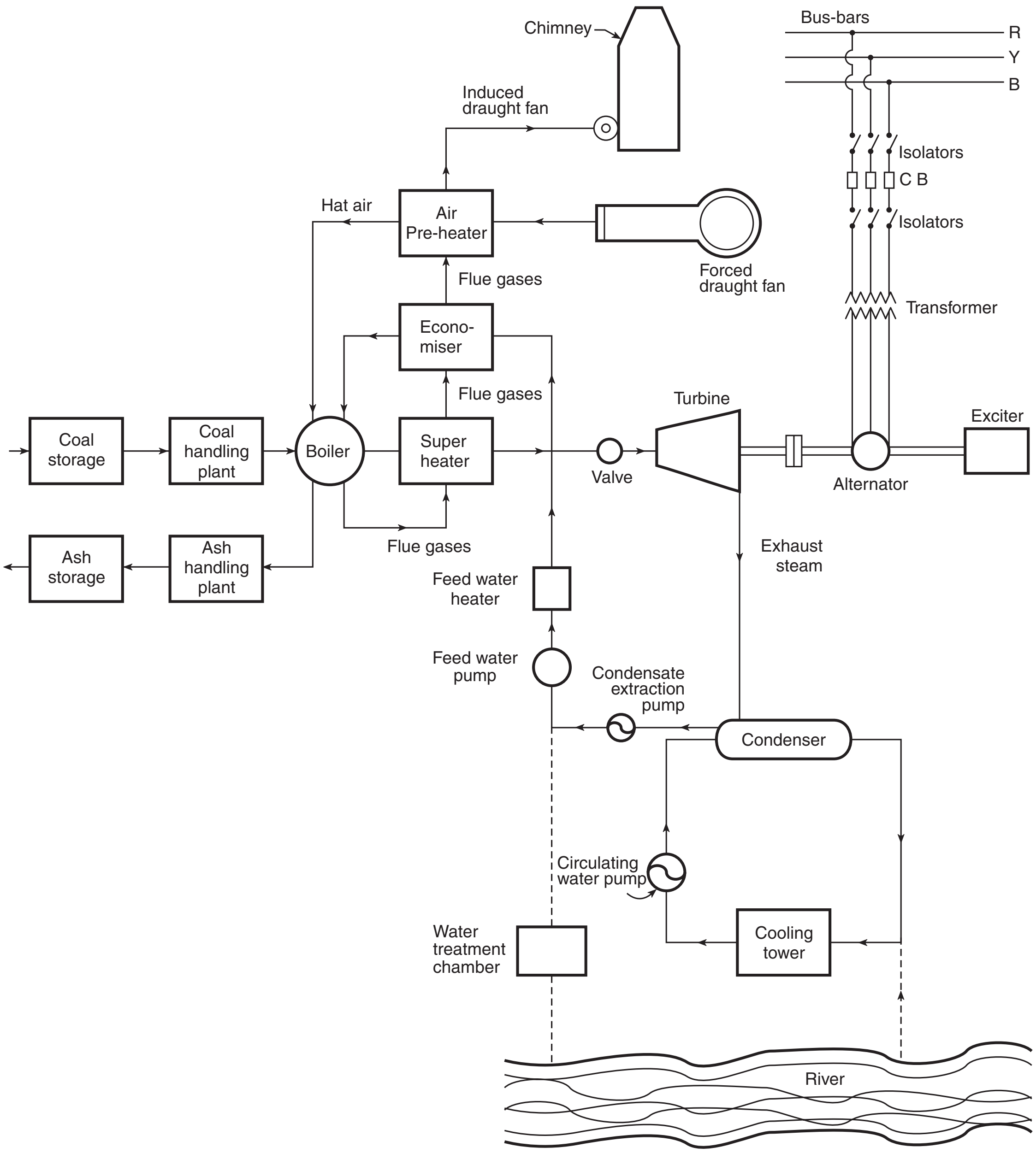

Fig. 2.9. Schematic arrangement of Steam Power Station

Economiser : An economiser is essentially a feed water heater and derives heat from flue gases for this purpose. The feed water is fed to the economiser before supplying to the boiler. The economiser extracts a part of heat of flue gases to increase the feed water temperature.

Air Preheater : An air preheater increases the temperature of the air supplied for coal burning by deriving heat from flue gases. Air is drawn from the atmosphere by a forced draught fan and is passed through air preheater before supplying to the boiler furnace. The air preheater extracts heat from flue gases and increases the temperature of air used for coal combustion. The principal benefits of preheating the air are : increased thermal efficiency and increased steam capacity per square metre of boiler surface.

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.

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.

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 economiser. This helps in raising the overall efficiency of the plant.

Cooling Arrangement : 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.

2.8 EFFICIENCY OF STEAM POWER STATION

The overall efficiency of a steam power station is quite low (about 29%) mainly due to two reasons : (*a*) a huge amount of heat is lost in the condenser and (*b*) 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.

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.*

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

2.10 CAPACITY OF POWER PLANTS

The installed capacity of the power plants can be determined by studying the load duration curve and the anticipated future demands. As a minimum requirement, the plant capacity must be equal to at least the peak load. Capacity of power plant can be determined by :

1. The present demand of power by the industry and other utilising organisations.
2. The future demand and prospects of developments of industry in the next 10 to 15 years, which can approximately be obtained by projecting the increase in load demand in the past 10 years or so.
3. Availability of water supply. The scarcity of water in abundance at a particular place plays definitely a limiting part in the capacity of the station.
4. Possibility of interconnection of power stations to the existing systems. Capacities of turbine and generator are related as :

$$\text{Turbine, kW} = \frac{\text{Generator kW}}{\text{Generator efficiency}}$$

Generator size should be larger, because larger units have

(*a*) lower cost per unit capacity;

(*b*) higher efficiency;

(*c*) lower space requirement for unit capacity.

Hence, larger size commensable with load curve should be chosen.

2.11 CHOICE OF SITE FOR THERMAL POWER STATIONS

In practice, the following plants should be considered in order to decide the location of the power station to achieve overall economy.

Cost and Type of Land : Thermal power stations should be located at a place where land is cheap. The cost of land will be high in the city, and will be low in rural areas. Moreover, the bearing capacity of land should be adequate so that heavy machinery could be installed. The land should be such that acquisition of private property should be minimum, preferably avoided.

Availability of Water : A large amount of water is required for condensers, etc. Approximately 560×10^3 kg of water is required for every 1 tonne of coal burnt. Therefore, thermal power plant should be located at the bank of a river or near a canal to ensure the continuous supply of water.

Supply of Fuel : The thermal power station should be located near the coal mines so that transportation cost of fuel is minimum.

Cost of Fuel : The fuel to be used in the power station should be cheap and available nearby or ample facilities for its transportation to the site should be available.

Nearness to Load Centre : In order to reduce the transmission cost, the plant should be located near the centre of the load. This is particularly important that dc supply system is adopted.

Distance from Populated Area : The plant should be located at a considerable distance from the populated area to minimise pollution in the populated areas.

Ample Space : There should be ample space for the future expansion of power station.

Disposal of Ash : Facility for the disposal of ash, etc. should be available.

Interest of National Defence : The site should be such as to serve the interests of national defence.

Ample Accommodation : Ample accommodation for the operational and maintenance staff should be available nearby at reasonable rates.

Obstruction : The chimney of the power station should not obstruct the flying of aeroplanes if the power station is near an aerodrome.

Design : The design of the plant should be such that the by-laws of country and town planning should not be infringed.

Foundation : The soil should be such as to provide good and firm foundation to the building and plants.

It is clear that all the above factors cannot be favourable at one place. In particular, a site by riverside, where sufficient water is available, no pollution of atmosphere occurs and fuel can be transported economically, may perhaps be an ideal choice.

2.12 MAIN PARTS AND WORKING OF STEAM POWER STATION

A steam power station basically works on the Rankine cycle. Steam is produced in a boiler, is expanded in the prime mover and is condensed in a condenser to be fed into the boiler again. In practice, however, a good number of modifications/improvements are affected so as to have heat economy and to increase the thermal efficiency of the station. Schematic layout of a typical coal fired modern power station is shown in Fig. 2.1. The plant can be divided into different circuits, namely

(*i*) Fuel and Ash Circuit
(*ii*) Air and Gas Circuit
(*iii*) Feed Water and Steam Generating Circuit
(*iv*) Steam Generating Equipment
(*v*) Condenser
(*vi*) Prime Movers
(*vii*) Water Treatment Plant
(*viii*) Cooling Water Circuit
(*ix*) Electrical Equipment

Fuel and Ash Circuit: Fuel (coal) from the storage is fed to the boiler through fuel feeding device. Ash produced as a result of combustion of coal collects at the back of the boiler and is removed to ash storage through ash handling equipment.

low pressure and high pressure after heaters from suitable extraction points of the turbine. The steam finally mixes with the feed water and is sent to the boiler drum.

Steam Generating Equipment : This is an important part of the steam power station. It is concerned with the generation of superheated steam and includes boilers, economiser, air-preheater, superheater and other heat reclaiming devices.

Boilers : Boiler is a closed vessel in which water is converted into steam by utilising heat of combustion. Steam boilers are briefly classified into two types : (1) fire tube and (2) water tube types. Generally, water tube boilers are used for electric power stations.

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. Water tube boilers have a number of advantages on fire tube boilers.

Fire tube boilers have low initial costs, are more compact but are more likely to explode. Further, because of water volume being more and circulation being poor they cannot meet quickly the changes in steam demand. For the same output the outer shell of a fire tube boiler is much larger than that of a water tube boiler. Water tube boilers have less weight of metal for a given size, are less liable to explosion, produce higher pressure, are easily accessible and can respond quickly to changes in steam demand. Tubes and drums of water tube boilers are smaller than those of fire tube boilers. Whereas the maximum working pressure in a fire tube boiler is limited to only 17 kg/cm^2 gauge, pressures as high as 125 kg/cm^2 gauge and temperatures from 315°C to 575°C are attainable with water tube boilers. Water tube boilers require lesser floor space. Figure 2.12 shows a water tube boiler in a simplified form.

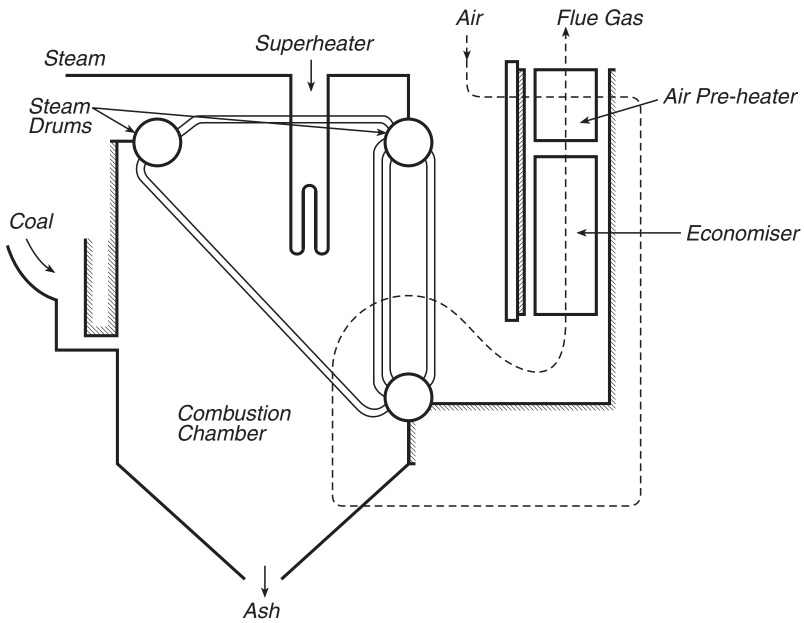

Fig. 2.12

In the boiler, heat transfer takes place through the walls of the tubes and the drum or drums are protected from direct contact with hot flue gases. The steam is superheated in a superheater before passing through the boiler to the prime mover. The fuel is burnt in the furnace of the boiler. For efficient combustion enough air has to be supplied. Natural draught is provided by the chimney and additional draught by I.D and/or F.D. fans. Heat is produced owing to combustion of the fuel. The gaseous products of combustion give most of their heat to the water in the tubes of the boiler and superheater. In order to make use of the remaining heat, the gases are made to pass through an economiser thereby heating the feed water in the economiser tubes. The gases then pass through an air heater arrangement thus providing initial heat to the air before it is admitted to the furnace. Finally the flue gases pass out to the atmosphere through the chimney.

Arrangements for feeding fuel to the boiler furnace are discussed in a subsequent section. Air is supplied through the F.D fans below the grate. The ash pits receive the burnt fuel in the form of clinker and ash. As stated earlier the flue gases after leaving the boiler damper flow through the economiser, air preheater and I.D. fan to the chimney.

Water tube boilers are available in a number of different designs : they may be straight or bent tubes, longitudinal or cross drum, horizontal, vertical or inclined tube, forced or natural circulation, single or multi-drum, etc.

The most important consideration in the design of a water tube boiler is the circulation of water within the tubes. Special designs of boilers using high steam pressures employ forced circulation while most of the conventional water tube boilers depend upon natural circulation of water through the tubes.

The boiler drum contains both steam and water, the former being tapped from the top of the drum where the highest concentration of dry steam exists. A number of accessories such as water level indicators, feed water regulators, safety valves, blow down valves, soot blowers, automatic alarms, pressure gauges etc. are usually fitted on the boiler. The use of these devices assists in adequate control and operation of the boiler as also in safety against accidents.

Economiser : The purpose of economiser is to heat feed water so as to recover a part of heat which would otherwise be lost through flue gases. 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. An economiser consists of a large number of closely spaced parallel steel tubes connected by headers of drums. The feed water flows through these tubes and the flue gases flow outside. A part of the heat of flue gases is transferred to feed water, thus raising the temperature of the latter.

Air Preheater : Since the entire heat of the flue gases cannot be extracted through the economizers air preheaters are employed to recover some of the heat in these gases. On an average an increase of 20°C in the air temperature results in an increase in the boiler efficiency by 1%.

The use of air preheater is more economical with pulverised fuel boilers because the temperature of flue gases going out is sufficiently large and high air temperature (250 to 350ºC) is always desirable for better combustion.

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.

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*.

(*a*) Impulse turbines (*b*) Reaction 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

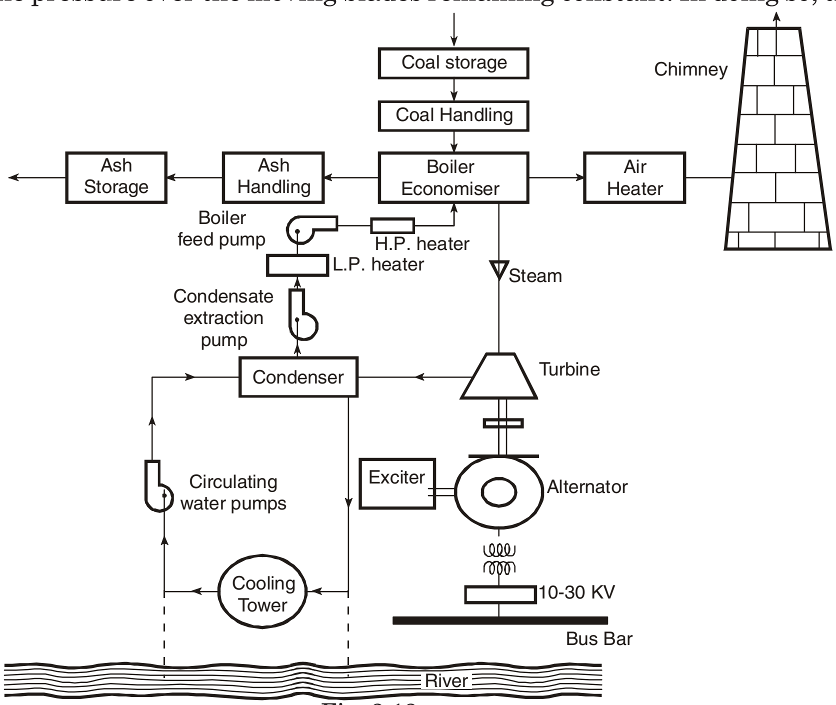

Fig. 2.13

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 set the rotor in motion.

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 suspended impurities are removed through sedimentation, coagulation and filtration. Dissolved gases are removed by aeration and degasification. The water is then '*softened*' by removing temporary and permanent hardness through different chemical processes. The pure and soft water thus available is fed to the boiler for steam generation.

The layout of a thermal power plant is shown in Fig. 2.13. The single line diagram of a typical transmission and distribution system is shown in Fig. 2.14.

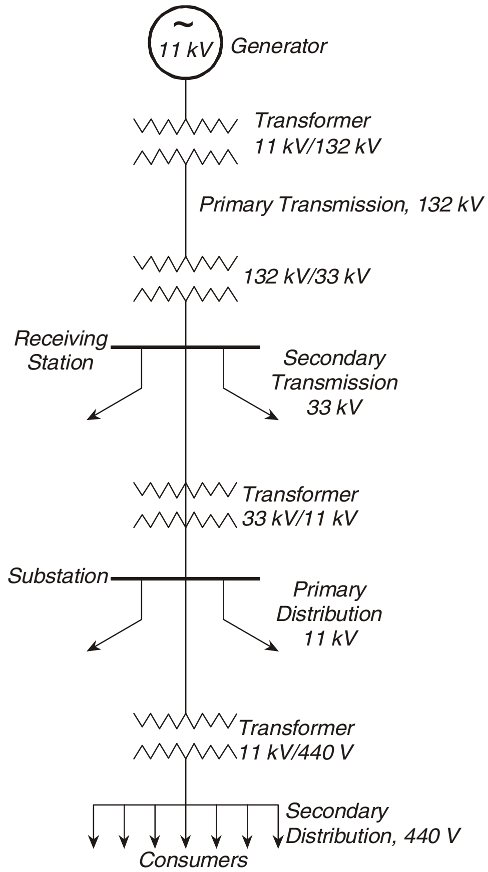

Fig. 2.14

1. Solid fuels such as coal.
2. Liquid fuels such as heavy oil, diesel oil and petrol.
3. Gaseous fuels like natural gas and coal gas.

Coal : Coal is a general term which consists of solid minerals with widely differing compositions and properties, although all are essentially rich in amorphous elemental carbon. Coals are classified in increasing order of heat value into following : peat, lignite, bituminous, semi-bituminous, semi-anthracite and anthracite.

Peat : It is considered the first geological step in coal's formation. Peat is heterogeneous material consisting of decomposed plant matter and inorganic materials. It contains upto 90% moisture. Because of its abundance, it is used in some electric generating plants and in district heating.

Lignite : The lowest grade of coal, lignite, derives its name from latin lignum which means wood. It is brown and laminar in structure, and remnants of wood fibre are often visible in it. It originates mostly from resin-rich plants and is therefore high in both inherent moisture, as high as 30%, and volatile matter. Because of high moisture content and low heating value, lignite is not economical to transport over long distances and it is usually burnt by utilities at the mine site.

Bituminous Coal : The largest group, bituminous coal, is a broad class of coals containing 46 to 86 mass per cent of fixed carbon and 20 to 40% of volatile matter of more complex content than that found in anthracite. Bituminous coal burns easily, especially in pulverised form. The bituminous rank is subdivided into five groups : low volatile, medium volatile and high volatile A, B and C. The lower the volatility, the higher the heating value. The low volatility group is grayish black and granular in structure, while the high volatility groups are homogenous or laminar.

Anthracite : This is the highest grade of coal. It contains a high content, 86 to 98 mass per cent of fixed carbon on a dry and low content of volatile matter, less than 2 to 14 mass percent, mainly methane. Anthracite is a slimy black dense hard brittle coal that borders on graphite at the upper end of fixed carbon. It is slow-burning and has a heating value just below that of bituminous coal. Its use in steam generators is largely confined to burning on stokers, and rarely in pulverised form.

The anthracite rank of coal is subdivided into three groups. In descending order of fixed carbon percent, they are meta-anthracite, greater than 98%; anthracite, 92 to 98%; and semi-anthracite 86 to 92%.

Liquid Fuels : Liquid fuels are an excellent energy source. They are easy to handle, store, burn and have nearly constant heating values. They are usually a mixture of hydrocarbon that may be represented by the molecule C_nH_m where m is a function of n that depends upon the family of the hydrocarbon. Some of commonly used liquid fuels for power engineering are the following :

(*i*) Gasoline or petrol. (*ii*) Paraffins.
(*iii*) Diesel oil. (*iv*) Heavy fuel oil.

Advantages

(*i*) Higher calorific value.

(*ii*) Low excess air is used to reduce the combustion losses.

(*iii*) Less space is required.

(*iv*) Cleanliness.

(*v*) Changes in load can be met easily.

(*vi*) Operational labour is less and overheads are reduced.

Liquid fuels are much commonly employed in IC engine plants.

Disadvantages

The great disadvantage of liquid fuels is that the heat produced is costly as compared to coal or gas. Moreover, in a country like India, where natural resources of oil are in short supply, application of oils for power production is limited.

Liquid fuel oil contains more percentage of hydrogen as compared to coal, the moisture carried by gas per kg of fuel burnt is considerably more. This results in lower overall combustion efficiency of the plant as compared to the coal burning.

Gaseous Fuels : These fuels can be broadly divided into natural gas and manufactured gas. Natural gas comes out of gas wells and petroleum wells. It contains 60% to 95% of methane with small amounts of other hydrocarbons. The natural gas is carried through pipes to distances which are hundreds of kilometres from the source. The cost of such transmission is often high. It is a colourless, odourless and non-poisonous gas.

Manufactured Gas : Manufactured gases are used for the generation of steam i.e. coal gas, blast furnace gas, coke oven gas, producer gas and town gas.

Gaseous fuels possess all the advantages of oil fuels except for ease of storage. The major limitation of using natural gas as fuel is that the power plant must be located near natural gas field otherwise the cost of transportation will be high.

2.14 CALORIFIC VALUE OF FUELS

The amount of heat produced by the complete combustion of a unit weight of fuel is known as its ***calorific value***.

It indicates the amount of heat available from a fuel. The greater the calorific value of fuel, larger is its ability to produce heat. In case of solid and liquid fuels, the calorific value is expressed in cal/gm or kcal/kg. However, in case of gaseous fuels, it is generally stated in cal/litre or kcal/litre. Table 2.1 gives various types of fuels and their calorific values along with composition.

1. The proper quantity of primary or secondary air needed for complete combustion.
2. Adequate stoker or grate area needed for burning particular quantity of fuel.
3. Attainment of proper designed temperature.
4. There should be no formation of caking during burning of fuel.
5. The operating and maintenance cost should be minimum.
6. The system should be easy to handle and dependable.

Mainly there are two ways of firing boilers :

(*a*) Solid fuel firing.
(*b*) Pulverised fuel firing.

2.17 THE SOLID FUEL FIRING

This type of firing can be achieved by the following two methods :

Hand Firing. Boiler of small output can be hand fired by putting the coal into the furnace frequently by shovels. The primary and secondary air required for combustion is regulated by dampers. Generally, the grate of such type of boilers consists of bars over which the coal is put.

Advantages

1. Hand firing is the simplest method of firing which involves very small capital investment.
2. Low grate type coal can be burnt.

Disadvantages

1. It is difficult to control the uniformity of combustion.
2. This method has lower combustion efficiency.
3. This method does not respond quickly to load fluctuations.

Mechanical Firing : The mechanical firing is a method of feeding the fuel into the furnace by means of mechanical stokers. The following are the advantages of mechanical stokers :

(*i*) The fuel can be uniformly fed into the furnace.
(*ii*) Combustion can be controlled.
(*iii*) Fluctuations of load demand can be met because of control of combustion.
(*iv*) The boiler output can be increased as more coal can be burnt.
(*v*) With proper control of primary and secondary air, poor grade of coals can also be burnt.
(*vi*) There is a saving in labour cost.

Mechanical stokers are of two types : (*a*) Under-feed stokers (*b*) Travel gate stokers. They are briefly explained below :

Under-feed stokers : In this type the fuel is burnt on the grate and the primary combustion air is fed under the grate and the secondary air is allowed at the top and as the fuel is burnt out it is pushed by forcing fresh fuel by means of rams or screw feeds under the fuel bed. The ignition occurs downwards against the primary airflow. The volatile matter filters through the bed and is completely burnt. If the rate of combustion of fuel is high, the ash contents are picked up by the primary air along with the combustion gases and delivered to atmosphere. When new fuel is fed over the bed of the stoker, most of the ash moves across the grate and falls into ash pit. Figure 2.15 represents the general scheme used for under-feed stokers.

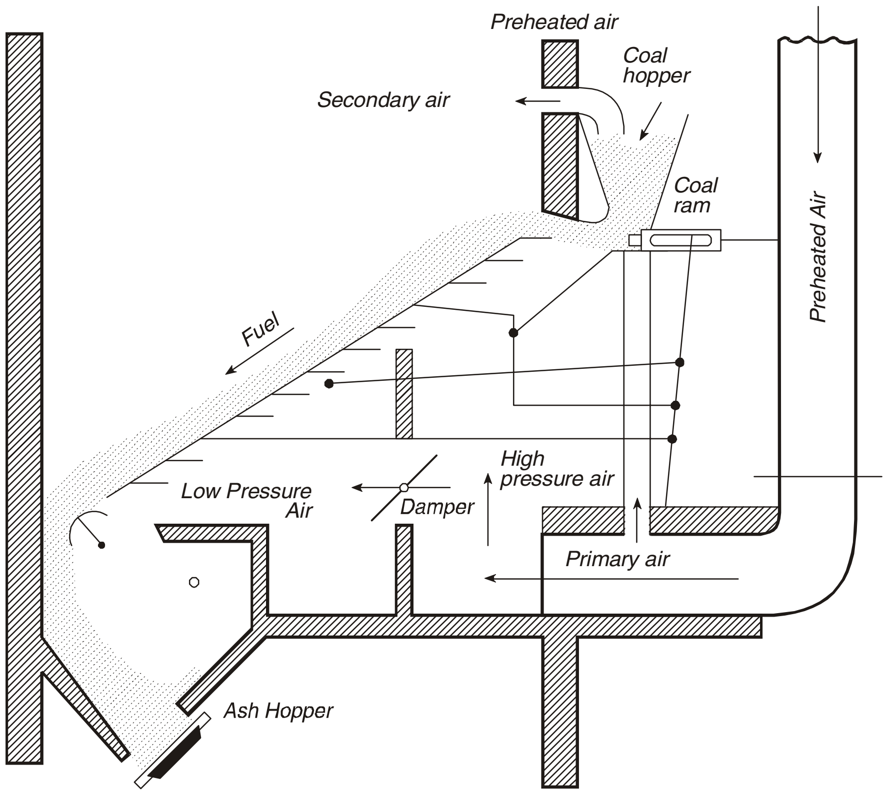

Fig. 2.15

Travel grate stoker. In this case the fuel is burnt on a chain grate which travels forward with a slow speed and by the time the travelling grate starts its back journey, the fuel over it is completely burnt out like the under-feed stokers, the ignition of the fuel takes place below the stoker and burning of the fuel takes place at the top. Again the ash contents are lifted up along with combustion gases and delivered to atmosphere unless checked. The dust content in flue gas is about 1/3rd less than in the under-feed stokers. Figure 2.16 shows the travel grate stoker.

5. This method is flexible and sudden variation in steam demand can be met.
6. The furnace has no moving parts subjected to high temperatures.
7. The surface area is increased.
8. The rate of evaporation is increased.
9. The efficiency of boiler is improved.
10. Firing of boiler becomes easy.
11. Fluctuation of loads can be easily met.
12. Losses due to banked fires are avoided.

However, the pulverised fuels have the following disadvantages:

1. The initial cost of pulverization plant is high.
2. Larger building space would normally be required especially with central system.
3. The running cost of pulverization plant from energy utilization point of view is also quite high.
4. The high furnace temperatures, unburnt fuel and the fluxing effect of ash, etc., deteriorate the refractory material.
5. Higher combustion temperatures cause high thermal losses in the flue gases.
6. There is danger of explosion.
7. Additional power is needed for pulverising coal.
8. It becomes difficult to arrest fine particles of coal going in the flue gases.

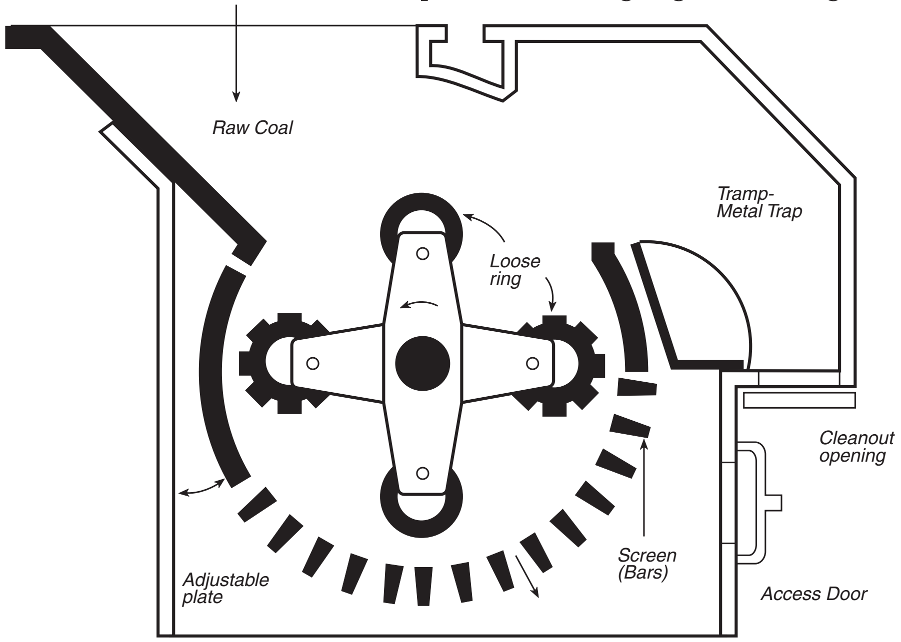

Fig. 2.17

For pulverisation, first the coal is passed into a preliminary crusher in which coal is crushed to 2.5 cm or less. Coal is usually delivered to a plant site already sized to meet the feed size required by the pulverising mill or the cyclone furnace. If the coal is too large, however, it must go through crushers, which are part of the plant coal handling system and are usually located in a crusher house at a convenient transfer point in the coal conveyor system.

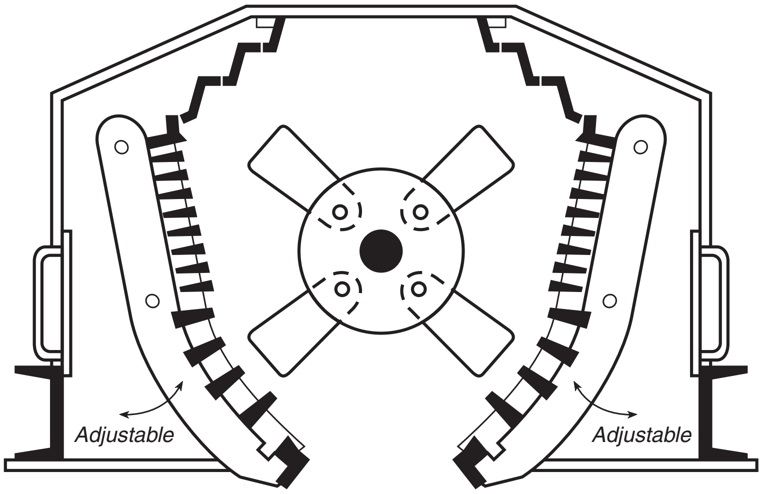

Fig. 2.18

Crushers : Although there are several types of commercially available coal crushers, a few stand out for particular uses. To prepare coal for pulverisation, the *ring crusher,* or *granulator* as shown in Fig. 2.9 and the *hammer mill* (Fig. 2.19) are used. The coal is fed at the top and is crushed by the action of rings that pivot off centre on a rotor or by swinging hammers attached to it.

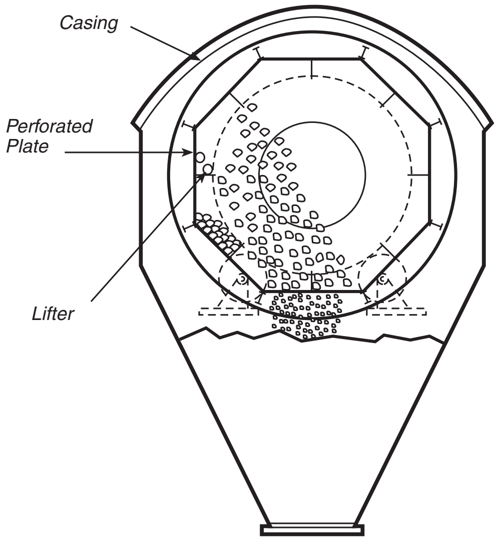

Fig. 2.19

are between a top stationary race or ring and rotating bottom ring, which is driven by the vertical shaft of the pulveriser. Primary air causes coal feed to circulate between the grinding elements, and when it becomes fine enough, it becomes suspended in the air and is carried to the classifier.

Hammer mill : High-speed pulverisers use *hammer beaters* that revolve in a chamber equipped with high-wear-resistant liners. They are mostly used with low-rank coals with high-moisture content and use flue gas for drying. They are not widely used for pulverised coal systems.

2.19 THE PULVERISED COAL SYSTEM

A total pulverised-coal system comprises pulverising, delivery, and burning equipment. It must be capable of both continuous operation and rapid change as required by load demands. There are two main systems : the bin or storage system and the direct-firing system.

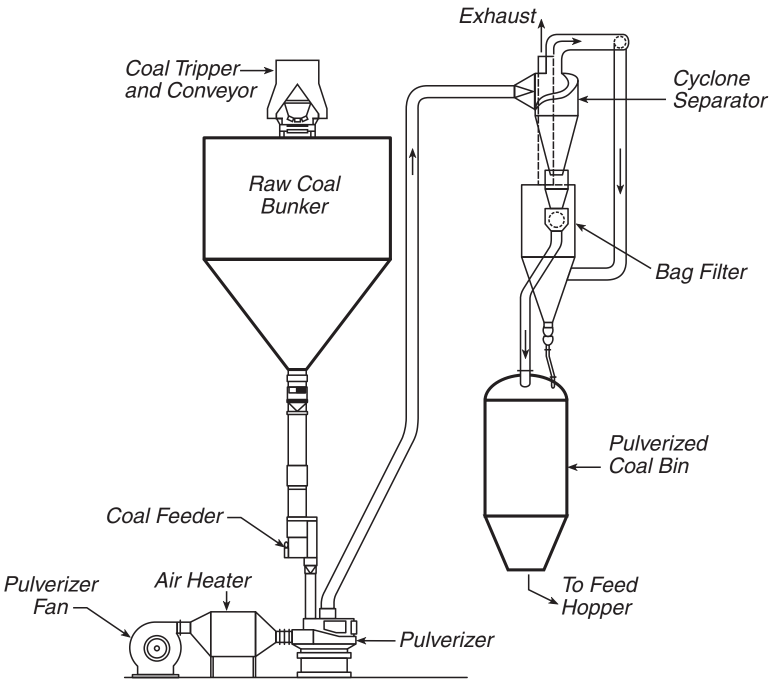

Fig. 2.20

The *bin system* is essentially a batch system by which the pulverised coal is prepared away from the furnace and the resulting pulverised-coal-primary-air mixture goes to a cyclone separator and fabric bag filter that separate and exhaust the moisture-laden air to the atmosphere and discharge the pulverised coal to storage bins shown in Fig. 2.20. From there, the coal is pneumatically conveyed through pipelines to utilization bins near the furnace for use as required. The bin system was widely used before pulverising equipment became reliable enough for continuous steady operation. Because of the many stages of drying, storing, transporting, etc., the bin system is subject to fire hazards. Nevertheless, it is still in use in many older plants. It has, however, given way to the direct-firing system, which is used exclusively in modern plants.

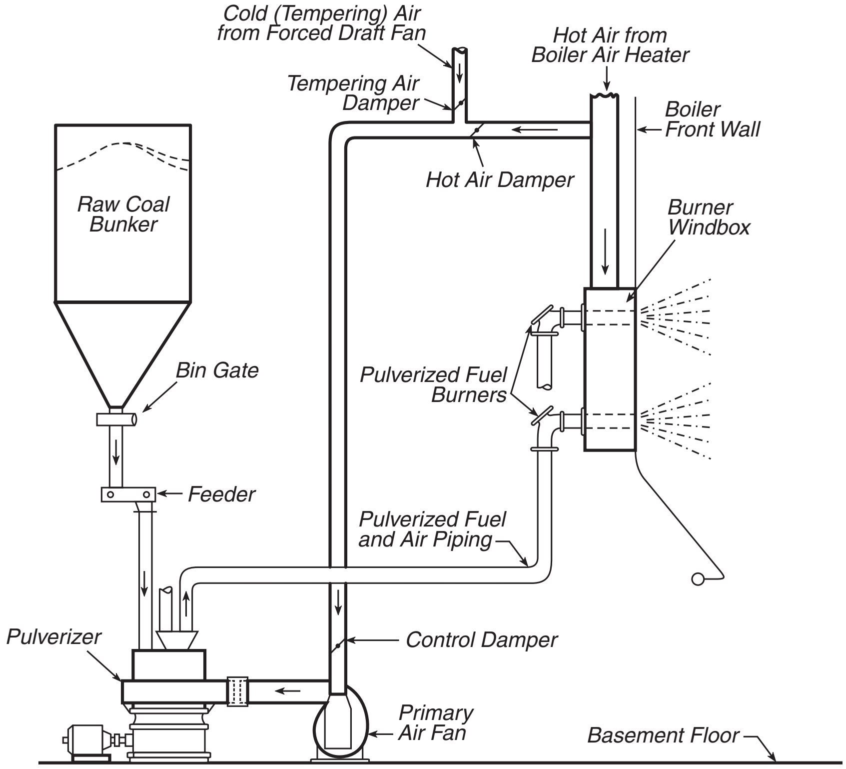

Fig. 2.21

Compared with the bin system the *direct firing system* has greater simplicity and hence greater safety, lower space requirements, lower capital and operating costs, and greater plant cleanliness. As its name implies, it continuously processes the coal from the storage receiving bunker through a feeder, pulveriser, and primary-air fan, to the furnace burners (Fig. 2.21). Fuel flow is suited to load demand by a combination of controls on the feeder and on the primary-air fan in order to give air-fuel ratios suitable for the various steam-generator loads. The control operating range on any one direct-firing pulveriser system is only about 3 to 1. Large steam generators are provided with more than one pulveriser system, each feeding a number of burners, so that a wide control range is possible by varying the number of pulverisers and the load on each of them.

Burners : A pulverised-coal *burner* is not too dissimilar to an oil burner. The latter must atomize the liquid fuel to give a large surface-to-volume ratio of fuel for proper interaction with the combustion air. A pulverised-coal burner already receives dried pulverised coal in suspension in the primary air and mixed it with the main combustion air from the steam-generator air preheater. The surface-to-volume ratio of pulverised coal or fineness requirements vary, though not too greatly, from coal to coal (the higher the fixed carbon, the finer the coal).

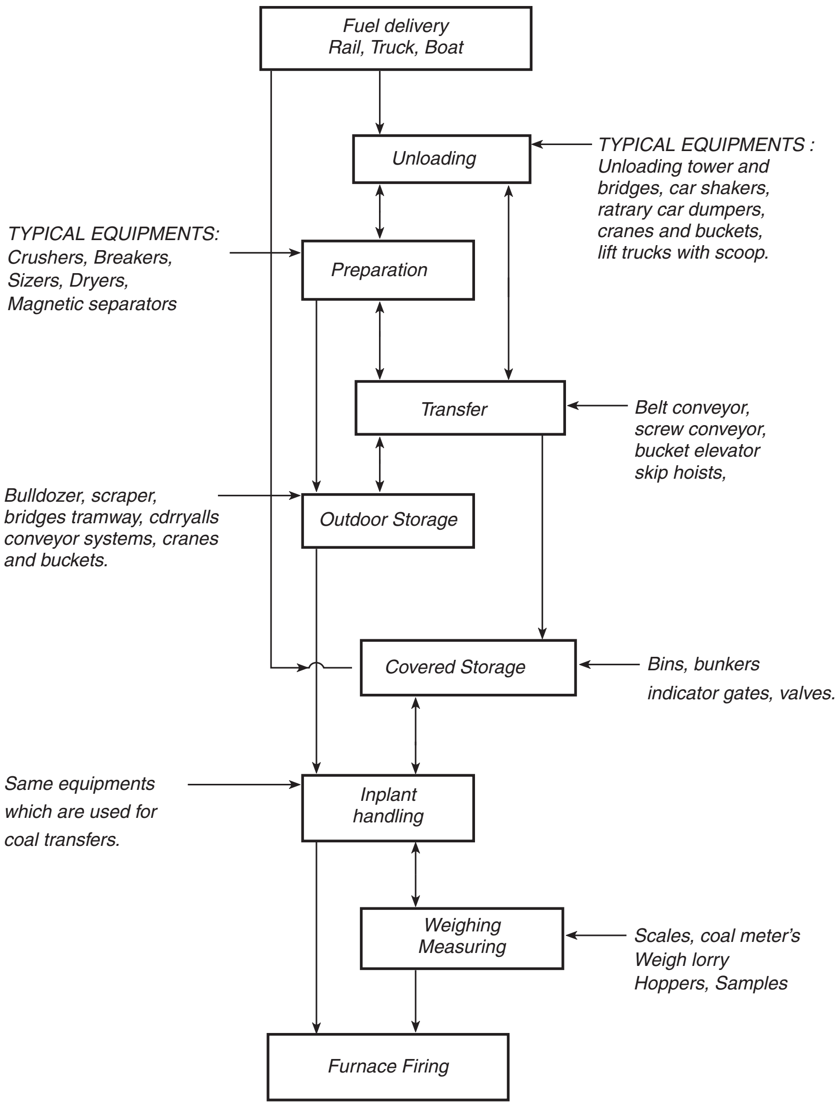

Fig. 2.22

Transfer : This means carrying coal from unloading point to the storage site from where it is discharged to the firing equipment. It may require one or more than one equipment depending on local conditions. Equipment used for this purpose may be one or more of the following:

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

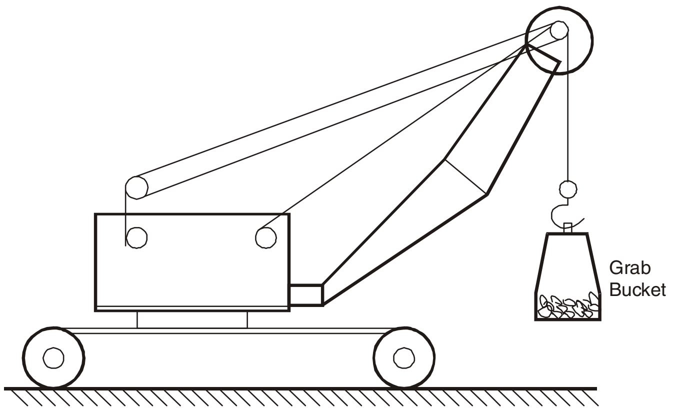

Fig. 2.23

Grab Bucket Conveyors : The grab conveyor can be used with crane or tower as shown in Fig. 2.23. This device is useful for lifting and conveying operations. It is a costly device consisting of 2 cubic metre bucket operating over a distance of 60 m may give transfer of about 100 tons/hr.

Belt Conveyor : It is used for hoisting and conveying. It is used for inclinations upto 20° to horizontal. With a load of about 50 to 100 tonnes/hr, its average speed ranges from 60 to 100 mt/minute to transfer the load through 400 metres. It consists of a belt of rubber or canvas, running over a pair of end drums of pulleys and supported at intervals by a series of rollers called *idlers*.

Advantages

The advantages of belt conveyor are given below:

1. The operation is clean and smooth.
2. The coal over the conveyor belt can be easily protected from wind and rain by providing overhead covers.
3. Large and continuous quality of coal can be transferred.
4. The repair and maintenance costs are minimum.
5. Power consumption is less as compared with other types of transport system.

Disadvantages

1. It is not suitable for short distances and greater heights.
2. Maximum inclination at which coal can be transported is limited to 20°.

Screw Conveyor : It consists of an endless helicoid screw rotating in a trough. The movement of the screw drives the material from one end of the conveyor to the other, and a discharge at any convenient part can be arranged through suitable slide gate. This conveyor is well suited for small applications where space limitations are there.

Advantages and disadvantages of screw conveyor are listed below:

would require equipment such as chutes, pulverising mills, feeders, weighing equipment and many others for inplant handling.

Coal Weighing : As stated earlier, cost of fuel is the major running cost of the plant. It is, therefore, very necessary to weigh coal at unloading point and also that used as feed to individual boilers. A correct measurement of coal enables one to have an idea of total quantity of coal delivered at the site and also whether or not proper quantity has been burnt as per load on the plant. Some of the methods used for weighing coal are:

(*a*) Weigh bridge
(*b*) Belt scale
(*c*) Automatic recording system

2.21 BOILERS

The boiler is one of the most essential elements in thermal power station. It consists of a closed vessel into which water is heated until it is turned into steam at the required pressure.

The following are the primary requirements of boilers :

1. The boiler must be capable of producing and maintaining the desired steam pressure safely.
2. The boiler should be capable of delivering safely the steam at the desired rate, pressure, temperature and quality.
3. The boiler should be such that it should be capable of supplying normally full load.
4. The boiler must be capable of burning high ash content coal efficiently.
5. As the units in operation may be required to shut down during off peak hours; it is necessary that the boiler must be capable of quick starting and loading.
6. The boiler must have minimum refractory material used, in order to increase its efficiency.
7. The boiler must be equipped with superheater, economizer and preheater.
8. Each boiler should be equipped with a mechanical ash precipitator or an electrostatic precipitator to extract about 97% of fly ash content in the flue gases.

Types of Boilers : The pressure boilers can be classified according to contents of tubular heating surface, *i.e.* water or gas and thus resulting into fire-tube boilers and water-tube boilers.

Fire-tube Boiler: It consists of tubes through which hot gases are passed and the water surrounds these tubes. Thus, it essentially consists of a shell which supports the fire-tube and contains water for steam. As water and steam both are in the same shell, higher pressures of steam are not possible the maximum pressure which can be had is about 17.5 kg/cm^2 and with a capacity of 9000 kg of steam per hour.

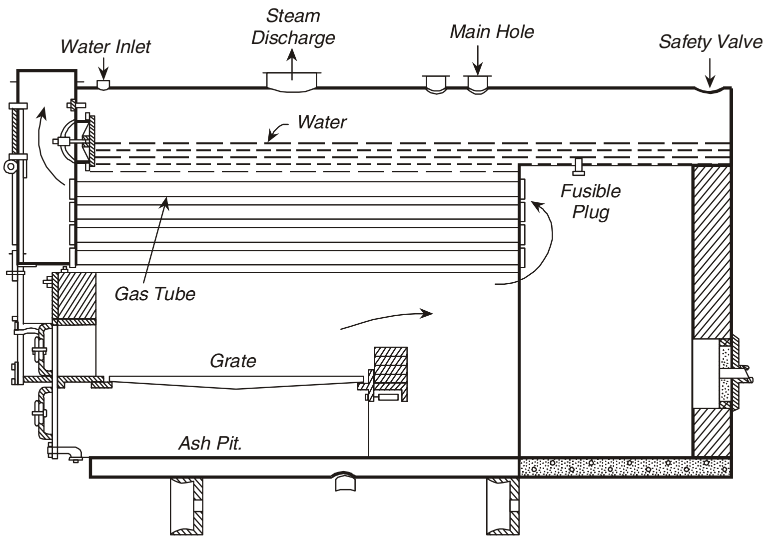

Fig. 2.24

It also consists of a horizontal drum into which are laid the fire tubes horizontally shown in Fig. 2.24. The tubes are submerged in water. The fuel is burnt below this horizontal drum and the combustible gases move to the rear, from where they enter into the fire tubes and travel towards the front into the smoke box. During its travel the products of combustion transfer their heat to water and the steam bubbles up and the pressure is developed in the drum.

The advantages of this type of boiler are :

1. It is quite compact.
2. Fluctuations of steam demand can be met easily.
3. It is quite cheap.

The disadvantages of fire tube boilers are :

1. Due to large quantity of water in the drum it requires larger time for steam raising.
2. High pressures of steam are not possible, maximum pressure that can be attained is about 17.5 kg/cm^2.
3. The output of the boiler is also limited.
4. The steam attained is generally wet.

Water-tube Boilers : Generally for pressure above 10 kg/cm^2 and capacities in excess of 7000 kg of steam per hour water boilers are used. It essentially consists of drums and tubes. The drums store steam and water. The tubes are always external to drum. In comparison to fire-tube boilers the drum in these types of boilers do not contain any tubular heating surface, so they can be built in smaller diameters and consequently they will withstand higher pressures. Normally, these boilers have natural water circulation due to convection current. Only Babcock and Wilcox boilers with longitudinal drum and bent tube boiler have been discussed here.

The advantages of water-tube boiler are :

diameter and length. The header design and tube diameter change with the pressure, being smaller for higher pressures. Baffles are arranged normally for two or three passes of combustion gases past the tubes. This type of boiler is suitable for all types of fuels and for hand and stoker firing. The pressure range is normally 11.5 to 17.5 kgf/cm^2, but it can be as high as 40 to 42 kgf/cm^2 and the steaming rates are normally up to 20000 kg per hour, but it can be as high as 40000 kg per hour. Figure 2.25 explains all the normal locations of the mountings on the boiler, the connections between the headers and the drum, supporting beams for the drum, the superheater section and the water tubes. It can be seen that the whole structure is more or less supported independent of the brick work.

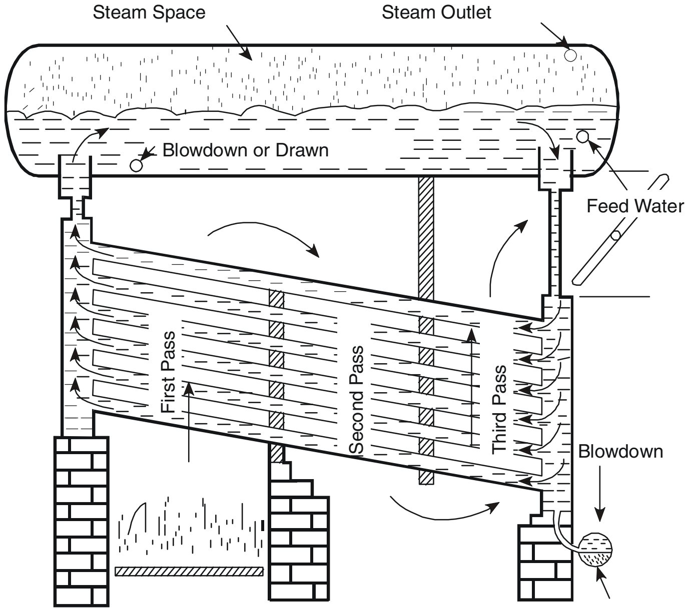

Fig. 2.26

In order to follow the path of combustion refer Fig. 2.26. The heat combustion gases rise up past the first portion of water tubes. They are compelled to go up due to the baffle provided. Due to another baffle, they course downward giving a second pass through the tubes, again rising up and giving a third pass before they pass out from below the drum to the stack. This arrangement of baffles varies in some boiler installations and the gases finally pass out to stack from the bottom.

The steam and water rise along the inclined tubes from the rear header to the front header. Then through the headers and the circulation tubes or risers to the drum. The front portion of the tubes and the header are in contact with higher temperature gases as compared to rear portion and thus more heat is received by front portion and more steam production is there and thus the density of combined water and steam is less in front portion as compared to rear portion. This argument becomes less and less effective with higher pressures. The water then circulates through the down comers to the rear header and finally to the tubes. Thus, the circuit is completed. If the tubes discharge to the drum at or above the water level line, the boiler is called exposed tube type boiler, otherwise it is submerged tube type.

Bent Tube Boiler : The bent tube boilers are now mostly used for power generation as there is more heating surface available. There are no headers used and the bent tubes are connected to drum and are so arranged to give better circulation.

The main elements of bent-tube, water-tube boiler are essentially drums or drums and headers connected by bent tubes. Most of the popular modern boiler designs for large central power station practice fall in this classification. Steaming capacities as high as 50000 kg per hour and pressure as high as 60 kgf/cm are obtainable with superheated steam up to about 450ºC.

2.22 ECONOMISER

Function of economiser is to recover some of the heat from the heat carried away in the flue gases up the chimney and utilize for heating the feed water to the boiler. It is placed in the passage of flue gases in between the exit from the boiler and the entry to the chimney. By its use fuel is economised and steaming rate is increased.

2.23 BOILER AUXILIARIES

The boiler auxiliaries are of two types (*a*) dealing with feed water equipment and, (*b*) flue gas equipment. The feed water equipment consists of

(*i*) Boiler feed pumps
(*ii*) Feed water regulators
(*iii*) Closed feed water heaters
(*iv*) Deaerating heaters
(*v*) Evaporator

The flue gas equipment consists of the following :

(*i*) Chimney
(*ii*) Breeching
(*iii*) Induced draught fans
(*iv*) Forced draught fans
(*v*) Dust collectors

A brief discussion of above auxiliaries is given below.

2.24 BOILER FEED PUMPS

The boiler feed pump is one of the most important auxiliaries. Function of a feed pump is to pump water to the water space of a boiler. There are many types of feed pumps—rotary and reciprocating. Rotary pumps are either driven by electric motors or small steam turbines. Reciprocating pumps are commonly run by the steam from the same boiler to which water is to be fed.

Therefore, weight of chimney gas = $(w + 1)$ kg/kg fuel.

Volume of 1 kg of flue gases at 0°C (273°K)

$$\approx \text{Volume of 1 kg of air at 273°K}$$

and $$V = \frac{RT}{P} = \frac{29.27 \times 273}{1.03 \times 10^4} = 0.7734 \text{ m}^3$$

where R is a constant equal to 29.27 and P is the atmospheric pressure.

The pressure difference being very small, of the order of a maximum of 25 mm of water column, the pressure can be treated as constant at furnace and chimney base for purposes of the calculation of volumes at highest temperatures.

Therefore, volume of 1 kg of air at temperature T_1°K = $0.7734 \times \frac{T_1}{273}$

or Volume of w kg of air at T_1°K = $\frac{0.7734 \times w \times T_1}{273}$ ...(*i*)

Volume of $(w + 1)$ kg of chimney gases at T°K

$$= 253H\left[\frac{1}{T_1} - \left(\frac{w+1}{w}\right) \times \frac{1}{T_1}\right] \text{ kgf.m}^2$$

$$Q = \frac{0.7734 \times \omega \times T}{273}$$

Density d of air at T_1°K = $\frac{\text{Mass}}{\text{Volume}}$

Using eqn. (*i*), $$d = \frac{w \times 273}{0.7734 \times w \times T_1} = 1.238 \frac{273}{T_1} \text{ kg/m}^3$$

Density of chimney gases at T °K

$$= \frac{\text{Mass of chimney gases}}{\text{Volume of chimney gas}}$$

$$= \frac{(w+1) \times 273}{0.7734 \times w \times T}$$

$$= 1.293\left(\frac{w+1}{w}\right) \times \frac{273}{T} \quad ...(ii)$$

Let H = height of the chimney required in metres measured from the grate level.

Pressure exerted per sq. metre at the fire grate level by a column of hot gas 1 metre height

= weight of one cubic metre

= density of gas in kg/m^3

Therefore, pressure exerted by a column of hot gas of H metre height

= density × H kgf/m^2

$$= 1.293\left(\frac{w+1}{w}\right)\times\frac{273}{T}\times H \ \text{kgf/cm}^2$$

Similarly, pressure exerted by a column of cool air of H metre height

$$= 1.293\times\frac{273}{T}\times H \ \text{kgf/cm}^2$$

Since the draught P in kgf/m^2 is due to the static pressure difference between the hot gas column in chimney of height H, and cool air column outside of height H,

therefore,
$$P = \left[\left(1.293\times\frac{273}{T}\times H\right)-\left(1.293\left(\frac{w+1}{w}\right)\times\frac{273}{T}\times H\right)\right] \text{kgf.m}^2$$

$$= 1.293\times 273\times H\left[\frac{1}{T_1}-\left(\frac{w+1}{w}\right)\times\frac{1}{T_1}\right] \text{kgf.m}^2$$

$$= 353H\left[\frac{1}{T_4}-\left(\frac{\omega+1}{\omega}\right)\times\frac{1}{T}\right]\text{kgf/m}^2$$

As 1 kgf/m^2 is equal to 1 mm of water column, therefore, if the draught is h mm of water column

$$h = 353H\left[\frac{1}{T_1}-\left(\frac{w+1}{w}\right)\times\frac{1}{T}\right] \text{mm of water}$$

Let the draught pressure P kgf/m^2 be produced by H' height (in metres) of hot gas column.

$$\therefore \quad H' = \frac{P\ (\text{kg/m}^2)}{\text{Density (kg/m}^3)} \text{ metre}$$

$$= \frac{1.293\times 273\times H\left\{\frac{1}{T_1}-\frac{w+1}{w\times T}\right\}}{1.293\times 273\left(\frac{w+1}{w}\right)\times\frac{1}{T}}$$

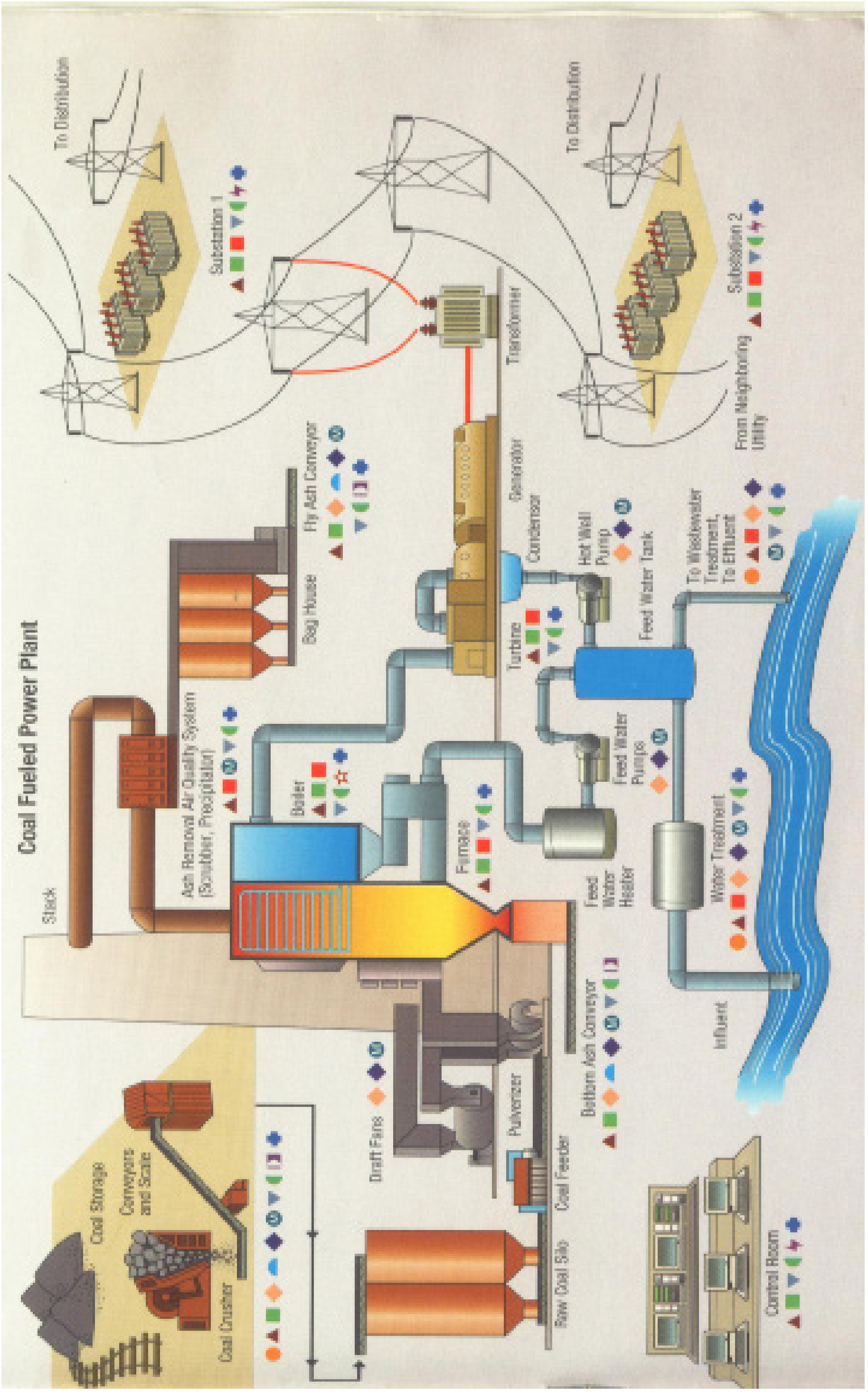
Coal Fueled Power Plant
Stack
Ash Removal Air Quality System (Scrubber, Precipitator)
Bag House
Fly Ash Conveyor
Boiler
Furnace
Turbine
Generator
Condenser
Transformer
Hot Well Pump
Feed Water Tank
Feed Water Pumps
Feed Water Heater
Water Treatment
To Wastewater Treatment, To Effluent
Influent
Coal Storage
Conveyors and Scale
Coal Crusher
Raw Coal Silo
Coal Feeder
Pulverizer
Draft Fans
Bottom Ash Conveyor
Control Room
Substation 1
Substation 2
To Distribution
To Distribution
From Neighboring Utility

Fig. 2.27.

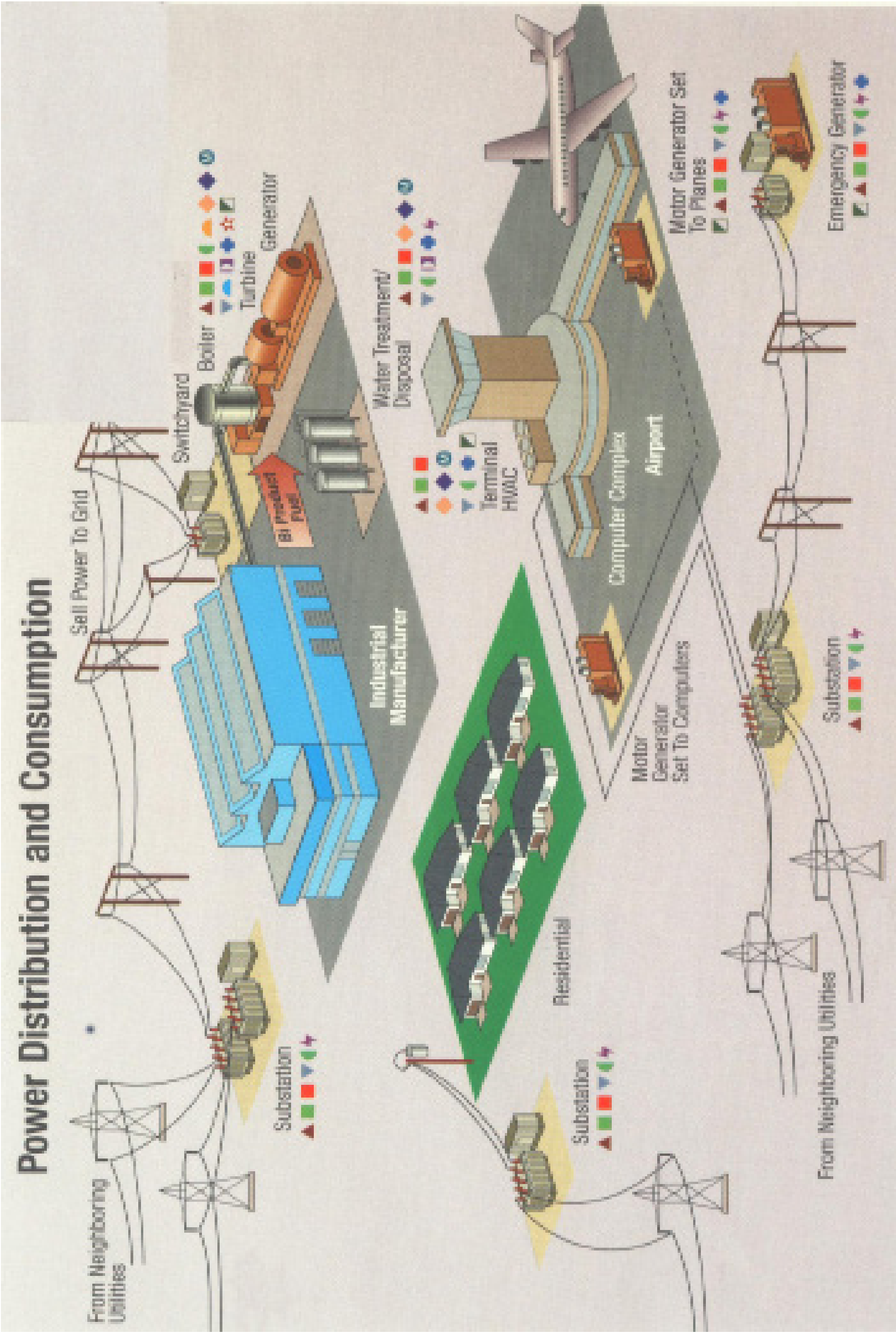
Power Distribution and Consumption
From Neighboring Utilities
Substation
Sell Power To Grid
Switchyard
Boiler
Turbine
Generator
Bi Product Fuel
Industrial Manufacturer
Water Treatment/ Disposal
Terminal HVAC
Computer Complex
Airport
Residential
Substation
Motor Generator Set To Computers
Substation
Motor Generator Set To Planes
Emergency Generator
From Neighboring Utilities

Fig. 2.28.

A Distributed Automated Control System (DACS) can be provided in power transmission and distribution system by allowing seamless integration of delivery system components. By distributing control decisions to the substation PLC, the Energy Management System and system operator can focus on higher level tasks. Power distribution and consumption for various consumers is shown in Fig. 2.28.

Industrial controls, such as the SMC Dialog Plus™ smart motor controller which features a phase rebalance function that extends motor life can be integrated seamlessly into a control system.

PLC controllers-based solutions can play a critical role in any system architecture, including master and remote SCADA functions. Programmable controllers can integrate several industry-specific protocols, like UCA, Ethernet™ and DNP 3.0, into one platform. In addition, these architectures are smart enough to provide stand-alone control, freeing the master to handle higher level tasks and applications.

Operation

Data exchange is critical to the smooth operation of today's electric power facilities. Automation products facilitate better data acquisition and improved operator efficiency. For example, PLC controllers with analog modules can be used to gather data, and using a wide range of Microsoft-compatible software tools, can depict various measurements remotely. The compiled data can be used for a variety of purposes, including daily reports and process improvement efforts.

Software RSView™ and RSTools™ human-machine interface packages include alarms, data trending and logging, and overall supervisory control features to help operators pinpoint critical problems immediately. On the plant floor, electronic operator interfaces such as Panel View maximize productivity through intuitive screens and displays, and allow data archiving to allow operators to analyze a problem later. Solutions also empower operators, through prioritized process alarming and simplified reports, to quickly recover from system level faults.

In large plants, SCADA solutions facilitate prompt remote identification and resolution of power quality problems. Integrating distributed process control and telemetry components optimizes performance, helping reduce peak demand charges. Finally, PLC solutions can adjust substation equipment parameters to react to line variations, also enhancing performance.

Automation is committed to help extending automation equipment's life through plant and process-specific maintenance programs, as well as tailored training for maintenance personnel. Field engineering services, long-term service contracts, inventory management services, and local distributor support can be provided by the Industry. Finally, remote diagnostics offer the opportunity for proactive maintenance.

Vibration monitors can be integrated into a generator control system, to help identify and relay any irregular information, triggering a "repair needed" readout for maintenance personnel. Power monitor device and Line Synchronization Modules (LSMs) help ensure reliability by optimizing loads, controlling line conditioning apparatus, and controlling co-generation equipment. Reliance motors and Kato generators feature "smart" diagnostics, alerting operators to maintenance needs.

$$V \propto \frac{T}{P}$$

or $$V = \frac{RT}{P}$$

where R is the characteristic constant of gas, P is the absolute pressure of gas in kgf per square metre, V is the volume of gas in cubic metres and T is the absolute temperature of gas in °K.

Difference of pressure (ΔP) = height of chimney (H)[$\rho_{air} - \rho_{flue}$] kg/ mm^2

As h mm of water $= h$ kg/m^2

$\therefore$ $$\Delta P = 20 \text{ kg/m}^2$$

$$\rho_{air} = \frac{1}{V} = \frac{P}{RT}$$

Barometer reading = 762 mm of Hg.

But 735.5 mm of Hg = 1 kgf/cm^2

$$P = \frac{762}{735.5} = 1.036 \text{ kgf/cm}^2$$

$$= 1.036 \times 10^4 \text{ kgf/m}^2$$

$$\rho_{air} = \frac{1}{V} = \frac{1.036 \times 10^4}{29.27 \times (273 + 25)}$$

$$= \frac{1.036 \times 10^4}{29.27 \times 298} = 1.188 \text{ kg/m}^2$$

$$\rho_{flue} = \frac{1}{V} = \frac{P}{RT}$$

$$= \frac{1.036 \times 10^4}{26 \times (273 + 280)}$$

$$= \frac{1.036 \times 10^4}{26 \times 553}$$

$$= 0.720 \text{ kg/m}^2$$

$$H = \frac{20}{1.188 - 0.720} = \frac{20}{0.468}$$

$$= 42.74 \text{ m}$$

REVIEW EXERCISE

1. Define the first law of thermodynamics and open system.
2. Describe the second law of thermodynamics and its applicablility to the steam power plants.
3. Discuss the various operations of Rankine-cycle.
4. Explain a regenerative cycle with diagram.
5. Give the advantages and disadvantages of regenerative cycle over Rankine cycle.
6. Explain the working of binary vapour cycle.
7. How are steam power plants classified?
8. Give the layout of a modern steam power plant and explain it briefly.
9. What are the essential requirements of steam power station design?
10. What factors should be taken into consideration while selecting the site for steam power plant?
11. How can the capacity of a steam power plant be determined?
12. On what factors does the choice of steam conditions depend?
13. Explain with the help of a diagram the working of a "cyclone separator".
14. Define the "collection efficiency" of a dust separator?
15. What is the function of a boiler chimney?
16. Why is there no chimney in the case of a locomotive boiler?
17. What do you understand by the term "boiler draught"?
18. What are the limitations of chimney draft?
19. Define the chimney efficiency and find out the expression for the same.
20. What are the various types of draughts used in usual practice?
21. What are the advantages of artificial draught over natural draught?
22. What do you understand by steam jet draught? Where is it generally employed?
23. How are boilers classified?
24. Explain with neat sketches the construction and working of any two of the following high pressure boilers?

    (*a*) LaMont boiler (*b*) Loeffler boiler (*c*) Benson boiler (*d*) Velox boiler
25. Write short notes on the following :

    (*a*) Supercharged boilers (*b*) Supercritical boiler
26. Why are the accessories used in a boiler?
27. Explain briefly any two of the following boiler accessories.

    (*a*) Economiser (*b*) Air preheater (*c*) Superheater
28. How are feed water heaters classified?
29. What is an evaporator? How are evaporators classified? Write short notes on the following:

    (*a*) Equivalent evaporation (*b*) Factor of evaporation (*c*) Boiler efficiency

8. Tick out the *correct* statment.
   A. The stiffer the shaft is, the higher is its critical speed.
   B. The stiffer the shaft is, lower is its critical speed.
   C. The stiffness of shaft has nothing to do with its critical speed.
   D. Large size machines have their critical speed higher than their synchronous speed.
9. Induced draft fans are located at :
   A. The top B. The bottom
   C. In the middle part
   D. Can be anywhere, in the cooling tower
10. The overall thermal efficiency of a thermal power plant lies in the range
   A. 25% to 30% B. 35% to 40%
   C. 45% to 60% D. 65% to 80%
11. Economisers are normally used when boiler pressure exceeds
   A. 70 kg/cm^2 B. 50 kg/cm^2
   C. 30 kg/cm^2 D. for all pressures
12. In power plants, the condenser normally used is
   A. Surface type
   B. Jet type
   C. Both surface and jet type
   D. Regenerative type
13. For a thermal power plant, which is not the fixed cost ?
   A. Interest on capital
   B. Depreciation
   C. Cost of fuel
   D. All of these
14. Air will not be the working substance in a
   A. Diesel engine
   B. Petrol engine
   C. Open cycle gas turbine
   D. Closed cycle gas turbine
15. Major share of power produced in India is through
   A. Thermal power plant
   B. Hydro electric power plants
   C. Nuclear power plants
   D. Diesel power plant
16. A thermal power station was designed to burn coal containing 12% ash. When the plant actually started operating, coal having 22% ash was made available. Which unit of the plant will need modifications?
   A. Water treatment plant
   B. Pulverising unit
   C. Ash handling unit
   D. Cooling towers
17. In a thermal power station of moderate size, the electrical power is generated at a voltage of
   A. 11 V B. 230 V
   C. 440 V D. 11 kV
18. The electrical power being transmitted from generating point is called
   A. secondary transmission
   B. secondary distribution
   C. primary transmission
   D. primary distribution
19. The transmission line feeding power on either side of the main transmission line is called
   A. secondary transmission
   B. secondary distribution
   C. primary transmission
   D. primary distribution

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8. (A) 9. (C) 10. (B) 11. (C) 12. (A) 13. (B) 14. (A)
15. (A) 16. (C) 17. (D) 18. (C) 19. (B)