2. Dissolved gases

(*i*) Carbondioxide (*ii*) Oxygen
(*iii*) Nitrogen (*iv*) Methane
(*v*) Hydrogen sulphide.

3. Minerals and salts

(*i*) Iron and manganese (*ii*) Sodium and potassium salts
(*iii*) Flourides (*iv*) Silica.

4. Mineral acids. Their presence in water is always undesirable as it may result in the chemical reaction with the boiler material.

5. Hardness. The salts of calcium and magnesium as bicarbonates, chlorides, sulphates etc. are mainly responsible for the formation of a *very hard surface which resists heat transfer and clogs the passages in pipes*. Presence of these salts is known as hardness.

3.22.2. Troubles caused by the Impurities in Water

The impurities in water may cause one or more of the following troubles :

1. Scale formation 2. Corrosion
3. Carry over 4. Embrittlement.

1. Scale formation. The *formation of scale reduces heat transfer* and *simultaneously raises the temperature of the metal wall*. When temperature of boiler tube material reaches 450°C to 500°C, there is a serious danger of *overheating* and consequently *rupture of boiler plates*. The *scaling results from the decrease of solubility of some salt with increase of temperature*. It is formed by crystallisation of scale-forming salts from a locally super-saturated layer of water lying on the heating surface. This forms an incrustation at the point of evaporation. Scale is due to mainly the salts of *calcium* and *magnesium* as also to a certain extent the salts of *silicates*. *Calcium sulphate* is essentially responsible for the formation of scale.

The scale chokes the flow in the piping system and thus requires increased pressure to maintain water delivery. The accumulation of scale may become so thick that the temperature drop from gas to water is through the scale only. This will result in *overheating, blistering* and *rupturing*. When scale is formed, tubes are cleaned with electric-powered rotary brushes and cutters are pushed through the tubes during boiler overhaul.

2. Corrosion. *The corrosion is the eating away process of boiler metal.* Corrosion in power-plant equipment produces pits, grooves and cracks or a general wastage of the wall material. Allowed to continue, *corrosion ultimately makes metal parts fail.*

The corrosion is caused by an acid or low pH in addition to the presence of *dissolve oxygen and carbon dioxide* in the boiler feed water. The presence of oxygen is mostly responsible for corrosion among all other factors. Oxygen generally enters a closed system through make-up condenser leakage and condensate pump packings. The *carbon dioxide* is next to oxygen which is responsible for corrosion, it comes out of bicarbonates on heating and it combines with water to form weak acid known as carbonic acid. This acid slowly reacts with iron and other metals to form their bicarbonates. The new bicarbonates of metals formed are decomposed by heat once more and carbon dioxide is again liberated. This gas again unites with water to form carbonic acid and the cycle is repeated.

The corrosion can be controlled by adding alkali salts to neutralise acids in water and raise the pH value (it is the logarithm of the reciprocal of hydrogen ion concentration). The effect of CO_2 is neutralised by the addition of ammonia for neutralising amines in water. This is necessary because CO_2 lowers the pH of the boiler feed water. The effect of oxygen is reduced only by removing the oxygen from water. The corrosion of metal surfaces can be prevented by applying protecting coating of amines to the internal surfaces of boilers and economisers.

3. Carryover. Water solids carried over in the steam leaving a boiler drum are called *"carry-over"*. *Foaming* or *priming* of the boiler water forms the carry-over. In *"foaming"*, *bubles form on the* *water surface and may fill the drum steam space. Excessive amounts of sodium alkalinity,* or *finaly divided calcium phosphate, or oil may cause foaming. "Priming" refers to the vigorous and periodic surging of water in the boiler drum and throws water slugs into the leaving steam.* This may be *caused by excessive steaming rate, too high or fluctuating a water level, and improper boiler-water circulation.* Carryover may originate from mechanical or chemical causes.

The following detrimental results are caused by the carry-over. The water droplets carrying solids evaporate and build deposits in the valves, superheaters, and piping and even in the turbine or engine.

(*i*) *Superheater deposits reduce heat transfer and raise the tube-metal temperatures.*

(*ii*) *Deposits on turbine blade reduce efficiency and capacity and may unbalance the rotor.*

(*iii*) *Deposits forming on governing valves raise a serious hazard.*

Foaming and *priming* can be checked by taking the following prrecautions :

1. Valves not to be opened suddenly to maximum.
2. Water level in the boiler should be at its minimum possible level.
3. The boiler water should not contain oil, soap and other suspended impurities.

4. Embrittlement. *The caustic embrittlement is the weakening of boiler steel as a result of inner crystalline cracks.* Presence of certain concentration of sodium hydroxide causes embrittlement.

The following *three conditions contribute to embrittlement :*

(*i*) Slow boiler-water leaks through cracks or seams vapourises to leave behind a built-up of salts.

(*ii*) The metal must be stressed by cold working during fabrication, or riveting, or from expansion and contraction.

(*iii*) The concentrated water in a crack must have chemical properties that will attack the metal.

This defect is not very common but very important. It affects the drum and its presence cannot be traced so easily.

To *measure embrittlement, a detector is installed in the boiler* where boiler water will circulate over it continuously, as in a continuous blowdown line.

Some of the methods to *control embrittlement* are listed below :

1. Elimination of free sodium hydroxide from boiler water.
2. Maintenance of a definite ratio of sodium nitrate to sodium hydroxide.
3. Using waste sulphite liquor.

3.22.3. Methods of Feed Water Treatment

The different treatments adopted to remove the various impurities are enumerated and discussed as follows :

1. Mechanical treatment

(*i*) Sedimentation (*ii*) Coagulation

(*iii*) Filteration (*iv*) Interior painting.

2. Thermal treatment

(*i*) Deaeration (*ii*) Distillation by evaporators.

3. Chemical treatment

(*i*) Cold lime-soda softening process (*ii*) Hot lime-soda softening process

(*iii*) Lime-phosphate softening process

(*iv*) Ion exchange process which may be sodium zeolite process or hydrogen zeolite process.

4. Demineralisation

5. Blow down

(*i*) Hot lime-soda and hot zeolite process

(*ii*) Adding acid to control alkalinity and *vice-versa*.

1. Mechanical Treatment

(*i*) **Sedimentation.** In this process the water is allowed to stand at stand-still in big tanks so that solid matter settles down. The water at a very low velocity will also have the same process. These solid matters settled down could be removed from the bottom either periodically or continuously. Clear water is then drained out from the tank surface.

(*ii*) **Coagulation.** Coagulation of minute colloidal suspensions make them settle out easily. Adding a coagulation like aluminium sulphate or sodium aluminate improves the sedimentation or filtration process. A reaction between these salts and alkalinity in the water forms a gelatinuous material which makes small particles adhere to each other, forming larger particles that settle out or filter out more easily.

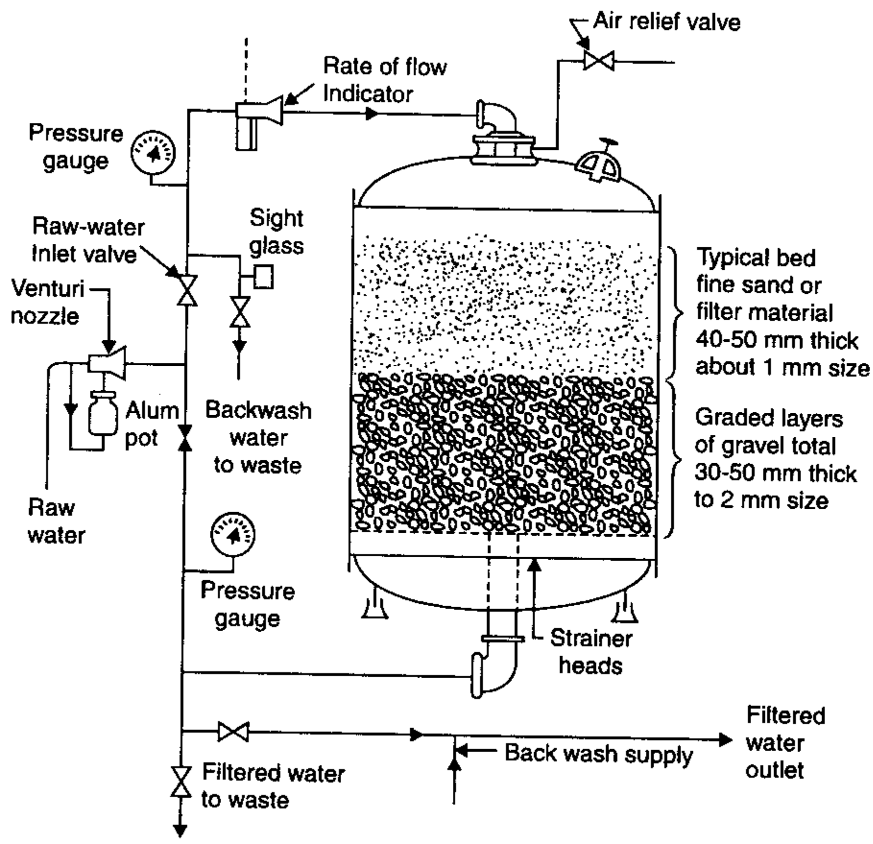


Fig. 3.139. Pressure filter.

(*iii*) **Filtration.** The suspended matter which cannot be removed during sedimentation are removed with the help of filtration. The water is allowed to pass through a bed of fine sand or graded sand and then a layer of gravels etc. as shown in Fig. 3.139. The suspended matter adheres to the filter material leaving the water clear as it drains from the bottom. The beds must be backwashed periodically to remove the dirt that collects in the voids of the filter material.

In case of pressure filter (Fig. 3.139) the water is forced through the filter by means of a pump whereas in gravity filter the water flows by gravity.

2. Thermal Treatment

(*i*) **Deaeration.** The *process of removing dissolved oxygen is known as* ***deaeration.*** This is done in deaerating heaters. If water is heated to a temperature of about 110°C with subsequent agitation, the dissolved oxygen is expelled.

Fig. 3.140 shows a *tray type deaerating heater.* In this heater feed water after passing through the vent condenser is sprayed upwards in the spray pipe. Water falls in the form of uniform showers over the heating trays and air separating trays and finally gets collected in the storage space. Steam enters the heater through a nozzle fitted in the side of heater shell. The entire space between the shell and tray compartment gets filled with steam. The steam makes its way downwards through the perforations in the top plate of tray compartment. While flowing downward the steam comes in contact with the falling water. Most of the steam condenses in between the spray and heating trays. From the bottom of heating trays, the remaining steam and separated gases such as oxygen etc. flow to the vent condenser. The steam used for heating may be main turbine bled steam or may be from other sources. Storage tank with controls help to add make up water when needed to maintain the feed water level.

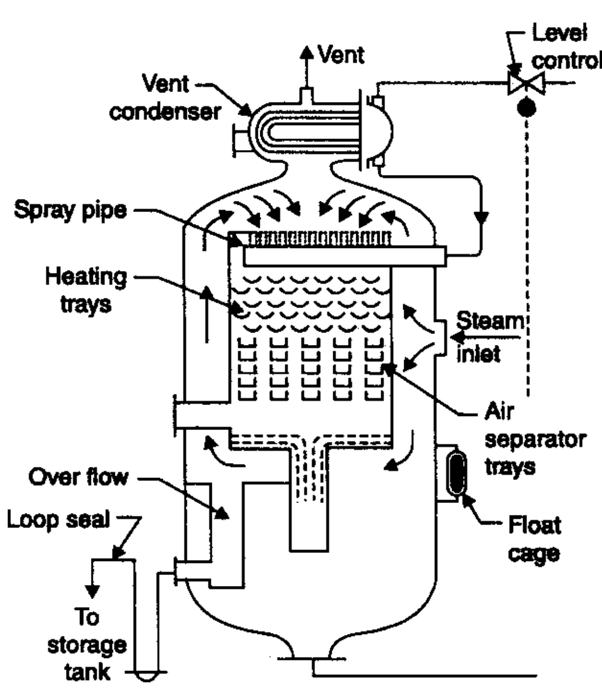


Fig. 3.140. Tray type deaerating heater.

(*ii*) **Distillation by evaporators.** An evaporator's function is to produce from raw water, vapour that can be condensed to distilled water for boiler feed make-up. In some cases the use of evaporators is required where the make-up water percentage is small say upto 4 per cent. In case of regenerative cycle, the evaporator is quite useful as the steam used for evaporation is being used in feed water itself. It has the advantage of requiring lesser or very little blow down of deconcentration in the boiler. An evaporator system may be *single effect* where steam is produced from one evaporator or *multiple effect* in which steam is produced from several evaporators in series. They may also be classified as *film type, flash type* and *submerged tube type.*

3. Chemical Treatment

Lime-soda softening process. This process uses calcium hydroxide (lime) and sodium carbonate (soda ash), to remove dissolved calcium and magnesium salt, by precipitating them. This may be done by either a *cold process* or *hot process*. The processes use these types of reactions :

$$Mg(HCO_3)_2 + 2Ca(OH_2) = Mg(OH)_2 \downarrow + 2CaCO_3 \downarrow + 2H_2O \quad ...(3.81)$$

$$MgCl_2 + Ca(OH)_2 = Mg(OH)_2 \downarrow + CaCl_2 \quad ...(3.82)$$

$$CaCl_2 + Na_2CO_3 = CaCO_3 \downarrow + 2NaCl \quad ...(3.83)$$

$$CaSO_4 + Na_2CO_3 = CaCO_3 \downarrow + Na_2SO_4 \quad ...(3.84)$$

The arrows show the molecule precipited from the solution.

Eqn. (3.81) : *All the carbonate hardness is precipitated out, leaving pure water.*

Eqns. (3.82 to 3.84) : *The non-carbonte hardness precipitates, to be replaced by soluble sodium salts.*

The magnesium hydroxide [$Mg(OH)_2$] acts as a coagulant and has the property of absorbing soluble silica from solution. The original matter hardness usually is not completely removed in hot process softner (used in power plants) because of the chemical cost. Even when some excess chemicals are used, the effluent hardness will range from 10 to 30 ppm (parts per million).

Hot-process phosphate softening uses trisodium phosphate and caustic sode to precipitate and remove calcium and magnesium hardness. The reactions are as follows :

$$3Ca(HCO_3)_2 + 6NaOH = 3CaCO_3 \downarrow + 3Na_2CO_3 + 6H_2O \quad ...(3.85)$$

$$3CaCO_3 + 2Na_3PO_4 = Ca_3(PO_4)_2 \downarrow + 2Na_2CO_3 \quad ...(3.86)$$

$$Mg(HCO_3)_2 + 4NaOH = Mg(OH)_2 \downarrow + 2Na_2CO_3 + 2H_2 \quad ...(3.87)$$

$$3CaSO_4 + 2Na_3PO_4 = Ca_3(PO_4)_2 \downarrow + 3Na_2SO_4 \quad ...(3.88)$$

Phosphates also remove silica compounds, which are troublesome in high pressure boilers. Phosphate chemicals cost more than lime-soda.

Ion Exchange Processes

(*i*) **Sodium zeolite process.** The zeolites are solid materials of a sandy texture. They remove various ions from the water replacing them with other iions of like charge. In case of sodium zeolite, the reactions are as follows :

$$Ca(HCO_3)_2 + Na_2Z = CaZ + 2NaHCO_3 \quad ...(3.89)$$

$$CaSO_4 + Na_2Z = CaZ + Na_2SO_4 \quad ...(3.90)$$

$$CaCl_2 + Na_2Z = CaZ + 2NaCl \quad ...(3.91)$$

(Z is the symbol used for zeolite).

Fig. 3.141 shows a typical zeolite softener. It consists of a shell holding a bed of active sodium zeolite supported by layers of graded gravel lying over a water distribution and collection system. *Zeolites almost completely remove hardness but do not reduce alkalinity or total solids.* Turbid water does not react well with zeolite sands. They do not remove silica and may even add it. The exhaustion capacity of the zeolite bed should be known, because regeneration should be started as soon as the exhaustion starts.

First back washing should be done by passing a strong current of water upwards. A measured quantity of common salt solution should then be injected in the softner. The salt reacts with the zeolite thus removing calcium and magnesium in the form of soluble cholrides. After salt rinse zeolite filter is ready to be used again. The equation of this reaction is :

$$CaZ + 2NaCl = Na_2Z + CaCl_2 \quad ...(3.92)$$

$$MgZ + 2NaCl = Na_2Z + MgCl_2 \quad ...(3.93)$$

The entire regeneration period should not consume more than 3 to 4 minutes.

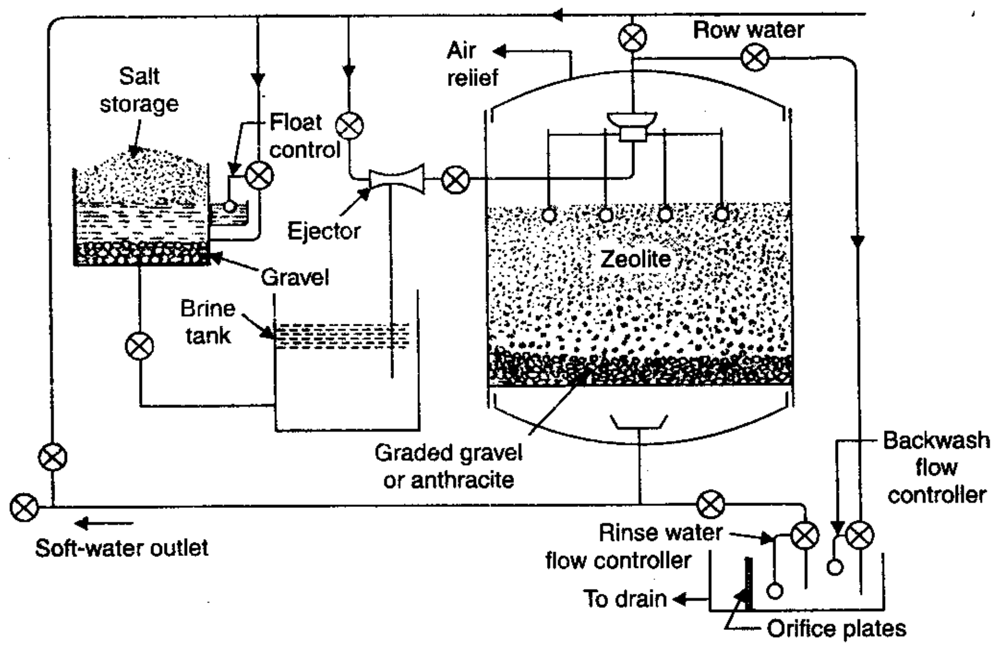


Fig. 3.141. Sodium zeolite softner.

(*ii*) **Hydrogen-zeolite process.** Non-silicious material can be used to exchange the hydrogen ions for cations as calcium and magnesium. The synthetic zeolites developed are sulphonated coal and polystyrene resins which withstand acid and when regenerated with acid could be used to exchange hydrogen for the metals of salt in solution.

The equations for reactions are :

$$Ca(HCO_3)_2 + H_2Z = CaZ + 2H_2CO_3 \quad ...(3.94)$$

$$CaSO_4 + H_2Z = CaZ + H_2SO_4 \quad ...(3.95)$$

$$CaCl_2 + H_2Z = CaZ + 2HCl \quad ...(3.96)$$

$$CaZ + H_2SO_4 = H_2Z + CaSO_4 \quad \text{...in case of regeneration } (3.96)$$

The main merit of this process is that *the water high in carbonates including sodium carbonate or bicarbonate can be softened easily without replacing the water with some other salt.*

4. Demineralisation. The mineral content of water may be removed by evaporation or by series of cation and anion exchangers to produce essentially distilled water. *Demineralisation is often*

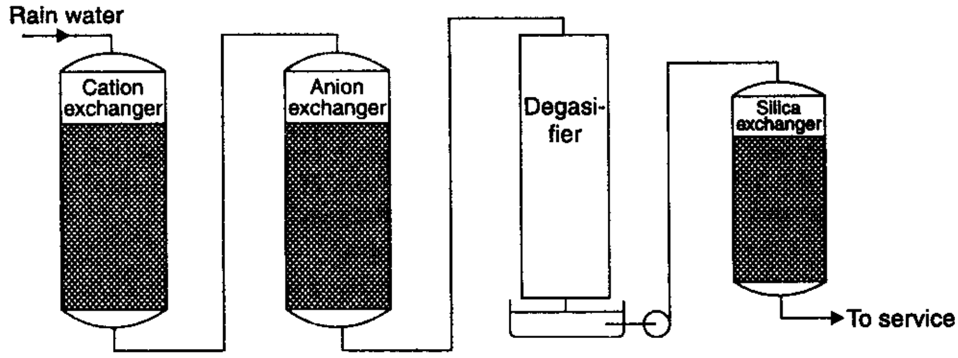


Fig. 3.142. Demineralising process.

the most economical method of producing make-up water for high-pressure boilers. Fig. 3.142 shows a series process for demineralisation. A simple demineraliser would use only the first two units.

Strong-base anion-exchange material absorbs weak acids (silica types) as well as strong acids. Weak-base anion exchange materials are most efficient for removing chlorides, sulphates and nitrates.

5. Blow down. There may be some dissolved solids in the water entering the boiler. As the water gets evaporated the concentration of these solids goes on increasing. Beyond a certain limit of concentration, these solids may cause foaming and priming. The concentration of these solids can be reduced by drawing off some of the quantity of the boiler water from the bottom of boiler drain. This is called *blowing down* and *discharged water is known as* ***blow down.***

3.22.4. pH Value of Water

pH value of water is the logarithm of the reciprocal of hydrogen ion concentration. It is number from 0 to 14 with 7 indicating neutral water.

A sample of water having pH value *less than 7 indicates acidity* of water and the samples having value *more than 7 are alkaline.* Acidic or alkaline nature of a sample depends upon whether the hydrogen or hydroxyl ions predominate. In a mixture of bases and water, hydroxyl ions result. Hydrogen ions make a solution acidic whereas hydroxyl ions make it alkaline. When a sample contains one (OH) ion for every (H) ion, the acid effect of one balances the alkaline effect of the other. Result is a neutral solution with a pH value of 7.0.

pH value of a sample of water can be easily determined by a pH meter. A pH meter is essentially a comparator which compares sample colour with that of many standards to determine the value.

3.23. PIPING SYSTEM

Many fluids such as steam, water, oil, gas, air etc. are used in power plants. These fluids must be completely controlled–co-ordinated. The piping system can be divided into following categories :

1. **Steam piping :** For main auxiliary, reheat, bleed, exhaust and process steam.
2. **Water piping :** For condensate, feed-water, raw water etc.
3. **Blow off piping :** For boiler, evaporator and feed treatment.
4. **Others :** Including service water, fuel, lubricating oil, compressed air, soot blowing, fire protecting, chemical feed etc.

The pipes employed for different purposes have different specifications. Mostly the pipes used are for *steam* and *water*. Standards for different classification of piping have been laid down for the pipes working under different temperatures and pressures.

The pipes may be broadly divided into various categories as *low pressure pipes, medium pressure pipes* and *high pressure pipes* at high temperature. The temperature of the fluid in the pipes plays an important role specially at higher pressures.

3.23.1. Requirements of Steam Piping System

The piping system used for carrying the steam must fulfil the following *requirements* :

1. Maximum reliability.
2. Should be of necessary size to carry the required flow of fluids.
3. Must withstand the pressure to which it is subjected.
4. It should be possible to carry out inspection and maintenance on any section of the plant without the need for complete shut-down.

5. The pipes should be made in longest possible lengths to reduce the number of joints.
6. Should be able to withstand the temperature and expansion caused due to the temperature changes.
7. The piping supports, anchors and joints should be in accessible positions so that inspection is possible throughout the life of the plant.
8. The pipe should run as direct and straight as possible.
9. The piping system should ensure an efficient drainage of all pipes.
10. To reduce the erection time the template pipes should be as few as possible.
11. Steam piping system should be installed in such a way that the horizontal runs should slope in the direction of steam flow.

3.23.2. Materials used for Pipes

The materials for steam piping fall into following three general classes :

1. Wrought iron
2. Cast iron
3. Steel.

1. Wrought iron. Wrought iron pipe is used where *corrosive conditions* exist especially in hot water lines, underground piping and special plumbing installation.

2. Cast iron. Cast iron pipes are also used for low pressure. It is used for water services upto a pressure of 15 kgf/cm^2 or for gas, drain piping etc. *Steam pipes do not use cast iron.*

3. Steel. Steel pipes are being widely used having different percentage of metals in the alloy of steel depending upon the purpose for which they are used.

— For '*steam pipes*' of high temperature *alloy steels are used.*

— For temperature above 450°C alloy steel containing *chromium, vanadium, molybdenum* and *nickel* is used. *Chromium improves corrosion and oxidation resistance. Nickel adds toughness to the materials. Molybdenum improves creep strength.*

— *Stainless steel* is also used in a number of modern power plants where the pressures and temperatures of steam are quite high.

— *Pipe of large size carrying very high pressure and temperature steam is made by turning and boring solid forgings.*

3.23.3. Insulation of Steam Piping

Insulating hot pipes not only conserves heat but also avoids an uncomfortable overheated atmosphere in the vicinity of pipe. The insulating material used for steam pipes should possess the following properties :

1. Should possess high *insulating-efficiency* $\left(= \frac{\text{bare surface loss} - \text{insulated loss}}{\text{bare surface loss}}\right)$.
2. Should not be too costly.
3. Should be easily moulded and applied.
4. Should not be affected by moisture.
5. Should have high mechanical strength.
6. Should be able to withstand high temperature.
7. Should not cause corrosion of pipes if chemically decomposed.
8. Should not overload the pipe by its dead weight.

3.23.4. Steam Pipe Fittings

These are used to assemble piping system and make connections. They various fittings which are in common use are elbows, bends, tees, crosses, plugs and reducers. In Fig. 3.143 are shown the various fittings. The material used for fittings depends on service as regard pressure and temperature.

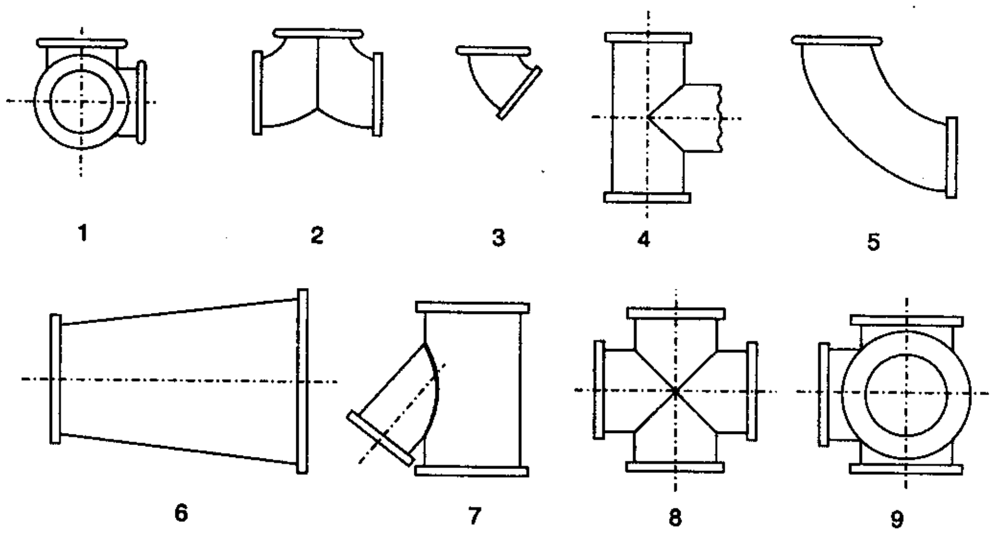


Fig. 3.143. Steam pipe fittings.

3.23.5. Pipe Expansion Bends

As the forces produced by expansion are practically irresitible, the pipe is invariably allowed to expand and its movement is prevented from unduly stressing the fittings and connections by providing (*i*) suitable bends, (*ii*) expansion joints.

Fig. 3.144 shows the standard expansion bends.

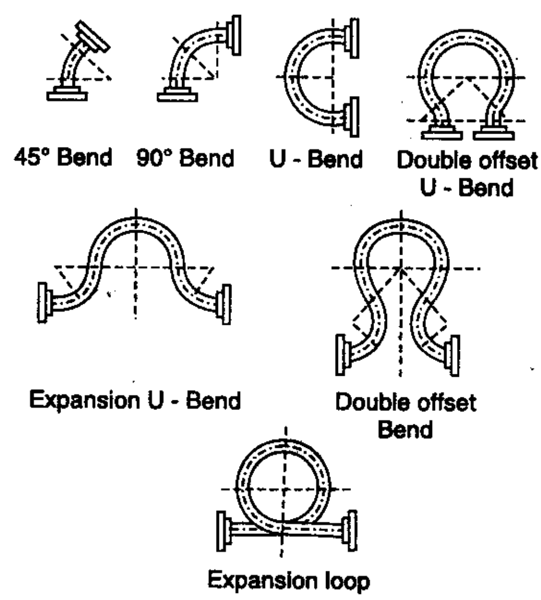


Fig. 3.144. Pipe expansion bends.

Expansion joints provide flexibility to the piping system by permitting relative motion between pipe sections. They compensate for changes in dimensions due to temperature variations. These joints being flexible, can isolate vibration and can allow the ground settling if used underground. Most of the joints permit considerable axial movement.

Fig. 3.145 shows the expansion joint.

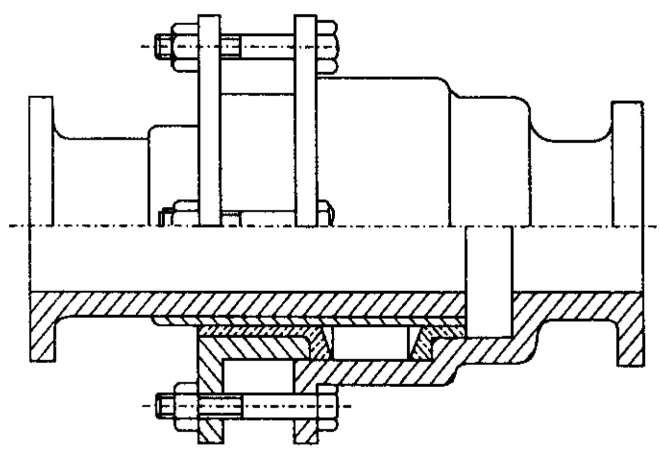


Fig. 3.145. Expansion joint.

Screwed, welded and socket and spigot joints are shown in Figs. 3.146, 3.147 and 3.148 respectively.

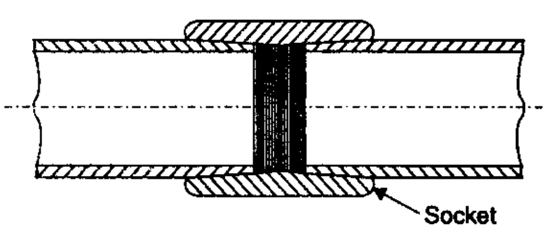


Fig. 3.146. Screwed joint.

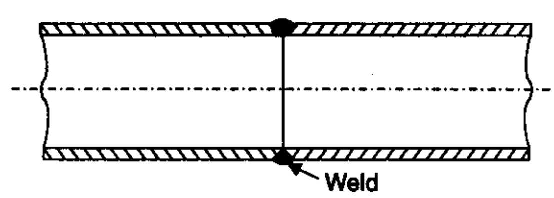


Fig. 3.147. Welded joint.

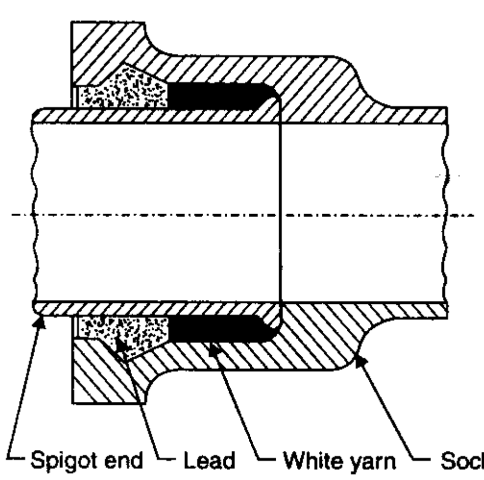


Fig. 3.148. Socket and spigot joint.

3.24. ADVANTAGES AND DISADVANTAGES OF STEAM POWER PLANTS

Advantages of Steam Power Plants :

1. They can respond to rapidly changing loads without difficulty.
2. A portion of the steam generated can be used as a process steam in different industries.
3. Can be loacated very conveniently near the load centre.
4. As these plants can be set up near the industry transmission costs are reduced.
5. Steam engines and turbines can work under 25 per cent of overload continuously.
6. Fuel used is cheaper.
7. Less space is required in comparison with that for hydro-electric plants.
8. Cheaper in production cost in comparison with that of diesel power stations.
9. Cheaper in initial cost in comparison with that of diesel power stations.

Disadvantages :

1. Maintenance and operating costs are high.
2. The cost of plant increases with increase in temperature and pressure.
3. Long time required for erection and putting into action.
4. A large quantity of water is required.
5. Great difficulty experienced in coal handling.
6. The plant efficiency decreases rapidly below about 75 per cent load.
7. Presence of troubles due to smoke and heat in the plant.

3.25. MISCELLANEOUS

3.25.1. Plant Arrangement

Fig. 3.149 shows the typical arrangement of various equipment used in steam power plant. The following factors should be taken into consideration while installing various components :

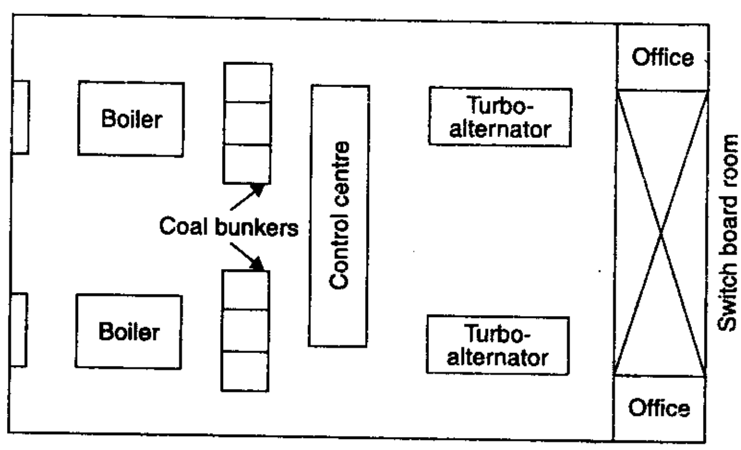


Fig. 3.149. Plant arrangement.

1. Similar items such as turbines, boilers, transformers, bunker bays and other mechanical and electrical components—to be arranged in parallel lines.

Individual boiler, turbo-generator etc.—to be arranged at right angles rows.

2. The chimneys should be installed independent of station building. Each chimney may serve two or more boilers.

3. The following components should be located behind the boiler house :

(*i*) Main flue (*ii*) Draught fans

(*iii*) Outdoor precipitators.

4. The unit transformers and outdoor generator should be located in front of the turbine house.

5. Coal supply to bunkers, circulating water supply and lifting equipment should be properly placed.

Fig. 3.150 shows a **typical layout/schematic arrangement of a steam power plant,** the stepwise description of which is as follows :

— The coal is fed (from the bunker) to stoker hopper and then on the travelling grate stoker. Ash from the grate falls into the ash hopper from where it can be disposed off periodically.

— Forced draught fan supplies the air underneath the stoker *via* air *preheater*. The preheater is a tubular type heat exchanger with flue gases passing through the tubes and air flowing around the tubes. In air preheater, some heat of the outgoing gases is utilised to increase the temperature of air which promotes better combustion in the furnace.

— The flue gases pass on their heat to *boiler tubes* and *superheater* and then move into a *dust collector*. From here, the flue gases move on to the *economiser* where some of their heat is utilised to increase the temperature of the feed water before it is fed into the boiler. Therefore the flue gases travel through the air preheater, induced draught fan to the chimney.

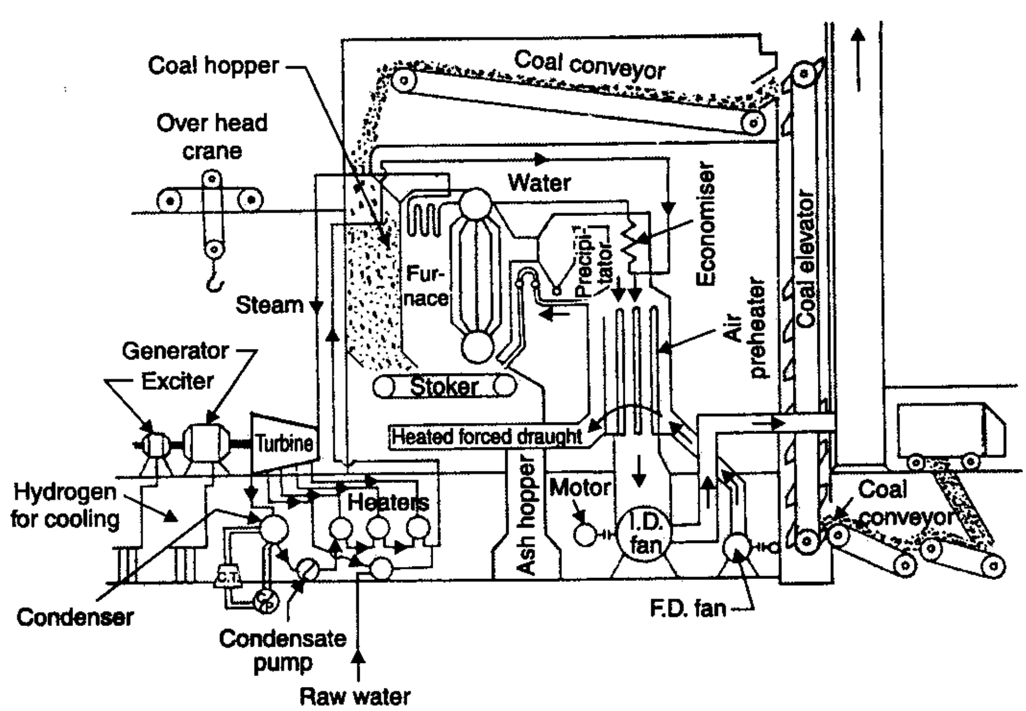


Fig. 3.150. Typical layout/schematic arrangement of a steam power plant.

— From the economiser the feed water is discharged to the boiler drum. The water flows through the water tubes due to natural circulation. Forced circulation can also be done with the help of pumps.

— The steam generated then flows through the superheater tubes into steam header. From here the steam enters the steam turbine through a pipe.

— Steam expands in the turbine and work done is utilised to run a hydrogen cooled generator.

— Bled steam for feed water heating in feed water heaters is extracted fromthe turbine at three points.

— The exhaust steam flows into a surface type condenser where it is condensed by means of cooling water. There is a cooling tower to recool this circulating water.

— The condensate is first heated in open or closed type feed heater and then enters the boiler drum *via* the economiser.

3.25.2. Useful Life of Steam Power Plant Components

Approximate useful life of some of the components of a steam power plant is given below :

Components	*Life (years)*
1. Water tube boiler	20
2. Coal and ash machinery	10 to 20
3. Steam turbines	15 to 20
4. Steam condensers	20
5. Turbo-generators	10 to 20
6. Feed water heater	30
7. Pumps	15 to 20
8. Transformers	[illegible]5 to 20
9. Motors	[illegible]0
10. Air compressors	20 to 25
11. Buildings	50

3.25.3. Steam Power Plant Pumps

The pumps used in a steam power plant are classified as follows :

1. Reciprocating
   (*i*) Direct acting (*ii*) Power
2. Rotary
   (*i*) Vane (*ii*) Screw
   (*iii*) Gear (*iv*) Lobe
3. Centrifugal
   (*i*) Volute (*ii*) Diffuser
   (*iii*) Axial flow (*iv*) Mixed flow

The above mentioned pumps are used for the following services :

(*i*) Boiler feed (*ii*) Circulating water
(*iii*) Evaporator feed (*iv*) Condensate
(*v*) Well water (*vi*) Ash sluicing
(*vii*) Fuel oil.

3.25.4. Cost of Steam Power Plant

A typical subdivision of investment cost of steam power station is as follows :

Components	*Investment cost*
1. Building etc.	25%
2. Boiler Plant	18%
3. Turbo-generators and condensers	25%
4. Fuel handling	6%
5. Switch yard, switching and wiring	16%
6. Piping	5%
7. Miscellaneous	5%

3.25.5. Comparison of Various types of Power Plants

S. No.	Particulars	Steam power plants	Hydro-electric power plants	Diesel power plants	Nuclear power plants
1.	*Site*	Located near load centres but other factors water supply, land cost, transportation facilities are to be kept in view. Location of steam power plant is somewhat flexible as compared with that of hydro-plants.	The site should be such that sufficient area, huge quantity of water at a sufficient head, cheap and rocky land and transportation facilities should be available. These plants are usually at a far off distance from the load centres.	Can be installed anywhere.	Located near the load centre.
2.	*Initial cost*	*Low* as compared to hydroelectric and atomic power plants.	*High* as compared to steam power plant on account of large amount of excavation work and heavy cost of transportation of the plant and machinery.	Initial cost is the *minimum*.	The capital cost is *very high* as compared to all other types of power plants on account of heavy cost of nuclear reactors and heavy cost of erection as highly specialised and expert engineers are required for its erection work.
3.	*Fuel transportation cost*	*High,* especially when the power plants are away from the coal mines and has no railway siding.	*Nil* (as no fuel is required).	Higher than that of atomic power plant but lower than that for steam power plants.	Very low (since quantity of fuel required is very small).

4.	*Operating cost*	Very high as compared to hydro-plants and atomic power plants but low as compared to diesel power plant.	Practically nil (since no fuel is required for the operation of the plant).	Very high as compared to all other types of power plants.	Very low as compared to all other types of power plants except that of hydro-electric plants.
5.	*Maintenance cost*	Higher as compared with that of hydro-plants and diesel power plants (because large operating staff and more skilled engineers are required).	Maintenance cost is comparatively low (because few skilled engineers and small operating staff is required).	Maintenance cost is comparatively lower (because lesser operating and supervising staff is required).	Maintenance cost is comparatively higher (because skilled and well trained staff is required for its operation and maintenance).
6.	*Limit of source of power*	Source of fuel *i.e.*, *coal* reserve all over the world is considered to be fixed and therefore coal mines are being exhausted and time may come when all of these might get exhausted.	Source of power *i.e.*, *water* in case of hydro-plants is not dependable because it depends upon the rainfall which is at the whim of nature.	Source of fuel *i.e.*, *diesel* is not available in plenty.	The source of power is unlimited since large deposits of fissionable materials all over the world are available.
7.	*Transmission and distribution cost.*	Low (because short transmission lines are required).	*Very high* (because long transmission lines are required).	Transmission cost is *nil* and distribution cost is also *very small*.	*Very low.*
8.	*Reliability*	Less reliable.	More reliable.	Less reliable.	Reliable.
9.	*Simplicity and cleanliness*	Atmosphere is polluted by fumes and residues of pulverised fuels.	Most simple and clean.	Simple and clean than steam plants and atomic power plants.	The handling of atomic power plant is quite complicated as radiation hazards are involved in it. Special outfits are designed and explored by the operating staff.
10.	*Field of application*	Most economical if sited near coal mines and by the side of river or canal.	Most economical where water source is available at a sufficient head.	These plants are installed to supply power is emergency.	Where neither water nor coal as a source of power is available, as in Rajasthan these plants are more feasible and adopted.

3.25.6. Thermal Power Stations in India

Some of the thermal power stations installed in the country or under the process of installation are as follows :

S. No.	State	Name of power station	Capacity (MW)
1.	Andhra Pradesh	Kothagndam	240
2.	Assam	Gauhati	40
3.	Bihar	(*i*) Barauni	140
		(*ii*) Bokaro	225
		(*iii*) Patratu	400
4.	Delhi	(*i*) Rajghat and I.P. thermal power station	350
		(*ii*) Badarpur	300
5.	Gujrat	(*i*) Dhuvaran	530
		(*ii*) Ukai	240
6.	Haryana	(*i*) Faridabad	200
		(*ii*) Panipat	220
7.	Madhya Pradesh	(*i*) Kobra	420
		(*ii*) Satpura	300
		(*iii*) Amarkantak	180
8.	Maharashtra	(*i*) Nagpur (Koradi)	480
		(*ii*) Nasik	280
		(*iii*) paras	90
9.	Orissa	Talcher	254
10.	Tamil Nadu	(*i*) Neyveli	600
		(*ii*) Eunore	450
11.	Uttar Pradesh	(*i*) Hardnaganj	540
		(*ii*) Obra	550
12.	West Bengal	(*i*) Santaldih	480
		(*ii*) Chandrapur	420
		(*iii*) Bandel	330
		(*iv*) Durgapur	290

3.25.7. Indian Boilers Act

For steam boilers Government of India enforced an Act known as Indian Boilers At, 1923. This Act came in force from 1st January, 1924 (and later an ended in 1953). Some of the sections of the Act are given below :

1. **Definition.** *Accident.* Accident means and explosion of a boiler or steam pipe or any damage to a boiler or steam pipe which is calculated to weaken the strength thereof so as to render it liable to explode.

Boiler. Boiler means any closed vessel exceeding 22.75 litres in capacity which is used expressly for generating steam under pressure and includes any mounting or other fitting attached to such vessel which is wholly or partly under pressure when steam is shut off.

Economiser. Economiser means any part of a feed pipe that is wholly or partly exposed to the action of flue gases for the purpose of recovery of waste heat.

Feed pipe. Feed pipe means any pipe or connected fitting wholly or partly under pressure through which feed water passes directly to a boiler and which does not form an integral part thereof.

Owner. Owner includes any person using a boiler as agent of the owner thereof and any person using a boiler which he has hired or obtained on load from the owner thereof.

Steam pipe. Steam pipe means any pipe through which steam passes from a boiler to a primemover to other user or both, if :

(*i*) the pressure at which steam passes from a boiler through such pipe exceeds 3.5 kilograms per square centimetre above atmospheric pressure ; or

(*ii*) such pipe exceeds 254 millimetres in internal diameter and includes in either case any connected fitting of a steam pipe.

"Structural alterations, addition or renewal" shall not be deemed to include any renewal or replacement or a petty nature when the part or fitting used for replacement is not inferior in strength, efficiency or otherwise to the replaced part or fitting.

To enforce this Act effectively, the State Governments employ Chief Inspector, Deputy Chief Inspectors and Inspectors.

2. **Prohibition of use of unregistered boilers.** No owner of a boiler shall use the boiler or permit it to be used :

(*a*) unless it has been registered in accordance with the provisions of this Act ;

(*b*) unless a certificate or provisional order authorising use of the boiler is for the time being in force under this Act.

(*c*) in the case of any boiler which has been transferred from one State to another until the transfer has been reported in the prescribed manner ;

(*d*) at a pressure higher than the maximum pressure recorded in such certificate or provisional order.

3. **Registration.** (*i*) The owner of any boiler which is not registered under the provisions of this Act may apply to the Inspector to have the boiler registered. Every such application shall be accompanied by the prescribed fee.

(*ii*) On receipt of an application under sub-section (*a*), the Inspector shall fix a date, within thirty days or such shorter period as may be prescribed from the date of the receipt, for the examination of the boiler and shall give the owner thereof not less than ten days' notice of the date so fixed.

(*iii*) On the said date the Inspector shall proceed to measure and examine the boiler and to determine in the prescribed manner the maximum pressure, if any, at which such boiler may be used, and shall report the result of the examination to the Chief Inspector in the prescribed form.

(*iv*) The Chief Inspector, on receipt of the report, may register the boiler and assign a register number thereto either forthwith or after satisfying himself that any structural alteration, addition or renewal which he may deem necessary has been made in or to the boiler or any steam pipe attached thereto, or (*b*) refuse to register the boiler :

Provided that where the Chief Inspector refuses to register a boiler, he shall forthwith communicate his refusal to the owner of the boiler together with the reason therefore.

(*v*) The Chief Inspector shall, on registering the boiler order the issue to the owner of a certificate in the prescribed form authorising the use of the boiler for a period not exceeding such maximum pressure as he thinks fit, and as is in accordance with the regulations made under this Act :

Provided that a certificate issued under this sub-section in respect of an economiser (or of an unfired boiler which forms an integral part of a processing plant in which steam is generated solely by the use of oil, asphalt or bitumen as a heating medium) may authorise its use for a period not exceeding 24 months.

(*vi*) The Inspector shall forthwith convey to the owner of boiler the orders of the Chief Inspector and shall in accordance therewith issue to the owner any certificate of which the issue has been ordered, and where the boiler has been registered, the owner shall within the prescribed period cause the register number to be permanently marked there on the prescribed manner.

4. **Renewal of Certificate.** (*i*) A certificate authorising the user of a boiler shall cease to be in force :

(*a*) On the expiry of the period for which it was granted ; or

(*b*) when any accident occurs to the boiler ; or

(*c*) when the boiler is moved : the boiler not being a vertical boiler, the heating surface of which is less than 18.58 sq. m or a portable or vehicular boiler ;

(*d*) when any structural alteration, addition or renewal is made in or to the boiler ; or

(*e*) if the Chief Inspector in any particular case so directs, when any structural alteration, addition or renewal is made in or to any steam pipe attached to the boiler ; or

(*f*) on the communication to the owner of the boiler of an order of the Chief Inspector or Inspectors prohibiting its use on the ground that it or any steam pipe attached thereto is in a dangerous condition.

(*ii*) Where an order is made under clause (*f*) of the sub-section (*i*), the grounds on which the order is made shall be communicated to the owner with the order.

(*iii*) When a certificate ceases to be in force, the owner of the boiler may apply to the Inspector for a renewal thereof for such period not exceeding 12 months as he may specify in the application ;

Provided that where the certificate relates to an economiser, the application for its renewal may be for a period not exceeding 24 months.

(*iv*) An application under sub-section (*iii*) shall be accompanied by the prescribed fee and, on receipt thereof, the Inspector shall fix a date, within 30 days or such shorter period as may be prescribed from the date of the receipt, for the examination of the boiler and shall give the owner thereof not less than 10 days' notice of the date so fixed ;

Provided that, where the certificate has ceased to be in force owing to the making of any structural alteration, addition or renewal, the Chief Inspector may dispense with the payment of any fee.

(*v*) On the said date the Inspector shall examine the boiler in the prescribed manner and if he is satisfied that the boiler and the steam pipe or steam pipes attached thereto are in good condition shall issue a renewal certificate authorising the use of the boiler for such period not exceeding 12 months and at a pressure not exceeding such maximum pressure as he thinks fit and as in accordance with the regulations made under this Act :

Provided that a renewed certificate issued under this sub-section in respect of a economiser, may authorise its use for a period not exceeding 24 months :

Provided further that if the Inspector :

(*a*) proposes to issue any certificate ;

— having validity for a less period than the period entered in the application, or

— increasing or reducing the maximum pressure at which the boiler may be used, or

(*b*) proposes to order any structural alteration, addition or renewal to be made in or to the boiler or any steam-pipe attached thereto, or

(*c*) is of opinion that the boiler is not fit for use, the Inspector shall, within 48 hours of making the examination, inform the owner of the boiler in writing of his opinion and the reasons therefor, and shall forthwith report the case for orders to the Chief Inspector.

(*vi*) The Chief Inspector, on receipt of a report under sub-section (5), may, subject to the provisions of this Act and of the regulations made hereunder, order the renewal of the certificate in such terms and on such conditions, if any, as he thinks fit, or may refuse to renew it :

Provided that where the Chief Inspector refuses to renew a certificate, he shall forthwith communicate his refusal to the owner of the boiler, together with the reasons therefor.

(*vii*) Nothing in this section shall be deemed to prevent an owner of a boiler from applying for a renewal certificate therefor at any time during the currency of a certificate.

5. **Provisional orders.** Where the Inspector reports the case of any boiler to the Chief Inspector under above sections he may, if the boiler is not a boiler the use of which has been prohibited, grant to the owner thereof a provisional order in writing permitting the boiler to be used at a pressure not exceeding such maximum pressure as he thinks fit and as is in accordance with the regulations made under this Act pending the receipt of the order of the Chief Inspector. Such provisional order shall be cease to be in force :

(*i*) on the expiry of 6 months from the date on which it is granted, or

(*ii*) on receipt of the orders of the Chief Inspector.

6. **Use of boiler pending grant of certificate.** Notwithstanding anything hereinbefore contained, when the period of the certificate relating to a boiler has expired, the owner shall, provided that he has applied before the expiry of that period for a renewal of the certificate, be entitled to use the boiler at the maximum pressure entered in the former certificate pending the issue of orders on the application.

7. **Revocation of certificate of provisional order.** The Chief Inspector may at any time withdraw or revoke any certificate or provisional order on the report of an Inspector or otherwise :

(*i*) if there is reason to believe that the certificate or provisional order has been fraudulently obtained or has been granted erroneously or without sufficient examination ; or

(*ii*) if the boiler in respect of which it has been granted has sustained injury or has ceased to be in good condition ;or

(*iii*) where the State Government has made rules requiring that boilers shall be in charge of persons holding, if the boiler is in charge of a person not holding the certificate required by such rules ; or

(*iv*) where no such rules have been made, if the boiler is in charge of a person who is not, having regard to the condition of the boiler, in the opinion of the Chief Inspector competent to have charge thereof :

Provided that where the Chief Inspector withdraws or revokes a certificate or provisional order on the ground specified in clause (*iv*), he shall communicate to the owner of the boiler his reasons in writing for the withdrawal of revocation, and the order shall not take effect until the expiry of thirty days from the receipt of such communication.

8. **Alterations and renewals to boilers.** No structural alteration, addition or renewal shall be made in or to any boiler registered under this Act unless such alterations, additions or renewals have been sanctioned in writing by the Chief Inspector.

9. **Alterations and renewals to steam pipes.** Before the owner of any boiler registered under this Act makes any structural alteration, addition or renewal in or to any steam pipe attached to the boiler, he shall transmit to the Chief Inspector a report in writing of his intention, and shall send therewith such particulars of the proposed alteration, addition or renewal as may be prescribed.

10. **Duty of the owner at examination.** (*i*) On any date fixed under this Act for the examination of the boiler, the owner thereof shall be bound :

(*a*) to afford to the Inspector all reasonable facilities for the examination and all such information as may reasonably be required of him ;

(*b*) to have the boiler properly prepared and ready for examination in the prescribed manner ; and

(*c*) in the case of an application for the registration of a boiler, to provide such drawings, specifications, certificates and other particulars as may be prescribed.

(*ii*) If the owner fails, without reasonable cause, to comply with the provisions of the sub-section (*i*), the Inspector shall refuse to make the examination and shall report the case to the Chief Inspector who shall, unless sufficient cause to the contrary is shown, require the owner to file a fresh application, and may forbid him to use the boiler notwithstanding any thing contained in section (F).

11. **Production of certificates, etc.** The owner of any boiler who holds a certificate or provisional order relating thereto shall, at all reasonable times during the period for which the certificate or order is in force, be bound to produce the same when called upon to do so by a District Magistrate, Commissioner of Police or Magistrate of the first class having jurisdiction in the area in which the boiler is, for the time being, or by the Chief Inspector or by any Inspector appointed under the Indian Factories Act, or by any person specially authorised in writing by a District Magistrate or Commissioner of Police.

12. **Transfer of certificate, etc.** If any person becomes the owner of a boiler during the period for which a certificate or provisional order relating thereto is in force, the preceding owner shall be bound to make over to him the certificate or provisional order.

13. **Power of entry.** An Inspector may, for the purpose of inspecting or examining a boiler or any steam pipe attached there to or of seeing that any provision of this Act or of any regulation or rule made hereunder has been or is being observed, at all reasonable times, enter any place or building within the limits of the area for which he has been appointed in which he has reason to believe that a boiler is in use.

14. **Report of accidents.** (*i*) If any accident occurs to a boiler or steam pipe, the owner or person incharge thereof shall, within 24 hours of the accident, report the same in writing to the Inspector. Every such report shall contain a true description of the nature of the accident and of the injury, if any, caused thereby to the boiler or to the steam pipe or to any person and shall be in sufficient detail to enable the Inspector to judge the gravity of the accident.

(*ii*) Every person shall be bound to answer truly to the best of his knowledge and ability every question put to him in writing by the Inspector as to the cause, nature or extent of his accident.

15. **Minor Penalties.** Any owner of a boiler who refuses or without reasonable excuse neglects :

(*i*) to surrender a provisional order as required,

(*ii*) to produce a certificate or provisional order when duly called upon to do so,

(*iii*) to make over to the new owner of a boiler a certificate or provisional order as required shall be punishable with fine which may extend to one hundred rupees.

16. **Penalties for illegal use of boiler.** Any owner of a boiler who, in any case in which a certificate or provisional order is required for the use of the boiler under this Act, uses the boiler either without any such certificate or provisional order being in force or at a higher pressure than that allowed thereby, shall be punishable with fine which may extend to Rs. 500 and, in the case of a continuing offence, with an additional fine which may extend to one hundred rupees for each day after the first day in regard to which he is convicted of having persisted in the offence.

17. **Other Penalties.** Any person who

(*i*) uses or permits to be used a boiler of which he is the owner and which has been transferred from one State to another without such transfer having been reported as required ;

(*ii*) being the owner of a boiler fails to cause the register number allotted to the boiler under this Act to be marked on the boiler as required ;

(*iii*) makes any structural alteration, addition or renewal in or to a boiler without first obtaining the sanction of the Chief Inspector when so required, or to a steam pipe without first informing the Chief Inspector when so required ;

(*iv*) fails to report an accident to a boiler or steam pipe when so required.

(*v*) tampers with a safety valve of a boiler so as to render it inoperative at the maximum pressure at which the use of the boiler is authorised under this Act.

18. **Penalty for tampering with registered mark.** (*i*) Whoever removes, alters, defaces, renders invisible or otherwise tampers with the register number marked on a boiler in accordance with the provision of this Act or any Act repealed hereby, shall be punishable with fine which may extend to five hundred rupees.

(*ii*) Whoever fraudulently marks upon a boiler a register number which has not been allotted to it under this Act or any Act repealed hereby, shall be punishable with imprisonment which may extend to 2 years, or with fine, or with both.

ADDITIONAL / TYPICAL EXAMPLES

Example 3.37. *The following data relate to a regenerative steam power plant generating 22500 kW energy, the alternator directly coupled to steam turbine :*

Condition of steam supplied to the steam turbine	*... 60 bar, 450°C*
Condenser vacuum	*... 707.5 mm*
Pressure at which steam is bled from the steam turbine	*... 3 bar*
Turbine efficiency of each portion of expansion	*... 87 percent*
Boiler efficiency	*... 86 percent*
Alternator efficiency	*... 94 percent*
Mechanical efficiency from turbine to generator	*... 97 percent*

Neglecting the pump work in calculating the input to the boiler, determine :

(*i*) *The steam bled per kg of steam supplied to the turbine.*

(*ii*) *The steam generated per hour if the 9 percent of the generator output is used to run the pumps.*

(*iii*) *The overall efficiency of the plant.*

Solution. The schematic arrangement of the steam power plant is shown in Fig. 3.151 (*a*), while the conditions of the fluid passing through the components are represented on *T-s* and *h-s* diagrams as shown in Fig. 3.151 (*b*) and (*c*). The conditions of the fluid entering and leaving the pump are shown by the same point as the rise in temperature due to pump work is neglected.

Given : Power generated = 22500 kW ;

$$p_1 = 60 \text{ bar} ; t_1 = 450°\text{C} ; p_2 (= p_2') = 3 \text{ bar} ;$$

$$p_3 (= p_3') = \frac{760 - 707.5}{760} \times 1.013 = 0.07 \text{ bar} ; \eta_{\text{turbine (each portion)}} = 87\% ;$$

$$\eta_{\text{boiler}} = 86\% ; \eta_{\text{alt.}} = 94\%, \eta_{\text{mech.}} = 97\%$$

- Locate point 1 corresponding to the conditions : $p_1 = 60$ bar ; $t_1 = 450°$C on the *h-s* chart (*Mollier chart*).

  From *h-s* chart ; we find : $h_1 = 3300$ kJ/kg.

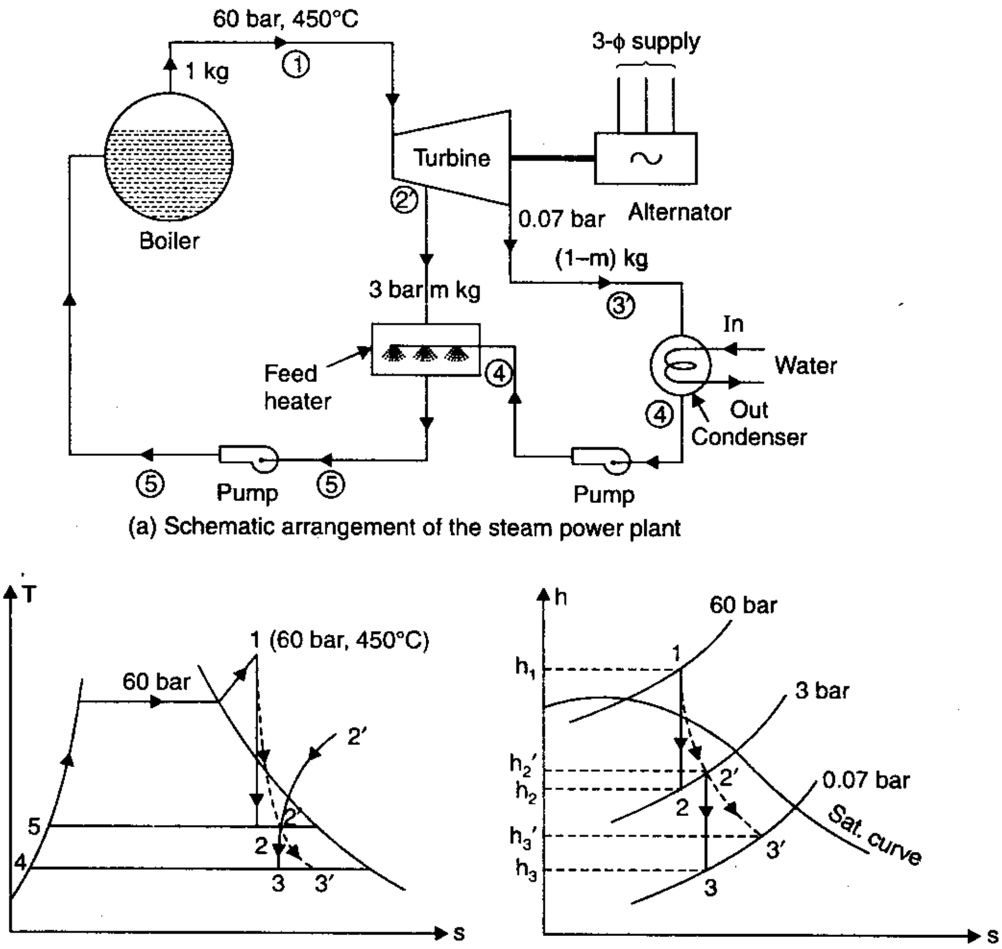
- Draw vertical line through point 1 till it cuts the 3 bar pressure line, then locate point 2.

$$\therefore \quad h_2 = 2607 \text{ kJ/kg}$$

Now, $$\eta_{\text{turbine}} = 0.87 = \frac{h_1 - h_2'}{h_1 - h_2} \quad \text{or} \quad 0.87 = \frac{3300 - h_2'}{3300 - 2607}$$

$$\therefore \quad h_2' = 2697 \text{ kJ/kg}$$

- Locate the point 2 on the h-s chart as enthalpy and pressure are known and then draw a vertical line through the point 2 till it cuts the 0.07 bar pressure line and then locate the point 3.



(a) Schematic arrangement of the steam power plant

(b) T-s diagram (Neglecting pump work)

(c) h-s diagram

Fig. 3.151

$\therefore \quad h_3 = 2165$ kJ/kg

Again, $\quad \eta_{turbine} = 0.87 = \dfrac{h_2' - h_3'}{h_2' - h_3} \quad$ or $\quad 0.87 = \dfrac{2697 - h_3'}{2697 - 2165}$

$\therefore \quad h_3' = 2234$ kJ/kg

From steam tables, corresponding to pressures 3 bar and 0.02 bar, the saturated liquid heats at points 4 and 5 are :

$$h_{f4} = 163.4 \text{ kJ/kg} \; ; \; h_{f5} = 561.4 \text{ kJ/kg}$$

(*i*) **The steam bled per kg of steam supplied to the turbine, m :**

Considering the *energy balance for feed heater* we have ;

$$m(h_2' - h_{f5}) = (1 - m)\,(h_{f5} - h_{f4})$$

or $\quad m(2697 - 561.4) = (1 - m)\,(561.4 - 163.4)$

or $$2135.6\, m = 398\, (1 - m)$$

$\therefore$ $$m = \mathbf{0.157\ kJ/kg\ of\ steam\ generated.}\quad \textbf{(Ans.)}$$

(*ii*) **Steam generated per hour :**

Work developed per kg of steam in the turbine

$$= 1(h_1 - h_2') + (1 - m)\,(h_2' - h_3')$$

$$= (3300 - 2697) + (1 - 0.157)\,(2697 - 2234) = 993.3 \text{ kJ/kg}$$

Actual work developed by the turbine

$$= \frac{22500}{\eta_{alt.} \times \eta_{mech.}} = \frac{22500}{0.94 \times 0.97} = 24676.5 \text{ kW}$$

$\therefore$ Steam generated per hour $= \dfrac{24676.5}{993.3} \times \dfrac{3600}{1000}$ tonnes/h = **89.43 tonnes/h. (Ans.)**

(*iii*) **The overall efficiency of the plant, $\eta_{overall}$:**

Net power available deducting pump power

$$= 22500\,(1 - 0.09) = 20475 \text{ kW}$$

Heat supplied in the boiler $= \dfrac{89.43 \times 1000\,(h_1 - h_{f5})}{0.86}$ kJ/h

$$= \frac{89.43 \times 1000\,(3300 - 561.4)}{0.86 \times 3600} \text{ kW} = 79106.3 \text{ kW}$$

$\therefore$ $$\eta_{overall} = \frac{\text{Net power available}}{\text{Heat supplied by the boiler}}$$

$$= \frac{20475}{79106.3} = 0.2588 \text{ or } \mathbf{25.88\%}.\quad \textbf{(Ans.)}$$

Example 3.38. *A steam power plant of 110 MW capacity is equipped with regenerative as well as reheat arrangement. The steam is supplied at 80 bar and 55°C of superheat. The steam is extracted at 7 bar for feed heating and remaining steam is reheated to 350°C, and then expanded to 0.4 bar in the L.P. stage. Assume indirect type of feed heaters. Determine :*

(*i*) *The ratio of steam bled to steam generated,*

(*ii*) *The boiler generating capacity in tonnes of steam / hour, and*

(*iii*) *Thermal efficiency of the cycle.*

Assume no losses and ideal processes of expansion.

Solution. The schematic arrangement of the plant is shown in Fig. 3.152 (*a*) and the processes are represented on *h-s* chart in Fig. 3.152 (*b*).

Given : Capacity of plant = 110 MW ;

$$t_1 = 350°\text{C } i.e., t_s \text{ at 80 bar} \simeq 295°\text{C} + 55°\text{C} = 350°\text{C})$$

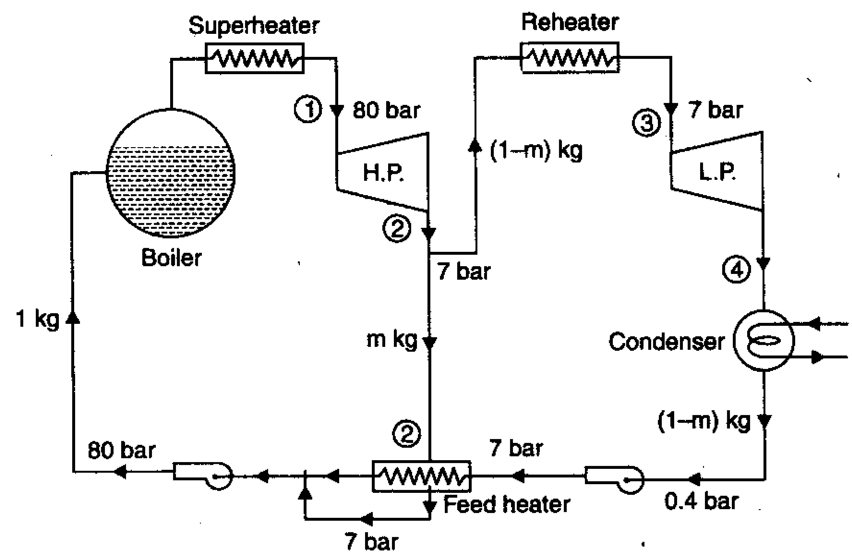
$$p_2 = p_3 = 7 \text{ bar} ;\ t_3 = 350°\text{C} ;\ p_4 = 0.4 \text{ bar}$$

- Locate point 1 corresponding to the condition p_1 = 80 bar and t_1 = 350°C, on the *h-s* chart.
- Locate point 2 by drawing vertical line through point 1 till it cuts the 7 bar pressure line.
- Locate point 3 as the cross point of 7 bar and 350°C temperature line.
- Locate point 4 by drawing vertical line through the point 3 till it cuts the 0.4 bar pressure line.

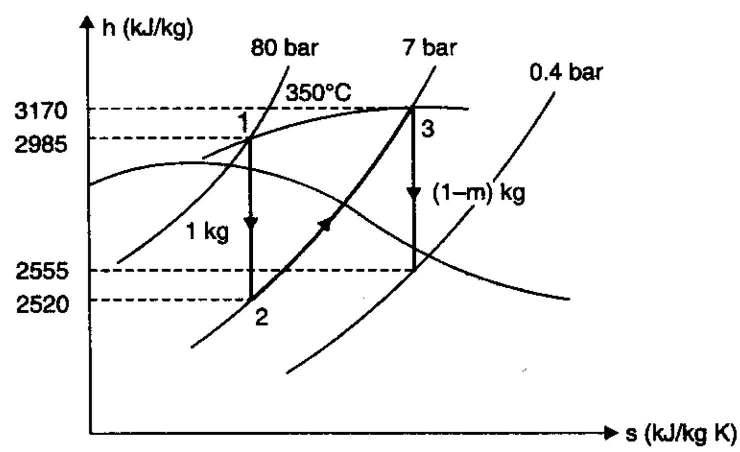
From *h-s* chart, we find :

$$h_1 = 2985 \text{ kJ/kg} ;\ h_2 = 2520 \text{ kJ/kg} ;$$

$$h_3 = 3170 \text{ kJ/kg} ;\ h_4 = 2555 \text{ kJ/kg}.$$



(a) Schematic arrangement of the plant



(b) h-s diagram

Fig. 3.152

Also, from steam tables, we have :

$$h_{f2} \text{ (at 7 bar)} = 697.1 \text{ kJ/kg} \; ; \; h_{f4} \text{ (at 0.4 bar)} = 317.7 \text{ kJ/kg}$$

(*i*) **The ratio of steam bled to steam generated :**

Consider energy/heat balance of feed heater :

Heat lost by m kg of steam = Heat gained by $(1 - m)$ kg of condensed steam

$$m(h_2 - h_{f2}) = (1 - m)(h_{f2} - h_{f4})$$

$$m(2520 - 697.1) = (1 - m)(697.1 - 317.7)$$

$$1822.9\, m = (1 - m) \times 379.4$$

$$\therefore \quad m = 0.172 \text{ kg}$$

i.e. Amount of steam bled per kg of steam supplied to the turbine = 0.172 kg

$$\therefore \quad \frac{\text{Steam generated}}{\text{Steam bled}} = \frac{1}{0.172} = \mathbf{5.814.} \quad \textbf{(Ans.)}$$

(*ii*) **The boiler generating capacity :**

If m_s is the mass of steam supplied to the power plant per second, then the work developed is given by :

$$m_s(h_1 - h_2) + m_s(1 - m)(h_3 - h_4) = 110 \times 10^3$$

or $$m_s(2985 - 2520) + m_s(1 - 0.172)(3170 - 2555) = 110 \times 10^3$$

or $$m_s(465 + 509.22) = 110 \times 10^3$$

$\therefore$ m_s = 112.91 kg/s or **406.48 tonnes/hour (Ans.)**

(*iii*) **Thermal efficiency of the cycle, $\eta_{thermal}$:**

$$\eta_{thermal} = \frac{\text{Output/kg of steam}}{\text{Input/kg of steam}} = \frac{(h_1 - h_2) + (1 - m)(h_3 - h_4)}{(h_1 - h_{f_2}) + (1 - m)(h_3 - h_2)}$$

$$= \frac{(2985 - 2520) + (1 - 0.172)(3170 - 2555)}{(2985 - 697.1) + (1 - 0.172)(3170 - 2520)}$$

$$= \frac{974.22}{2826.1} = 0.3447$$ or **34.47%. (Ans.)**

Example 3.39. *A steam power plant equipped with regenerative as well as reheat arrangement is supplied with steam to the H.P. turbine at 80 bar 470°C. For feed heating, a part of steam is extracted at 7 bar and remainder of the steam is reheated to 350°C in a reheater and then expanded in L.P. turbine down to 0.035 bar. Determine :*

(*i*) *Amount of steam bled-off for feed heating,*

(*ii*) *Amount of steam supplied to L.P. turbine,*

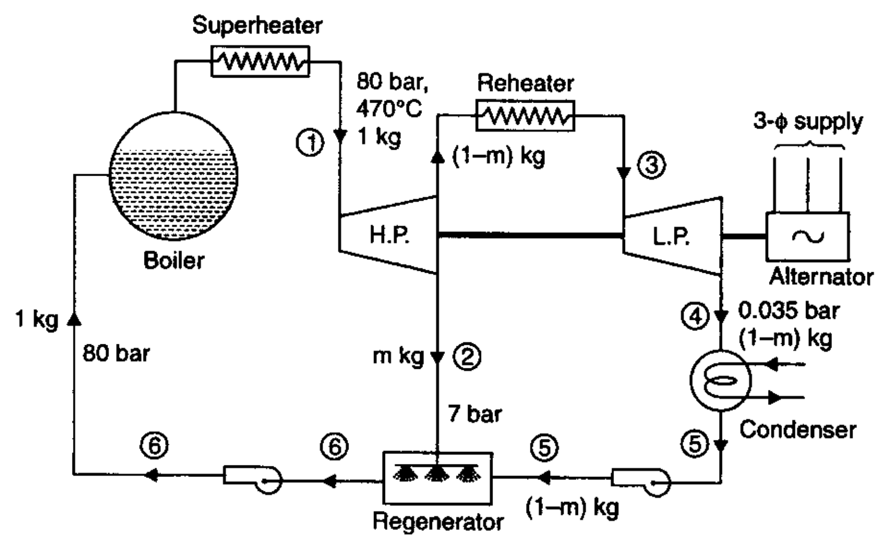
(*iii*) *Heat supplied in the boiler and reheater*

(*iv*) *Cycle efficiency, and*

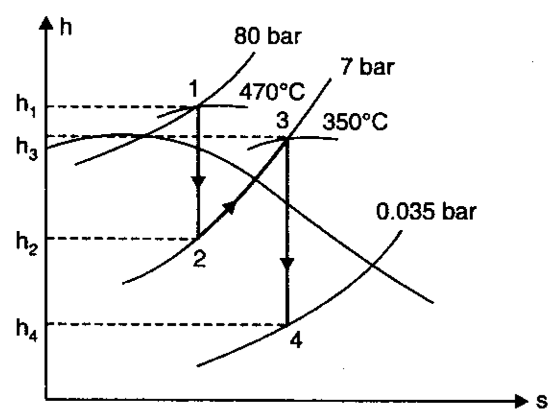
(*v*) *Power developed by the system.*

The steam supplied by the boiler is 50 kg/s. **(B.U. Dec., 2000)**

Solution. The schematic arrangement is the steam power plant of shown in Fig. 3.153 (*a*) and the processes are represented on *h-s* diagram as shown in Fig. 3.153 (*b*).



(a) Schematic arrangement of the steam power plant



(b) h-s diagram

Fig. 3.153

From h-s chart and steam tables, we have enthalpies at different points as follows :

$h_1 = 3315$ kJ/kg ; $h_2 = 2716$ kJ/kg
$h_3 = 3165$ kJ/kg ; $h_4 = 2236$ kJ/kg } From h-s chart

$h_{f6} = h_{f2} = 697.1$ kJ/kg ; $h_{f5} = h_{f4} = 101.9$ kJ/kg } From steam table.

(*i*) **Amount of steam bled off for feed heating :**

Considering *energy balance at regenerator, we have :*

Heat lost by steam = Heat gained by water

$$m(h_2 - h_{f6}) = (1 - m)(h_{f6} - h_{f5})$$

or $$m(h_2 - h_{f2}) = (1 - m)(h_{f2} - h_{f4}) \quad [\because \ h_{f6} = h_{f2} ; h_{f5} = h_{f4}]$$

or $$m(2716 - 697.1) = (1 - m)(697.1 - 111.9)$$

or $$2018.9\, m = 585.2\,(1 - m)$$

$\therefore$ $m = 0.225$ g of steam supplied

Hence amount of **steam bled off is 22.5% of steam generated by the boiler. (Ans.)**

(*ii*) **Amount of steam supplied to L.P. turbine :**

Amount of steam supplied to L.P. turbine

= 100 – 22.5

= **77.5% of the steam generated by the boiler. (Ans.)**

(*iii*) **Heat supplied in the boiler and reheater**

Heat supplied in the *boiler* per kg of steam generated

$= h_1 - h_{f6} = 3315 - 697.1 =$ **2617.9 kJ/kg. (Ans.)**

$(\because \ h_{f6} = h_{f2})$

Heat supplied in the *reheater* per kg of steam generated

$= (1 - m)(h_3 - h_2)$

$= (1 - 0.225)(3165 - 2716) =$ **347.97 kJ/kg. (Ans.)**

Total amount of heat supplied by the boiler and reheater per kg of steam generated,

$$Q_s = 2617.9 + 347.97 = 2965.87 \text{ kJ/kg}$$

(*iv*) **Cycle efficiency, η_{cycle} :**

Amount of work done by per kg of steam generated by the boiler,

$$W = 1(h_1 - h_2) + (1 - m)(h_3 - h_4), \text{ Neglecting pump work}$$

$$= (3315 - 2716) + (1 - 0.225)(3165 - 2236) \simeq 1319 \text{ kJ/kg}$$

$$\therefore \quad \eta_{cycle} = \frac{W}{Q_s} = \frac{1319}{2965.87} = 0.4447 \quad \text{or} \quad \mathbf{44.47\%} \quad \textbf{(Ans.)}$$

(*v*) **Power developed by the system :**

Power developed by the system

$$= m_s \times W = 50 \times 1319 \text{ kJ/s} = \frac{50 \times 1319}{1000}$$

$$= \mathbf{65.95 \ MW} \quad \textbf{(Ans.)}$$

Example 3.40. *A steam power plant operates on ideal Rankine cycle using reheater and regenerative feed water heaters. It has one open feed heater. Steam is supplied at 150 bar and 600°C. The condenser pressure is 0.1 bar. Some steam is extracted from the turbine at 40 bar for closed feed water heater and remaining steam is reduced at 40 bar to 600°C. Extracted steam is completely condensed in this closed feed water heater and is pumped to 150 bar before mixing with the feed water heater. Steam for the open feed water heater is bled from L.P. turbine at 5 bar. Determine :*

(*i*) *Fraction of steam extracted from the turbines at each bled heater, and*

(*ii*) *Thermal efficiency of the system.*

Draw the line diagram of the components and represent the cycle on T-s diagram.

(P.U. Dec., 2001)

Solution. The arrangement of the components is shown in Fig. 3.154 (*a*) and the processes are represented on *T-s* diagram as shown in Fig. 3.154 (*b*).

From *h-s* chart and steam tables we have enthalpies at different points as follows :

$$\left.\begin{aligned} h_1 &= 3578 \text{ kJ/kg}; \quad h_2 = 3140 \text{ kJ/kg}; \\ h_3 &= 3678 \text{ kJ/kg}; \quad h_4 = 3000 \text{ kJ/kg}; \\ h_5 &= 2330 \text{ kJ/kg}; \end{aligned}\right\} \text{From } h\text{-}s \text{ chart}$$

$$\left.\begin{aligned} h_{f1} &\text{ (at 150 bar)} = 1611 \text{ kJ/kg} \\ h_{f2} &\text{ (at 40 bar)} = 1087.4 \text{ kJ/kg}; \ h_{f4} \text{ (at 5 bar)} = 640.1 \text{ kJ/kg}; \\ h_{f5} &= h_{f6} \text{ (at 0.1 bar)} = 191.8 \text{ kJ/kg} \end{aligned}\right\} \text{Steam tables}$$

(*i*) **Fraction of steam extracted from the turbines at each bled heater $\mathbf{m_1, m_2}$:**

Considering *energy balance for closed feed heater,* we have :

$$m_1(h_2 - h_{f2}) = (1 - m_1)(h_{f2} - h_{f4})$$

$$m_1(3140 - 1087.4) = (1 - m_1)(1087.4 - 640.1)$$

or $$2052.6\, m_1 = (1 - m_1) \times 447.3$$

$$\therefore \quad \mathbf{m_1 = 0.179 \text{ kg/kg of steam supplied by the boiler.}} \quad \textbf{(Ans.)}$$

Considering *energy balance for open feed heater,* we have :

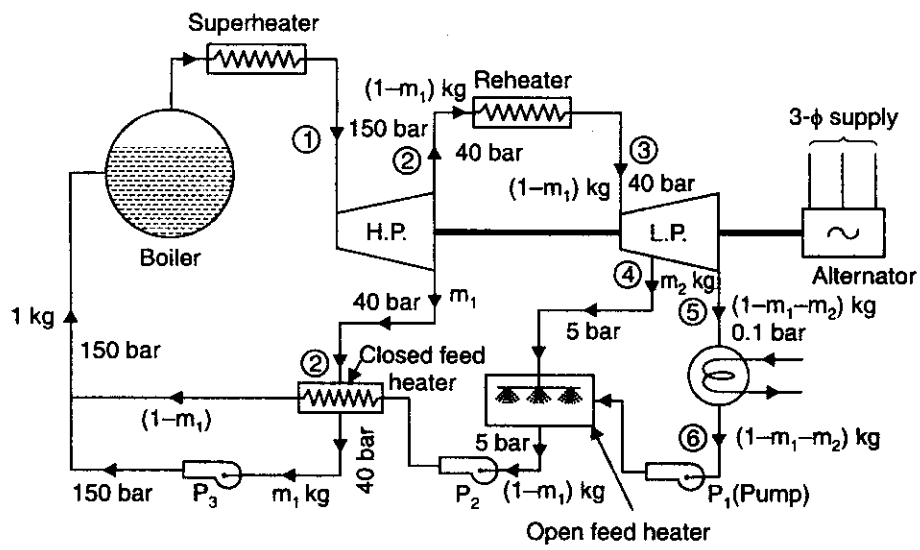
$$m_2(h_4 - h_{f4}) = (1 - m_1 - m_2)(h_{f4} - h_{f6})$$

or $$m_2(h_4 - h_{f4}) = (1 - m_1 - m_2)(h_{f4} - h_{f5}) \qquad (\because \ h_{f6} = h_{f5})$$

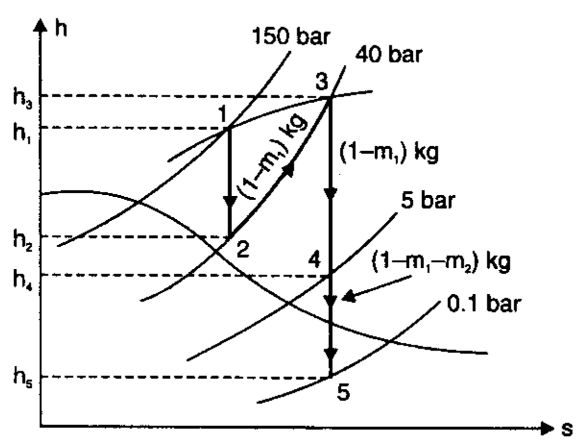
or $$m_2(3000 - 640.1) = (1 - 0.179 - m_2)(640.1 - 191.8)$$

or $$2359.9\, m_2 = (0.821 - m_2) \times 448.3 = 368.05 - 448.3\, m_2$$

$$\therefore \quad \mathbf{m_2 = 0.131 \text{ kg/kg of steam supplied by boiler.}} \quad \textbf{(Ans.)}$$



(a) Schematic arrangement of the steam power plant



(b) h-s diagram

Fig. 3.154

(*ii*) **Thermal efficiency of the system, $\eta_{thermal}$:**

Total work done per kg of steam supplied by the boiler

$$= 1 \times (h_1 - h_2) + (1 - m_1)(h_3 - h_4) + (1 - m_1 - m_2)(h_4 - h_5)$$

$$= (3578 - 3140) + (1 - 0.179)(3678 - 3000) + (1 - 0.179 - 0.131)(3000 - 2330)$$

$$= 438 + 556.64 + 462.3 = 1456.94 \text{ kJ/kg}$$

Work done by the pump P_1

$$W_{P1} = v_{w1}(1 - m_1 - m_2)(5 - 0.1) \times 10^5 \times 10^{-3} \text{ kJ/kg}$$

$$= \frac{1}{1000}(1 - 0.179 - 0.131)(5 - 0.1) \times 10^5 \times 10^{-3} = 0.338 \text{ kJ/kg}$$

$$\left[\text{Taking } v_{w1} = v_{w2} = v_{w3} = \frac{1}{1000} \text{ m}^3\text{/kg}\right]$$

Work done by the pump P_2,

$$W_{P2} = v_{w2}(1 - m_1)(150 - 5) \times 10^5 \times 10^{-3} \text{ kJ/kg}$$

$$= \frac{1}{1000}(1 - 0.179)(150 - 5) \times 10^5 \times 10^{-3} = 11.9 \text{ kJ/kg}$$

Work done by pump P_3,

$$W_{P3} = v_{w3} \times m_1 \times (150 - 40) \times 10^5 \times 10^{-3}$$

$$= \frac{1}{1000} \times 0.179\,(150 - 40) \times 10^5 \times 10^{-3} = 1.97 \text{ kJ/kg}$$

Total pump work $= W_{P1} + W_{P2} + W_{P3}$

$= 0.338 + 11.9 + 1.97 = 14.21$ kJ/kg of steam supplied by boiler

∴ Net work done by the turbine per kg of steam supplied by the boiler,

$$W_{net} = 1456.94 - 14.21 = 1442.73 \text{ kJ/kg}$$

Heat of feed water extering the boiler

$$= (1 - m_1) \times 1611 + m_1 \times 1611 = 1611 \text{ kJ/kg}$$

Heat supplied by the boiler per kg of steam,

$$Q_{s1} = h_1 - 1610 = 3578 - 1610 = 1968 \text{ kJ/kg}$$

Q_{s2} = Heat supplied in the reheater

$$= (1 - m_1)(h_3 - h_2) = (1 - 0.179)(3678 - 3140)$$

$= 441.7$ kJ/kg of steam supplied by the boiler

Q_{st} (Total heat supplied) $= Q_{s1} + Q_{s2} = 1968 + 441.7 = 2409.7$ kJ/kg

∴ $$\eta_{thermal} = \frac{W_{net}}{Q_{st}} = \frac{1442.73}{2409.7} = 0.5987 \quad \text{or} \quad \mathbf{59.87\%.} \quad \textbf{(Ans.)}$$

Example 3.41. *Steam at 70 bar and 450°C is supplied to a steam turbine. After expanding to 25 bar in high pressure stages, it is reheated to 420°C at the constant pressure. Next; it is expanded in intermediate pressure stages to an appropriate minimum pressure such that part of the steam bled at this pressure heats the feed water to a temperature of 180°C. The remaining steam expands from this pressure to a condenser pressure of 0.07 bar in the low pressure stage. The isentropic efficiency of H.P. stage is 78.5%, while that of the intermediate and L.P. stages is 83% each. From the above data, determine :*

(*i*) *The minimum pressure at which bleeding is necessary.*

(*ii*) *The quantity of steam bled per kg of flow at the turbine inlet.*

(*iii*) *The cycle efficiency.*

Neglect pump work. **(Roorkee University)**

Solution. The schematic arrangement of the plant is shown in Fig. 3.155 (*a*) and the processes are represented on *T-s* and *h-s* diagrams as shown in Fig. 3.155 (*b*) and (*c*) respectively.

(*i*) The minimum pressure at which bleeding is necessary :

It would be assumed that the feed water heater is an open heater. Feed water is heated to 180°C. So p_{sat} at 180°C ≃ 10 bar is the pressure at which the heater operates.

Thus, *the pressure at which bleeding is necessary is* **10 bar. (Ans.)**

From the *h-s* chart (Mollier chart), we have :

$$h_1 = 3285 \text{ kJ/kg} \; ; \; h_2 = 2980 \text{ kJ/kg} \; ; \; h_3 = 3280 \text{ kJ/kg} \; ; \; h_4 = 3030 \text{ kJ/kg}$$

$$h_3 - h_4' = 0.83(h_3 - h_4) = 0.83(3280 - 3030) = 207.5 \text{ kJ/kg}$$

∴ $$h_4' = h_3 - 207.5 = 3280 - 207.5 = 3072.5 \text{ kJ/kg}$$

$$h_5 = 2210 \text{ kJ/kg}$$

$$h_4' - h_5' = 0.83(h_4' - h_5) = 0.83(3072.5 - 2210) \simeq 715.9 \text{ kJ/kg}$$

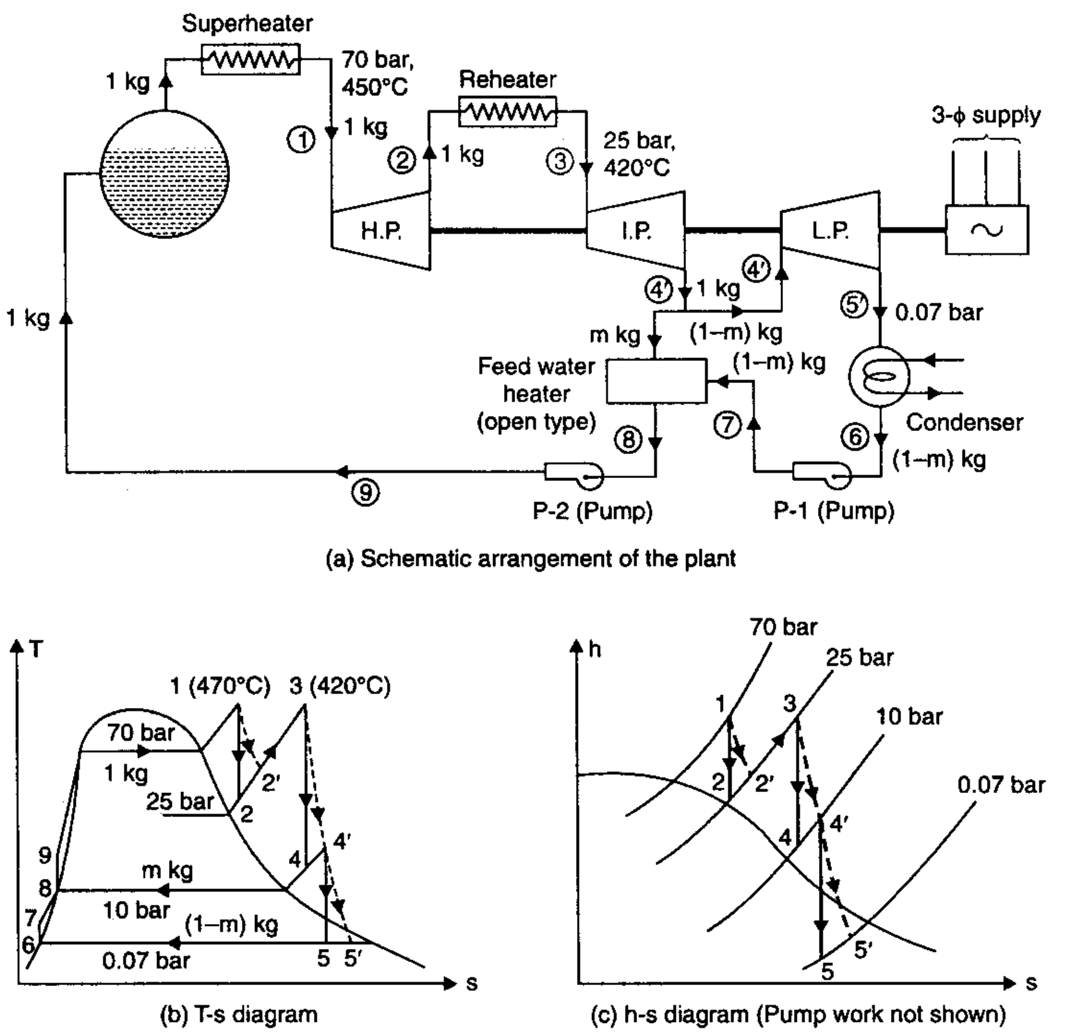
$$\therefore \quad h_5' = h_4' - 715.9 = 3072.5 - 715.9 = 2356.6 \text{ kJ/kg}$$

From steam tables, we have :

$$h_{f6} = 163.4 \text{ kJ/kg} \; ; \quad h_{f8} = 762.6 \text{ kJ/kg}$$

$$h_1 - h_2' = 0.785(h_1 - h_2) = 0.785(3285 - 2980) = 239.4 \text{ kJ/kg}$$

$$\therefore \quad h_2' = h_1 - 239.4 = 3285 - 239.4 = 3045.6 \text{ kJ/kg}$$



(a) Schematic arrangement of the plant

(b) T-s diagram

(c) h-s diagram (Pump work not shown)

Fig. 3.155

(*ii*) The quantity of steam bled per kg of flow at the turbine inlet, m :

Considering *energy balance for the feed water heater, we have :*

$$m \times h_4' + (1 - m)\, h_{f7} = 1 \times h_{f8}$$

$$m \times 3072.5 + (1 - m) \times 163.4 = 1 \times 762.6 \qquad (\because \; h_{f7} = h_{f6})$$

$$3072.5\, m + 163.4 - 163.4\, m = 762.6$$

$$\therefore \quad m = \frac{(762.6 - 163.4)}{(3072.5 - 163.4)}$$

$$= \mathbf{0.206 \text{ g of steam flow at turbine inlet.}} \quad \textbf{(Ans.)}$$

(*iii*) **Cycle efficiency, η_{cycle} :**

$$\eta_{cycle} = \frac{\text{Work done}}{\text{Heat supplied}} = \frac{1(h_1 - h_2) + 1(h_3 - h_4) + (1 - m)(h_4' - h_5')}{(h_1 - h_{f8}) + (h_3 - h_2')}$$

$$= \frac{(3285 - 3045.6) + 207.5 + (1 - 0.206)(715.9)}{(3285 - 762.6) + (3280 - 3045.6)} = \frac{1015.3}{2756.8}$$

$$= 0.3683 \text{ or } \mathbf{36.83\%.} \quad \textbf{(Ans.)}$$

Example 3.42. *A steam turbine plant developing 120 MW of electrical output is equipped with reheating and regenerative feed heating arrangement consisting of two feed heaters—one surface type on H.P. side and other direct contact typed on L.P. side. The steam conditions before the steam stop valve are 100 bar and 530°C. A pressure drop of 5 bar takes place due to throttling in valves.*

Steam exhausts from the H.P. turbine at 25 bar. A small quantity of steam is bled off at 25 bar for H.P. surface heater for feed heating and the remaining is reheated in a reheater to 550° C and the steam enters at 22 bar in L.P. turbine for further expansion. Another small quantity of steam is bled off at pressure 6 bar for the L.P heater and the rest of steam expands up to the back pressure of 0.05 bar. The drain from the H.P. heater is led to the L.P. heater and the combined feed from the L.P. heater is pumped to the high-pressure feed heater and finally to the boiler with the help of boiler feed pump.

The component efficiencies are : turbine efficiency 85%, pump efficiency 90%, generator efficiency 96%, boiler efficiency 90% and mechanical efficiency 95%. It may be assumed that the feed water is heated up to the saturation temperature at the prevailing pressure in feed heater. Work out the following :

(*i*) *Sketch the feed heating system and show the process on T-s and h-s diagrams.*

(*ii*) *Amounts of steam bled off.*

(*iii*) *Overall thermal efficiency of turbo-alternator considering pump work.*

(*iv*) *Specific steam consumption is kg/kWh.* **(AMIE Summer, 2001)**

Solution. (*i*) The *schematic arrangement* including feed heating system is shown in Fig. 3.156 (*a*), and *T-s* and *h-s* diagrams of the process are shown in Fig. 3.156 (*b*) & (*c*) respectively.

(*ii*) **Amounts of bled off.** The enthalpies at various state points as read from *h-s* diagram/steam tables, in kJ/kg, are :

$$h_1 = h_2 = 3460 \text{ kJ/kg}$$

$$h_3 = 3050, \text{ and } \therefore \; h_3' = 3460 - 0.85(3460 - 3050) = 3111.5$$

$$h_4 = 3385$$

$$h_5 = 3140, \text{ and } \therefore \; h_5' = 3585 - 0.85(3585 - 3140) = 3207$$

$$h_6 = 2335, \text{ and } \therefore \; h_6' = 3207 - 0.85\,(3207 - 2335) = 2466$$

$$h_7 = 137.8 \text{ kJ/kg } (h_f \text{ at } 0.05 \text{ bar})$$

$$h_8 = h_{10} = 962 \text{ kJ/kg } (h_f \text{ at } 25 \text{ bar})$$

and $$h_9 = 670.4 \text{ kJ/kg } (h_f \text{ at } 6 \text{ bar}).$$

Enthalpy balance for ***surface heater :***

$$m_1 h_3' + h_9 = m_1 h_8 + h_{10}, \text{ neglecting pump work}$$

or $$m_1 = \frac{h_{10} - h_9}{h_3' - h_8} = \frac{962 - 670.4}{3111.5 - 962} = 0.13566 \text{ kg}$$

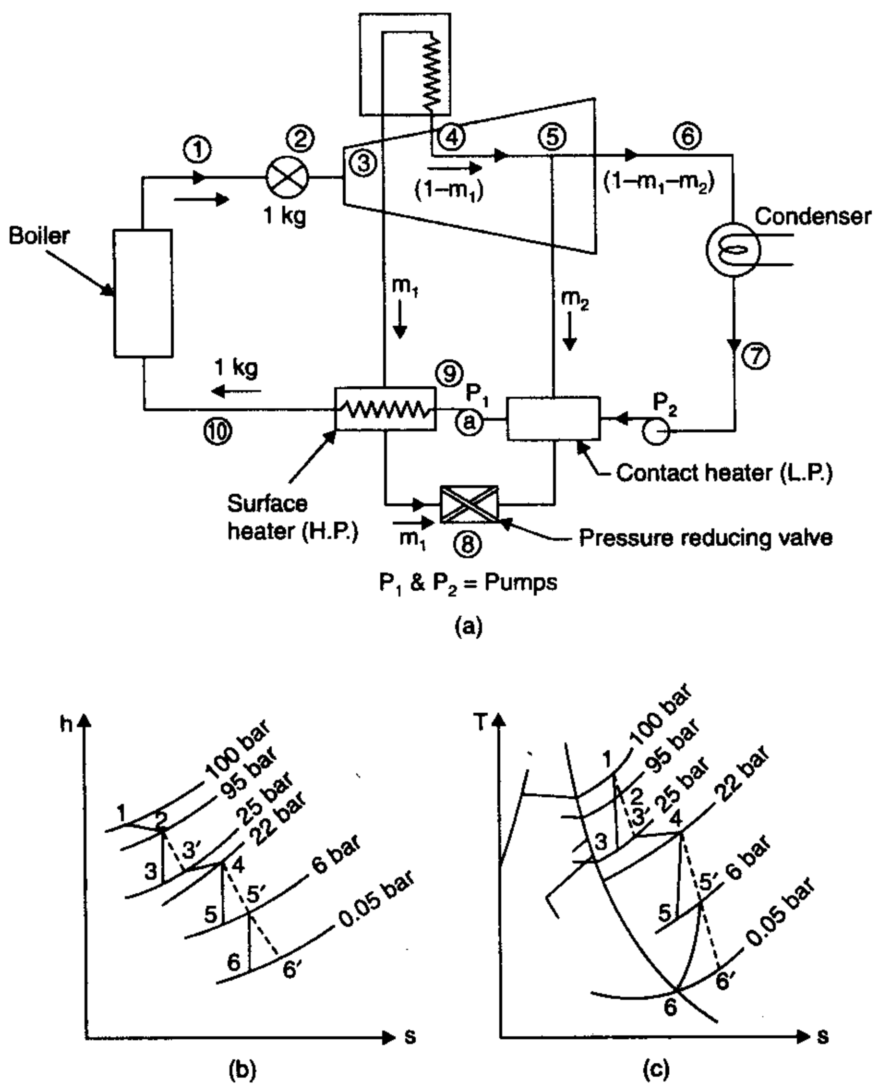


Fig. 3.156

Enthalpy balance for ***contact heater*** :

$$m_2 h_5' + (1 - m_1 - m_2)\, h_7 + m_1 h_8 = h_9, \text{ neglecting pump work}$$

or $$m_2 \times 3207 + (1 - 0.13566 - m_2) \times 137.8 + 0.13566 \times 962 = 670.4$$

or $$m_2 = 0.1371 \text{ kg.}$$

Pump Work. The specific volume of water as 0.001 m³/kg.

$$(W_{pump})_{L.P.} = (1 - m_1 - m_2)(6 - 0.05) \times 0.001 \times 10^2$$

$$= (1 - 0.13566 - 0.1371) \times 5.95 \times 0.1 = 0.4327 \text{ kJ/kg.}$$

$$(W_{pump})_{H.P.} = 1 \times (100 - 6) \times 0.001 \times 10^2 = 9.4 \text{ kJ/kg}$$

Total pump work (actual) $$= \frac{0.4327 + 9.4}{0.9} = 10.925 \text{ kJ/kg}$$

Turbine output (indicated)

$$= (h_2 - h_3') + (1 - m_1)(h_4 - h_5') + (1 - m_1 - m_2)(h_5' - h_6')$$
$$= (3460 - 3111.5) + (1 - 0.13566)(3585 - 3207) + (1 - 0.13566 - 0.1371)(3207 - 2466)$$
$$= 1214.105 \text{ kJ/kg}$$

Net electrical output = (Indicated work – pump work) × $\eta_{mech.}$ × $\eta_{gen.}$

$$= (1214.105 - 10.925) \times 0.9 \times 0.96 = 1039.55 \text{ kJ/kg}$$

[**Note.** All the above calculations are for 1 kg of main (boiler) flow.]

$$\therefore \quad \text{Main steam flow rate} = \frac{120 \times 10^3 \times 3600}{1039.55} = 4.155 \times 10^5 \text{ kJ/h.}$$

Amounts of bled off are :

(*a*) Surface (high pressure) heater,

= 0.13566 kg/kg or boiler flow

or = $0.13566 \times 4.155 \times 10^5$

i.e., = $\mathbf{5.6367 \times 10^4}$ **kg/h. (Ans.)**

(*b*) Direct contact (low pressure) heater

= 0.1371 kg/kg of boiler flow

or = $0.1371 \times 4.155 \times 10^5$

i.e., = $\mathbf{5.697 \times 10^4}$ **kg/h. (Ans.)**

(*iii*) **Overall thermal efficiency, $\eta_{overall}$:**

$$\text{(c) Heat input in boiler} = \frac{h_1 - h_{10}}{\eta_{boiler}} = \frac{3460 - 962}{0.9}$$
$$= 2775.6 \text{ kJ/kg of the boiler flow.}$$

$$\text{Heat input in reheater} = \frac{h_4 - h_3'}{\eta_{boiler}} = \frac{3585 - 3111.5}{0.9} = 526.1 \text{ kJ/kg of boiler flow}$$

$$\therefore \quad \eta_{overall} = \frac{1039.55}{2775.6 + 526.1} \times 100 = 31.48\%. \quad \textbf{(Ans.)}$$

(*iv*) **Specific steam consumption.**

$$\text{Specific steam consumption} = \frac{4.155 \times 10^5}{120 \times 10^3} = 3.4625 \text{ kg/kW-h.} \quad \textbf{(Ans.)}$$

Example 3.43. (*a*) *How does erosion of turbine blades occur ? State the methods of preventing erosion of turbine blades.*

(*b*) *What do you mean by TTD of a feed water heater ? Draw temperature-path-line diagram of a closed feed water heater used in regenerative feed heating cycle.*

(*c*) *In a 15 MW steam power plant operating on ideal reheat cycle, steam enters the H.P. turbine at 150 bar and 600° C. The condenser is maintained at a pressure of 0.1 bar. If the moisture content at the exit of the L.P. turbine is 10.4%, determine :*

(*i*) *Reheat pressure ;* (*ii*) *Thermal efficiency ;* (*iii*) *Specific steam consumption ; and* (*iv*) *Rate of pump work in kW. Assume steam to be reheated to the initial temperature.* **(AMIE Summer, 2000)**

Solution. (*a*) The erosion of the moving blades in *caused by the presence of water particles in (wet) steam in the L.P. stages.* The water particles strike the leading surface of the blades. Such impact, if sufficiently heavy, produces *severe local stresses in the blade material causing the surface metal to fail and flake off.*

The erosion, if any, is more likely to occur in the region where the stem is wettest. *i.e.*, in the last one or two stages of the turbine. Moreover, the water droplets are concentrated in the outer parts of the flow annuals where the velocity of impact is highest.

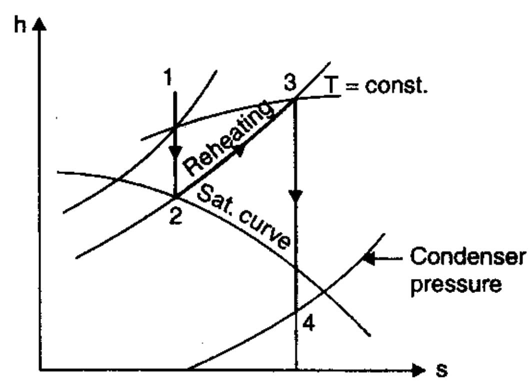


Fig. 3.157

Erosion difficulaties due to moisture in the steam may be avoided by reheating (see Fig. 3.157). The whole of steam is taken from the turbine at a suitable point 2, and a further supply of heat is given to its along 2-3 after which the steam is readmitted to the turbine and expanded along 3-4 to condenser pressure.

Erosion *may also be reduced by using steam traps in between the stages to separate moisture from the steam.*

(*b*) TTD means *terminal temperature difference.* It is the difference between temperatures of bled steam/condensate and the feed water at the two ends of the feed water heater.

The required temperature-path-line diagram of a closed feed water heater is shown in Fig. 3.158.

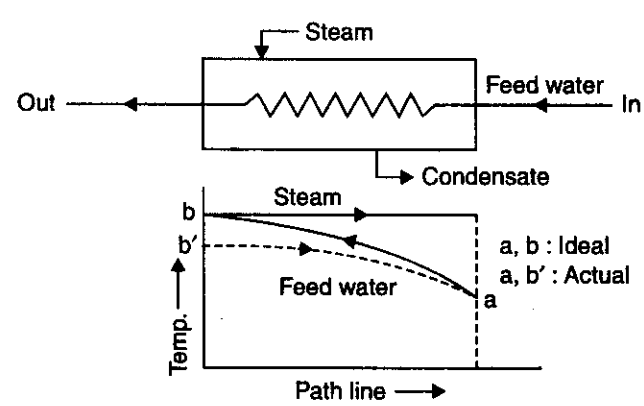


Fig. 3.158

(*c*) The cycle is shown on *T-s* (Fig. 3.159) and *h-s* (Fig. 3.160) diagrams. The following values are read from the Mollier diagram.

h_1 = 3580 kJ/kg, h_2 = 3140 kJ/kg, h_3 = 3675 kJ/kg, and h_4 = 2335 kJ/kg

Moisture contents in exit from L.P. turbine = 10.4%

$x_4 = 1 - 0.104 = 0.896$

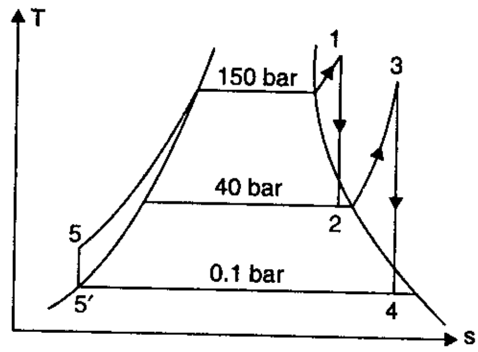


Fig. 3.159

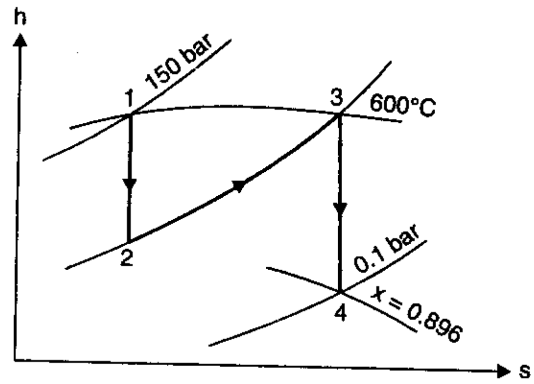


Fig. 3.160

(*i*) **Reheat pressure :** From the Mollier diagram, the **reheat pressure is 40 bar. (Ans)**

(*ii*) **Thermal efficiency, η_{th} :**

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

$= (3580 - 3140) + (3675 - 2335) = 1780$ kJ/kg.

Assuming specific volume of water

$= 10^{-3}$ m³/kg, the pump work $= 10^{-3}(150 - 0.1) = 0.15$ kJ/kg,

i.e., may be neglected in computing of η_{th},

$h_5 = h_4 = 191.8$ kJ/kg, (h_f at 0.1 bar) from steam tables

$Q_{input} = (h_1 - h_5) + (h_3 - h_2)$

$= (3580 - 191.8) + (3675 - 3140) = 3923.2$ kJ/kg

$$\%\eta_{th} = \frac{1780}{3923.2} \times 100 = \mathbf{45.37\%}. \quad \textbf{(Ans.)}$$

(*iii*) **Specific steam consumption :**

Steam consumption $= \dfrac{15 \times 10^3}{1780} = 8.427$ kg/s

Specific steam consumption $= \dfrac{8.427 \times 3600}{15 \times 10^3} = \mathbf{2.0225}$ **kg/kWh. (Ans.)**

(*iv*) **Rate of pump work :**

Rate of pump work $= 8.427 \times 0.15 = \mathbf{1.26}$ **kW. (Ans.)**

Example 3.44. (*a*) *Why is drum type construction preferred to disc type construction in reaction turbine ?*

(*b*) *Why is partial admission of steam adopted for H.P. impulse stages while full admission is essential for any stage of a reaction turbine ?*

(*c*) *In a 50% reaction turbine, the speed of rotation of a blade group is 3000 rpm with mean blade velocity of 120 m / s. The velocity ratio is 0.8 and the exit angle of the blades is 20°. It the mean blade height is 30 mm, calculate the total steam flow rate through the turbine. Neglect the effect of blade edge thickness of the annular area but consider 10% of the total steam flow rate as the tip leakage loss. The mean condition of steam in that blade group is found to be 2.7 bar and 0.95 dry.*

(*d*) *What do you mean by once through boiler ?* **(AMIE Summer, 1998)**

Solution. (*a*) The rotor of the turbine can be of drum type or disc type. *Disc type construction is difficult (complicated) to make, but lighter in weight.* Hence the centrifugal stresses are lower at a particular speed. On the other hand drum type construction is simple in construction, and it is easy to attach aerofoil shape blades. Further it is easier to design for tip leakage reduction which is a major problem in reaction turbines. Moreover due to small pressure drop per stage (larger number of stages) in reaction turbines, their rotational speeds are lower and so the *centrifugal stresses are not very high* (even the reaction blades are lighter). Therefore *drum type construction is preferred to disc type in reaction turbines.*

To accommodate increase in specific volume at lower pressures the drum diameter is stepped up which allows greater area without unduly increasing blade height. The *increased drum diameter also increases the torque due to steam pressure.*

(*b*) **In impulse turbines** there is no expansion of steam in moving blades, and the pressure of steam remains constant while flowing over the moving blades. The expansion takes place only in the nozzles at the inlet to the turbine in HP stages, or through the fixed blades in the subsequent stages. The nozzles need not occupy the complete circumference. Therefore partial admission of steam is feasible and adopted for HP impulse stages.

In reaction turbines, *pressure drop is required in the moving blades also. This is not possible with partial admission. Hence full admission is essential for all stages of a reaction turbine.*

(*c*) Refer Fig. 3.96

Given : $N = 3000$ r.p.m. ; $\phi = \alpha = 20°$; $C_{bl} = 120$ m/s ; $\frac{C_{bl}}{C_1} = 0.8$;

$$\therefore \quad C_1 = \frac{C_{bl}}{0.8} = \frac{120}{0.8} = 150 \text{ m/s}$$

Also $$C_{bl} = \frac{\pi DN}{60} \quad \text{or} \quad 120 = \frac{\pi DN}{60}$$

$$\therefore \quad D = \frac{120 \times 60}{\pi \times 3000} = 0.764 \text{ m.}$$

From steam tables, v_g (at 2.7 bar) = 0.668 m³/kg

$$v = 0.95 \times 0.668 = 0.6346 \text{ m}^3/\text{kg}$$

Flow area $$A = \pi Dh = \pi \times 0.764 \times \frac{30}{1000} = 0.072 \text{ m}^2$$

Flow velocity $$C_f = C_1 \sin \alpha = 150 \sin 20° = 51.3 \text{ m/s} \qquad (C_{f_1} = C_{f_0} = C_f)$$

Mass flow rate $$m = \frac{AC_f}{v} = \frac{0.072 \times 51.3}{0.6346} = 5.82 \text{ kg/s}$$

Accounting for 10 per cent leakage (of total steam flow), the total steam flow rate is

$$\frac{5.82}{0.9} = \mathbf{6.467 \text{ kg/s.}} \quad \textbf{(Ans.)}$$

(*d*) *Once through* boiler is a boiler which *does not require any water or steam drum.* It is a *monotube boiler* using a long tube arranged in the combustion chamber and the furnace. The *economizer, boiler and superheater are in series with no fixed surfaces as separators between the steam and water.*

Benson boiler is an example of once through boiler, operating at supercritical pressure. The tube length to diameter ratio of such a boiler is about 2500. Due to large frictional resistance the feed pressure should be about 1.4 times the boiler pressure.

Example 3.45. (*a*) *List the advantages of steam turbines over gas turbines.*

(*b*) *Determine the isentropic enthalpy drop in the stage of Parson's reaction turbine which has the following particulars :*

Speed =1500 rpm ; mean diameter of rotor = 1 m ;
stage efficiency = 80% ; speed ratio = 0.7 ;
blade outlet angle = 20°. **(AMIE Winter, 1998)**

Solution. (*a*) **Advantages of steam turbines over gas turbines :**

1. The load control in steam turbines is easy simply by throttle governing or cut-off governing. In gas turbines the air-fuel ratio becomes too high, 100 to 150 at part loads. This causes problems to sustain the flame.

2. The steam turbine works on Rankine cycle. In this cycle most of the heat is supplied at constant temperature in the form of latent heat of evaporation. Also the heat is rejected in the condenser isothermally. Hence the cycle is more efficient, and its efficiency is close to that of Carnot cycle. On the other head, the gas turbine works on Brayton cycle whose efficiency is much less than that of Carnot cycle working between the same maximum and minimum limits of temperatures.

3. The efficiency of steam turbine at part load is not very much reduced. In gas turbines the maximum cycle temperature decreases considerably at part load ; therefore its part load efficiency is considerably low.

4. The blade meterial for steam turbines is cheap. For gas-turbines the blade material is costly, as it is required to sustain considerably high temperatures.

(*b*) For Parson's reaction turbine, the velocity triangles are symmetrical, as shown in Fig. 3.96.

Given : $N = 1500$ r.p.m., $D = 1$ m, $\eta_{stage} = 80\%$;

Speed ratio, $\dfrac{C_{bl}}{C_1} = 0.7, \phi = \alpha = 20°$

$$C_1 = C_{r0} \quad \text{and} \quad C_{r1} = C_0$$

$$C_{bl} = \frac{\pi DN}{60} = \frac{\pi \times 1 \times 1500}{60} = 78.54 \text{ m/s}$$

$$\text{Speed ratio} = 0.7 = \frac{C_{bl}}{C_1}$$

$$\therefore \quad C_1 = \frac{78.54}{0.7} = 112.2 \text{ m/s}$$

$$C_{r1}^2 = C_1^2 + C_{bl}^2 - 2C_1C_{bl} \cos \alpha$$

$$= (112.2)^2 + (78.54)^2 - 2 \times 112.2 \times 78.54 \cos 20° = 2195.84$$

or $$C_{r1} = 46.86 \text{ m/s}$$

$$\Delta h = \text{Actual enthalpy drop for the stage}$$

$$= \tfrac{1}{2} [(C_1^2 - C_0^2) + C_{r0}^2 - C_{r1}^2)]$$

$$= \tfrac{1}{2} [(C_1^2 - C_{r1}^2) + (C_1^2 - C_{r1}^2)] = C_1^2 - C_{r1}^2$$

or $$\Delta h = [(112.2)^2 - (46.84)^2] \times 1/1000 \text{ kJ/kg} = 10.39 \text{ kJ/kg}$$

Isentropic enthalpy drop, $(\Delta h') = \dfrac{(\Delta h)}{\eta_{stage}} = \dfrac{10.39}{0.8} = \mathbf{12.99\ kJ/kg.}$ **(Ans.)**

Example 3.46. (*a*) *A 210 MW multistage steam turbine is supplied with steam at 100 bar and 500°C. Vacuum in the condenser is 71 cm of Hg when barometer reads 76 cm of Hg. Assuming stage efficiency of 75% for each stage and reheat factor of 1.04, find the volume rate of cooling water required for the condenser. The rise in cooling water temperature is limited to 10°C and the condensate is undercooled by 2°C.*

(*b*) *A steam turbine discharges 4000 kg of steam per hour at 40°C and 0.85 dry. The estimated air leakage into the condenser is 16 kg per hour. The temperature at the air pump suction is 32°C and the temperature of the condensate is 35°C.*

Find the capacity of the dry air pump if its volumetric efficiency is 80%.

(*c*) *What are the functions of the air cooling section in a surface condenser ?*

(AMIE Summer, 1998)

Solution. (*a*) $\eta_{int} = \eta_{stage} \times$ reheat factor $= 0.75 \times 1.04 = 0.78$

Condenser pressure $= (76 - 71) \times 10 = 50$ mm Hg

$$= \frac{50}{1000} \text{ (m)} \times (13.6 \times 1000) \text{ (kg/m}^3) \times 9.8 \times 10^{-5} = 0.0667 \text{ bar}$$

Corresponding $t_s = 38.1$°C, from Mollier's chart, overall isentropic enthaplpy drop, (Δh) is

$$(\Delta h) = h_1 - h_2 = 3370 - 2040 = 1330 \text{ kJ/kg}$$

Actual enthalpy drop

$$= h_1 - h_2' = (\Delta h) \times \eta_{int} = 1330 \times 0.78 = 1037.4 \text{ kJ/kg}$$

$$h_2' = 3370 - 1037.4 = 2332.6 \text{ kJ/kg}$$

$$h_f \text{ at } (38.1 - 2), \text{ i.e., } 36.1°\text{C} = 151 \text{ kJ/kg}$$

$$\text{Steam rate} = \frac{210 \times 10^3}{1037.4} = 202.429 \text{ kg/s}$$

Heat rejected in condenser

$$= \text{Steam rate} \times (h_2' - h_f)$$

Heat gained by cooling $= m_w \times c_{pw} \times (t_{w_2} - t_{w_1}) = m_w \times 4.187 \times 10$

$\therefore$ Cooling water rate, $\dot{m}_w = \dfrac{202.429(2332.6 - 151)}{4.187 \times 10}$

$= 10547.4$ kg/s $=$ **10547.4 kl/s. (Ans.)**

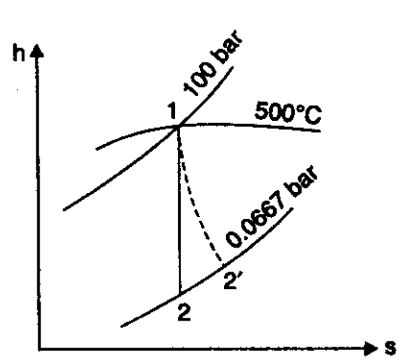


Fig. 3.161

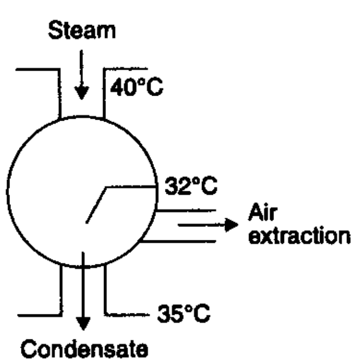


Fig. 3.162

(*b*) Specific volume of steam at inlet $= xv_g$ $(\because \; v_g = 19.52 \text{ m}^3/\text{kg at } 40°\text{C})$

$= 0.85 \times 19.52 = 16.59$ m³/kg

Volume rate of steam at inlet,

$$V_1 = \frac{4000 \times 16.59}{60} = 1106 \text{ m}^3/\text{min.}$$

This is also the volume rate of air at inlet.

$\therefore$ Partial pressure of air at inlet,

$$p_{a1} = \frac{m_a R T_1}{V_1} = \frac{16}{60} \times \frac{287 \times (273 + 40)}{1106} \times 10^{-3} \text{ kPa} = 0.0216 \text{ kPa}$$

Partial pressure of steam at inlet, at 40°C = 7.38 kPa.

∴ Total condenser pressure = 7.38 + 0.0216 ≃ 7.406 kPa

Partial pressure of steam at pump inlet (at 32°C) = 4.76 kPa

∴ Partial pressure of air at pump suction,

$$p_{a2} = 7.406 - 4.76 = 2.646 \text{ kPa}.$$

∴ *Dry air pump capacity,*

$$V_2 = \frac{m_a R T_2}{p_{a2} \times \eta_{vol}}$$

$$= \frac{16}{60} \times \frac{287 \times (273 + 32)}{(2.646 \times 10^3) \times 0.8} = \mathbf{11.03\ m^3}. \quad \textbf{(Ans.)}$$

(*c*) The total pressure in the condenser is the sum of partial pressures of water vapour and air. It remains constant at every section of the condenser, whereas the *partial pressure of steam depends upon the temperature at that section.*

In the condenser, air cooling section is provided near the air extraction pump suction. By circulating relatively cold water at this section the temperature is kept low, thereby *lowering the partial pressure of steam.* This serves *two functions :*

(*i*) This amount of steam lost to atmosphere (which is otherwise used as pure condensate for boiler feed) is considerably reduced.

(*ii*) The partial pressure of air in this section becomes considerably high, and so its density. For a given rate of air leakage into the condenser, the volume of air handled by the air-extraction pump is *reduced.* This enables the use of ***a small** capacity and power pump.*

Example 3.47. *A surface condenser with separate air pump for removing the air only and providing separate air-cooling section is designed to condense 20 tonnes of steam per hour. The air leakage per hour is 6 kg. The temperature of the condensate is 36°C and temperature near the suction of air pump is 28°C. The steam enters into the condenser at 39°C and dry-saturated condition. Find :*

(*i*) *Percentage reduction in air-pump capacity due to separate air-cooling section.*

(*ii*) *Minimum quantity of cooling water if the rise in temperature is limited to 15°C.*

(*iii*) *Saving in the condensate and heat supply in the boiler per hour due to incorporation of air cooling section.*

The loss of condensation is made up with water at 15°C. **(B.U., Dec. 2001)**

Solution. Refer Fig. 3.163

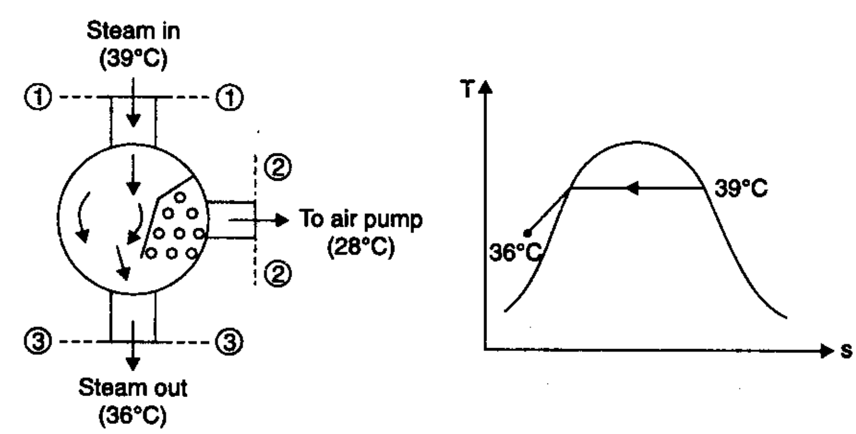


Fig. 3.163

Given : m_s = 20 tonnes/hour ; Air leakage, m_a = 6 kg/h ; t_1 = 39°C ; Condensate temperature, t_3 = 36°C ; Temp. near the suction of air pump, t_2 = 28°C

(*i*) **Percentage reduction in air-pump capacity due to separate air-cooling section :**

Consider section 1-1.

From steam tables, corresponding to t_1 = 39°C :

$$p_{s1} = 0.07 \text{ bar} ; v_{s1} = 20.53 \text{ m}^3\text{/kg} ; h_{s1} = 2572.5 \text{ kJ/kg}$$

Volume of steam entering the condenser,

$$V_{s1} = m_s \times v_{s1} = 20 \times 10^3 \times 20.53 = 410.6 \times 10^3 \text{ m}^3\text{/h}$$

By Dalton's law, $V_{a1} = V_{s1} = 410.6 \times 10^3 \text{ m}^3\text{/h}$

Applying the equation of state to the air at 1 – 1, we have :

$$p_{a1} = \frac{m_{a1} R_a T_{a1}}{V_{a1}} = \frac{6 \times 287(39 + 273)}{410.6 \times 10^3} = 1.31 \text{ N/m}^2 \text{ or } 1.31 \times 10^{-5} \text{ bar}$$

$$\therefore \quad p_t = p_{s1} + p_{a1} = 0.07 + 1.31 \times 10^{-5} = 0.070013 \text{ bar}$$

Consider section 2-2 :

From steam tables, corresponding to 28°C, we have :

$$p_{s2} = 0.0378 \text{ bar} ; v_{s2} = 36.69 \text{ m}^3\text{/kg} ; h_{s2} = 2552.6 \text{ kJ/kg}$$

$$p_{a2} = p_t - p_{s2} = 0.070013 - 0.0378 = 0.032213 \text{ bar}$$

Applying the equation of state to air at section 2-2, we get

$$p_{a2} V_{a2} = m_a R_a T_2$$

$$0.032213 \times 10^5 \times V_{a2} = 6 \times 287(28 + 273)$$

$$\therefore \quad V_{a2} = 160.9 \text{ m}^3\text{/h}$$

As per Daltor's law, $V_{s2} = V_{a2} = 160.9 \text{ m}^3\text{/h}$

Let m_{s2} = Mass of steam carried away with air at section 2-2

$$\therefore \quad V_{s2} = m_{s2} \times v_{s2} \text{ or } 160.9 = m_{s2} \times 36.69$$

or

$$m_{s2} = \frac{160.9}{36.69} = 4.38 \text{ kg/h}$$

Consider section 3-3 and air-pump is not used, then,

From steam tables, corresponding to 36°C, we have :

$$p_{s3} = 0.0595 \text{ bar} ; v_{s3} = 23.94 \text{ m}^3\text{/kg}$$

Then,

$$p_{a3} = p_t - p_{s3} = 0.070013 - 0.0595 = 0.010513 \text{ bar}$$

Applying equation of state to air at section 3-3, we get

$$p_{a3} V_{a3} = m_a R_a T_3$$

$$0.010513 \times 10^5 \times V_{a3} = 6 \times 287 (36 + 273)$$

$$\therefore \quad V_{a3} = 506.13 \text{ m}^3\text{/h}$$

$$V_{s3} = V_{a3} = 506.13 \text{ m}^3\text{/h}$$

But

$$V_{s3} = m_{s3} \times v_{s3} \quad \text{or} \quad 506.13 = m_{s3} \times 23.94$$

$$\therefore \quad m_{s3} = 21.14 \text{ kg/h}$$

∴ Percentage reduction in air pump capacity

$$= \frac{V_{a3} - V_{a2}}{V_{a3}} \times 100 = \frac{506.13 - 160.9}{506.13} \times 100 = \mathbf{68.21\%}. \quad \textbf{(Ans.)}$$

(*ii*) **Minimum quantity of cooling water required ; m_w :**

Applying energy balance to condenser, we have :

Heat lost by the steam and air = Heat gained by water + Heat in condensate

$$(m_{s1}h_{s1} - m_{s2}h_{s2}) + (m_{a1}h_{a1} - m_{a2}h_{a2}) = m_w(h_{w2} - h_{w1}) + m_c h_c$$

or
$$(m_{s1}h_{s1} - m_{s2}h_{s2}) + (m_{a1}h_{a1} - m_{a2}h_{s2}) = m_w c_{pw}(\Delta t_w) + m_{s1}h_c$$

($m_c = m_{s1}$ ... assumed)

$$\therefore \quad m_w c_{pw}(\Delta t_w) = (m_{s1}h_{s1} - m_{s2}h_{s2}) + (m_{a1}h_{a1} - m_{a2}h_{a2}) - m_{s1}h_c$$

$$m_w \times 4.18 \times 15 = (20 \times 10^3 \times 2572.5 - 4.38 \times 2552.6) + [6 \times 1.005 \times (39) - 6 \times 1.005 \times 28] - 20 \times 10^3 \times 4.18 \times (36)$$

(where $\Delta t_w = 15°C$ ..... Given)

$$62.7\, m_w = [(51450 \times 10^3 - 11180) + 66.33 - 3009600] = 48429.3 \times 10^3$$

$$\therefore \quad m_w \simeq 772.4 \times 10^3 \text{ kg/h (or 772.4 tonnes/h)} = \mathbf{214.55\ kg/s.} \quad \textbf{(Ans.)}$$

(*iii*) **Saving in condensate and heat supply in the boiler per hour :**

Saving in condensate $= m_{s3} - m_{s2} = 21.14 - 4.38 =$ **16.76 kg/h. (Ans.)**

Saving in heat supplied, Q = 16.76 × 4.18 (36 – 15) ≃ **1471.2 kJ/h. (Ans.)**

Example 3.48. *At a thermal power station where the boiler pressure is 80 bar and the required flow rate is 130 tonnes / hour, two multistage centrifugal pumps are used in series to pump water from the condenser to the boiler. Each pump is required to produce a head of approximately the total head and run at 1450 r.p.m. If the impellers in stages are identical and the specific speed of each impeller is not less than 15, find :*

(*i*) *The head developed per stage and required number of stages in each pump.*

(*iii*) *The required impeller diameters, assuming the speed ratio based on the outer tip diameter to be 0.98 and the shaft power input, if the overall efficiency of each pump is 0.76.*

What would you expect if the discharge valve is closed and pump is switched on ? What safety device would you recommend ? **(AMIE Summer, 1999)**

Solution. Boiler pressure, $p = 85$ bar ; flow rate = 130 tonnes/h

Speed of each pump, $N = 1450$ r.p.m. ;

Specific speed of each impeller, $N_s = 15$; speed ratio = 0.98

Overall efficiency of each pump, $\eta_{op} = 0.76$

(*i*) **Head developed per stage and no. of stages required in each pump :**

Total head $= \dfrac{p}{w} = \dfrac{80 \times 10^5}{9810} = 815.5$ m ($\because$ For water, $w = 9810$ N/m³)

Head per pump $= \dfrac{815.5}{2} = 407.75$ m

Let n_s = Number of stages per pump,

Then head per stage, $H = \dfrac{407.75}{n_s}$

Now, specific speed, $N_s = 15 = \dfrac{N\sqrt{Q}}{H^{3/4}}$

where $Q = \dfrac{(130 \times 1000) \times 9.81}{9810 \times 3600}$ m³/s = 0.0361 m³/s

$$\therefore \quad 15 = \frac{1450 \times \sqrt{0.0361}}{\left(\dfrac{407.75}{n_s}\right)^{3/4}} \quad \text{or} \quad \left(\frac{407.75}{n_s}\right)^{3/4} = \frac{1450 \times \sqrt{0.0361}}{15} = 18.37$$

or
$$\frac{407.75}{n_s} = (18.37)^{4/3} = 48.47 \quad \text{or} \quad n_s = \frac{407.75}{48.47} = 8.41$$

Actual number of stages in each pump = **8. (Ans.)**

Head developed per stage = $\frac{407.75}{8}$ = **50.97 m. (Ans.)**

(*ii*) **Diameter of each impeller (D) and shaft power input, P :**

$$\text{Speed ratio} = 0.98 = \frac{u_2}{\sqrt{2gH}} \text{ or } 0.98 = \frac{u_2}{\sqrt{2 \times 9.81 \times 50.97}}$$

or $$u_2 = 0.98 \times \sqrt{2 \times 9.81 \times 50.97} = 30.99 \text{ m/s}$$

Also, $$u_2 = \frac{\pi DN}{60} \text{ or } 30.99 = \frac{\pi D \times 1450}{60}$$

or $$D = \frac{30.99 \times 60}{\pi \times 1450} = \mathbf{0.408 \text{ m or } 408 \text{ mm.}} \quad \textbf{(Ans.)}$$

If the discharge valve is closed and pump is switched on, *a pressure wave will be reflected from the valve. A relief valve (safety device) may be used on the delivery side of the pump.*

HIGHLIGHTS

1. A steam power plant converts the chemical energy of the fossil fuels (coal, oil, gas) into mechanical/ electrical energy.
2. The layout of a modern steam power plant comprises of the following four circuits :
   (*i*) Coal and ash circuit (*ii*) Ash and gas circuit
   (*iii*) Feed water and steam flow circuit (*iv*) Cooling water circuit.
3. The choice of steam conditions depends upon the following :
   (*i*) Price of a the coal (*ii*) Capital cost of the plant
   (*iii*) Time available for erection (*iv*) Thermal efficiency obtainable
   (*v*) The station 'load factor'.
4. Automatic stokers are classified as follows :
   (*i*) Overfeed stokers (*ii*) Underfeed stokers.
5. Pulverised fuel handling systems are classified as :
   (*i*) Unit system (*ii*) Central system.
6. Pulverised fuel burners are classified as follows :
   (*i*) Long flame burners (*ii*) Turbulent burners
   (*iii*) Tangential burners (*iv*) Cyclone burners.
7. Oil burners are classified as follows :
   1. Vapourising oil burners :
      (*a*) Atmospheric pressure atomising burner (*b*) Rotating cup burner
      (*c*) Recirculating burner (*d*) Wick type burner.
   2. Atomising fuel burners :
      (*a*) Mechanical or oil pressure atomising burner
      (*b*) Steam or high pressure atomising burner
      (*c*) Low pressure air atomising burner.
8. Fluidised bed may be defined as the bed of solid particles behaving as a fluid.
9. Ash handling systems may be classified as follows :
   (*i*) Mechanical handling system (*ii*) Hydraulic system
   (*iii*) Pneumatic system (*iv*) Steam jet system.
10. The dust collectors may be classified as follows :
    1. Mechanical just collectors
       (*i*) Wet type (scrubbers)—(*a*) Spray type ; (*b*) Packed type ; (*c*) Impingement type.

(ii) Dry type—(a) Gravitational separators ; (b) Cyclone separators.

2. Electrical dust collectors

(i) Rod type (ii) Plate type.

11. The 'collection efficiency' of a dust collector is the amount of dust removed per unit weight of dust.

12. pH value of water is the logarithm of the reciprocal of hydrogen ion concentration. It is number from 0 to 14 with 7 indicating neutral number.

13. The small pressure difference which causes a flow of gas to take place is termed as a *draught.*

14. *Natural* draught is obtained by the use of a *chimney.*

The draught produced by the chimney is due to density difference between the column of hot gases inside the chimney and the cold air outside.

$$h_w = 353\, H\left[\frac{1}{T_a} - \frac{1}{T_g}\left(\frac{m_a + 1}{m_a}\right)\right].$$

The draught pressure produced by the natural draught system in height of hot gases column,

$$H_1 = H\left[\left(\frac{m_a}{m_a + 1}\right) \times \frac{T_g}{T_a} - 1\right].$$

15. Diameter (D) of the chimney is given by, $D = 1.128\sqrt{\frac{\dot{m}_g}{\rho g \, . \, C}}$

where $\dot{m}_g$ = mass of gases flowing through any cross-section of the chimney

ρ_g = density of gases

C = velocity of gases passing through the chimney.

16. Condition for maximum discharge through a chimney is : $\frac{T_g}{T_a} = 2\left(\frac{m_a + 1}{m_a}\right)$.

17. Efficiency of chimney, $\eta_{\text{chimney}} = \frac{\frac{H}{J}\left[\left(\frac{m_a}{m_a + 1}\right) \times \frac{T_g}{T_a} - 1\right]}{c_p\,(T' - T'')}$

where T' = absolute temperature of flue gases leaving the chimney to create the draught of h_w mm of water

T'' = absolute temperature of flue leaving the chimney in case of artificial draught of h_w mm of water.

18. Power required to drive fan :

Power of F.D. fan = $0.998 \times 10^{-8}\left(\frac{hV_a\, m_a M T_a}{\eta_f}\right)$ kW

Power of I.D. fan = $0.998 \times 10^{-8}\left(\frac{hV_a\, m_a M T_g}{\eta_f}\right)$ kW.

19. A '*boiler*' is defined as a closed vessel in which steam is produced from water by combination of fuel.

20. Heated feed water enables steam generators to produce more kg of steam and avoids severe thermal stressing by cold water entering a hot drum.

21. 'Equivalent evaporation' may be defined as the amount of water evaporated from water at 100°C to dry and saturated steam at 100°C.

22. A steam nozzle may be defined as a passage of varying cross-section, through which heat energy of steam is converted to kinetic energy.

23. The velocity, $C = 44.72\sqrt{kh_d}$ ...... in SI units

$C = 91.5\sqrt{kh_d}$ ...... in MKS units

24. Critical pressure ratio,

$$\frac{p_2}{p_1} = \left(\frac{2}{n+1}\right)^{\frac{n}{n-1}} \quad \text{...... condition for maximum discharge.}$$

25. The most important classification of steam turbines is as follows :

(*i*) Impulse turbines (*ii*) Reaction turbines

(*iii*) Combination of impulse and reaction turbines.

26. Force (tangential) on the wheel = $\dot{m}_s(C_{w_1} + C_{w_0})$ N-m

$$\left[= \frac{\dot{m}_s}{g}(C_{w_1} + C_{w_0}) \quad \text{...in MKS units.}\right]$$

Power per wheel $= \dfrac{\dot{m}_s(C_{w_1} + C_{w_0}) \times C_{bl}}{1000}$ kW

$$\left[\text{H.P. per wheel} = \frac{\dot{m}_2(C_{w_1} + C_{w_0}) \times C_{bl}}{g \times 75} \quad \text{... is MKS units.}\right]$$

Blade or diagram efficiency, $\eta_{bl} = \dfrac{2C_{bl}(C_{w_1} + C_{w_0})}{C_1^2}$

Stage efficiency, $\eta_{stage} = \dfrac{C_{bl}(C_{w_1} + C_{w_0})}{(h_1 - h_2)}$

$$\left[= \frac{C_{bl}(C_{w_1} + C_{w_0})}{gJ(h_1 - h_2)} \quad \text{... in MKS units.}\right]$$

27. The axial thrust on the wheel due to difference between the velocities of flow at entrance and outlet.

Axial force on the wheel $= \dot{m}_s(C_{f_1} - C_{f_0})$.

$$\left[= \frac{\dot{m}_g}{g}(C_{f_1} - C_{f_0}) \quad \text{...... in MKS units.}\right]$$

28. Energy converted to heat by blade friction = Loss of kinetic energy during flow over blades

$$= \dot{m}_s(C_{r_1}^2 - C_{r_0}^2).$$

$$\left[= \frac{\dot{m}_s}{g}(C_{r_1}^2 - C_{r_0}^2) \quad \text{...... in MKS units.}\right]$$

29. Optimum value of ratio of blade speed to steam speed is, $\rho_{opt.} = \dfrac{\cos\alpha}{4}$.

In general optimum blade speed ratio for maximum blade efficiency or maximum work done is given by

$$\rho_{opt.} = \frac{\cos\alpha}{2n}$$

and the work done in the last row = $\dfrac{1}{2^n}$ of total work,

where n is the number of moving rotating blade rows in series.

30. The degree of reaction of reaction turbine stage is defined as the ratio of heat drop over moving blades to the total heat drop in the stage.

31. The blade efficiency of the reaction turbine is given by $\eta_{bl} = 2 - \dfrac{2}{1 + 2\rho\cos\alpha - \rho^2}$;

η_{bl} becomes maximum when, $\rho = \cos\alpha$

and hence $(\eta_{bl})_{max} = \dfrac{2\cos^2\alpha}{1 + \cos^2\alpha}$.

32. The principal methods of steam governing are as follows :
(*i*) Throttle governing (*ii*) Nozzle governing
(*iii*) By-pass governing (*iv*) Combination of (*i*), (*ii*) and (*iii*).

33. Condenser efficiency is defined as the ratio of the difference between the outlet and inlet temperatures of cooling water to the difference between the temperature corresponding to the vacuum in the condenser and inlet temperature of cooling water.

34. The quantity of cooling water, m_w, is formed by the following expression :

$$m_w = \frac{m_s[xh_{fg} + c_{pw}(t_s - t_{w_2})]}{c_{pw}(t_{w_2} - t_{w_1})} \text{ kg/h} \qquad \text{...... Jet condenser.}$$

$$m_w = \frac{m_s[xh_{fg} + c_{pw}(t_s - t_c)]}{c_{pw}(t_{w_2} - t_{w_1})} \text{ kg/h} \qquad \text{......Surface condenser.}$$

THEORETICAL QUESTIONS

1. How are steam power plants classified ?
2. Give the layout of a modern steam power plant and explain it briefly.
3. What are the essential requirements of steam power station design ?
4. What factors should be taken into consideration while selecting the site for steam power plant ?
5. How can the capacity of a steam power plant be determined ?
6. On factors does the choice of steam conditions depend ?
7. Enumerate the means by which the coal from coal mines can be transported.
8. What are the requirements of good coal handling plant ?
9. Enumerate and explain the steps involved in handling of the coal.
10. Explain with the help of a neat diagram the arrangement of the Fluidised bed combustion (FBC) system.
11. State the characteristics of a good ash handling plant.
12. Enumerate and explain various modern ash-handling systems.
13. How are dust collectors classified ?
14. Explain with the help of a diagram the working of a 'cyclone separator'.
15. How do you define the 'collection efficiency' of a dust separator ?
16. What are the uses of ash and dust ?
17. Give the general layout of ash handling and dust collection system.
18. What is the function of a boiler chimney ?
19. Why is there no chimney in the case of a locomotive boiler ?
20. What do you understand by the term "Boiler draught" ?
21. What are the limitations of chimney draft ?
22. Define the chimney efficiency and find out expression for the same.
23. What are the various types of draughts used in usual practice ?
24. What are the advantages of artificial draught over natural draught ?
25. What do you understand by steam jet draughtd ? Where is it general employed ?
26. How are boilers classified ?
27. Explain the unique features of the high pressure boilers.
28. Explain with neat sketches the construction and working of any two of the following high pressure boilers ?
(*i*) LaMont boiler (*ii*) Loeffler boiler
(*iii*) Benson boiler (*iv*) Velox boiler.
29. Write short notes on the following :
(*i*) Supercharged boilers (*ii*) Supercritical boilers.
30. Why are the accessories used in a boiler ?

31. Explain briefly any two of the following boiler accessories :
(*i*) Economiser (*ii*) Air preheater
(*iii*) Superheater.

32. How are feed water heaters classified ?

33. What is an evaporator ? How are evaporators they classified ?

34. Define the following :
(*i*) Equivalent evaporation (*ii*) Factor of evaporation
(*iii*) Boiler efficiency.

35. Define the term 'steam nozzle'. Explain various types of nozzles.

36. What is the effect of friction on the flow through a steam nozzle. Explain with the help of a *h-s* diagram.

37. What do you mean by a super-saturated flow ? Explain with the help of *h-s* diagram.

38. Define the following in relation to steam turbines :
(*i*) Speed ratio (*ii*) Blade velocity coefficient
(*iii*) Diagram efficiency (*iv*) Stage efficiency.

39. Discuss various methods of compounding steam turbines ?

40. Describe briefly the various methods of 'steam turbine governing'.

41. Define a steam condenser and state its functions.

42. Explain the reasons for inefficiency in surface condensers.

43. Explain the effects of air leakage in a condenser.

44. What is a cooling tower ? How are cooling towers classified ? Explain any one of them with a neat sketch.

45. How are impurities in water classified ?

46. Enumerate various methods of feed water treatment.

47. Explain briefly any two of the following methods of feed water treatment :
(*i*) Sodium zeolite process (*ii*) Deaeration
(*iii*) Coagulation.

48. What are the requirements of steam piping system ?

49. List the advantages and disadvantages of steam power plants.

50. Give comparison between steam, hydro-electric, diesel and nuclear power plants.

UNSOLVED EXAMPLES

CHIMNEY DRAUGHT

1. Calculate the quantity of air supplied per kg of fuel burnt in the combustion chamber of a boiler when the required draught of 1.85 cm of water is produced by a chimney of 32 m height. The temperatures of the flue gases and ambient air recorded are 370°C and 30°C respectively. [**Ans.** 15.3 kg]

2. Determine the draught produced in cm of water by a chimney of 50 metres height when the temperature of the flue gases passing through the chimney is such that the mass of flue gases discharge is maximum in a given time. The ambient air temperature is 20°C. [**Ans.** 30.2 mm]

3. A boiler is provided with a chimney of 24 m height. The ambient temperature is 25°C. The temperature of flue gases passing through the chimney is 300°C. If the air flow through the combustion chamber is 20 kg/kg of fuel burnt, find (*i*) the theoretical draught in cm of water, (*ii*) velocity of the flue gases passing through the chimney if 50% of the theoretical draught is lost in friction at grate and passage. [**Ans.** 12.9 mm of water, 14 m/s]

4. A forced draught fan discharges 1,200 m^3 of air per minute through the outlet of 2.1 m^2 and maintains a static pressure of 10 cm of water. The temperature of air is 27°C. Calculate the BHP of the motor to drive the forced draught fan if the efficiency of the fan is 80%. Assume that the weight of 1 m^3 of air at N.T.P. is 1.293 kg. [**Ans.** 35.15]

5. Calculate the quantity of air required per kg of coal burnt in a boiler fitted with 32 m high stack. Draught produced is 18.5 mm of water when the temperature of flue gases in the chimney is 370°C and that of boiler house is 30°C. Calculate also the draught produced in terms of height of a column of hot gas in metres. [**Ans.** 15.3 kg, 31.65 m]

6. Forced draught fan delivers air at 10 m/s against a draught of 25 mm of water across the fuel bed on the grate. Determine the H.P. required to drive the fan if 10000 kg of coal is burnt per hour with 13 kg of air required per kg of coal burnt. Barometer reading is 1 kgf/cm^2. Boiler house temperature is 20°C. Assume the efficiency of the fan to be 81.5 per cent. [**Ans.** 16]
7. With a chimney of height 40 metres, the temperature of flue gases with natural draught was 350°C. The same draught was developed by induced draught fan and the temperature of the flue gases was 150°C. Mass of the flue gases formed is 20 kg per kg of coal fired. The boiler house temperature is 38°C. Determine the efficiency of the chimney. Assume c_p = 0.24 kcal/kg°K for the flue gases. [**Ans.** 1.177%]
8. In a steam power plant, the height of the chimney installed is 30 metres. When the plant was working with natural draught, the temperature of the gases was observed to be 327°C. Induced fan was installed and same draught was produced with the temperature of gases falling to 227°C. The gases formed per kg of coal amount to 20 kg. The atmospheric air temperature of surrounding is 27°C. Determine the efficiency of the chimney. Assume c_p = 0.25 kcal/kg °C for gases. [**Ans.** η = 0.254%]
9. A steam plant developing 1500 H.P. has a 55 m high chimney. The coal consumption is 2.27 kg/H.P. hr and air supplied is 19 kg/kg of fuel burnt. Assume an air temperatures of 30°C and the discharge through the chimney is maximum, find the diameter of the chimney. [**Ans.** 1.12 m]
10. A boiler is to use 1500 kg of coal per hour with the formation of 16 kg of flue gases per kg of fuel burnt. The draught losses are given below :

    Loss through the grate = 4.5 mm of water ; loss through the flues = 7.8 mm of water ; loss through bends etc. = 3.4 mm of water ; head equivalent to velocity of gas flow = 0.5 mm of water.

    The average temperature of the outside air is 27°C and the chimney gases have a mean temperature of 25°C. The actual draught produced may be assumed to be 80% of the theoretical draught, and the velocity of flow coefficient may be assumed to be 0.35, find the height and diameter of the chimney.

    [**Ans.** H = 44.25 m, D = 2.8 m]
11. In a boiler plant a draught of 33.25 m column of hot gases is produced with the help of a chimney of 42.5 m height. The mass of flue gases formed per kg of flue burnt is 20 kg. Assuming an ambident air temperature of 33°C, find the following :

    (*i*) Temperature of flue gases leaving the chimney.

    (*ii*) Extra heat carried away by flue gases if the same draught can be produced by forced draught fan reducing the gas temperature to 120°C which is the limit imposed due to condensation of water vapour. Take c_p (for flue gases) = 0.25 kcal/kg °C.

    (*iii*) Efficiency of the chimney.

    (*iv*) Percentage of heat of fuel used for creating the draught.

    (*v*) Temperature of chimney gases and corresponding draught for the condition of maximum discharge through the chimney. Take calorific vaue of fuel = 7500 kcal/kg.

    [**Ans.** (*i*) 302°C, (*ii*) 45.5 kcal/kg of gas, (*iii*) 0.1712%, (*iv*) 12.13%, (*v*) 372°C and 24.5 mm of water column]

PERFORMANCE OF BOILERS

12. 8 kg of steam is produced at 14 bar and 0.95 dryness in a boiler fed with water at 39°C, per kg of coal consumed. Determine the equivalent evaporation from and at 100°C. [**Ans.** 8.96 kg/kg of coal]
13. A boiler with superheater generates 6000 kg/hour of steam at 15 bar and 0.8 dryness. The boiler exit temperature is 300°C. The feed water temperature is 60°C. The overall efficiency of the plant is 85%. Determine the consumption rate, assuming a calorific value of 30,000 kJ/kg. Also find the equivalent evaporation from and at 100°C. What will be the area of superheater surface if the overall heat transfer coefficient is 450,000 kJ/m^2-h ? [**Ans.** 646 kg/h, 7200 kg/h, 3.86 m^2]
14. A boiler generates 500 kg/hour of steam at 18 bar the steam temperature being 325°C. The feed water temperature is 49.4°C. The efficiency of the boiler is 80%. When using oil of calorific value 44,500 kJ/kg, the steam generated is supplied to a turbine developing 500 kW, and exhausting at 1.8 bar, the dryness of exhaust steam 0.98. Calculate the oil burnt per hour and turbine efficiency. Also find the energy available in the exhaust steam above 49.4°C. [**Ans.** 2448.8 kJ/kg]
15. 5400 kg of steam is produced per hour at a pressure of 7.5 bar in a boiler with feed water at 41.5°C. The dryness fraction of steam at exit is 0.98. The amount of coal burnt per hour is 670 kg of calorific value 31000 kJ/kg. Determine :

    (*i*) The boiler efficiency (*ii*) Equivalent evaporation.

    [**Ans.** 66.2%, 9.12 kg/kg of coal]

16. A boiler with superheater generates 600 kg/hour of steam at 15 bar and 0.98 dryness. The boiler exit temperature is 300°C. The feed water temperature is 80°C. The overall efficiency of the plant is 85%.

(*i*) Determine the coal consumption rate if calorific value of coal is 30,000 kJ/kg.

(*ii*) Find the equivalent evaporation from and at 100°C.

(*iii*) What will be the area of superheater surface if the overall heat transfer coefficient is 450000 kJ/m^2-h ? [**Ans.** 646 kg/h, 7200 kg/h-m, 3.86 m^2]

17. During a boiler trial the following observations were made :

Duration of trial = 1 hour ; steam generated = 35500 kg ; steam pressure = 12 bar ; steam temperature = 250°C ; temperature of water entering economiser = 17°C, temperature of water leaving economiser = 77°C ; oil burnt = 3460 kg ; calorific value of oil = 39500 kJ/kg.

Calculate :

(*i*) Equivalent evaporation per kg of fuel (*ii*) Thermal efficiency of plant

(*iii*) Percentage of heat energy of the fuel energy utilised by the economiser.

[**Ans.** (*i*) 13.02 kg, (*ii*) 74.4%, (*iii*) 6.52%]

18A. In a boiler trial of one hour duration the following observations were made :

Steam generated = 5250 kg ; coal burnt = 695 kg ; calorific value of coal = 30200 kJ/kg ; dryness fraction of steam = 0.94 ; rated pressure of the boiler = 12 bar ; temperature of steam leaving the superheater = 240°C ; temperature of hot well = 47°C.

Calculate :

(*i*) Equivalent evaporation per kg of fuel without superheater.

(*ii*) Equivalent evaporation per kg of coal with superheater.

(*iii*) Thermal efficiency of the boiler without superheater.

(*iv*) Thermal efficiency of boiler with superheater.

(*v*) Heat supplied by the superheater per hour.

Take c_p of steam 2.184.

[**Ans.** (*i*) 8.26 kg/kg of fuel, (*ii*) 9.04 kg/kg of fuel, (*iii*) 61.7%, (*iv*) 67.53%, (*v*) 1.22 × 10^5 kJ/h]

18B. A boiler is provided with an economiser and a superheater. The steam is generated at 21 bar and 0.97 dry. This steam is passed onto a superheater and it leaves the superheater at 250°C. Feed water is supplied to the economiser at 38°C and leaves the economiser at 77°C. The quantity of feed water supplied is 10 kg/kg of fuel which has a calorific value of 32600 kJ/kg. Determine :

(*i*) Efficiency of the entire boiler plant.

(*ii*) Percentage of heat received in the economiser.

(*iii*) Percentage of heat received in the superheater. [**Ans.** (*i*) 88.9%, (*ii*) 5.6%, (*iii*) 3.4%]

19. The following observations were made during a boiler trial :

Weight of feed water = 1520 kg/h ; temperature of feed water = 30°C ; steam pressure = 8.5 bar ; steam temperature = 172.9°C ; dryness fraction of steam = 0.95 ; coal burnt = 200 kg/hour ; calorific value of coal = 27200 kJ/kg ; ash and unburnt coal collected = 16 kg/hour ; calorific value of ash and unburnt coal = 2720 kJ/kg ; weight of flue gases = 17.3 kg/kg of coal, temperature of flue gases = 330°C ; boiler room temperature = 18°C ; c_p for gases = 1.006 kJ/kg °C.

Calculate the boiler efficiency. [**Ans.** 70%]

20. Compare the thermal efficiency of two boilers for which the data are given below :

	Boiler 1	*Boiler 2*
Steam pressure	14 bar	14 bar
Steam produced per kg of coal fired	10 kg	14 kg
Quality of steam	0.9 dry	superheated to 240°C
Feed water temperature	27°C	27°C
Calorific value of fuel	3400 kJ/kg	46000 kJ/kg

Specific heat of feed water is 4.18 kJ/kg K and specific heat of steam is 2.1 kJ/kg K.

Which boiler is more efficient = ? [**Ans.** $\eta_{boiler\ 1}$ = 7.3%, $\eta_{boiler\ 2}$ = 79.5%]

STEAM NOZZLES

21. Dry saturated steam enters a steam nozzle at pressure of 12 bar and is discharged to a pressure of 1.5 bar. If the dryness fraction of a discharged steam is 0.95 what will be the final velocity of steam ? Neglect initial velocity of steam. If 12% of the heat drop is lost in friction, find the percentage reduction in the final velocity. [**Ans.** 633.3 m/s, 6.2%]
22. In a steam nozzle, the steam expands from 3 bar to 1.0 bar. The initial velocity is 90 m/s and initial temperature is 150°C. The nozzle efficiency is 0.95. Determine the exit velocity. [**Ans.** 594 m/s]
23. Steam initially dry and saturated is expanded in a nozzle from 12 bar to 0.95 bar. If the frictional loss in the nozzle is 10% of the total heat drop, calculate the mass of steam discharged when exit diameter of the nozzle is 12 mm. [**Ans.** 224.3 kg/h]
24. The inlet conditions of steam to a convergent-divergent nozzle is 22 bar and 260°C. The exit pressure is 4 bar. Assuming frictionless flow upto the throat and a nozzle efficiency of 85%, determine :
    (*i*) The flow rate for a throat area of 32.2 cm^2.
    (*ii*) The exit area. [**Ans.** (*i*) 11 kg/s ; (*ii*) 60.5 cm^2]
25. In a steam nozzle, dry and saturated steam is expanded from 10 bar to 0.1 bar. Using steam tables, calculate :
    (*i*) Dryness fraction of steam at exit (*ii*) Heat drop
    (*iii*) The velocity of steam at exit from the nozzle when initial velocity is 135 m/s.
    [**Ans.** (*i*) 0.79 ; (*ii*) 694 kJ/kg ; (*iii*) 1185.8 m/s]
26. Determine throat area, exit area and exit velocity for a steam nozzle to pass 0.2 kg/s when the inlet conditions are 12 bar and 250°C and the final pressure is 2 bar. Assume that the expansion is isentropic and that the inlet velocity is negligible. Take $n = 1.3$ for superheated steam.
    [**Ans.** 1.674 cm^2, 2.015 cm^2, 831.6 m/s]
27. The inlet conditions to a steam nozzle are 10 bar and 250°C. The exit pressure is 2 bar. Assuming isentropic expansion and negligible velocity, determine :
    (*i*) The throat area. (*ii*) The exit velocity.
    (*iii*) The exit area of the nozzle. [**Ans.** (*i*) 1.44 cm^2 ; (*ii*) 795 m/s ; (*iii*) 2.15 cm^2]
28. Dry saturated steam is passed at 7 bar through a convergent-divergent nozzle. The throat cross-sectional area is 4.5 cm^2. Find the mass of steam passing through the nozzle per minute.
    [**Ans.** 27 kg/min.]

IMPULSE TURBINES

29. A steam jet enters the row of blades with a velocity of 380 m/s at an angle of 22° with the direction of motion of the moving blades. If the blade speed is 180 m/s and there is no thrust on the blades, determine the inlet and outlet blade angles. Velocity of steam while passing over the blades is reduced by 10%. Also determine the power developed by turbine when the rate of flow of steam is 1000 kg per minute. [**Ans.** 879 kW]
30. In a simple impulse turbine, the nozzles are inclined at 20° to the direction of motion of moving blades. The steam leaves the nozzles at 375 m/s. The blade speed is 165 m/s. Find suitable inlet and outlet angles for the blades in order that the axial thrust is zero. The relative velocity of steam as it flows over the blades is reduced by 15% by friction. Determine also the power developed for a flow rate of 10 kg/s.
    [**Ans.** 34°, 41°, 532 kW]
31. In an impulse turbine the nozzles are inclined at 24° to the plane of rotation of the blades. The steam speed is 1000 m/s and blade speed is 400 m/s. Assuming equiangular blades, determine :
    (*i*) Blade angles (*ii*) Force on the blades in the direction of motion
    (*iii*) Axial thrust (*iv*) Power developed for a flow rate of 1000 kg/h.
    [**Ans.** (*i*) 39°, (*ii*) 1.135 kN, (*iii*) 113.5 kW]
32. In a De Laval turbine, the steam issues from the nozzles with a velocity of 850 m/s. The nozzle angle is 20%. Mean blade velocity is 350 m/s. The blades are equiangular. The mass flow rate is 1000 kg/min. Friction factor is 0.8. Determine : (*i*) blade angles, (*ii*) axial thrust on the end bearing, (*iii*) power developed in kW, (*iv*) blade efficiency, (*v*) stage efficiency, if nozzle efficiency is 93%.
    [**Ans.** (*i*) 33°, 33°, (*ii*) 500 N, (*iii*) 4666.7 kW, (*iv*) 77.5%, (*v*) 72.1%]

33. In a single stage impulse turbine the nozzles discharge the steam on to the blades at an angle of 25° to the plane of rotation and the fluid leaves the blades with an absolute velocity of 300 m/s at an angle of 120° to the direction of motion of the blades. If the blades have equal inlet and outlet angles and there is no axial thrust, estimate :

(*i*) Blade angle (*ii*) Power produced per kg/s flow of steam

(*iii*) Diagram efficiency. [**Ans.** 36.3°, 144 kW, 0.762]

34. Steam enters the blade row of an impulse turbine with a velocity of 600 m/s at an angle of 25° to the plane of rotation of the blades. The mean blade speed is 255 m/s. The blade angle on the exit side is 30°. The blade friction coefficient is 10%. Determine :

(*i*) Work done per kg of steam (*ii*) Diagram efficiency

(*iii*) Axial thrust per kg of steam/s. [**Ans.** (*i*) 150.45 kW, (*ii*) 83.6% (*iii*) 90 N]

35. The nozzles of an impulse turbine are inclined at 22° to the plane of rotation. The blade angles both at inlet and outlet are 36°. The mean diameter of the blade ring is 1.25 m and the steam velocity is 680 m/s. Assuming shockless entry determine :

(*i*) the speed of the turbine rotor in r.p.m.,

(*ii*) the absolute velocity of steam leaving the blades, and

(*iii*) the torque on the rotor for a flow rate of 2500 kg/h.

[**Ans.** (*i*) 4580 r.p.m., (*ii*) 225 m/s, (*iii*) 290.5 N-m]

36. A single stage steam turbine is provided with nozzles from which steam is released at a velocity of 1000 m/s at an angle of 24° to the direction of motion of blades. The speed of the blades is 400 m/s. The blade angles at inlet and outlet are equal. Find :

(*i*) Inlet blade angle,

(*ii*) Force exerted on the blades in the direction of their motion,

(*iii*) Power developed in kW for steam flow rate of 40,000 kg/h. Assuming that the steam enters and leaves the blades without shock. [**Ans.** (*i*) 30°, (*ii*) 1135 N, (*iii*) 4540 kW]

37. In a single row impulse turbine the nozzle angle is 30° and the blade speed is 215 m/s. The steam speed is 550 m/s. The blade friction coefficient is 0.85. Assuming axial exit and a flow rate of 700 kg/h, determine :

(*i*) Blade angles (*ii*) Absolute velocity of steam at exit

(*iii*) The power output of the turbine. [**Ans.** (*i*) 46°, 49° ; (*ii*) 243 m/s ; (*iii*) 19.8 kW]

38. In a steam turbine, steam expands from an inlet condition of 7 bar and 300°C with an isentropic efficiency of 0.9. The nozzle angle is 20°. The stage operates at optimum blade speed ratio. The blade inlet angle is equal to the outlet angle. Determine :

(*i*) Blade angles

(*ii*) Power developed if the steam flow rate is 0.472 kg/s. [**Ans.** 36°, 75 kW]

39. Steam at 7 bar and 300°C expands to 3 bar in an impulse stage. The nozzle angle is 20°, the rotor blades have equal inlet and outlet angles and the stage operates with the optimum blade speed ratio. Assuming that isentropic efficiency of nozzles is 90% and velocity at entry to the stage is negligible, deduce the blade angles used and the mass flow required for this stage to produce 50 kW. [**Ans.** 36°, 0.317 kg/s]

40. In a two stage velocity compounded steam turbine, the mean blade speed is 150 m/s while the steam velocity as it is issued from the nozzle is 675 m/s. The nozzle angle is 20°. The exit angle of first row moving blade, fixed blade and the second row moving blades are 25°, 25° and 30° respectively. The blade friction coefficient is 0.9. If the steam flow rate is 4.5 kg/s, determine :

(*i*) Power output (*ii*) Diagram efficiency. [**Ans.** (*i*) 807 kW, (*ii*) 78.5%]

REACTION TURBINES

41. At a particular stage of reaction turbine, the mean blade speed is 60 m/s and the steam pressure is 3.5 bar with a temperature of 175°C. The identical fixed and moving blades have inlet angles of 30° and outlet angles of 20°. Determine :

(*i*) The blade height if it is $\frac{1}{10}$th of the blade ring diameter, for flow rate of 13.5 kg/s.

(*ii*) The power developed by a pair.

(*iii*) Specific enthalpy drop if the stage efficiency is 85%. [**Ans.** (*i*) 64 mm, (*ii*) 218 kW, (*iii*) 19.1 kJ/kg]

42. In a stage of impulse reaction turbine operating with 50% degree of reaction, the blades are identical in shape. The outlet angle of the moving blades is 19° and the absolute discharge velocity of steam is 100 m/s in the direction at 100° to the motion of the blades. If the rate of flow of steam through the turbine is 15000 kg/h, calculate the power developed by the turbine in kW. **[Ans.** 327.5 kW]

43. At a stage in a reaction turbine the pressure of steam is 0.34 bar and the dryness 0.95. For a flow rate of 36000 kg/h, the stage develops 950 kW. The turbine runs at 3600 r.p.m. and the velocity of flow is 0.72 times the blade velocity. The outlet angle of both rotator and rotor blades is 20°. Determine at this stage :

(*i*) Mean rotor diameter. (*ii*) Height of blades. **[Ans.** (*i*) 0.95.1 m, (*ii*) 115 mm]

44. In a multi-stage reaction turbine at one of the stages the rotor diameter is 1250 mm and speed ratio 0.72. The speed of the rotor is 3000 r.p.m. Determine :

(*i*) The blade inlet angle if the outlet blade angle is 22°,

(*ii*) Diagram efficiency,

(*iii*) The percentage increase in diagram efficiency and rotor speed if turbine is designed to run at the best theoretical speed.

[Ans. (*i*) 61.5°, (*ii*) 82.2%, (*iii*) 30.47%]

45. In a 50 per cent reaction turbine stage running at 3000 r.p.m., the exit angles are 30° and the inlet angles are 50°. The mean diameter is 1 m. The steam flow rate is 10000 kg/min and the stage efficiency is 85%. Determine :

(*i*) Power output of the stage. (*ii*) The specific enthalpy drop in the stage.

(*iii*) The percentage increase in relative velocity of steam when it flows over the moving blades.

[Ans. (*i*) 11.6 MW (*ii*) 82 kJ/kg, (*iii*) 52.2%]

46. Twelve successive stages of a reaction turbine have blades with effective inlet and outlet angles of 80° and 20° respectively. The mean diameter of the blade row is 1.2 m and the speed of rotation is 3000 r.p.m. Assuming constant velocity of flow throughout, estimate the enthalpy drop per stage. For a steam inlet condition of 10 bar and 250°C and on outlet condition of 0.2 bar, estimate the stage efficiency.

Assume a reheat factor of 1.04, determine the blade height at a stage where the specific volume is 1.02 m^3/kg.

[Ans. 40.4 kJ/kg, 70.3%, 57 mm]

STEAM CONDENSERS

47. A primemover uses 16,000 kg of steam per hour and develops 2600 kW. The steam is supplied at 30 bar and 300°C. The exhaust from the primemover is condensed at 725 mm Hg (0.984895 bar) when barometer records 755 mm Hg (1.006584 bar). The condensate temperature from the condenser is 30°C and the rise of temperature of circulating water is from 7°C to 17°C. Determine :

(*i*) The quality of steam entering the condenser.

(*ii*) The quantity of circulating cooling water and the ratio of cooling water.

Assume all mechanical drive losses are negligible and no air is present in the condenser.

[Ans. (*i*) 0.9496, (*ii*) 873028 kg/h, 54.56 kg/kg]

48. The observations recorded during the trial on a steam condenser are given below :

Condenser vacuum = 685 mm Hg ; Barometer reading = 765 mm Hg ; Mean condensate temperature = 34°C ; Hot well temperature = 28°C ; Condensate formed per hour = 1750 kg ; Circulating cooling water inlet temperature = 18°C, Circulating cooling water outlet temperature = 30°C ; Quantity of cooling water = 1300 kg/min.

Determine :

(*i*) Vacuum efficiency, (*ii*) Undercooling of condensate,

(*iii*) Condenser efficiency, (*iv*) Condition of steam as it enters the condenser,

(*v*) Mass of air per kg of uncondensed steam.

Take : R for air = 0.287 kJ/kg K.

Specific heat of water = 4.186 kJ/kg K. **[Ans.** (*i*) 94.47%, (*ii*) 6°C, (*iii*) 37.5%, (*iv*) 0.898, (*v*) 1.613 kg]

49. A surface condenser is fitted with separate air and condensate outlets. A portion of the cooling surface is screened from the incoming steam and the air passes over these screened tubes to the air extraction and becomes cooled below the condesate temperature. The condenser receives 20000 kg/h of steam dry saturated at 36.2°C. At condensate outlet, the temperature is 34.6°C, and at the air extraction the temperature is 29°C. The volume of air plus vapour leaving the condenser is 3.8 m^3/min. Assuming constant pressure throughout the condenser, calculate :

(*i*) The mass of air removed per 10000 kg of steam.

(*ii*) The mass of steam condensed in the air cooler per minute.

(*iii*) The heat to be removed per minute by the cooling water.

Neglect the partial pressure of the air inlet to the condenser.

[**Ans.** (*i*) 2.63 kg, (*ii*) 0.492 kg, (*iii*) 807050 kJ]

50. Separate air pump and water pump are installed in a condenser. Steam enters the condenser at 40°C and condensate is removed at 37°C. The quantity of air infilrating into the condenser through various zones is 5 kg/hour.

(*i*) What will be the volume of air handled by the air pump.

(*ii*) What will be the quantity of handled by a combined air and condensate pump at 38°C.

Make suitable assumptions and list all such assumptions. [**Ans.** 400.8 m^3/h ; 776 m^3/h]

COMPETITIVE EXAMINATIONS QUESTIONS

1. An input-output curve of a 10 MW thermal station is given by an equation :

$$I = 10^6 (18 + 12L + 0.5 L^2) \text{ kcal/hr}$$

where I is in kcal per hour and L is the load on power plant in MW.

Find out (*a*) the load at which the efficiency of the plant will be maximum, and (*b*) the increase in input required to increase the station output from 5 MW to 7 MW by using the input-output equation and by incremental rate curve.

2. (*a*) Explain the different methods used for supplying pulverised fuel to the combustion chambers of the boilers. Discuss the advantages and disadvantages of each.

(*b*) Draw a neat diagram of a cyclone burner and describe its working. What are its outstanding features compared with other burners ? Why are such burners useful for Indian coal ?

3. (*a*) How does dust collection system differ from ash collection ? Explain the working of electrostatic precipitator with neat diagram.

(*b*) It is requried to estimate the equivalent evaporation and efficiency of the boiler from the data given below :

Quantity of steam generated	= 5500 kg/hour
Condition of steam generated	= 8.5 kgf/cm^2 and 0.98 dry
Temperature of feed water	= 36.5°C
Coal consumption	= 680 kg/hour
Calorific value of coal	= 7450 kcal/kg

If by fitting an economiser, the temperature of feed water is raised to 100°C, what will be saving in coal consumption per hour if the other data remains unchanged and there is 5% increase in the efficiency of the boiler ?

4. (*a*) What are the different methods of burning solid coal on a grate ?

(*b*) Explain the over-feed system of combustion.

(*c*) Explain with the help of neat diagram spreader stoker and also explain its advantages over other type of stoker.

5. (*a*) Sketchand describe the elements of a hydraulic ash handling system for slag tap furnace.

(*b*) (*i*) What is the purpose of feed water heating in a steam power plant ?

(*ii*) What are the different types of feed water heaters ?

(*iii*) Explain with the help of a diagram the direct contact feed water heating.

6. (*a*) Explain with the help of neat sketches the working of 'forced draft' and 'induced draft' cooling towers.

(*b*) What is the importance of high purity water in high pressure boilers ? Explain the method used for water purifying when the make up water is required for high pressure boilers.

7. Write notes on *any two* of the following :

(*a*) Scope of tidal power in India ;
(*b*) Super-thermal pwoer stations in India ;
(*c*) Selection of site for a hydro-power station.

8. (*a*) Why is superheating of steam essential in steam power ?

(*b*) A small steam turbine develops 100 H.P. and used 7 kg of steam per horse power hour. The steam is supplied to the turbine pressure of 15 kg/cm^2 at 240°C and the steam is exhausted to condenser at a pressure of 0.1 kg/cm^2. The condensate leaves at 34°C. Calculate the dryness fraction of the exhaust steam entering the condenser. Cooling water is supplied at 10°C and leaves at 22°C. Calculate the amount of cooling water supplied per hour.

Specific heat of superheated steam is 0.6.

9. (*a*) What are the ash handling systems ?

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

(*b*) Draw a neat line diagram of inplant coal handling system and explain the equipment used at different stages.

10. (*a*) Describe with the help of neat diagram the working of a plate type air heater used in a modern power plant.

(*b*) What are the requirements of the burners used for firing pulverised coal ? Describe with line sketches the various types of burners used and their relative merits and demerits.

11. (*a*) Describe the working of a contact type feed water heater with the help of neat diagram.

(*b*) Draw an outline of ash disposal equipment. State the advantages of hydraulic system of handling ash. What are the problems of has disposal ?

12. (*a*) What are characteristics of turbo-alternators ?

(*b*) During a trial of 20 minutes the following observations were made on a single cyclinder double-acting steam engine when running on light load—barometer 76 cm of Hg ; total steam used 51 kg ; gauge pressure of steam in valve chest 2 kgf/cm^2 ; the engine rejected exhaust steam into a condenser at the pressure of atmosphere which is 1.03 kgf/cm^2. The state of the steam in the valve chest was found to be dry and saturated. Mean engine speed 120 r.p.m. ; mean effective pressure : outstroke 1.06 kgf/cm^2, instroke 0.984 kgf/cm^2 ; piston rod diameter 21.5 cm ; stroke 30.8 cm ; piston rod diameter 3.7 cm. Net brake load (*W-S*) 50.5 kg. Brake wheel radius = 1.2 m condensate at the rate of 2.850 kg/hr with a rise in temperature of 24°C. Temperature of the condensate leaving the condenser 60°C.

Calculate :

(*i*) The steam consumption in kg/1 HP-hr ;
(*ii*) The mechanical efficiency ;
(*iii*) The brake thermal efficiency of the engine.

Draw up a heat balance sheet for the plant on minute basis taking condensate temperature as datum.

13. (*a*) Describe methods of loading steam stations, hydrostations and nuclear stations.

(*b*) State the criteria for optimum loading of power plant.

14. (*a*) Describe with a neat sketch the working of a travelling grate stoker of a steam boiler.

(*b*) Describe pneumatic ash handling system in a modern steam generator.

15. (*a*) Draw *P-V* and *T-S* diagrams for the most commonly used thermodynamic cycle for a thermal station.

(*b*) Steam at pressure 40 kgf/cm^2 and 400°C temperature is supplied to a steam turbine and is exhausted at pressure of 0.07 kgf/cm^2. A single bleed is taken between the H.P. cylinder and L.P. cylinder of the turbine at 2.5 kgf/cm^2 forregenerative feed heating. The isentropic efficiency for both the cylinders of the turbine is 85%. The temperature of the bleed condensate coming out of heat exchanger is 10°C lower than the temperature of the bleed steam. Find out :

(*i*) Amount of bleed steam/kg of steam supplied to the turbine ;
(*ii*) The thermal efficiency of the plant.

(Consider no losses and pump work as negligible. Let the condensate coming out from the heat exchanger and condenser be led to the hot well).

16. Write detailed notes on the following :

(*a*) Switch gears for power stations ;
(*b*) Combined loading of thermal and hydroplants ;
(*c*) Power from tides.

17. (*a*) What are the advantages of high pressure boilers ? Discuss the guide lines for the selection of boilers for steam power plants.

(*b*) A steam power plant working on regenerative cycle utilises steam at 42 kgf/cm^2 and 400°C and the condenser pressure is 0.963 kgf/cm^2 vacuum. After expansion in the turbine to 5 kgf/cm^2, a part of steam is extracted from the turbine for heating feed water from condenser in the open heater. Draw the cycle on *T-S* diagram and find the thermal efficiency of the plant. Assume the heat drop to be isentropic and the atmospheric pressure may be taken equal to 1.033 kgf/cm^2.

18. (*a*) Make a list of the advantages of pulverised coal firing in a steam power plant.

(*b*) Discuss in brief the ash handling systems in P.F. boilers. What are the difficulties in the handling of ash in a thermal power station ?

19. (*a*) Discuss how coil is handled in a medium capacity thermal power plant.

(*b*) Make a list of advantages and disadvantages of stoker firing and explain the working of chain grate stoker with simple sketch.

20. A steam turbine using regenerative feed heat cycle generates 27000 kW through a directly coupled electric generator. Steam at 60 kgf/cm^2 and 450°C is supplied to the turbine. The condenser pressure is 730 mm Hg vacuum. The steam is bled from steam turbine at 3 kgf/cm^2. The heating of feed water is done in direct contact heater. Find :

(*a*) Steam bled/kg of steam supplied ; (*b*) Steam generated/hour ;

(*c*) Overall efficiency of the plant.

Assume turbine η of each portion of expansion as 86%, boiler η = 90% alternator η = 95%, mechanical η from turbine to generator 98% and 10% of generator output is used to run the pump. Neglect pump work in calculating input to the boiler.

21. (*a*) Explain the advantages of combined of power plants.

(*b*) Explain the effect of load factor of an electric power station on the cost of energy generated.

(*c*) The steam consumption rates in kg/hr for two steam turbines is given by the following equations ;

$F_1 = 2{,}000 + 10\,P_1 - 1 \times 10^{-4}\,P_1^{\,2}$

$F_2 = 4{,}000 + 7\,P_2 - 5 \times 10^{-5}\,P_2^{\,2}$

wehre *P* represents the load in kW.

Determine the most economical loading when the total load taken by both units is 30 MW.

22. (*a*) Explain how combustion takes place in overfeed and underfeed stokers. Discuss their relative performance.

(*b*) Explain the working of an electrostatic precipitator and list its outstanding features.

23. (*a*) Show that the thermal efficiency of a regenerative cycle is greater than simple Rankine cycle.

(*b*) Steam at 50 kgf/cm^2 and 400°C is supplied to a two stage turbine. The steam is first expanded in high pressure turbine to 5 kgf/cm^2. The steam is reheated at 5 kgf/cm^2 to 250°C using 0.96 dry steam from the boiler at 50 kgf/cm^2. The reheated steam is passed through low pressure stage and then exhausted to a condenser at 0.03 kgf/cm^2. The isentropic efficiency of high pressure and low pressure stage may be assumed same as 80%. Assuming that the mechanical efficiency is 99% and generator efficiency is 96%, find the weight of steam generated by the boiler per kWh. Assume that the heating steam in the reheater given up heat by condensing only and the pump work and other losses are neglected.

24. (*a*) Explain how the load distribution between two alternators of a generating station can be divided for best economy.

(*b*) The input-output curve of a 10 MW thermal station is given by :

$$I = (10 + 8L + 0.4L^2)\,10^6 \text{ kcal/h}$$

where *L* is in MW. Find out the load at which the plant runs at maximum efficiency and also the value of the maximum efficiency.

25. (*a*) Draw an explanatory line diagram of an ash handling system used for a modern high capacity steam power plant. State its merits.

(*b*) Describe, giving a neat diagram the working of a cyclone burner. Why are such burners preferred for Indian coals ?

(*c*) Prove that for the same plant the power required by an inducted draught fan will be more than that required by a forced draught fan assuming that the efficiencies of both the fans are the same.

26. (*a*) List the advantages and disadvantages of a surface condenser.

(*b*) Draw the flow diagram of a steam turbine plant using reheating and regeneration. Represent the various thermodynamic processes on a *T-S* diagram.

(*c*) A steam turbine develops 2.5 MW when the steam is supplied at 10 kgf/cm^2 abs and 250°C. The pressure in the condenser is 0.14 kgf/m^2 abs. Assuming the expansion efficiency through the turbine stage as 80%, determine :

(*i*) Specific steam consumption of the plant ;

(*ii*) Thermal efficiency of the plant.

27. (*a*) What are the advantages of burning coal in pulverised form ? Name the different types of coal pulverizing mills and discuss the outstanding features of each.

(*b*) Explain, with the help of neat sketch, the working of an electrostatic precipitator and give its outstanding features over other collectors.

28. (*a*) What are the sources of air leakage into a condenser ? Discuss the effect of air leakage on the performance of a condenser.

(*b*) A two-stage regenerative cycle used steam at 70 kgf/cm^2, 400°C with 25 mm of Hg back pressure. Station auxiliary power is 15% of turbine output. The overall electrical and mechanical efficiency of turbine generator is 80% and the boiler efficiency is 85%. The turbine has an engine efficiency of 88%. Compute the overall station heat rate in kcal/kWh.

29. The following data refers to a boiler trial of a steam power plant :

Coal consumption	= 4,0000 kg/hr
Calorific value of coal	= 8,500 kcal/kg
Ultimate analysis of coal	C = 80%, H_1 = 5%, H_2O = 7%, ash = 8%
Orsat analysis of the gases	CO_2 = 10%, O_2 = 8%, CO = 2%, N_2 = 80%
Temperature of the gases	= 300°C
Boiler room temperature	= 20°C
Steam generated	= 40,000 kg/hr
Pressure of steam at stop valve	= 14 kg/cm^2 dry
Specific heat of gases	= 0.24
Specific heat of superheat steam	= 0.50
Feed water temperature	= 50°C

Draw the heat balance sheet of boiler based on 1 kg of coal.

Calculate also the amount of air needed in kg/hour if 50% excess air is supplied.

30. (*a*) What difficulties are experienced in ash handling ? Describe with the help of a diagram the working of a pneumatic ash handling system.

(*b*) Explain clearly the difference between overfeed and underfeed systems of coal firing. Which is preferred for high volatile coal and why ?

31. (*a*) Draw a neat schematic diagram and temperature entropy diagram of thermodynamic cycle used in steam power plants and explain it in brief.

(*b*) A steam turbine power plant working on Rankine cycle receives steam at a pressure of 90 kgf/cm^2-ab and temperature of 500°C. Steam is expanded in the first stage of turbine to a pressure of 12 kgf/cm^2-ab. It is then reheated to its initial temperature and then expanded in the second stage to a pressure of 0.07 kgf/cm^2-ab.

Find :

(*i*) The efficiency of the cycle assuming isentropic expansion efficiency of turbine in each stage to be 90% ;

(*ii*) Steam flow rate required to develop 10 MW of power ;

(*iii*) Dryness fraction of steam leaving the turbine.

32. (*a*) What are the advantages of burning fuel in pulverised form ?

(*b*) Name the different types of coal pulverising mills and discuss outstanding features of each. Name one which is commonly used.

(*c*) What are the different methods used for supplying pulverised fuel to combustion chambers ?

33. (*a*) Draw a general layout of a thermal power plant and explain the working of difference circuits.
(*b*) What factors are considered in selecting a site for a big thermal power plant.

34. (*a*) Draw a line diagram of pneumatic ash handling system used for modern capacity power plant. Explain the difficulties encountered in its design and operation. When is this system preferred over other systems ?
(*b*) Draw a neat line diagram of Benson boiler and explain its working. Discuss its relative merits and demerits.

35. (*a*) Draw a neat diagram of multiretort under feed stoker and explain its working. Discuss its merits over other types of stokers.
(*b*) What are the advantages of burning the fuels in pulverised form ?

36. Write brief notes on the following :
(*i*) Heat balance in steam power plant ; (*ii*) Pumped storage hydroelectric power plant ;
(*iii*) Lubrication system in diesel electric plant ; (*iv*) Open cycle gas turbine.

37. (*a*) List out the major advantages of high pressure boilers in modern thermal power plants.
(*b*) Draw a neat diagram of a volex boiler and discuss its merits. Explain its working principle.

38. (*a*) Explain the working principle of the following :
(*i*) Economisers ; (*ii*) Air preheaters ; (*iii*) Superheaters.
(*b*) The steam at 90 kgf/cm^2 ab. and 480°C is supplied to a steam turbine. The steam is reheated to its original temperature passing the steam through reheater at 12 kgf/cm^2 ab. The expansion after the reheating, takes place to condenser pressure of 0.07 kgf/cm^2 ab. Find the efficiency of reheat cycle and work output if the flow of steam is 1 kg/s. Neglect the pressure loss in the system and assume the expansion through the turbine as isentropic. Do not neglect the pump work.

39. (*a*) Explain with neat diagram the working principle of travelling grate stoker.
(*b*) Why ash should be discharged ? Give reasons. List the difficulties encountered in the ash handling plant layout. Mention the places of disposal of ash.

40. (*a*) Give the classification of coal in the increasing order of their heat value. Discuss each of them.
(*b*) Discuss the following pulverised fuel handling systems :
(*i*) Unit system ;
(*ii*) Central or Bin system. Mention the advantages and disadvantages of them.

41. (*a*) What is the function of cooling tower in a modern steam power plant ? Describe briefly with a neat sketch the working of a hyperbolic cooling tower.
(*b*) The steam at 90 kgf/cm^2-ab and 480°C is supplied to a steam turbine. The steam is reheated to its original temperature passing the steam through reheater at 12 kgf/cm^2-ab. The expansion after reheating takes place to condenser pressure 0.07 kgf/cm^2-ab. Find the efficiency of reheat cycle and work output if the flow of steam is 1 kg/sec. Neglect the pressure loss in the system and assume the expansion through the turbine is isentropic. Do not neglect the pump work.

42. (*a*) What do you understand by the term "Draught" ?
How is the draughts classified ? Explain with neat sketch the balanced draught.
(*b*) What are the advantages of high pressure boiler ? Draw a neat line diagram of LaMont boiler and explain its working.

43. (*a*) What do you understand by proximate and ultimate analysis of coal ? Discuss the role played by each constituent.
(*b*) Explain the coal preparation plant.
(*c*) Explain *any three* equipment used for the transfer of coal from unloading point to the storage site.

44. (*a*) Describe the burning sequence of coal in 'overfeed' and 'underfeed' stokers. Which types of stoker is suitable to burn
(*i*) High ash clinkering coals, (*ii*) High volatile matter coal and
(*iii*) Low ash content coals ?
(*b*) Why ash and dust handling problem is more difficult than coal handling problems ? Explain them.

45. Write short notes on the following :
(*i*) Electrostatic precipitator ; (*ii*) Mechanical draft cooling tower ;
(*iii*) Excitor and circuit breaker in a power plant.

46. (*a*) Discuss briefly, with a line sketch, the different types of burners used in firing pulverized coal in steam boilers.

(b) The following observations were taken during a test on a steam generator :
Quantity of coal burnt per hour 750 kg
Feed water supplied per hour 7,000 kg
Calorific value of coal fired 8,100 kcal/kg
Feed water temperature entering economizer 25°C
Feed water temperature leaving economizer 80°C
Steam pressure 10 kgf/cm^2
Dryness fraction of steam leaving boiler drum 0.95
Temperature of steam leaving superheater 250°C
Determine the thermal efficiency of the plant and also calculate the heat absorbed by feed water in various components as a percentage of the total heat absorbed.

47. (a) Name the different boiler accessories.

(b) With a neat line sketch explain the working principle of Schimdt-Hartmann boiler.

(c) Why is it important to purify water in high pressure boiler ? How are dissolved oxygen and silica removed from feed water ?

48. (a) Why is condenser used in steam power plant ? Discuss the working of different parts of surface condenser.

(b) The steam at 100 kgf/cm^2 and 500°C expands in the turbine upto 8.5 kgf/cm^2 with an isentroic efficiency of 80%. The steam is then reheated to original temperature and then it expands in the lower stage of the turbine upto the condenser pressure of 0.05 kgf/cm^2. The isentropic efficiency of the lower stage of the turbine is 85%. Find the thermal efficiency of the cycle assuming the pressure loss in the reheater of 0.5 kgf/cm^2.

If the expansion of the steam is allowed to continue in the lower part of the turbine with an isentropic efficiency of 75% without reheating, then find the thermal efficiency of the cycle. Neglect the pump work in both case.

49. (a) How is the efficiency of a steam plant improved through regenerative cycle ? Show the cycle on temperature-enthropy diagram and deduce an expansion for its ideal efficiency.

(b) In a single stage regenerative cycle, steam is supplied to the steam turbine at 16 kgf/cm^2 abs and 300°C and exhausts at 0.05 kgf/cm^2 abs. The steam for feed heating is to be extracted at 1.6 kgf/cm^2 abs. The drain from the closed heater, at saturation temperature of bled steam pressure, is returned to the system at a point downstream from the heater and the feed water is heated to saturation temperature of bled steam. Determine the regenerative cycle efficiency and compare it with Rankine cycle working between the same terminal conditions. Neglect pump work. Represent the processes on enthalpy-entropy plane, if used.

50. (a) What are the advantages of using high pressure boilers in modern thermal power stations ? Discuss briefly high temperature effects on steam piping in modern boilers.

(b) Steam is supplied to a 10 MW turbo-alternator at 40 kgf/cm^2 abs and 400°C. Auxiliaries consume 7 per cent of the output. The condenser pressure is 0.05 kgf/cm^2 abs and the condensate is subcooled to 30°C. Take boiler efficiency as 85 per cent and the relative efficiency of turbine as 0.8 and the mechanical efficiency of the alternator as 95 per cent. Determine :
(i) The steam consumption per hour ; (ii) The overall efficiency of the plant ;
(iii) The quality of steam at exit from turbine.
Sketch the relevant portion of Mollier diagram, if used for the solution.

51. (a) What are meant by 'primary air' and 'secondary air' with regard to combustion for stoker firing and pulverised fuel firing ?

(b) Describe briefly with a flow sheet the pulverised coal preparation systems and the method of firing of pulverised fuel. Discuss briefly the advantages and disadvantages of pulverised coal firing.

52. Describe briefly the elements of a hydraulic ash handling system for a boiler furnance in a power station.

53. The following data were obtained during a trial of a coal fired steam boiler with natural draught :

Feed water temperature	= 75°C
Feed water supplied per hour to boiler	= 4500 kg
Steam pressure	= 11 kg/cm^2 abs

Dryness fraction of steam generated in boiler	= 0.95
Coal fired per hour	= 400 kg
Higher calorific value of coal	= 9400 kcal/kg
Moisture in coal 4.25 per cent by mass	
Temperature of flue gases discharged	= 270°C
Boiler room temperature	= 30°C

Analysis of dry coal by mass was : C = 89%, H_2 = 3%, Ash = 4% and other volatile matter = 4%

The analysis of flue gas by volume was : CO_2 = 10.9%, CO = 1.1%, O_2 = 7% and N_2 = 81%.

Draw up the heat balance for the boiler per kg of coal fired, and also determine the thermal efficiency of the boiler. Assume sp. heat of dry flue gases as 0.23 and sp. heat of superheated steam in products of combustion as 0.48. Also assume partial pressure of water vapour in flue gases as 0.027 kg/cm^2 abs.

54. (*a*) What are the different methods to control superheat temperature in steam generators ?

(*b*) What are the differences between a feed water heater and an economiser ?

(*c*) Discuss briefly the working of an economiser used in modern steam generator. How soot is cleaned from economiser tubes ?

55. (*a*) What are the advantages of using reheat steam cycle ?

(*b*) How in actual practice reheating is done in steam power.

(*c*) In a reheat cycle, with two stages of reheating, steam at 210 kgf/cm^2 and 550°C, enters the turbine and expands to 41 kgf/cm^2 abs. At this point the whole steam is passed to the first reheater. The steam re-enters the turbine at the same pressure and expands further to 10 kgf/cm^2 abs pressure. After expansion the whole steam is passed to the second reheater. The steam after second stage of reheating further expands to condenser pressure of 0.126 kgf/cm^2 abs. The exist of steam from both the reheaters is at 550°C and there is no pressure drop in the reheaters. For the ideal reheat cycle determine the thermal efficiency.

56. (*a*) Explain how required vacuum is maintained in the condenser of a steam power plant.

(*b*) What are the disadvantages of 'pulverised fuel firing system' ? Discuss how these disadvantages are eliminated in more advanced methods of fuel firing system.

(*c*) What are the harmful effects caused by using impure water in boiler ? State the various methods of purifying feed water.

57. In a 60 MW steam turbine plant steam is supplied to the HP unit at 70 kgf/cm^2 and 450°C. Steam is expanded to 25 kgf/cm^2 in the HP unit and before entering the IP unit steam is reheated at constant pressure to 420°C. Expansion continues upto 10 kgf/cm^2 in the IP unit when a portion of steam held at 10 kgf/cm^2 is taken to a closed feed-water heater with drains pumped ahead. The remaining steam expands to the condenser pressure of 0.07 kgf/cm^2 in the LP unit. The isentropic efficiency of the HP stages 80% while that of IP and LP stages is 83% each. using the following data only, determine :

(*a*) Quantity of steam bled per kg of flow at the turbine inlet ;

(*b*) Thermal efficiency ; and

(*c*) Steam consumption in tonnes/hour.

Neglect all pump work assume that feed-water is heated to the bled steam temperature in the heater. Draw the schematic diagram of the plant and the corresponding *T-S* diagram.