

19.1. Necessity of Feed-Water Treatment. 19.2. Different Impurities in Water. 19.3. Effects of Impurities. 19.4. pH-Value of the Water and its Importance. 19.5. Different Methods of Water Treatment. 19.6. Internal Boiler Water Treatment for Scale Prevention. 19.7. External Treatment System. 19.8. Sea Water Treatment Using Reverse Osmosis (RO). 19.9. Nuclear Reactors and Importance of Water Purity.

19.1. NECESSITY OF FEED-WATER TREATMENT

The natural water contains solid, liquid and gaseous impurities and, therefore, this water cannot be used for the generation of steam in the boilers. The impurities present in the water should be removed before its use for steam generation.

The necessity for reducing the corrosive nature and quantity of dissolved and suspended solids in feed water has become increasingly important with the advent of high pressure, critical and supercritical boilers. With the introduction of once through boilers, the problem of removing the dissolved solids has become more important because, even very small quantities of dissolved and suspended solids in feed water pass through the turbine and condenser. The effects of these solids are the corrosion and erosion of boiler tubes, turbine blades and condenser tubes. These solids further blockage the boiler tubes and result is tube failure due to overheating. Therefore, it is necessary to polish the condensate and condenser leakage (compensating feed water) to remove any contamination caused by corrosion.

Although a considerable volume of knowledge is now available, even then the internal boiler corrosion remains a problem, especially in plants operating at 60 bar and above.

The external water is used as a "make-up" to the feed water system in order to counterbalance the loss of working medium throughout the cycle from blow-down, leaks etc. This loss varies from 1 to 3% during normal operation and 5% during start-up period.

The total make-up water required per hour for a 400 MW capacity plant is of the order of 100 to 150 tons per hour. Therefore, it is absolutely necessary to have a separate water-softening plant to polish the water taken from outside source (well, lake or river) to counterbalance the losses in the system. The general outline of the feed water supply system is shown in Fig. 19.1.

The most probable reason of condensate contamination is leakage since the system is not sufficiently tight under normal load conditions or because of cyclic operating conditions such as frequent start-up and stop.

Another cause of contamination is condenser tube leakage. Condenser cooling water is generally oxygen saturated and contains enormous quantity of solids. Therefore, the condenser tube leakage introduces oxygen and solids in the feed water system. This leakage can seriously upset operating conditions where the condenser cooling-water system consists of cooling towers because of further concentration of salt in cooling water due to evaporation over

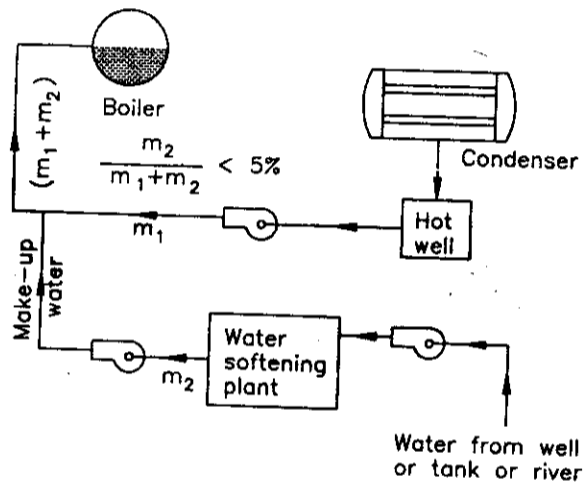


Fig. 19.1. Position of water softening plant.

cooling towers. Even small leaks in condenser permit a surprising amount of low quality cooling water to contaminate high purity condensate. For example, if a 500 tons/hr condensate flow is contaminated each hour with 0.025% its weight in cooling water of 300 ppm solids, the boiler feed water takes in 300 kg of solid per year. This one example is sufficient to illustrate the importance of water-softening plant.

The water supplied by water-softening plant is of very high quality, 10 – 50 ppb silica and less than 500 ppb total solid content being typical of a present-day make-up water sample. Although the solid content entering into the boiler is reduced with the help of water softening plant, these solids become concentrated at low blow-down rates and continue to threaten high heat transfer area. As the problem of tube failure still exists, contamination of condensate has been considered one of the major causes.

Most of the percolated water through the ground contains dissolved salts, mainly of calcium and magnesium. These cannot be removed by filtering and would form a sludge or scale on heating surfaces if left in the feed water. The initial effect of this scale formation would be to reduce the rate of heat transfer thus causing overheating of the tubes and if it is allowed to continue, there would be a gradual build-up of deposits with subsequent reduction of flow areas together with an additional risk of carryover causing formation of deposits in superheater tubes and build-up on turbine blades. Therefore, some preliminary treatment of feed water is necessary.

The overall objective of the water softening plant is to maintain the operation at the best possible levels of availability, economy and efficiency and to attain this objective, chemical control of the water and steam system is directed to prevent the corrosion in the boiler, and steam turbine, to prevent the scale and deposit formations on heating surfaces and to maintain high level purity of the steam.

19.2. DIFFERENT IMPURITIES IN WATER

Very rarely, the water can be used without treatment for steam generation. More often, the water contains impurities and, therefore, those must be removed before use. First step in selecting the treatment is a survey of available water supply because the impurities present depend upon the source of water available as well water, lake water, river water or municipal water. The impurities (dissolved) present in well water are much greater than river or lake water as the water passes through the solid containing number of dissolving salts and minerals. Surface waters, except for very large lakes or rivers, vary greatly in composition during a year. Maximum impurities in river can range upto 400 times the minimum amounts during the year.

The impurities present in the feed water are classified as given below :

1. Undissolved and suspended solid materials
2. Dissolved salts and minerals.
3. Dissolved gases.
4. Other materials (as oil, acid) either in mixed and unmixed forms.

1. Undissolved and Suspended Materials

(a) **Turbidity and Sediment.** Turbidity in the water is suspended in soluble matter including coarse particles (mud, sediment, sand etc.) that settle rapidly on standing. Amounts range from almost zero in most ground waters and 60,000 ppm in muddy and turbulent river water. The turbidity of feed water should not exceed 5 ppm. These materials can be removed by settling coagulation and filtration. Their presence is undesirable because heating or evaporation produces hard stony scale deposits on the heating surface and clog fluid system. Both are objectionable as they cause damage to the boiler system.

A standard of measurement of hardness is taken as being the amount of calcium carbonate (CaCO_3) in the water and is referred to in part per million (ppm) or grains per gallon ($\text{grains/gallon} \times 17.1 = \text{ppm}$).

(b) **Sodium and Potassium Salts.** These are extremely soluble in water and do not deposit unless highly concentrated. Their presence is troublesome as they are alkaline in nature and accelerate the corrosion.

(c) **Chlorides.** Majority of the chlorides cause increased corrosive action of water.

(d) **Iron.** Most common soluble iron in water is ferrous bicarbonate. The water containing ferrous bicarbonate deposits becomes yellowish and reddish sediment of ferric hydroxide if exposed to air. Majority

of ground surface water contains less than 5 ppm but even 0.3 ppm can create trouble in the feed water system by soft scale formation and accelerating the corrosion.

(e) **Manganese.** It also occurs in similar form as iron and it is also equally troublesome.

(f) **Silica.** Most natural water contains silica ranging from 1 to 100 ppm. Its presence is highly objectionable as it forms very hard scale in boilers and forms insoluble deposits on turbine blades. In modern high pressure boilers, its presence is reduced as low as 10—50 ppb.

(g) **Microbiological Growths.** Various growths occur in surface water (lake and river). The micro-organisms include diatoms, molds, bacterial slimes, algae ; manganese and sulphate reducing bacteria and many others. These can cause coating on heat exchanger and clog the flow passages and reduce the heat transfer rates.

(h) **Colour.** Surface waters from swampy areas become highly coloured due to decaying vegetation. Colour of feed water is objectionable as it causes foaming in boilers and may interfere with treatment processes. It is generally removed by chlorination or adsorption by activated carbon.

2. Dissolved Salts and Minerals

(a) **Calcium and Magnesium Salts.** The calcium and magnesium salts are present in the water in the form of carbonates, bicarbonates, sulphates and chlorides. The presence of these salts is recognised by the hardness of the water (hardness of water is tested by soap test). The hardness of water is classified as temporary and permanent hardness. The temporary hardness is caused by the bicarbonates of calcium and magnesium and can be removed by boiling. The boiling converts the soluble bicarbonates into less soluble carbonates which can be removed by simple blow-down method. The permanent hardness of the water is caused by the presence of chlorides, sulphates and nitrates of calcium and magnesium and they cannot be removed just by boiling because they form a hard scale on heating surfaces.

3. Dissolved Gases

(a) **Oxygen.** It is present in surface water in dissolved form with variable percentage depending upon the water temperature and other solid contents in water. Its presence is highly objectionable as it is corrosive to iron, zinc, brass and other metals. It causes corrosion and pitting of water lines, boilers and heat exchangers. Its effect is further accelerated at high temperatures.

(b) **Carbon Dioxide.** The river water contains 50 ppm and well water contains 2 to 50 ppm of CO_2 . It also causes the corrosion of steam, water and condensate lines. It also helps to accelerate the corrosive action of oxygen.

The other gases are H_2S , CH_4 , N_2 and many others but their percentages are negligible, therefore, their effects are not discussed here.

4. Other Materials

(a) **Free Mineral Acid.** Usually present as sulphuric or hydrochloric acid and causes corrosion. The presence is reduced by neutralization with alkalies.

(b) **Oil.** Generally the lubricating oil is carried with steam into the condenser and through the feed system to the boiler. It causes sludge, scale and foaming in boilers. It is generally removed by strainers and baffle separators.

The effects of all the impurities present in the water are the scale formation on the different parts of the boiler system and corrosion. The scale formation reduces the heat transfer rates and clogs the flow passage and endangers the life of the equipments by increasing the temperature above same limit. The corrosion phenomenon reduces the life of the plant rapidly. Therefore, it is absolutely necessary to reduce the impurities below a safe limit for the proper working of the power plant.

19.3. EFFECTS OF IMPURITIES

The major troubles caused by the feeding of water of undesirable quality are scale formation, corrosion, foaming, caustic embrittlement, carryover and priming. The details are described below.

In the internal treatment system, the chemicals are added in feedwater which causes dissolved solids to form a non-sticky soft sludge. The form sludge is removed by blowing down method.

The scale prevention or removal problem becomes more severe in case of high pressure boilers. Because, higher boiler-water temperature produces faster chemical reactions and higher tube temperatures. Since the tube metal being closer to its sagging point, scale formation can cause bagging, blistering and rupture more quickly. This is the main reason of maintaining high purity of feedwater in modern high pressure boilers.

2. Corrosion. The corrosion is the eating away process of boiler metal. It causes deterioration and failure of the equipments. Eventually this calls for major repairs or expensive shutdowns or replacement.

The corrosion of boilers, economisers, feedwater heaters and piping is caused by an acid or low pH in addition to the presence of dissolved oxygen and CO_2 in the boiler feed water. The presence of oxygen is mostly responsible for corrosion among all other factors. The permissible limit of oxygen content varies with the acidity of the water. Generally it should not exceed 0.5 cc. per litre. This limit is also not permissible in high pressure boilers as the action of O_2 is rapid under high pressure and temperature conditions. 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. The CO_2 comes out of bicarbonates on heating and it combines with the water to form weak acid known as *carbonic acids*. This acid slowly reacts with iron and other metals to form their bicarbonates. The newly bicarbonates of metals formed are decomposed by heat once more and CO_2 is again liberated. This gas again unites with water to form carbonic acid and the cycle is repeated.

The corrosion causes pitting and grooving on metal surfaces. This further reduces the strength of the metal and effect is total failure of the system.

The corrosion can be minimised by adding alkali salts to neutralise acids in water and raise the pH value. The effect of carbon dioxide is neutralised by the addition of ammonia or 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. Use of mechanical deaeration followed by scavenger chemicals (reducing agents such as sodium sulphates, hydrazine, tannin) to remove the last traces of oxygen from the water is also very effective.

The corrosion of metal surfaces can be prevented by applying protective coating of amines to the internal surfaces of boilers and economizers.

3. Priming, Foaming and Carryover. Priming, foaming, and carryover are closely associated terms, Each describes the condition that causes boiler water and dissolved solids to leave the boiler together.

The priming is a violent discharge of water with steam from the boiler. It can be compared to the bumping of water that frequently accompanies rapid heating on an open vessel. In a priming, the water level in the boiler undergoes rapid and great changes and there are violent discharges of bursting bubbles. Therefore, the "slugs" of boiler water is thrown over with the steam. The priming is caused due to improper boiler design, improper method of firing, overloading, sudden load changing (pulsating steam demand) or a combination of these factors. The priming effect is reduced by installing steam purifiers, lowering water level in the boiler-drum and maintaining constant load on boiler.

The foaming is the formation of small and stable bubbles throughout the boiler water. The high percentage of dissolved solids, excessive alkalinity and presence of oil in water are responsible for foaming. When the concentration of solids in water increases and it also becomes contaminated with oil, numerous small-sized steam bubbles are formed. These smaller bubbles are much more stable and do not burst easily. Therefore, a thick layer of small-sized bubbles accumulates on the surface and this ultimately produces violent foaming. The foaming contaminates the steam with appreciable amounts of boiler water which contains the corrosive salts.

Boiler water solids are also carried over in the moisture mixed with steam even when there is no indication of either priming or foaming. This is known as “*Carryover*”. The carryover of boiler water solids is partly a mechanical and partly a chemical problem. The mechanical causes include boiler design, high water level, overloading and fluctuating loads on boiler.

The boiling effect is more violent if the steam is produced with a faster rate. But if the steam space above the water level is large enough, the steam leaving the boiler will not show any evidence of carryover. When the steam storage space above water level is too small, the possibility of carryover is more. Therefore, the size of the steam heater and velocity of the steam leaving the boiler are important factors in the design of the boiler drum to avoid carryover. Deliberate overloading of the boiler, sudden opening of the steam valve or cutting up the boiler too quickly speeds up the production of the steam and causes violent bubbling and carryover.

Normally, a steam from boiler carries 0.5 to 1.5% moisture in the form of mist or fog. This is not permissible in high-pressure modern power plants and, therefore, moisture percentage is limited to 0.1%.

Whatever may be the cause of priming, foaming or carryover, the effect is to carry the water which contains dissolved salts or undissolved slugs with the steam. The carryover of boiler water solids disrupts operation of the equipments coming in contact with the steam. The deposits are formed in the steam piping, valves, superheaters and turbine blades. These deposits erode the turbine blades, superheater tubes and interfere with lubrication system.

Carryover is a serious problem both for the safety of the boiler and steam carrying equipments. Therefore, necessary steps must be taken to correct the steam condition. Steam washers and mechanical separators in the boiler drums effectively control carryover within reasonable and tolerable limits. Notable exception to this is silica which is carried with the steam in form of vapour at operating pressures above 40 bar. Proper water treatment including the right amount of blowdown is the key for maintaining these limits.

The following table shows the maximum allowable concentrations Vs pressure to prevent carryover under normal operating conditions :

Boiler pressure bar	0—20	20—30	30—40	40—50	50—60
Allowed solid in ppm.	3500	3000	2500	2000	1500

The amount of suspended solids and alkalinity in the boiler water is also equally important for carryover. The following table gives allowed alkalinity at various operating conditions :

Boiler pressure in bar		0—20	20—30	30—40	40—50	50—60
Total alkalinity ppm as CaCO ₃	Minimum	200	160	120	120	120
	Maximum	700	600	500	400	300

Small amounts of organic matter and oil are also undesirable. To fix the control limit of allowable solids in a boiler plant, it is first necessary to make sure that oil and organic matters are kept completely out of boiler.

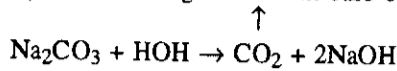
Remarkable strides have been made in last few years in developing antifoam treatment chemicals because to maintain the solids in water below the allowable range is highly economical. With the use of antifoam chemicals, the boilers can be safely operated at high concentrations than the limits mentioned in the literature. With the use of antifoam chemicals, 30,000 ppm solids are allowed in the boiler feed water without development of carryover. Another advantage of antifoam chemicals is reduced rate of blowdown which saves heat normally lost with the blowdown otherwise.

The antifoam chemicals are complicated organic matters. The polymerized esters, alcohols and amides are most effective known antifoam compounds.

4. Caustic Embrittlement. The caustic embrittlement is the weakening of boiler steel as a result of inner crystalline cracks. This is caused by long exposure of boiler steel to a combination of stress and highly alkaline water.

The caustic embrittlement takes place under following conditions :

1. When the boiler water contains free hydroxide alkalinity and some silica, it has been always found that the feedwater was high in sodium-bicarbonate which broke down into sodium carbonate in the boiler and partially hydrolyzed as shown by the following reaction in case of embrittlement.



2. Slow leakage of boiler water through a joint or seam.
3. Boiler metal is highly stressed at the point of leakage. This may be caused by faulty riveting, misalignment and expansion.

The problem of caustic embrittlement is not as common as many other boiler water troubles. However, it must be considered in every water treatment plant and measures must be taken to prevent it.

Prevention of embrittlement consists of reducing the causticity or adding inhibiting agents to the feed water. The most practical method of preventing caustic embrittlement is to regulate the chemical composition of the boiler water. The obvious solution to embrittlement is to eliminate all free NaOH from the boiler water. One method to eliminate free NaOH has been developed using phosphates. The pH value of the feed water is controlled by the addition of phosphate so that any solid material deposited at the point of concentration is trisodium phosphate and not free NaOH. The pH value of water with respect of phosphate concentration is shown in Fig. 19.2. If the pH of boiler water is maintained below the value indicated on the curve, the boiler water will not have any free NaOH.

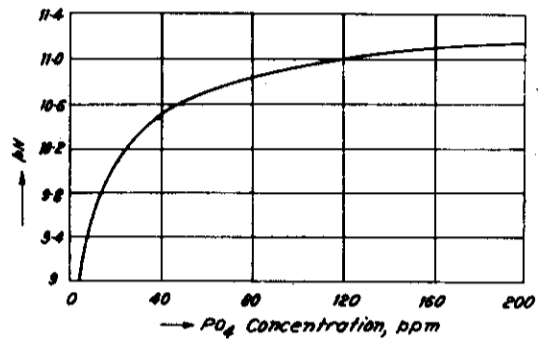


Fig. 19.2. Effect on phosphate concentration on pH value.

Another method to prevent the caustic embrittlement is to keep free NaOH as low as possible. Then the chemicals that are capable to maintain low level of free NaOH must be added in the water. The common chemicals used are sulphate liquor, quebracho tannin and sodium nitrate. Sodium nitrate lends itself more easily than quebracho tannin and it is preferred where this feature is more important. But the quebracho tannin has other beneficial properties over sodium nitrate that is the ability to absorb oxygen and promote the more sludge forming tendency to the feed water.

Embrittlement control calls for maintaining low-hydroxide alkalinity in boiler feed water avoiding leaks at stressed metal areas and adding special chemical inhibiting agents.

Boiler water troubles are often interrelated. There is no general rule saying that scale formation, corrosion, carryover and caustic embrittlement cannot take place simultaneously. Therefore, in any system of water treatment, all these factors must be considered as potential operation difficulties.

19.4. pH VALUE OF THE WATER AND ITS IMPORTANCE

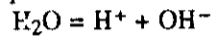
The pH value of the feed water plays very important role in controlling the corrosion. To understand the importance of pH value for controlling the corrosion, it is necessary to know little about electro-chemical theory of corrosion.

Electro-chemical Theory of Corrosion. Each substance (even metals) dissolves in water to a certain extent like sugar and salt. No doubt, the amount of dissolved substance required for saturation varies considerably according to the nature of the substance. A limited amount of any given substance dissolves in water, no matter how much of the substance is added.

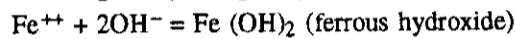
All metals also tend to dissolve in water to a certain extent according to electro-chemical theory. Water in contact with iron dissolves very small quantity of iron into solution. The water quickly becomes saturated with iron which stops further dissolving. The dissolved iron remains in different conditions from that in the solid metallic state. Every iron particle going into solution takes on an electric charge and is known as ferrous ion.

$\text{Fe (metallic state)} = \text{Fe}^{++}$ (ferrous ion when goes into solution)

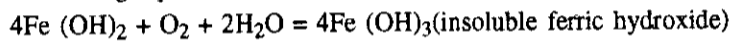
Water in natural condition also ionizes to a very small extent and forms positive H^+ ions and negative hydroxyl ions as given by the following equation :



The ferrous ions combine with negatively charged hydroxyl ions to form a ferrous hydroxide

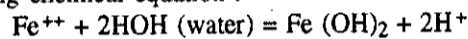


The dissolved oxygen of water oxidizes and converts ferrous hydroxide to ferric hydroxide as given by the following equation :

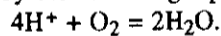


The formed ferric hydroxide is much less soluble than the ferrous hydroxide and tends to precipitate. This in turn allows more ions to go into the solution.

Another important role is played by excess hydrogen ions that form on the metal surface to accelerate corrosion. Hydroxyl ions from the water unite with the ferrous ions and hydrogen ions are left free in the water as given by the following chemical equation :



These excess hydrogen ions form a protective coating over the metallic surface and tend to prevent further solution of metallic ion. The dissolved oxygen in the water also tends to combine with free excess hydrogen ions and forms water again as given by the following equation :



Therefore, the dissolved oxygen also removes the protective layer of hydrogen ions and allows more iron to dissolve in the water.

The above explained electro-chemical theory of corrosion states that the corrosion is controlled by the free hydrogen ions (hydrogen ion concentration) present in the water. The acidic or alkaline nature of the water is also responsible for the corrosion as mentioned earlier. The acidity or alkalinity of the water is also determined by the quantity of hydrogen ions present in water. Higher hydrogen content means increased acidity.

pH and its role in corrosion. The pH is a number denoting the degree of acidity or alkalinity of a substance. It does not indicate the quantity of acid or alkaline in a solution as found by titration method. It is derived by measuring the amount of hydrogen ion (H^+) in grams per litre of solution. For example, pure water ionizes to produce (10^{-7}) grams of H^+ ions per litre. Therefore, any substance producing 10^{-7} grams of hydrogen ions per litre is considered to be a neutral solution. The greater the amount of hydrogen ions present in solution its acid reaction becomes stronger. Therefore, pure water being neutral solution, any solution producing more hydrogen ion than pure water will be acidic and degree is governed by the difference. Other solution producing less hydrogen ions than pure water will be alkaline and the degree is also governed by the difference.

The pH value of all solutions is accommodated between 0 and 14. The selection of the numbers 0 to 14 is not arbitrary but is actually the number of decimal places required to record the measure of weight of H^+ ions per litre of solution having ascending or descending values of acid and alkaline. Thus a solution

having no decimal place is represented by 1 or 1 gram of H^+ ions per litre. This solution would be highly acidic as compared with water. Such value on pH scale is represented as zero. Acid or alkaline nature of a solution depends on whether hydrogen or hydroxyl (OH) ions predominate.

The pure water also contains H^+ and OH^- ions as mentioned earlier. The extent to which this dissociation is present in a given sample depends upon temperature. At $20^\circ C$, the concentration of these ions is of the order of 10^{-14} . Due to this, pH scale has been spread upto 14.

The table for the pH scale is given below :

pH value	Hydrogen ions (H^+) in grams per litre		Number of times acidity or alkalinity exceeds that of pure water
0	1.0	10^0	10,000,000
1	0.1	10^{-1}	10,000,00
2	0.01	10^{-2}	100,000
3	0.001	10^{-3}	10,000
4	0.0001	10^{-4}	1000
5	0.00001	10^{-5}	100
6	0.000001	10^{-6}	10
7	0.0000001	10^{-7}	1
8	0.00000001	10^{-8}	10
9	0.000000001	10^{-9}	100
10	0.0000000001	10^{-10}	1000
11	0.00000000001	10^{-11}	10,000
12	0.000000000001	10^{-12}	100,000
13	0.0000000000001	10^{-13}	1,000,000
14	0.00000000000001	10^{-14}	10,000,000

The pH value of the water is the logarithm of the reciprocal of hydrogen ion concentration. It is numbered from 0 to 14 indicating 7 for neutral water. A solution having pH less than 7 indicates acidity and more than 7 indicates alkalinity. As the pH is a logarithmic function, solution having a pH as 6, 5 or 4 are respectively 10, 100 and 1000 times more acidic than one with pH value as 7.

The law of mass action in mass dissociation is $OH^- \times H^+ = 10^{-14}$. For instance, if H^+ is 10^{-9} then OH^- 10^{-5} gram ions per litre and pH 9 designates the solution which is alkaline as OH ions predominate.

The role of pH in corrosion of metals is extremely important. The corrosion rate of iron in the absence of oxygen is proportional to pH upto a value of 9.6. At this point, hydrogen gas formation and dissolving of iron practically stop. This is the same pH produced by a saturated solution of ferrous hydroxide $Fe(OH)_2$.

The oxygen in the water unites with the ferrous hydroxide to form ferric hydroxide. This reaction lowers pH of the solution and tends to stimulate corrosion.

Alkalinity adjustment and film formation are closely related. The pH value of feed water should be maintained greater than 9.6 to reduce the corrosion effects caused by the reason mentioned above. The required alkalinity of feed water is adjusted by adding soda ash, caustic soda or trisodium phosphate.

Film formation occurs when the alkalinity is kept in the desired range. The simplest film is composed of the iron hydroxide initially formed on the metal surface. As long as the alkalinity is high enough, the iron hydroxide remains insoluble and acts as a protective layer. Complex reactions between the alkaline chemicals added and the minerals constituents in the water also result in the formation of protective layer.

pH and its role in scale formation. The calcium hardness alkalinity and pH are inter-related variables in scale control. Calcium carbonate is one of the most troublesome deposits responsible for scale formation. The factors controlling deposition at a given temperature are shown in Fig. 19.3.

Referring to Fig. 19.3, water with 700 ppm calcium hardness and 100 ppm alkalinity at 7 pH lies at point A on the curve shown. The calcium carbonate will not precipitate being point A on the curve. If the water at the point B having 700 ppm calcium hardness and 130 ppm alkalinity is considered, the water is not in equilibrium being the point above the curve, the calcium carbonate will precipitate. The area below the curve indicates a tendency for CaCO_3 to dissolve. Water at point B can be brought back on the curve by reducing the hardness or alkalinity as shown in figure. Therefore, waters with the same calcium hardness may have different scale-forming tendencies.

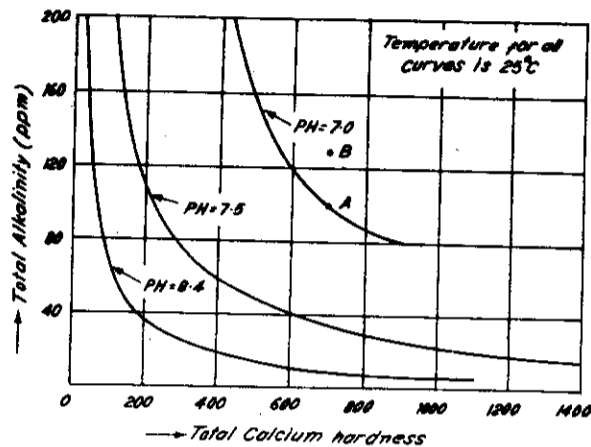


Fig. 19.3. Relation of calcium hardness alkalinity and pH in scale formation.

19.5. DIFFERENT METHODS OF WATER TREATMENT

The basic objective of the water treatment

system is to remove the suspended solids, dissolved solids and dissolved gases from the water before supplying the water to the boiler. The dissolved solids are either removed from the water before supplying to the boiler or after supplying to the boiler. If the dissolved solids in the water are removed in the boiler itself by a chemical treatment then the method is known as "*Internal Treatment*" and if they are removed from the water before supplying to the boiler then it is known as *External Treatment*.

19.6. INTERNAL BOILER WATER TREATMENT FOR SCALE PREVENTION

Treating water in the boiler during evaporation is commonly known as Internal Treatment. The aim of this treatment is to adjust boiler water chemically to prevent scale formation, corrosion, steam contamination and embrittlement. Some form of this treatment is given to every boiler except once-through and super-critical boilers. The amount and type of treating chemicals used depend on the plant operating conditions and feed water analysis.

An internal treatment is accomplished by adding chemicals to the boiler water either to precipitate the impurities so that they can be removed in the form of sludge or to convert them into salts which will stay in water and do no harm.

The following table gives the various sludges which are formed from the compounds of calcium and magnesium originally present in the incoming water.

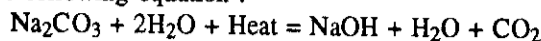
Compounds in raw water	Treating chemicals	Sludge formed
Calcium bicarbonate	1. Caustic soda or soda ash. 2. Phosphates.	1. Calcium carbonate. 2. Tricalcium phosphate.
Calcium sulphate	1. Caustic soda or soda ash. 2. Phosphates.	1. Calcium carbonate. 2. Tricalcium phosphate.
Magnesium sulphate	1. Caustic soda.	1. Magnesium hydroxide.

The common internal treatments used are discussed below :

1. Sodium carbonate (Soda Ash) treatment. The added sodium carbonate reacts with sulphates of calcium and magnesium in boiler water to form calcium and magnesium carbonates as given by the following equation :



The sodium carbonate at high pressure and temperature conditions react with water to form some free caustic soda as given by the following equation :



The free caustic soda formed reacts with the soluble magnesium salts to form desirable insoluble magnesium hydroxide sludge as given by the following equation :



This system of cleaning destroys sulphate hardness.

The system finds use in many small low pressure boilers. This method is more economical when the boiler water contains high hardness (70 ppm) and high alkalinity. The sludge formed by this method is more easy to handle than phosphate type.

The main disadvantage of this system is, it forms CO_2 which goes with steam and dissolves in the condensate to form carbonic acid. This lowers pH and accelerates the rate of oxygen corrosion.

2. Phosphate treatment. The rate of decomposition of sodium carbonate to caustic soda in sodium carbonate treatment increases rapidly with an increase in pressure and temperature of the boiler water. Free caustic alkalinity increases very rapidly and it is impossible to maintain the required alkalinity needed to ensure calcium carbonate precipitation. The CO_2 generating rate also increases with an increase in pressure and temperature. Therefore the use of sodium carbonate treatment is limited to boiler pressure of 10 bar.

For higher pressure and temperature conditions, the required degree of alkaline stability is obtained with treatment by phosphate compounds. The phosphates give good results at all operating pressures.

The common phosphates which are used are Trisodium phosphate ($\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O}$) highly alkaline, Disodium phosphate ($\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$) moderately alkaline and mono-sodium phosphate (NaH_2PO_4) slightly acidic.

Choice of each depends upon economics and alkalinity of the boiler feed water. Calcium cannot be precipitated properly below pH of 9.5. Therefore, it is necessary to select a phosphate that adjusts pH to the optimum value. Trisodium phosphate is most desirable for treatment as it is most alkaline in nature when the alkalinity of boiler water is low. If the boiler water alkalinity is sufficient, the disodium phosphate is more preferred. But the alkalinity in the boiler water is too high and requires to be reduced then monosodium phosphate being acidic in nature is preferred.

The precipitation of salts is maximum at optimum value of pH of boiler water. Therefore, alkalinity and resulting pH must be kept high enough (> 10.5) for this reaction to take place.

The phosphate precipitate will be either tricalcium phosphate or hydroxyapatite [$\text{Ca}_{10}(\text{OH})_2(\text{PO}_4)_6$] if hydrate content of boiler water is high enough. The hydroxyapatite is more preferable form of precipitate as it is less sticky than tricalcium phosphate.

The phosphate treatment should be given directly to the boiler drum with a chemical pump. Because if introduced into the suction or the boiler feed pump, most phosphates will react with the impurities of water and cause deposits in pumps, piping feed water regulators and valves.

The phosphate method should not be used to boiler water which is very hard because the sludge produced is heavy and tends to aggravate carryover conditions in the boiler. The solution to this problem is to reduce the hardness with external treatment before the use of phosphate treatment or to use sodium carbonate treatment in combination with proper colloidal materials to improve the properties of the resulting sludge.

3. Colloidal treatment. Sometimes the sludge formed either with carbonate system or phosphate system is not carried satisfactorily along with the water during blow-down. Sometimes the sludge formed by the phosphate method is objectionable, therefore, organic compounds are added in the feed water to keep the sludge in circulation until it can be removed through blowdown.

To remove the sludge formed effectively from the boiler, proper colloidal materials are added to the boiler water which will condition the sludge so that it can be more easily removed by blow-down. The colloidal materials have excellent absorbing and coagulating properties. The formed inorganic sludges are readily absorbed onto the surface of the colloidal. The colloidal materials prevent precipitated particles from sticking to each other or to the boiler drum surfaces.

The common colloidal materials used are tannins, lignins, starch and seaweed derivatives. Other organic colloids used are sodium mannuronate and sodium alginate which react with calcium and magnesium salts to form a floc that entangles precipitates. The use of colloidal materials solves many problems in low and medium pressure boilers. They are not generally used in high pressure boilers.

Another approach to internal boiler water treatment is the use of chemicals which prevent the precipitation of scale forming materials. These chemicals have chelating power, so calcium, magnesium and other common metals are tied up in the water. This action prevents the formation of either scale or sludge in boilers, heat exchangers and piping and is effective over the normal range of alkalinity encountered in boiler plant operation. A compound known as EDTA (ethylene diaminetetra acetic acid) is the common material used for this purpose.

4. Use of Volatile Amines. Alkalinity of the feed water is one of the important parameters to control corrosion of boilers because in alkaline solution, the cathodic as well as anodic reaction rates slow down due to less number of hydrogen ions. Ammonia, cyclohexylamine and morpholine are the main volatile amines used for the purpose. Morpholine is better volatile alkaline chemical for corrosion control compared with other amines because it increases pH of steam as well as condensate and neutralises carbonic acid and other corrosion causing acid components. Its dose of 1 to 2 ppm produces pH of 9.1 to 9.3 at condensate pump. It is the only amine in which, the concentration in the condensate is greater than in the steam (*i.e.* 4 ppm in condensate and 1.6 ppm in steam and stable upto 175 bar and 650°C temperature. For each ppm of CO₂ in water, 7.3 kgs of morpholine are required per million kg of steam generated.

5. Blowdown Systems. All dissolved and suspended solids entering in the boiler with the feed water remain in the tubes and drum as steam is generated. Continued addition of make-up water containing more dissolved impurities produces higher and higher solid concentration in the boiler drum. There is upper limit for the dissolved salts beyond which concentration of total dissolved solids may produce undesirable foaming and carryover. The upper limit is 2500 to 5000 ppm for low pressure boilers and 500 ppm or even less for high pressure boilers.

The internal treatment precipitates undesirable salts in most desirable form. This removes the hardness of water but produces equivalent amount of sludge that is potentially troublesome.

The control of concentration of feed water when internal treatment is used is obtained by blowing-off some of the concentrated boiler water. Draining off some of the boiling water carrying excessive concentration solids and replacing it with fresh water keeps the solid concentration within safe limits. This process is known as *Blowing Down* and discharged water is called *blowdown*. The required blow-down that will maintain a given status of boiler water is readily determined by a balance of solids in and out of the boiler as shown in Fig. 19.4.

m_s = Steam generated during a given interval.

m_b = Blowdown water required to maintain the status of boiler water.

x = Fraction of make-up in entire feed water.

\therefore Make-up = $x(m_s + m_b)$.

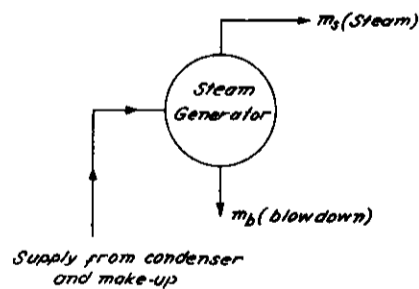


Fig. 19.4. Mass balance of impurities.

C_b = Concentration maintained in boiler, ppm.

C_m = Concentration in make-up water, ppm.

C_f = Concentration in feed water, ppm.

The balance of solid is given by the following equation

$$C_b \cdot m_b = x \cdot C_m (m_s + m_b) = C_f (m_s + m_b).$$

If x is make-up as fraction of steam generation, then the mass balance is given by

$$C_b \cdot m_b = C_m (x \cdot m_s + m_b) = C_f (m_s + m_b).$$

The blowdown may be done either intermittently or continuously,

Intermittent Blowdown. The blowdown is carried out intermittently through a point located lowest in the circulation system. A special blowoff valve is fitted at the bottom and it is opened manually to remove the accumulated sludge. This is done after every 4 to 8 hours.

The major disadvantages of this system of blowdown are listed below :

(1) There is waste of heat energy carried with blowdown.

(2) The control of boiler water concentration is irregular.

(3) The operator must maintain a rigid blowdown schedule otherwise it is possible to have priming and foaming with resulting carryover as shown in Fig. 19.5.

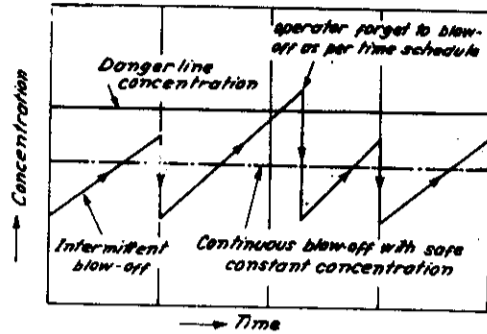


Fig. 19.5. Concentration of boiler water for intermittent and continuous blowdown system.

Continuous Blowdown Systems. The continuous blowdown systems are generally adopted to overcome the disadvantages of intermittent blowdown system.

The advantages of continuous blowdown system over intermittent system are listed below.

1. It maintains the concentration relatively constant with minimum attention. There is no danger of increasing the solid content above the danger concentration.

2. It recovers the amount of heat carried with blowdown by passing through an heat exchanger where the feed water is heated before entering into the boiler.

The continuous blowdown system is further classified as non-flash system and flash system.

Non-flash System. The arrangement of non-flash blowdown system is shown in Fig. 19.6.

This system of blowdown is generally used for low capacity low pressure boilers with low-blowdown rates.

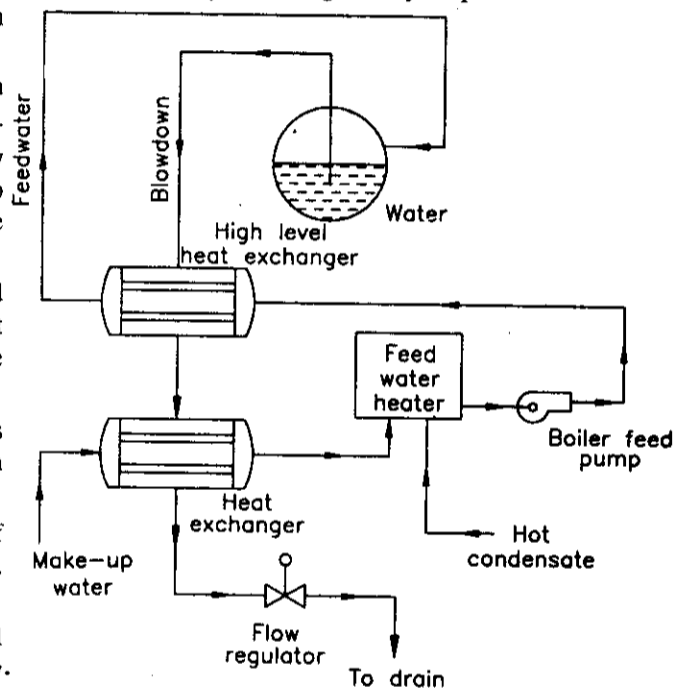


Fig. 19.6. Non-flash blowdown system.

Flash System. The arrangement of the flash system is shown in Fig. 19.7.

Flash system is more economical for larger capacity power plants where the resulting blowdown is considerable. The blowdown is first flashed as shown in Fig. 19.7 and resulting flash steam is used more economically as shown in figure. For high pressure boilers one or more flash tanks may be added in series for economical utilisation of blowdown heat. The remaining blowdown from flash tank is finally cooled with 5 to 10°C of the inlet temperature of the heat exchanger on the make-up water line.

The continuous blowdown in both the systems varies from 1 to 10% of boiler feed depending upon the concentrations of sludge formed in the boiler.

19.7. EXTERNAL WATER TREATMENT SYSTEMS

When the make-up water quantity is large and contains considerable suspended and dissolved solid material, then the external treatment of water becomes essential. The suspended solid material is generally removed by mechanical means. The dissolved gases are generally removed by thermal treatment and dissolved solids are removed with the use of chemical treatment.

1. Removal of Suspended Solids. The suspended material is generally removed with the use of the following mechanical means :

(a) **Sedimentation.** In this method, the water is allowed to remain stand-still in big tanks or to flow at a very low velocity. The solid matter settles down due to gravity and it is removed either periodically or continuously. The clean water is taken from the surface of the settling chambers.

The settling of solid material is accelerated many times by adding a coagulant like aluminium sulphate or sodium aluminate. The reaction between these salts and alkalinity in the water forms a floc which makes small particles adhere to each other, forming larger particles that settle out more easily.

Alum operates well at pH range of 5.5 to 8. At pH between 8 to 11, ferrous or ferric sulphate is a better selection. Ferric sulphate at pH 5 to 6 is always effective for difficult colour removal. Recently, ferric sulphate treatment is replaced by water soluble long chain polyelectrolytes. They have several advantages like reducing the volume of the sludge considerably, non-affecting pH of solution, not adding total dissolved solids (TDS) to the treated water (whereas each ppm of alum adds 0.45 ppm of SO_4 ion in treated water). To remove organic impurities, the usual practice is to use oxidising agents like chlorine or potassium permanganate and then passed through granular activated carbon filters. Residual chlorine of more than 0.5 ppm should be maintained in the chlorinated water at low pH value for rapid destruction of micro-organisms.

(b) **Filtration.** The suspended solids which cannot be removed during sedimentation are removed with the help of filtration.

Water is filtered by passing it through a fine strainer or other porous media to remove suspended solids mechanically. The degree of filtration depends on the fineness of filtration media.

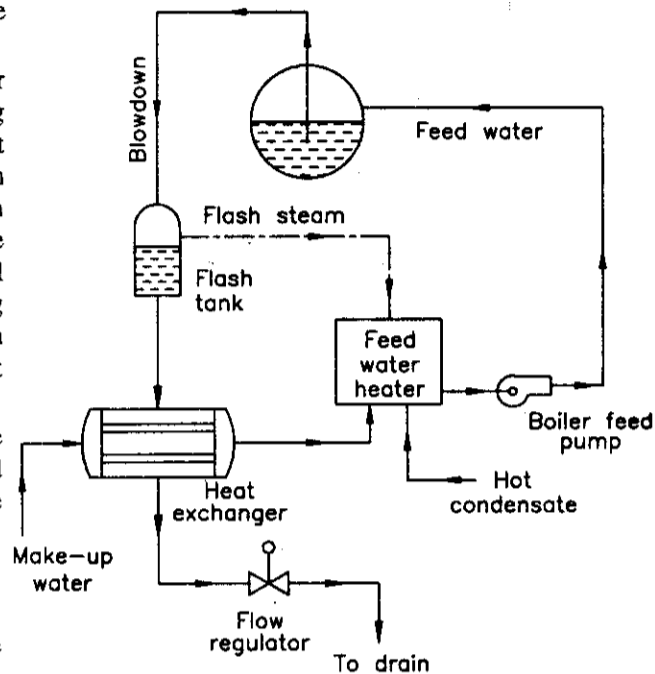


Fig. 19.7. Flash system of blowdown.

The suspended matter adheres to the filter materials leaving the water clear as it drains from the bottom. It is necessary to wash the beds periodically to remove the dirt collected in the voids of the filter material.

The different types of the filters which are in use presently are, pressure filters, gravity filters, horizontal filters, tubular filters, compartmented type and cartridge type and many others. A pressure type filter which is commonly used is shown in Fig. 19.8.

2. Removal of Dissolved Gases. The water generally contains oxygen, carbon dioxide, air, H₂S and other gases in dissolved condition. It is absolutely necessary to remove these gases before supplying the water to the boiler as they are fully responsible for corrosion as mentioned earlier.

The removal of gases is accomplished by heating the water to 105–110°C with subsequent agitation during heating. The simple heating removes the dissolved gases from water because the absorbing capacity of water is reduced at higher temperatures. In all types of gaseous removal equipments, the water is sprayed through towers to give the water a maximum surface which provides maximum possibility of gas absorption.

The different types of deaerators are steam deaerators, forced draft degasifiers, pressure aerators, coke tray aerators and wood slat aerators. It is not possible to give the constructional and working details of these deaerators in this text due to limited space.

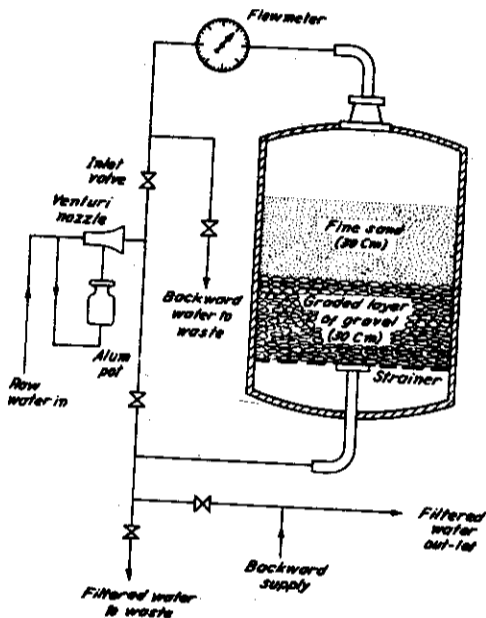


Fig. 19.8. Pressure type filter.

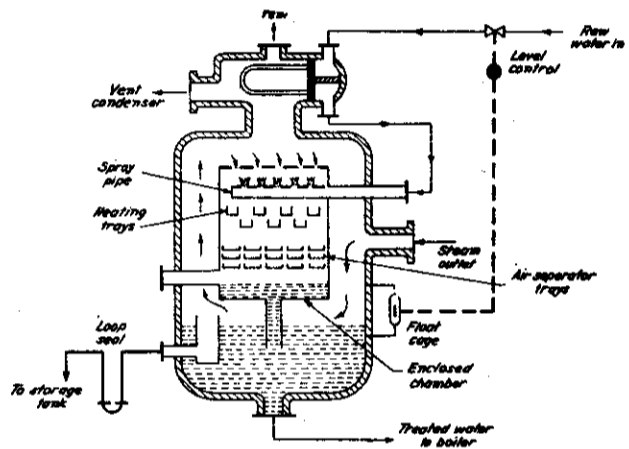


Fig. 19.9. Tray type deaerator.

A common tray type deaerator used in many modern power plants is shown in Fig. 19.9. The water which is to be deaerated is first passed through the vent condenser where it is preheated by the gases and air is liberated from the water and part of steam carried with the gases. Then it is passed through a spray distributor as shown in the figure. The projected water from distributor falls over an entire width of heating tray in a form of uniform shower. The water from the heating trays falls over the air separating trays and then it passes into storage space of the deaerator.

The released air and part of the steam is vented passing over the condenser. The heated gases give their heat to the make up water and the steam carried with gases is also condensed. This condenser reduces the steam consumption and economises the deaerating process.

The steam enters through the nozzle in the side of the shell as shown in figure filling the entire space between the shell and tray compartment. It then flows downward through perforations in the top plate meeting the water sprayed upward through the distributor.

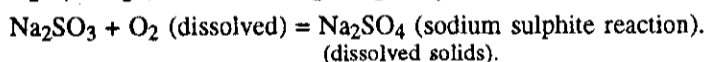
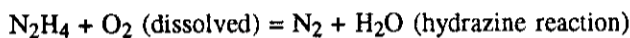
With this type of deaerator, the oxygen content can be reduced below 0.005 cc. per litre almost the limit of sample tested by chemical means. As CO₂ is also removed, the increase in pH value of water also gives an indication of deaeration efficiency.

Oxygen-Scavenging Compounds. The compounds which are used for degassing are discussed below.

(a) **Sodium Sulphite (Na₂SO₃).** Sodium sulphite is used as O₂-scavenging compound as it is a faster O₂ scavenger than hydrazine, but at low temperatures. Sodium sulphite reacts with O₂ to form sodium sulphate a soluble salt which increases total dissolved solids in boiler water. As a result, more blowdown is required to avoid permissible total dissolved solids (TDS) in the boiler water. This consumes additional energy as well as wastes water treatment chemicals.

(b) **Hydrazine (N₂H₄).** This is another compound which is commonly used for O₂-scavenging and is much superior to sodium sulphite particularly at high temperatures.

Hydrazine reacts with O₂ to form nitrogen and water and no solids are formed like sodium sulphite as given by following chemical reactions :



This is the reason, hydrazine is the only O₂ scavenger ever used in high temperature, high pressure systems where no dissolved solids can be tolerated.

Another and more important measure of scavenging compound is the ability to promote a barrier of magnetite between the tube metal surface and boiler water. Hydrazine promotes a uniform magnetite coating on iron surface above 50°C and it rapidly reduces rust (non-protective red iron oxide) to magnetite at temperatures above 140°C. The quantity of hydrazine required to do all the things is fraction of ppm.

(c) **Azamina-8001-RD.** This is a new conditioning product recently developed (May 1976) for preventing corrosion arising from the presence of O₂ and CO₂ in the feed water of boiler by degassing the O₂ and CO₂.

For removing the gases O₂ and CO₂, alkalizing and deoxidating volatile products are injected into boiler feed water or directly into the steam lines. Their efficiency always depends on various factors mainly the degassing power in relation to O₂, and the alkalizing power.

The newly developed product Azamina-8001-RD is a polyvalent and completely organic and is able to meet all requirements of degassing in minimum time under the most severe operating conditions with a dose of 100 ppm at 20°C water temperature, the complete oxygen (4 ppm) can be removed within 20 minutes. This time is further reduced to 5 minutes by increasing the temperature of water to 60° or to 2 minutes by increasing the dose of Azamina to 200 ppm.

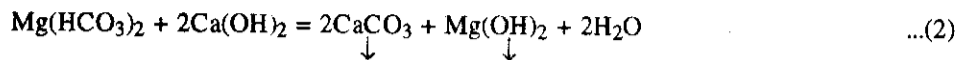
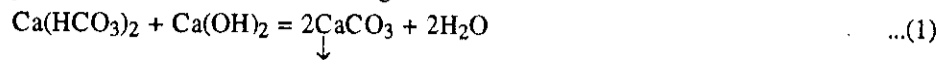
3. Removal of Dissolved Solids. The external water softeners are mainly divided into precipitation type and ion-exchange type.

(A) **Hot-Lime [Ca(OH)₂] – Soda (Na₂CO₃) – Process.** This process uses lime (calcium hydroxide) and soda ash (sodium carbonate) as treating elements. These treating elements react with all types of calcium

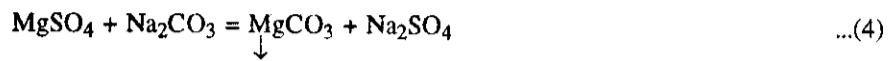
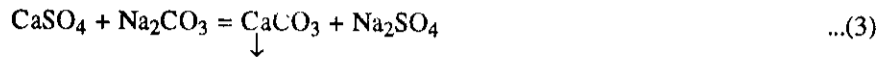
and magnesium salts and precipitate them. These reactions are generally carried out at the boiling point (100°C) of the water where the water is heated with the help of the steam.

The reactions which take place are listed below.

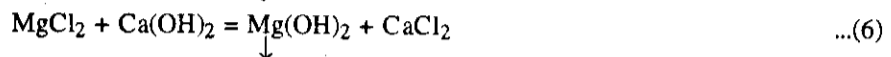
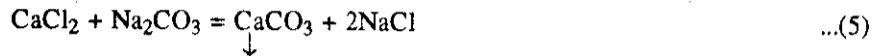
The lime precipitates the carbonate hardness as given below.



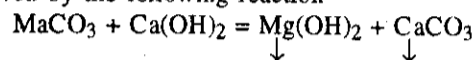
The sulphate hardness of calcium and magnesium is removed by soda ash. The reactions are as given below.



The chloride hardness of calcium and magnesium is also removed by soda and lime respectively. The reactions are given below.



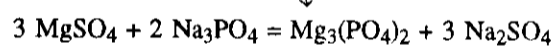
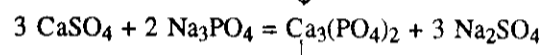
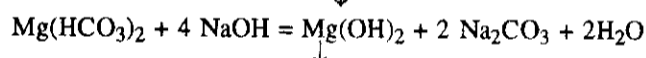
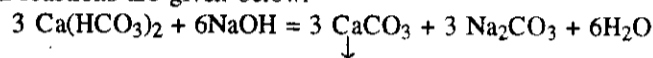
The magnesium carbonate formed as given by equation (4) further reacts with lime and forms magnesium hydroxide sludge as given by the following reaction



The magnesium hydroxide formed in the above reaction has coagulating properties and helps for rapid precipitation. It also absorbs soluble silica from the solution. If the magnesium hydroxide thus formed is not enough, to act, magnesium oxide is purposely added to the water to remove the silica effectively.

Sometimes trisodium phosphate and caustic soda are also used in addition to lime and soda. The phosphate is very effective in removing the calcium and magnesium salts as well as silica.

The chemical reactions are given below.



A few outstanding features of this process are listed below :

1. The equipment is more compact and degree of softening is considerably high.
2. Hot process is more economical in time and capacity of equipment as chemical reaction is eight times faster than cold process at the boiling point of water.
3. The size of the settling tank is reduced as the precipitate is larger in size and settles more quickly.
4. The silica is effectively removed from the water.
5. It is capable of treating large quantities of water in a relatively small unit.

Some of the drawbacks of this system are listed below.

1. The softness produced by this method is not so great as by zeolite process, therefore, the use of this method is limited to only low hardness water.

2. Controlling of hot-process unit is generally more difficult than controlling a zeolite softener.
3. The softened water must be filtered before use to avoid to carry the precipitate with water. The precipitate which does not settle in reaction tank is removed by filtration.
4. Another major difficulty experienced is the removal of the precipitate formed, because the removal of the precipitate formed is always difficult.
5. Back-washing of the filters intermittently is essential to increase the filtration efficiency of the filters.

A typical hot-process lime soda softener with filtration is shown in Fig. 19.10. The raw make-up water enters through a float controlled regulating valve and then passes over vent condenser and then sprayed into the reaction chamber. Water is heated by spraying it into the upper steam space. Inlet flow actuates a

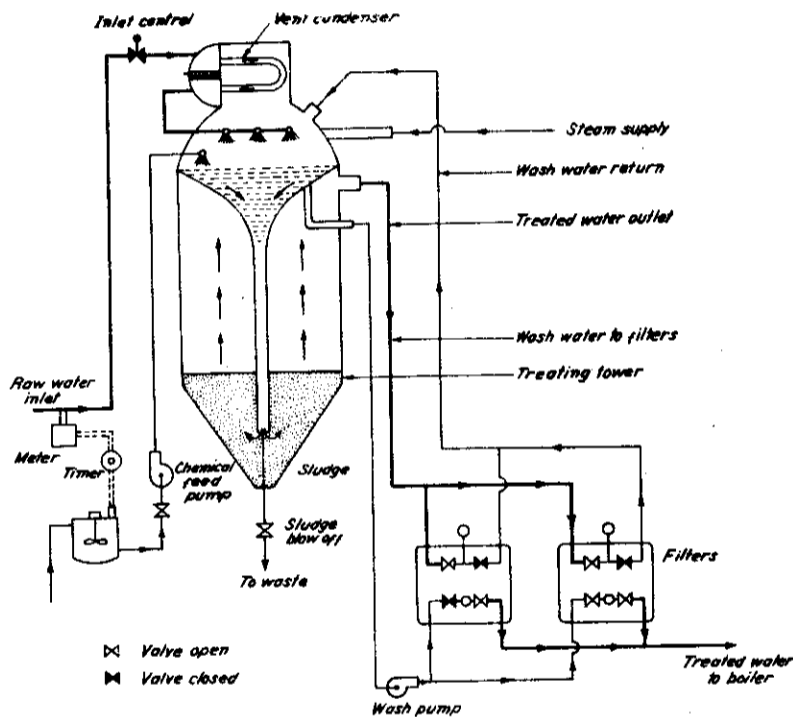


Fig. 19.10. Hot lime-soda process.

proportioning device to control the amount of lime and soda fed to the heating and mixing zone. Chemical reactions already described take place almost instantly. The sludge collecting cone receives the precipitates at the bottom and discharges to the sewer periodically. The softened water leaves the settling tank and then is further fed to the anthracite filters for further polishing.

(B) Ion-exchange or Zeolite Process. Impurities that dissolve in water dissociate to form positively and negatively charged particles known as ions and these impurities are known as electrolytes. The positive ion is named as "Cation" and negative ion is named as "Anion". These ions exist in the solution and act almost independently.

There are some ion-exchange materials which have the ability to exchange one ion for other, hold it temporarily in chemical combination and give it up to a strong regenerative solution. The name "Zeolite" was given by the geologists to certain class of minerals having the property of base exchange. The term "zeolite" was originally applied to naturally occurring minerals such as glauconite and green sand, but it has become a more or less generic term applied to a variety of exchange materials artificially produced such

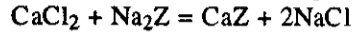
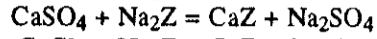
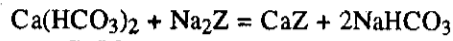
as hydrated double silicates, sulphonated coals and resinous materials having the desired exchange and regeneration properties.

The most used form is sodium zeolite, $\text{Na}_2(\text{Al}_2\text{Si}_2\text{O}_7)$, simplified symbol is Na_2Z . Recently organic zeolites have been developed containing no silica.

Sodium-zeolite Softener. A sodium zeolite water softener is used for water treatment. Sodium is much like an ordinary pressure filter, holds a bed of active zeolite supported by layers of graded gravel lying over a water distribution and collection system.

The raw water is supplied to the zeolite tank at the top as shown in Fig. 19.11.

Either gravity or pressure system of feeding water may be used but pressure system is favoured in all modern power plants. The water sprayed at the top of the shell flows downward through the zeolite bed and the hardness of the water is removed by ion exchange. Typical sodium zeolite actions on hard water are listed below.



The reactions of zeolite on magnesium salts are similar as given above.

The coating made from ion-exchange resin ground to 80–600 mesh and applied in 5 mm layers is used for the purpose until either the pressure drop developed is across it or the effluent conductivity becomes too high.

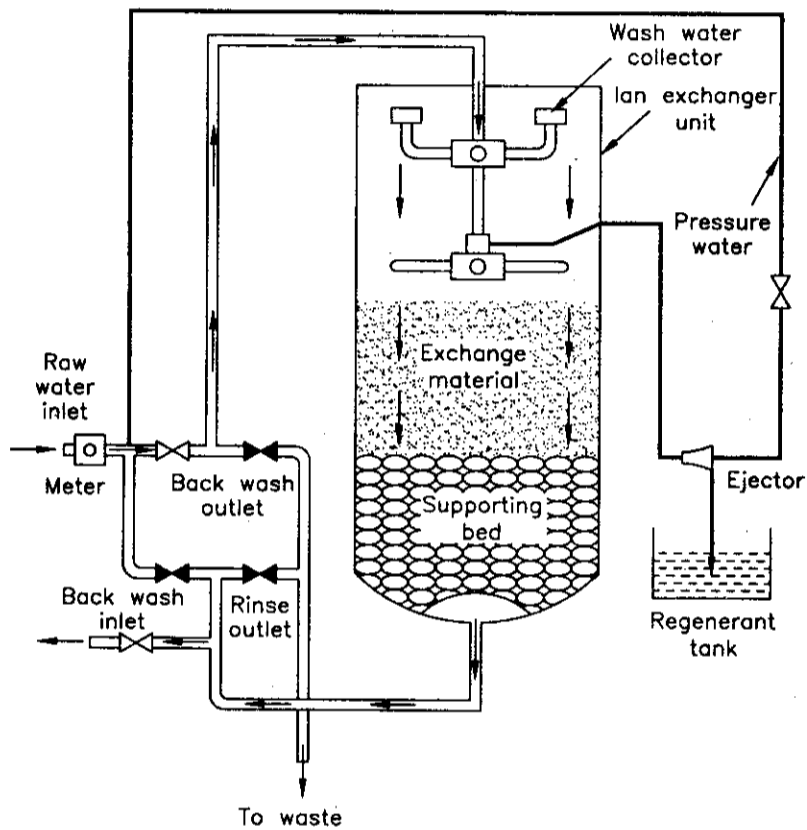
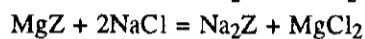
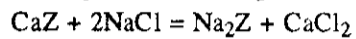


Fig. 19.11. Sodium zeolite softener showing flow with valve next for generation, back-washing, injecting chemicals and rinsing.

Note. During washing, the open valves remain closed and closed valves shown remain open.

The hard water flows through the zeolite bed and emerges as soft water. During the ion exchange process, there is loss of sodium and gain of calcium by the zeolite. Eventually, the bed capacity of softening the water is exhausted. Therefore, it is necessary to reactivate the bed. Fortunately, zeolite possesses another desirable property of regeneration. The zeolite is reactivated by back-washing the bed with suitable brine (NaCl solution). The reactions of regenerations are given below.



The regeneration can also be accomplished with the use of caustic soda (NaOH).

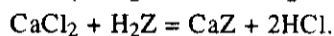
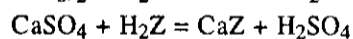
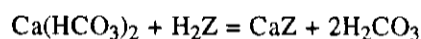
Once the bed is saturated ; a strong current of water is first passed through the softener which loosens and brings the zeolite bed into a semi-suspended condition. The water washing removes the dirt that might have collected on the top of the zeolite bed during normal downflow.

Then the sodium chloride salt solution of predetermined strength and predetermined amount is injected with the help of hydraulic rejector as shown in figure at the top of the vessel. This sodium chloride salt solution then passes down over the zeolite bed evenly. The sodium salt solution reactivates the bed again as per the reactions given above.

Once the bed is reactivated, rinse water is admitted to flush out calcium, magnesium and remaining brine, then the zeolite filter becomes ready for service. The reactivation process takes about one hour.

The regeneration cycle can be made fully automatic by adding time control devices. Two or more units usually operate in parallel to supply a continuous flow of treated water. Regenerations are staggered so only one unit at a time is off the line.

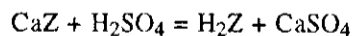
Organic zeolite softener. The working of organic zeolite softener is exactly same as sodium zeolite softener except sodium zeolite is replaced by organic zeolite. The typical softening reactions of organic zeolite softener are listed below :



The above reactions show that the softened water is acidic in nature and requires neutralization. The acid is neutralized by adding caustic soda or blending the acid water with water softened by sodium zeolite process. It is also necessary to construct the softener of corrosion resistant material.

The acid washing is required for the regeneration of the bed.

The regenerating reaction during acid washing is given below :



As the hydrogen zeolite process leaves acids in the effluent, a demineralization is possible if the zeolite is followed by degasification to remove CO_2 and anion exchanger (another type of zeolite exchanger) to absorb acids. This is a chemical alternative to evaporation as a demineralizing action.

The hydrogen zeolite process is advantageously used with raw water high in carbonates.

The outstanding features of zeolite systems over lime-soda system are listed below :

Different Exchange Materials

Ion-exchange material	Flow rate litres/m ²	Regeneration	
		Chemical used	kg/m ³ (capacity required)
Cation Exchangers			
<i>Sodium Cycle</i>			
Natural green sand	250	NaCl	20
Synthetic gel	300	NaCl	75
Sulphonated coal	340	NaCl	50
Styrene resin	400	NaCl	150
<i>Hydrogen Cycle</i>			
Sulphonated coal	340	H ₂ SO ₄	30
Styrene resin	400	H ₂ SO ₄ HCl	75 150
Anion Exchangers			
Aliphatic amine (weakly basic)	300	Na ₂ CO ₃	60
Phenolic (weakly basic)	300	Na ₂ CO ₃	60
Styrene (weakly basic)	300	NaOH	90
Strongly basic Type I and II	300	NaOH	60

1. This is very effective in removing hardness and at the same time it is easy and inexpensive in operation.

2. The hardness of the water is disposed off as a solution of precipitation of solids. Therefore, there is no problem of filtration and sludge removal.

The zeolite process does not operate satisfactorily with turbid water, therefore, filtration of water is essential before it is passed through the process. The variety of exchange materials with their production capacities is listed in the table given above.

When the bicarbonate hardness of the water is high, it is always desirable to use zeolite process in combination with lime process. The dissolved carbonate hardness is first reduced by lime treatment and water is then softened completely in the zeolite process.

(C) **Demineralizing (Catexer-Anexer) Water Treatment.** The mineral content of the raw water can be completely removed by a series of cation and anion exchangers. This system is most economical and desirable method to produce distilled water required for high pressure boilers.

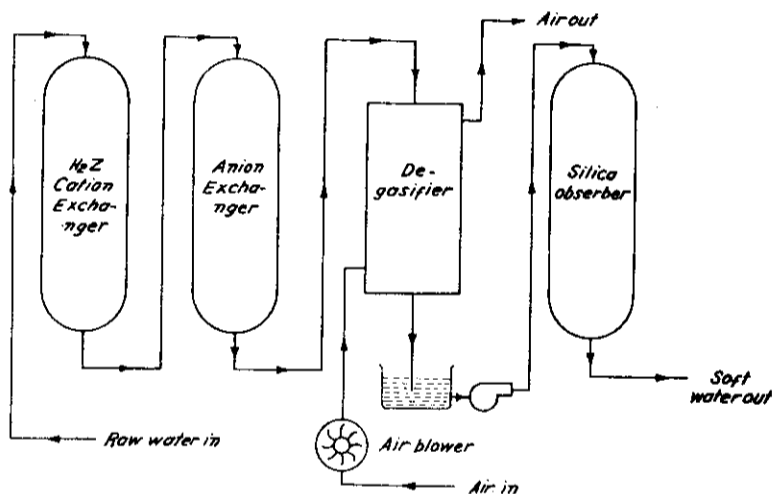
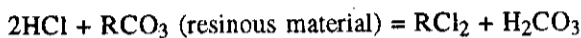


Fig. 19.12. Demineralizing process.

The arrangement of Catexer (acid-regenerated cation exchanger)—Anexer (caustic-soda-regenerated anion absorber), with degasifying tower and silica absorber is shown in Fig. 19.12.

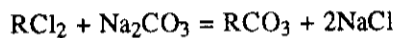
The raw water is initially passed through a weak acid cation exchanger to remove the bicarbonates. Water coming out contains dilute carbonic acid, hydrochloric acid and sulphuric acid.

The water coming out of Catexer is passed through Anexer. In Anexer, anions such as chlorides, sulphates and nitrates are removed from water with certain resinous materials. Anexer also exchanges acid radicals as given by the following equation



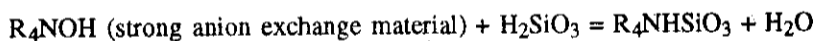
The water coming out of Catexer and Anexer is practically free from dissolved solids.

The reactivation of Catexer is done by circulating acid solution as mentioned earlier. The reactivation of anexer is done by circulating the solution of NaOH or Na₂CO₃ through the Anexer bed. The reaction for reactivation is given below :

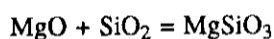


The water coming out of Catexer and Anexer is passed through a degassing tower as shown in figure. This tower is filled with porcelain packing. The water flows downward through the tower and is distributed over very large surface area provided by the packing. Thus the water comes in contact with the low pressure air blown in at the bottom. The CO₂ is thereby liberated and is vented from the top of the tower. The degassed water containing about 2 to 5 ppm CO₂ is collected in the sump beneath the tower.

The water then is passed through strong base-anion resin tower. This resin reduces the silica to 0.02 ppm. The reaction which shows the adsorption of silica is given below :



Strong base anion exchangers are specially designed to remove dissolved silica. The other form of silica known as colloidal or non-reactive silica can be removed by coagulation followed by efficient filtration. Magnesium compounds have been used successfully to lower down silica levels. The reaction of MgO with silica is given below :



It has been estimated that 50 ppm of MgO is required for 20 ppm of SiO₂ to bring down silica level to 2 ppm. Silica in high pressure boiler water should be controlled with a view to maintain 20 ppm of silica as SiO₂ in steam due to its high solubility in steam. A boiler feed water should not contain more than 1 ppm when working at 140 bar pressure.

Different Types of Resins. Two important characteristics of resins are physical stability of bed and ion exchange capacity.

There are mainly two types of resins, gel-type and macroporous resin. Both of them exhibit exceptional physical stability for mixed bed condensate polishing in high flow rate.

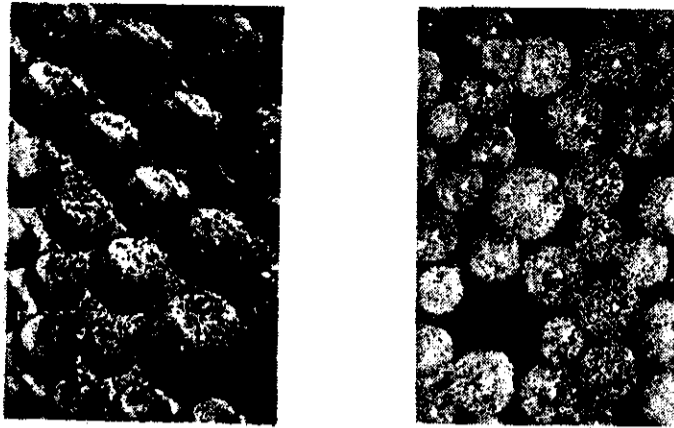
The gel-type cation resin has a notably higher exchange capacity. On the other hand, macroporous anion resin offers a minimal margin of physical strength over gel type anion resin. The additional strength of macroporous gives longer bed life and possibly lower resin replacement costs but this comparison is possible when the relative capacities of two regions are weighted. Although stronger macroporous resin is considerably lower in ion exchange operating capacity. On the other hand, as anion resins age, their functional efficiency decreases.

Water softeners use cation exchange resins, demineralizers use both cation and anion exchange resins. Softeners are regulated with salts, demineralizers with acid and caustic. Cation exchange resins generally retain good efficiency for 5 to 10 years ; anion exchange resins retain only for 3 to 5 years. Capacity of

cation exchangers decreases about 3% per year, whereas anion exchangers lose as much as 25% within a couple of years.

Both resins are shown in Fig. 19.13.

Recently, a new type of exchanger called Sirothern resin has been marketed by Dioposium France, for desalting blackish water containing upto 3000 ppm TDS. This resin is thermally regenerable and can produce water containing less than 500 ppm TDS. Sirothern resins contain weak acid and weak base functional groups in the same bed.



Gel-type cation/anion mixture. Macroporous cation/anion mixture.
Fig. 19.13.

Feed water impurities limit for high pressure drum type boilers		Impurity limits for once through boilers		
Species	Limit in ppb	Species	Starting	Normal Running
			10^{-6} gms/litre	10^{-6} gms/litre
Total Solids	50	Total salts	250	10
Iron	10	Iron	50	10
Copper	10	Copper	20	2
Silica	20	Silica	30	20
Dissolved O ₂	5	Dissolved O ₂	10	5
Hydrazine	10—20	N ₂ H ₄	20—30	10—15
pH	8.8—9.2	pH	9.2—9.4	9.2—9.4

With an increase in operating pressures and temperatures of modern boilers, the demineralisation method of purification is being increasingly employed.

Demineralizing produces better make-up water than any of the methods discussed so far. The advantages include reduced boiler blowdown and big assist for the production of higher quality steam. This is why more plants in the medium pressure range are going for demineralizing systems.

The outstanding feature of the demineralizing process is to supply the purest quality feed water irrespective of flow quantity and its quality. If a serious breakdown in the condenser increases, feedwater contamination suddenly increases from ppb level to ppm level, but the demineralizing process can continue to supply high quality feedwater for the period needed to bring about an orderly shutdown to repair the condenser. This process is a means of keeping a condenser with normal leakage on the line until the earliest possible outage time or a more seriously leaking condenser on the time long enough to effect an orderly shutdown.

The main drawback of the system is high equipment cost and high operating cost.

In all modern thermal power plants, the make-up water is mainly softened with the use of external treatments and required purity is adjusted with the help of internal treatment systems.

(D) Evaporators. Dissolved and suspended solids are removed from water effectively by purely mechanical process of vaporizing water with heat. After pretreating the raw water by filtration, by coagulation and softening, the boiler feed make-up is prepared by evaporation when used for medium or high pressure plants.

The pretreated raw water is evaporated with use of high pressure steam in the evaporator which is a simple pressure tank and vapour is condensed in a separate heat exchanger to form pure water.

Well designed evaporators can produce vapour containing less than 0.25 ppm total dissolved solids. This type of purification method is economical if the make-up percentage is less than 3%.

Different types of evaporators which are used for supplying pure make-up feed water are discussed below.

1. Multiple effect immersed type evaporator.

A three unit system is shown in Fig. 19.14 (b). In this system vapour generated in first evaporation

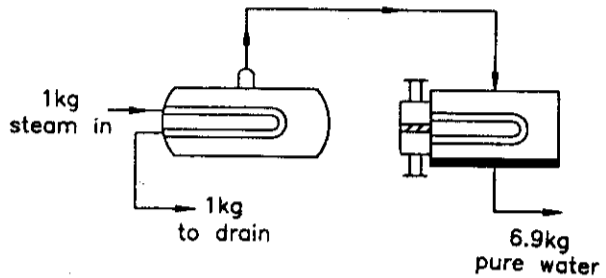


Fig. 19.14. (a) Single effect evaporation.

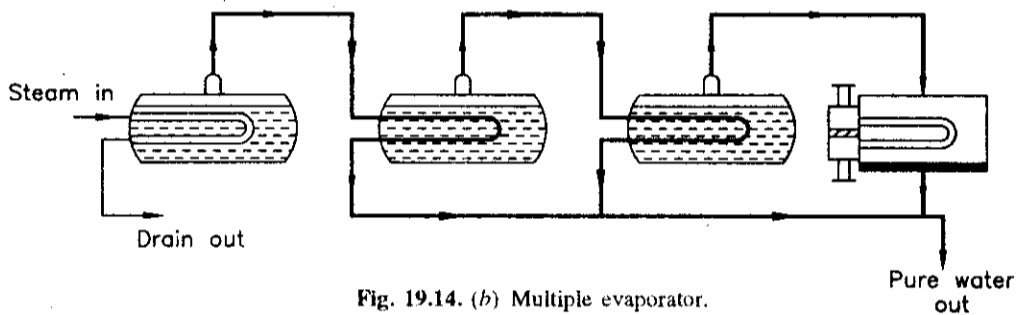


Fig. 19.14. (b) Multiple evaporator.

is condensed in the heating coil of the next and so on. Pure water from each follows to a common outlet line as shown in figure. Single effect evaporator as shown in Fig. 19.14 (a) is preferred for boiler feed make-up because more water is produced by given amount of evaporation tube surface.

2. Vapour compression system.

The vapour compression type evaporation is shown in Fig. 19.15.

The compression type distillation plant was developed during second world war.

In this evaporator, the external heat source required during evaporation is removed by combining the condenser and evaporator into a single piece of equipment.

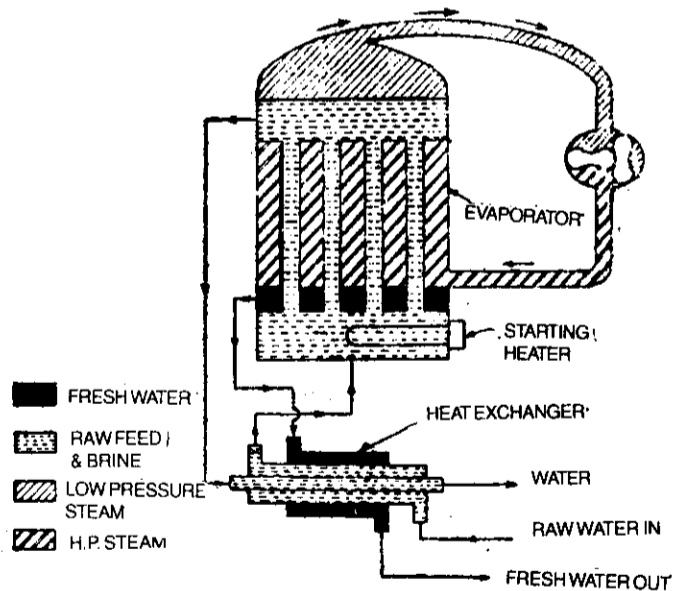


Fig. 19.15. Compression type evaporator.

The low pressure water vapour from the evaporator shell flows to the thermo-compressor and is discharged at high pressure to the condenser coil as shown in Fig. 19.15. The saturation temperature maintained on the condenser coil is sufficiently above the saturation temperature in the evaporator shell to support the evaporation. Thus the condenser acts as a heat source for the evaporator.

The thermal performance of the system is further improved by introducing preheaters as shown in figure. Here the cold feed on its way to the evaporator abstracts heat of distillate and below down.

3. Flash type evaporator. The arrangement of the system is shown in Fig. 19.16.

The raw water is throttled through the nozzle into the vacuum chamber as shown in figure. Part of the water is flashed out in form of vapour. This vapour is condensed by using a refrigeration system.

(E) Reverse Osmosis Process. The treatment of water for power plant use in the past has been limited largely to the distillation and ion exchange processes. In the thermal distillation process, the energy required for the conversion of saline feedwater to high purity product is essentially the same as that for low solids feed water. Therefore, the economics relegate this process to the treatment of feed water of high dissolved solids. Conversely, the economics of the ion exchange treatment process generally limits its use of the treatment of feedwater upto concentrations of 2000 ppm due to excessive chemical costs above this level.

As our fresh water supplies continue to dwindle, more emphasis must be placed on the use of brackish and seawater. Water planners must utilize all the tools available for the design and selection of water treatment equipments. The Reverse Osmosis is a tool that holds great promise for this purpose.

Principle. The reverse osmosis process purifies feedwater by applying high pressure to force pure water through a membrane. In the osmosis process, when two liquid chambers containing liquids of different concentrations are separated by a semi-permeable membrane, the pure water from the less concentrated liquid will naturally flow through the membrane to the more concentrated liquid. This flow continues until pressure in the more concentrated side increases to a point where the flow ceases. This pressure is the osmotic pressure which is a function of the initial concentration differential. By reversing this process (*i.e.*, by applying hydraulic pressure higher than the osmotic pressure to the more concentrated liquid) it is possible to produce fresh water from the concentrated feed water. This is called Reverse Osmosis. The principle is exhibited in Fig. 19.17.

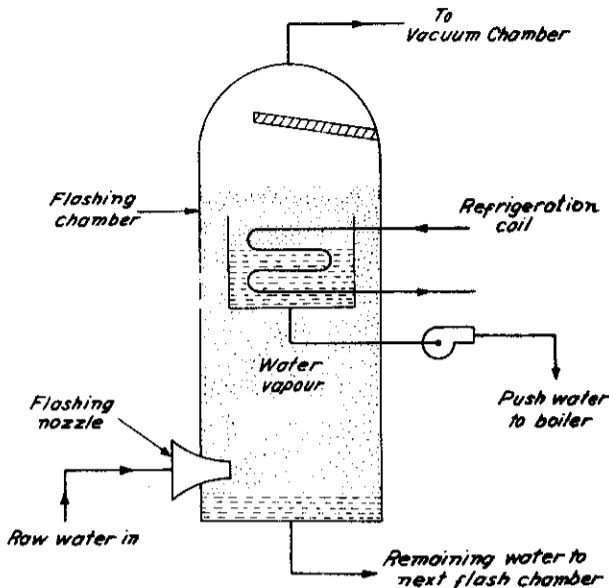


Fig. 19.16. Flash type evaporator.

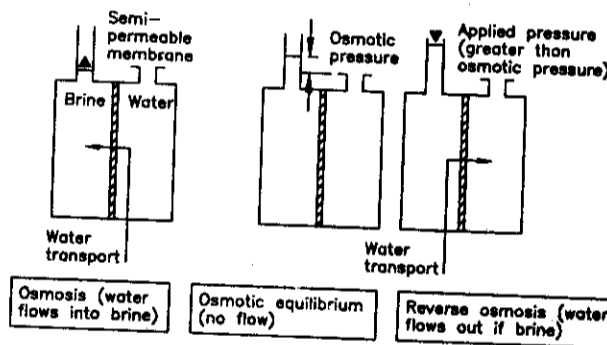


Fig. 19.17.

Design. Several systems have been developed for commercial production of fresh water by the Reverse Osmosis process. One of these is the hollow fine-fibre configuration developed by Dupont and Dow (U.K.) chemical company. The hollow fibres are between 25 and 250 μ in diameter and have a wall thickness in order of 5 to 50 μ . The high pressure concentrated feed water is fed to the outside surface of the fibres. Fresh water passes through the wall and exits along the internal surface. The arrangement of the system is shown in Fig. 19.18.

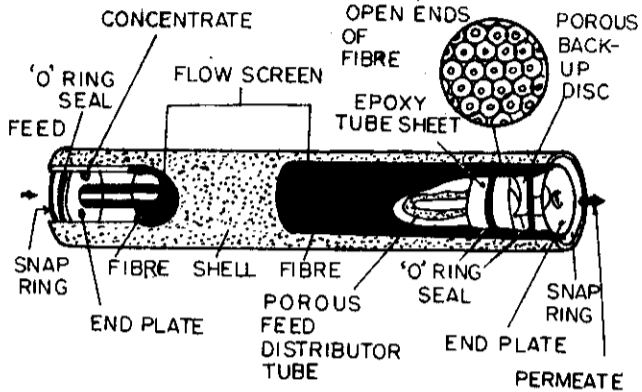


Fig. 19.18.

A second reverse osmosis arrangement employs spiral wound membranes. This system was developed by Gulf Environmental Company. The membrane, with accompanying backing material, is wound on a permeator tube. These modules are then sealed into the pipe sections which act as the pressure vessel. Feed water enters the sheet side under high pressure, forcing fresh water through and then along the membrane. It exits from the pressure vessel through the permeator tube. The arrangement is shown in Fig. 19.19.

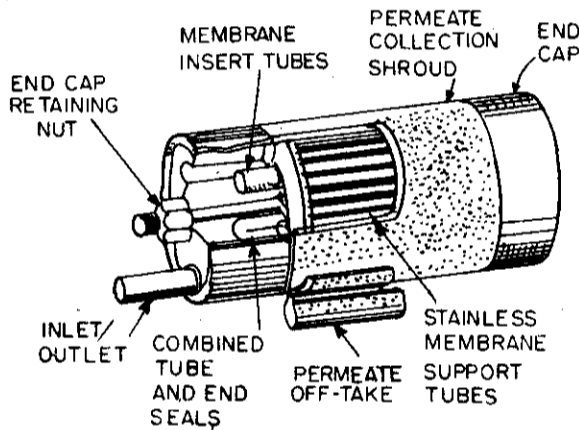


Fig. 19.19.

The energy required by the reverse osmosis process is primarily for high pressure pumping and can be supplied by steam turbines or electrical pump drivers. Pumping pressure for blackish water treatment is in the range of 25 bar to 80 bar. Generally, the specific power consumption of this system lies in the range of 10 – 15 kW-hr/1000 gal of fresh water produced. This process is more economical and competitive to other processes in the 5000 to 10,000 ppm or higher range. The economics of this process can be further improved

by the use of a hydraulic turbine. A hydraulic turbine placed in the concentrate waste stream can recover much of the power required by the feed booster pumps as shown in Fig. 19.20.

The pretreatment of water before passing through this system is essential to minimise scaling and fouling of the membrane surfaces. Scaling and fouling occurs from calcium sulphate, calcium carbonate, magnesium hydroxide, iron and magnesium. If allowed to enter the system unchecked, these feed water constituents would build up on the membrane surfaces resulting in decreased water output and possibly damage the membranes, therefore, the pretreatment of the water is essential. The pretreatment procedures employed follow conventional water treatment methods. Sometimes, pretreatment of water may not stop scaling, and in these cases special membrane cleaning procedures can be carried out periodically to restore the plant capacity. Chemical

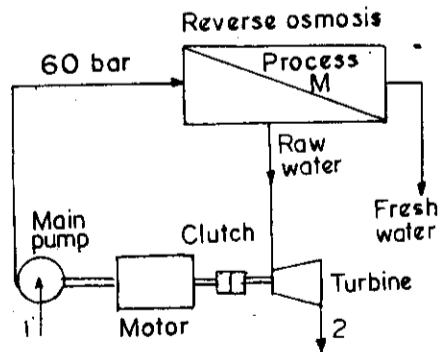


Fig. 19.20.

cleaning techniques have been found to be very effective. Recent developments in Electrodialysis process have shown that reverse polarity operation has been effective in keeping these membranes clean.

19.8. SEA WATER TREATMENT USING REVERSE OSMOSIS (RO)

A simplified diagram for sea water treatment is shown in Fig. 19.21. Pretreatment of sea water before passing through RO system depends upon the clarity of the raw water. First chlorine is passed through the water to oxidise organic products and kill marine life. Then aluminium sulphate (coagulant) is added to precipitate colloidal material and colour. Then HCl or H₂SO₄ is added to reduce the pH value to about 6 and suppress calcium carbonate scaling. The water is then filtered passing through sand filters and activated carbon filters. The chemical treatment is further continued by adding sodium hexameta phosphate (NaHSO₃) to suppress carbonate scaling still further. Finally water is passed through 5 µm cartridge filter to remove remaining suspended matter. Then finally, water is pumped through OR-system with the help of pump to get pure water for boiler feed.

Special attention is needed to select the materials for construction as sea water is highly corrosive. Glass-reinforced plastic, cupro-nickel, monel and nickel alloys are generally used. In addition to this, care must be taken in siting the sea water intake to avoid ingress of silt and weed. High level of algae in the water requires the use of a clarification stage prior to filtration and this can be achieved using settlement clarifiers. This problem is particularly associated with shallow tidal regions in the Arabian Gulf.

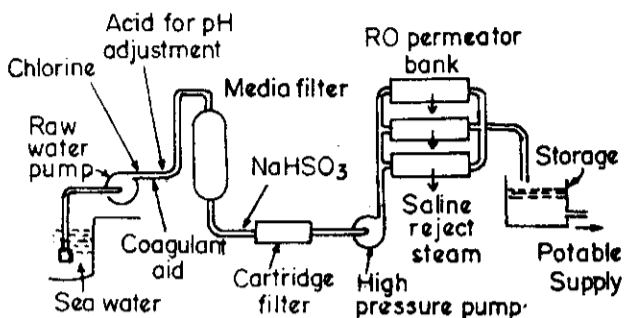


Fig. 19.21.

The past few years have seen a tremendous increase in the number of membrane desalting facilities in commercial operation. The office of the Water Research and Technology (U.K.) lists a total of 370 membrane plants with capacities of 25,000 million gpd throughout the world as on January 1, 1975. Of this number, 212 were purchased during two-year period of 1973-74.

A 216,000 gpd capacity reverse-osmosis plant installed in June 1974 at Tait Generating Station (Ohio) turned out more than 18.5 million gal of boiler feed water without a hitch within one year. Maintenance of the plant has been minimum requiring less than two hours a day of station personnel's time, mostly for record-keeping purposes. Costs, too, have been relatively low, 46/1000 gal for chemicals including regeneration of bed and softener and 15/1000 gal for labour. The power consumption remained as 8 kW-hr per 1000 gal of product water. The unit reduced the dissolved solid content from 500 ppm to 50 ppm.

Another notable plant of this type is established at Venezuela Planta Centro for a Cadafe power station of 800 MW capacity. This plant supplies 800,000 gal/day. This purification system is designed to treat sea water containing 38,000 ppm total dissolved solids and provide 1000 ppm in the product. The treated sea water is then processed in RO system to provide water containing 100 ppm solid or less. The pressure of the water used for RO-system is 60 bar.

The recent operating experiences of these systems have shown that this method can be employed more economically in the range of dissolved solids from 2,000 ppm to 10,000 ppm or more. This process may be more competitive with thermal distillation for the conversion of sea water into boiler make-up feed.

Greater demand by power plants throughout the world for fresh feed water may lead to increased use of membrane processes to supply fresh water from brackish or seawater sources.

19.8. HIGH PRESSURE BOILERS AND IMPORTANCE OF WATER PURITY

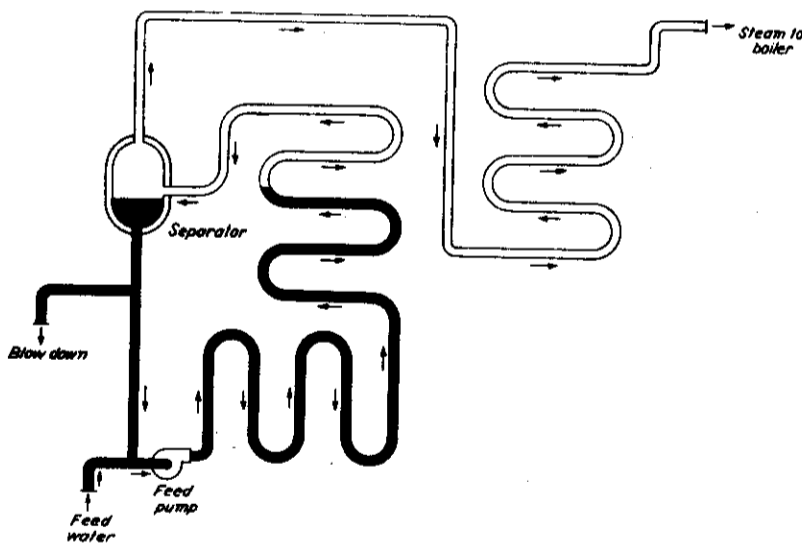
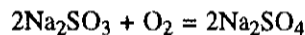
The purity of the water plays important role in high pressure boilers like "once through boilers" and "supercritical pressure boilers". Because there is no boiler drum as shown in Fig. 19.22 and therefore, all water entering the circuit passes out as supercritical fluid. Any solids present in the feed water are carried with the steam. These leave troublesome deposits in the superheater and turbine. The limits for the different solids in feed water used for high pressure boilers are listed below.

Type of the solid	Total dissolved solid	Silica	Iron	Copper	Oxygen	pH
Allowed Limit in ppb	50 to 500	20	10	10	5 to 7	9 to 9.6

The main troublesome impurities are oxygen dissolved in water and silica because their bad effects are accelerated at elevated temperatures. The effects of each content and method of its control are discussed below.

Dissolved oxygen and its removal. Oxygen is carried into the boiler through the feed water in dissolved form. Much of it is liberated when the water enters the boiler drum but small quantity still remains in solution. Small quantities of dissolved oxygen are capable of causing severe corrosion in boilers. It is, therefore, necessary to reduce it to a tolerable limit of 5 ppb.

Until about 1954, in power stations where physical deaeration was unable to produce a sufficiently low level of dissolved oxygen in the feed water, sodium sulphite was commonly added to the boiler water as a chemical deoxygenator. Sodium sulphite reacts with oxygen and reduces its content as given by the following reaction :

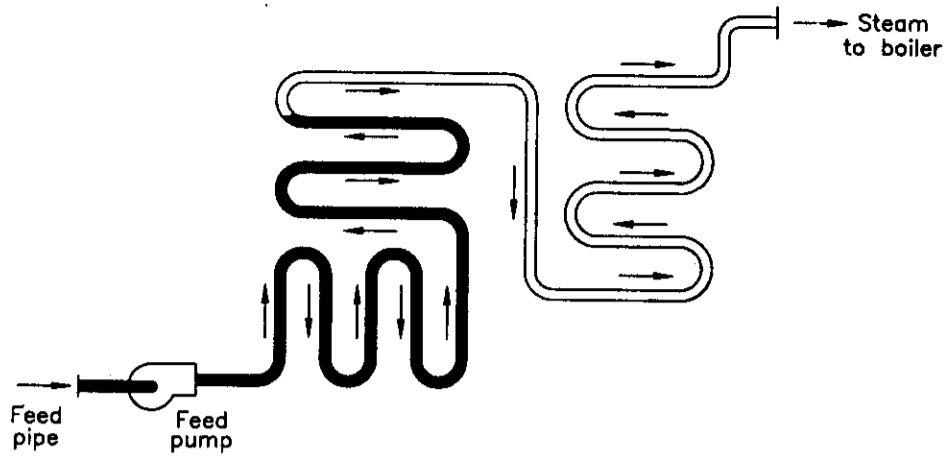


(a) Once through sub-critical boiler with separator.

Fig. 19.22.

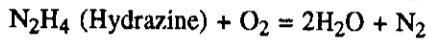
The sodium sulphite was added to boiler water on a continuous or slug dosing basis so as to produce a reserve of 25 ppm of sodium sulphite in the boiler water. The main disadvantage of this deoxygenator is of caustic embrittlement.

Recently 'hydrazine' is introduced as a chemical deoxygenator. It is a powerful reducing agent which reacts with dissolved oxygen to produce water and nitrogen



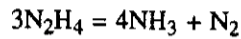
(b) Super-critical boiler once through type without drum or separator.

Fig. 19.22. Few forms of high pressure boilers.



Hydrazine is thus capable of removing dissolved oxygen from the boiler feed without increasing the total dissolved solids concentration, therefore, it is preferred in high pressure boilers.

Direct decomposition of hydrazine also takes place under boiler working conditions as given by the following reaction :



The ammonia carried with the steam is dissolved in the condensate coming out of condenser and helps to maintain pH value of feed water at satisfactory level. The hydrazine is generally added at the extraction pump.

Silica and its removal. Main impurity receiving critical attention in high pressure boilers is silica. Silica in boiler water volatilises at high pressure (60 bar and above) and passes with steam to the turbine. As the steam expands in the turbine, the silica deposits on the turbine blades. This cuts the flow area, creates the imbalance of the rotor and reduces the efficiency and, therefore, turbine must be shut-down for thorough cleaning. Experience in United States has shown that heavy deposits of various oxides of iron, copper and silica have occurred on turbine blades. This had led to losses of turbine output amounting to 1% in 6 months, 9% in a year and 14% in 5 years. This one example itself is sufficient to illustrate the importance of controlling the solid constituents in the feed water.

The silica content in water is controlled by (a) limiting the silica content by careful control of demineralisation plant, (b) controlling the silica level of the boiler water by blow down, (c) limiting the silica bearing materials into the feed and boiler systems.

There are two general sources of impurities that enter the cycle and cause troubles. The first is mineral impurities in the condensate, usually coming through the condenser leakage and second is metal oxides from pre-boiler corrosion.

Proper condenser design cuts the cooling water leakage but cannot be totally eliminated. The general practice is to treat all the condensate passing through demineralizer. Both hydrazine and ammonia are typical vapour type chemicals used for oxygen removal and corrosion control in the preboiler cycle of today's high pressure power plants.

19.9. NUCLEAR REACTORS AND IMPORTANCE OF WATER PURITY

In pressurised water and boiling water reactors, the water directly comes in contact with fuel elements, therefore, its purity plays very important role. The purity of water must be comparable to that used for supercritical boilers.

The cooling water passing through the reactor becomes radioactive and if the manganese, cobalt and sodium are left in the feedwater, then the effect of radio-radiation is predominant as these elements produce highly energetic gamma-rays due to absorption of radio-radiations.

The ion exchangers are commonly used for its purification. Multibed systems are preferred and it is often better to discard the used resins without regeneration to maintain the water quality.

If the water is badly contaminated, evaporators are best for removing impurities. After cleaning the water in the evaporator, it is passed through ion exchanger beds to maintain the high purity of the water.

EXERCISES

- 19.1. Why the feed water treatment is necessary before supplying to the boiler ?
- 19.2. What are the major impurities of make-up water ?
- 19.3. What are the effects of impurities in feed water on the boiler ?
- 19.4. What is corrosion ? Explain the electro-chemical theory of corrosion. Explain the importance of pH value to control the corrosion phenomenon.
- 19.5. Define priming and foaming. What factors control this phenomenon ? What are the effects of priming and foaming on the performance of boiler and turbine ? What preventive measure should be taken to avoid them ?
- 19.6. What do you understand by caustic embrittlement ? How this is prevented in practice ?
- 19.7. Define pH. Why high pH value ($> 9 < 10$) is preferred to prevent the corrosion ?
- 19.8. What do you understand by internal boiler water treatment ? Explain the working of sodium carbonate and phosphate treatments. Which treatment is more suitable for medium pressure boiler ? List out the limitation of each.
- 19.9. Discuss the different methods of blowdown system. List out the merits of continuous type over intermittent system. Why continuous is preferred over intermittent ?
- 19.10. What do you understand by external treatment of feed water ? Why external treatment is essential ?
- 19.11. Why the dissolved gases in make-up are objectionable ? Describe one method for their removal.
- 19.12. Describe the working of hot lime-soda process with a neat sketch giving different chemical reactions. What are the advantages and disadvantages of this system over ion-exchange system ?
- 19.13. Describe the principle of "zeolite process" and explain the working of sodium zeolite softener with neat sketch and giving all types of chemical reactions.
- 19.14. Describe the working of organic zeolite softener with neat sketch and giving all chemical reactions. List out its merits and demerits over sodium zeolite softener.
- 19.15. Describe the working of demineralising water treatment system with neat sketch. Why this system is preferred over others ?
List out its merits over other systems.
- 19.16. What is the importance of high purity water in high pressure boilers ? Explain a method used for water purifying when the make-up water is required for high pressure boiler.
- 19.17. Describe a method used for purifying make-up water supplied to a high pressure boiler when the make-up water contains sufficient dissolved salts and there is possibility of considerable condenser leakage.
Draw the outline of the plant showing the water purifying systems.
- 19.18. What are the principal causes of deterioration in performance of demineralization plant and in what way do they effect plant performance ?
What consideration should be given to the chemical constituents of waste effluents from demineralization plant, for discharge into sewer or river ?
- 19.19. What factors influence effective precipitation and settlement in lime-soda softeners ?
Describe the function of coagulants in water softening plant and suggest how optimum dosage of coagulant may be determined.
- 19.20. In considering three alternative sources of raw water, namely river, deep chalk well and local public supply, to be used to prepare boiler feed make-up water, what factors would influence your choice of supply for a new generating station ?



20

Steam Piping

20.1. Steam Piping. 20.2. Steam Pipe Fittings. 20.3. Expansion Joints and Loops. 20.4. Piping Supports. 20.5. Design of Steam Piping. 20.6. Steam Piping Materials. 20.7. Insulation of Steam Piping. 20.8. Piping Layouts.

20.1. STEAM PIPING

The steam piping system is an essential part of steam power plant. The piping used for carrying the steam must fulfill the following requirements :

1. The piping adopted must ensure maximum reliability.
2. It should be possible to carry out inspection and maintenance on any section of the plant without the need for complete shut-down.
3. The piping should be of necessary size to carry the required flow of fluids.
4. The pipes carrying the fluids at high temperature should be able to withstand the temperature and expansion caused due to the temperature changes.
5. The piping supports, anchors, and joint should be in accessible positions so that inspection is possible throughout the life of the plant.
6. The piping system must withstand the pressure to which it is subjected.
7. The pipe should run as direct and straight as possible. The number of fittings and bends required to make the necessary connections should be as minimum as possible to reduce the pressure loss. This is also desirable for easy inspection and maintenance.
8. Valves and interconnection pipes should be as few as possible, but the necessity for sectionalising and load transfer in times of emergency, inspection or maintenance should not be overlooked.
9. Consideration should be given to the efficient drainage of all pipes although the number of drainage points should not be as few as possible consistent with safety.
10. The pipes should be made in the longest possible lengths to reduce the number of joints.
11. Template pipes should be as few as possible, to reduce erection time.
12. The piping system, used for steam, should be installed in such a way that the horizontal runs should slope in the direction of steam flow. The steam traps along the piping should be provided to drain the line and to prevent an accumulation of water during steam flow.

With advancing temperatures and pressures and with the increasing complexity of the central station cycle in modern power plants, the cost of piping system has become one of the major items of expense and its selection and arrangement has also become one of the major items of design.

20.2. STEAM PIPE FITTINGS

Steam pipe fittings are used to assemble piping system and make connections. Fittings are made in variety of forms such as screwed or welded fittings. These are generally used in sizes upto 8 cm in diameter. For large pipe sizes, flanged or welded fittings are used. The various fittings which are in common use are

elbows, bends, tees, crosses, plugs and reducers. The different fittings are shown in Fig. 20.1.

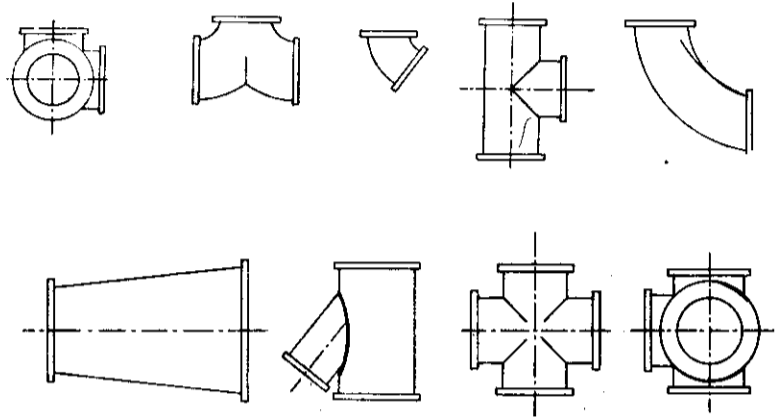


Fig. 20.1. Different types of steam pipe fittings.

Elbow is used to change the directions of two pipes. Tee is used for joining two pipe runnings in same direction and to provide outlet for a branch pipe. Reducers are used to join the pipes of different sizes. Plugs and caps are used to close the ends of fittings and pipes.

The material used for fittings depends on service as regard pressure and temperature.

The present power plants largely use welded connections for major steam lines to make the connections light. Welding method of fitting the pipes makes pipe insulation application easier.

20.3. EXPANSION JOINTS AND LOOPS

The steam at high temperature passing through the pipe decreases allowable working stress of the pipe material, accelerates oxidation and corrosion and produces expansion along the length of the pipe. Expansion of pipe material stresses the pipe supports and connected equipments. The thermal expansion is given by

$$L_t = L_o \left[1 + a \frac{T}{1000} + b \left(\frac{T}{1000} \right)^2 \right]$$

where L_t and L_o are the lengths at temperatures $T^\circ\text{C}$ and 0°C and a and b are constants. The values of these constants depend upon the material used for pipes.

To reduce the expansion stresses, piping systems use sliding expansion joints, expansion bends, normal bends and corrugated sections.

The various types of expansion bends used are shown in Fig. 20.2.

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.

The different expansion joints are shown in Fig. 20.3.

Bellow type expansion joint is used for intermediate pressure. These are pipe sections made of ductile material (rubber) which permits repeated flexing without fatigue failure. For satisfactory service at higher temperature, the bellows can be reinforced with special bands.

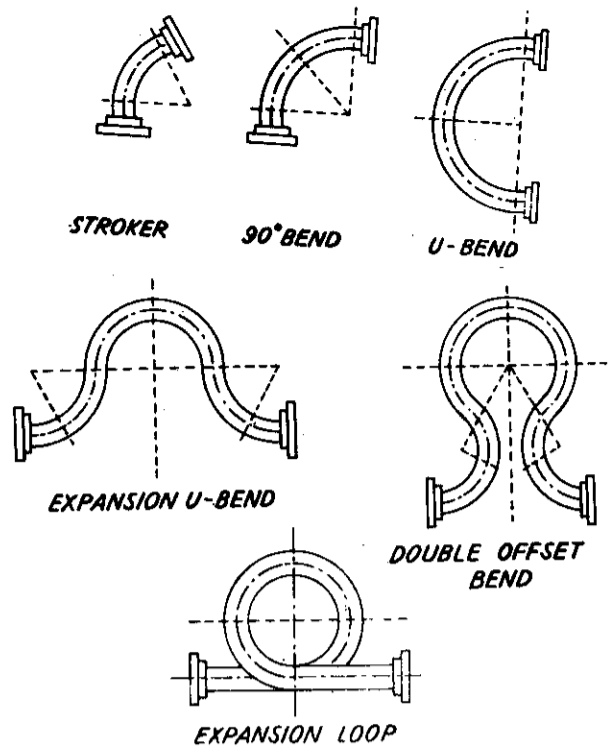


Fig. 20.2. Different types of bends.

Sleeve type expansion joints are used on plain end pipe. It provides almost infinite axial movement and some angular misalignment. They can also be used to connect pipes with different diameters.

Ball type joints allow angular movement only, but two of them can set up with a short intermediate section of pipe at 90° to permit axial movement. They are used for higher pressure and temperature of the steam.

20.4. PIPING SUPPORTS

Steam pipes are usually supported intermittently by hangers, brackets, rollers etc. The piping system should be anchored at definite points to limit the maximum expansion and contraction strains.

The supported pipes should be free to move on their supports in any direction except at the point of anchorage. The supports are generally designed to take up any difference in level whether the pipes are hot or cold. The strains set up by expansion are safeguarded by bends or straight corrugated pipes as mentioned earlier. The summation effect on a long length is reduced by anchoring the pipes at intervals. Thus, the movements set up by expansion or contraction are thus minimised and controlled. The supports should be arranged in such a way that any one pipe can be withdrawn without disturbing the piping system.

Different forms of pipe supports are used in practice. Rigid hangers can be used to fasten overhead beams or embedded in concrete. The rollers can be incorporated if axial movement is desired.

Spring type hangers can be used when the dimensional changes are caused by temperature variations. The load carrying capacity of simple spring hangers varies slightly throughout its travel. To overcome this difficulty, constant support hangers are used. These have compensating springs to insure constant support.

20.5. DESIGN OF STEAM PIPING

Various codes and standards specify minimum pipe dimensions and materials to meet certain safety requirements.

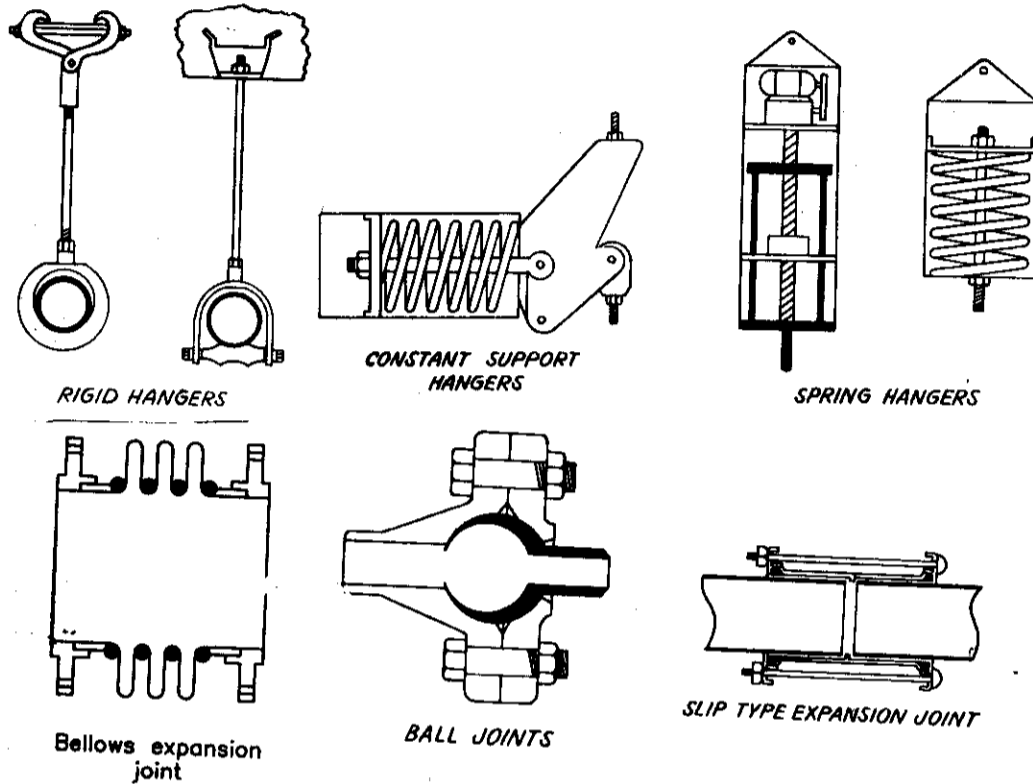


Fig. 2.3. Different types of expansion joints.

The design of pipe size should include the internal pressure of steam, thermal expansion restraints, extraneous movement of supports and dead weight of pipes, fitting and insulation.

The pipe wall thickness to meet the code requirement can be calculated by using the following formula :

$$t_m = \frac{d_o p}{2(f + Bp)} + C$$

where t_m is minimum thickness of pipe, p is the steam pressure, d_o is outside diameter of pipe, f is allowable stress. B and C are constants depending upon the temperature of steam and materials used.

The pipe thickness for all diameters is designated by schedule number. The stress and schedule number are interrelated by the following formula :

$$S_n \text{ (schedule number)} = \frac{1000 p}{f}$$

Another important problem in the steam piping is the selection of diameter for most economic use. The steam mass flow through the pipe is given by,

$$m_s = A V_{ps} \cdot \rho$$

If the mass of steam to be transported and the allowable velocity of steam through the pipe with its condition are known then the pipe diameter can be easily determined.

To determine the correct size of pipe with least cost, the usual practice is to assume a velocity based on previous experience and use the above equation for determining the diameter if the mass of steam with

its condition to be carried is known. The following table helps as a guide to select the allowable velocity of the steam :

<i>Condition of steam</i>	<i>High pressure saturated steam</i>	<i>Low pressure saturated steam</i>	<i>High pressure superheated steam</i>	<i>High-vacuum exhaust steam</i>
Allowable velocity (m/min)	2000 to 3300	1300 to 2000	3300 to 5000	6600 to 8000

The long runs of pipe, thick-walled, alloy steel high pressure pipe requires an economic analysis of optimum pipe size. The higher the velocity of steam used, the smaller the required size of pipe, but the friction loss increases as a square of the velocity. Therefore in economic analysis, a search is made for that pipe size for which the annual fixed cost including insulation, plus the annual operating cost resulting from friction loss should be minimum. The pipe sizing used in power plant often does not warrant a least cost economic analysis.

The following procedure is suggested as a guide to take the successive steps in designing the piping system :

1. Select the material to be used in the various sections of the piping system of the plant.
2. Calculate the diameters (d_i and d_o) required and specify the nominal sizes.
3. Select the materials for insulation and determine the most economical thickness.
4. Provision should be made for expansion.
5. Provision should be made for draining condensate from steam pipe lines.
6. Examine the complete layout for clearances.
7. Examine for accessibility and convenience of operation.
8. Examine the layout for its appearance.
9. Provision should be made for supports along the pipe line.
10. Prepare the final drawings.

Every care should be taken in the pipe layout to reduce the length of the piping to minimum considering alternative arrangement.

20.6. STEAM PIPING MATERIALS

Turbine throttle condition of 60 bar and temperature of 500°C were considered high for central station power plants a decade back. Today the pressure of 400 bar and temperature of 670°C are common in present day modern power plants.

Alloy steels are nowadays commonly used to carry the high pressure, high temperature steam from boiler to turbine. Cr MO steels are commonly used for steam services. The percentage of MO is 0.5% and percentage of Cr varies from 1 to 5% depending on the temperature to be met. P22 type alloy (in the ASTM—A335 group) is the highest chrome alloy normally required for steam service. Corrosion caused by impurities in the steam demands higher chrome-alloy. ASME-312 and 376 austenitic stainless steels are especially well-suited for very high pressure temperature range.

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

20.7. INSULATION OF STEAM PIPING

Bare pipes carrying high temperature steam lose much heat to the atmosphere. The heat lost through pipe has high potential for work, therefore, practically every hot pipe in the modern power plant is insulated.

By insulating the hot pipes, there is not only conservation of heat but it also avoids an uncomfortable overheated atmosphere in the vicinity of pipe.

The insulating material used for steam pipes should possess the following properties :

- (1) It should have high insulating-efficiency*. The maximum heat loss from insulated pipe should not exceed 4 kJ per hour per m² per°C.
- (2) It should have high mechanical strength so it will not be adversely affected by vibrations and knocks.
- (3) It should not be affected by moisture.
- (4) It should not cause corrosion of pipes if chemically decomposed.
- (5) The material should be easily applied or removed.
- (6) It should be able to withstand the temperature to which it will be subjected.
- (7) It should be stable and resist deterioration over the working life of the pipe.
- (8) It should be easily moulded and applied.
- (9) It should not overload the pipe by its dead weight.
- (10) It should not be too costly.

The materials most commonly used for steam pipe insulation are asbestos, magnesia, cork, hair felt, wool felt, rock wool and diatomaceous earths. Most commercial insulations are either built up from corrugated asbestos paper or laminated asbestos paper artificially roughened to produce air spaces or are moulded or felted with asbestos.

A very common and effective insulation for temperature upto 400°C is the moulded 85% magnesia (85% carbonate of magnesia and 15% binder). The insulation used for higher temperature should have inner layer of some special high temperature insulation as high temperature decomposes the inner layer of magnesia. High temperature breaks down the magnesia into asbestos fibre and magnesium oxide and, therefore, destroys cohesion between the pipe and insulation. A layer of glass silk before giving the layer of magnesia is generally used for pipe insulation when the temperature is above 500°C. Glass silk has an advantage of cleanliness, is non-inflammable and can withstand vibration and rough handling without losing its form or thermal efficiency. The packing density varies between 100 to 150 kg per cubic metre according to requirements.

Generally steam pipes are lagged to a thickness of 8.5 cm with plastic magnesia which is reinforced with galvanised wire netting and covered with 1.5 cm thick hard setting of non-conducting material. The lagging finally covered by a wrapping of canvas and two coats of selected paints are given to the surface.

The small steam pipes should have the same insulation thickness as large ones as the heat loss per m² on a small pipe is higher than large pipe.

The insulation manufacturers publish 'insulation efficiency' data for different thicknesses of their different grades of insulation. Such tables generally provide the efficiency data against two variables as pipe size and temperature difference.

The amount of insulation to be applied is an economic problem like many other power plant design problems. The cost of insulation must be weighed against the saving of heat.

Economic Thickness of Insulation. The economic thickness of insulation depends on the first cost and maintenance cost and annual value of heat loss which depends on the cost of producing the steam and thermal conductivity of the lagging.

The heat loss through an insulation on the pipe per metre length is given by

$$Q = 2\pi K \left[\frac{(T_1 - T_2)}{\log_e \left(\frac{r_2}{r_1} \right)} \right]$$

* Insulating efficiency = $\frac{\text{Bare surface loss} - \text{Insulated loss}}{\text{Bare surface loss}}$

where T_1 and T_2 are inner and outer surface temperatures of insulation and r_1 and r_2 are inner and outer radii of insulation and K is the conductivity of insulating material.

The cost of insulation material per metre length

$$= \pi(r_2^2 - r_1^2)C_1$$

where C_1 is the cost of lagging material in rupees per cu-metre.

Let p be the percentage of the first cost that must be expended annually on investment and maintenance and let C_2 be the loss in rupees due to heat loss of 4 to 5 kJ per hour.

∴ Total hourly cost per metre length of insulation is given by

$$C = \frac{2\pi K(T_1 - T_2)}{\log_e \left(\frac{r_2}{r_1} \right)} \cdot C_2 + \frac{\pi(r_2^2 - r_1^2)}{8760} \cdot \frac{p \times C_1}{100}$$

If K , T_1 , T_2 , C_1 , p , C_2 and r_1 are fixed, but r_2 may be varied to make C minimum.

To find out the maximum value of r_2 to make C minimum, the required condition is

$$\frac{dC}{dr_2} = 0 \text{ or } \frac{dC}{dR} = 0 \text{ where } R = \frac{r_2}{r_1}$$

$$\therefore \frac{d}{dR} \left[\frac{2\pi K(T_1 - T_2)C_2}{\log_e (R)} + \frac{\pi r_1^2 (R^2 - 1)}{8760 \times 100} \cdot pC_1 \right] = 0$$

$$\therefore -\frac{2\pi K(T_1 - T_2)C_2}{R(\log_e R)^2} + \frac{\pi r_1^2 pC_1}{100 \times 8760} \times 2R = 0$$

$$(R \log_e R)^2 = \frac{K(T_1 - T_2) C_2}{r_1^2 pC_1} \times 100 \times 8760$$

$$\therefore R \log_e (R) = \frac{10}{r_1} \sqrt{\frac{KC_2(T_1 - T_2) \times 8760}{p \cdot C_1}}$$

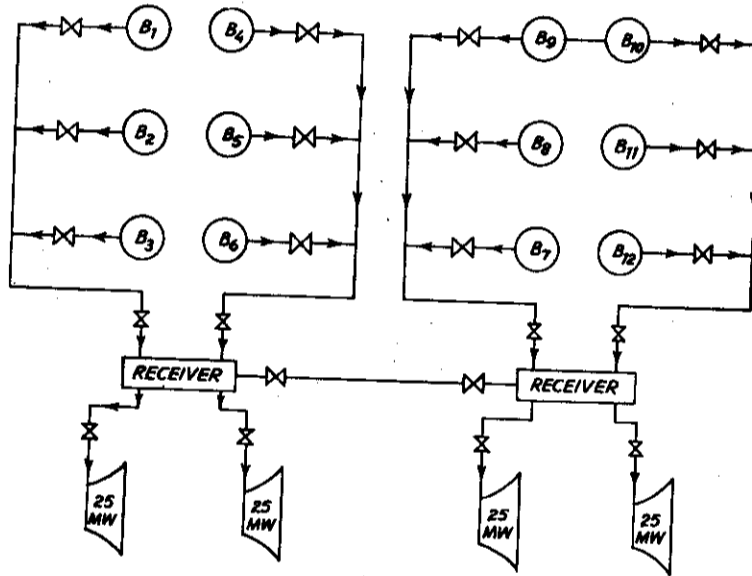


Fig. 20.4. Layout of steam piping for 100 MW station.

It is not always possible and easy to calculate the value of R or r_2 by using the above formula. The charts are available for finding out the economic value of r_2 (or $r_2 - r_1$) considering number of variables.

20.8. PIPING LAYOUTS

The main high steam pipe work comprises running from boilers to the turbines.

The pipe work should run as direct as possible having regard to appearance and provision for expansion. All piping should be arranged with a gradual fall towards the steam flow, so that the condensate collected can be removed easily.

It is common to employ multiple steam pipes in large capacity boilers (200 tons/hr). The purpose is to provide greater flexibility of connection which is always a problem with high pressure and high temperature piping.

Two piping arrangements for 100 MW and 200 MW power plants are shown in Figs. 20.4 and 20.5.

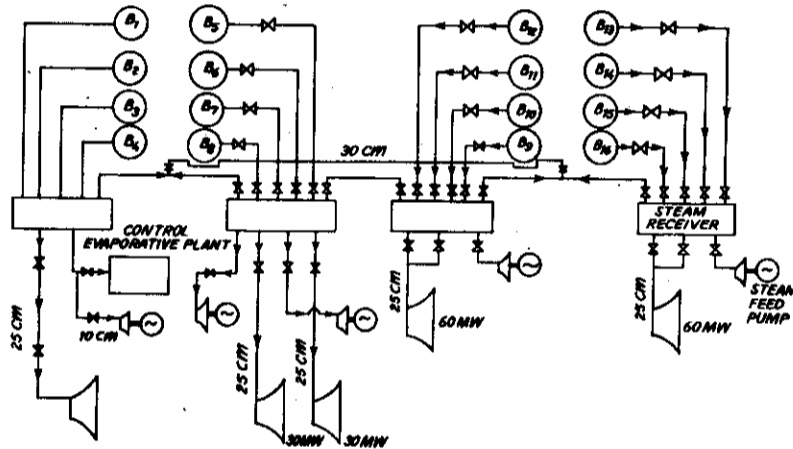


Fig. 20.5. Layout of steam piping for 200 MW capacity power plant.

Ultimately the final piping layout depends upon the location of the plant and the plant components. The route used for piping with minimum cost mostly depends upon experience of the engineer.

EXERCISES

- 20.1. What are the basic requirements of steam piping used in present day power plants ?
- 20.2. Draw different pipe fittings and mention their field of use.
- 20.3. Why expansion joints are necessary in steam piping system ? Draw any four joints and mention their specific use.
- 20.4. Draw any five piping supports and mention their field of use.
- 20.5. What different factors are considered in designing the steam pipings ?
- 20.6. What piping materials are used ? Discuss their relative merits and demerits.
- 20.7. What are the basic requirements of insulating materials used for steam piping ? Mention any five insulation materials used for steam piping.
- 20.8. What do you understand by economic thickness of insulation ? Develop an expression for finding economic thickness taking all factors into consideration.



21.1. General Design of Power Plants. 21.2. Architectural Features. 21.3. Inline Arrangement of Units. 21.4. Units Perpendicular to each other or Parallel to Division Wall. 21.5. One-room one-floor station. 21.6. Unit Plan Station. 21.7. Outdoor Type Steam Electric Station. 21.8. Lighting of Steam Power Plants.

21.1. GENERAL DESIGN OF POWER PLANTS

In the design of a power generating station, consideration must be given to the arrangement of main and auxiliary machinery. The various important factors which are considered for the economic design of power plant are volume and area required per kW capacity of the plant, reliability of operation, ease of control, convenience of access to all important equipments and station cost per kW capacity.

The details of each factor are discussed below :

1. Volume and Area Requirements. Less volume as well as less area requirements are essential features of a good design of power plants. Less area requirement reduces land cost and less volume requirement reduces the construction cost of the plant.

Some typical figures on the square metre of the floor area and cubic metre per kW of installed capacity for different components of power plant as an average are listed below.

Capacity between 100 to 250 MW

<i>Station Equipment</i>	<i>Boiler room</i>	<i>Turbine room</i>	<i>Switch house</i>	<i>Office</i>	<i>Intake works</i>	<i>Total</i>
Floor area in m ² per kW	0.026	0.015	0.003	0.003	0.0025	0.0495
Volume in m ³ per kW	0.8	0.5	0.04	0.1	0.06	1.5

2. Reliability. The reliability of operation is another important factor of design intimately associated with the cost of the plant. Many times, it has been proved by experience that the low cost plant is more expensive in operation than high cost plant due to non-reliability of operation. The use of inferior equipment or omission of certain apparatus necessary for precautionary control always results in unsatisfactory operation of the plant. This is due to high outage of plant or high maintenance cost.

3. Ease of control and access to equipments. The control system must be highly efficient in operation. This is very essential to avoid the total shut down or breakage of the power plant under emergency conditions.

Easy access to all equipments is absolutely necessary for easy repair and maintenance. This reduces the time required for repair and maintenance cost.

4. Station Cost. The total station cost includes the cost of equipments, buildings and land. The total cost of the thermal plant lies between 10000 to 15000 Rupees per kW of installed capacity. The construction cost of the plant can be reduced with careful check during the progress of the plant design.

The net generating cost depends upon the station cost and operating costs. Therefore, the generating cost depends to a great extent upon the degree of refinement attempted in the reduction of heat rate and upon initial pressure and temperature of the steam used for power generation.

21.2. ARCHITECTURAL FEATURES

In the design of modern power plant buildings, enough attention has been given to an architecture of the building. It is proved fact better architecture of the building provides psychologically pleasant atmosphere for the workers.

The size, arrangement and shape of the building are principally affected by the type and size of the power plant. A very careful thought should be given in the design of ventilation system of the power plant without disturbing the look of the building due to the duct arrangement carrying the conditioned air.

The roofs are generally constructed flat, with covering of built-up tar and gravel composition. The roof deck is carried on trusses on reinforced concrete slab beams. The floors are generally constructed of concrete as it is fire-resistant and impervious to rot.

21.3. INLINE ARRANGEMENT OF UNITS

Majority of the modern power plants are provided with division wall between the turbine room and boiler room.

A typical arrangement of turbines and boilers being in line is shown in Fig. 21.1.

The advantages and disadvantages of this arrangement are listed below :

1. The unit plan can be followed by setting the boilers on the turbine shaft centre line.

2. The throttle of each turbine can be placed near the division wall and, therefore, the steam lead to each machine is relatively short.

3. In a turbine room of any greater length, light will penetrate easily to the auxiliary equipment in the turbine room basement.

4. The electrical connections will be short and direct if the outdoor type switch board is used and located adjacent to the turbine room with this arrangement.

5. The switch house, generator bus-bars, meters, controls and circuit-breakers can be easily located adjacent to the turbine room with this arrangement.

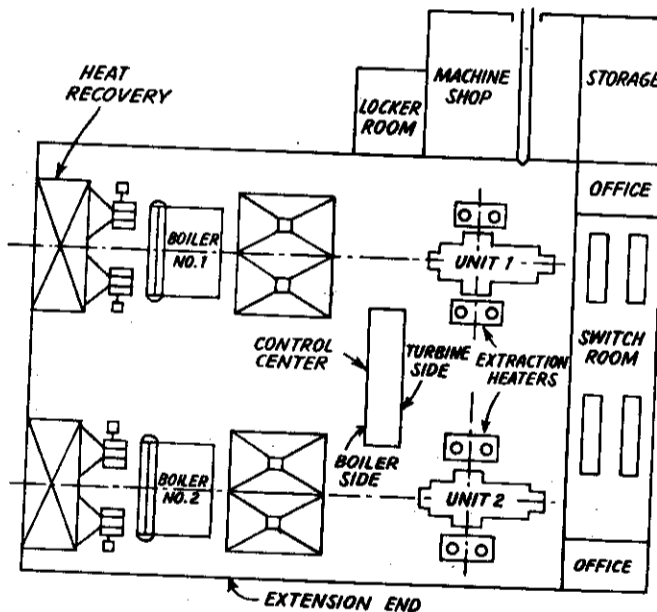


Fig. 21.1. Inline arrangement of units.

If sufficient clearance is not allowed between the end of the generator shaft and the wall of the maximum capacity of unit contemplated ; it becomes necessary to widen the turbine room in future with this arrangement.

The development of boilers room and the arrangement of prime mover depends on the number of boilers used per turbine.

Nowadays, boilers of high capacity (one boiler can generate the steam to supply to 200 MW capacity plant) are developed, therefore, the number of boilers used per prime mover becomes a matter of reliability.

Some design engineers prefer three boilers for two turbines, one being a spare. But in large capacity plants, one boiler per turbine is economically justified if reliable electrical interconnections are available.

21.4. UNITS PERPENDICULAR TO EACH OTHER OR PARALLEL TO DIVISION WALL

The arrangement of the units is shown in Fig. 21.2. In this arrangement, the turbine units are set much closer compared with the previous arrangement. The condensers under the turbine have their long dimensions parallel to the turbine shafts to make close spacing possible. With this type of condenser arrangement, careful construction is necessary in order not to block the space for turbine extraction lines, generator leads and air coolers. This arrangement is more flexible, therefore, turbine units of greater length can be installed in future without increasing the width of the turbine room.

In old power plants of this arrangement, cross compounding of turbine is used. The real reason for adopting the cross compounding is the division of steam flow to two or more low pressure units and the preservation of the initial turbine room width. During those days, a suitable large single shaft generator could not be constructed and, therefore, cross compounding was invariably used.

Presently, in modern power plants, it is a matter of heat economy whether future machines will be of this type since a tandem compound steam turbine driving one generator can be built in sufficient large size to satisfy practically any load increase.

In old power plants, it was customary to place gas reheat boiler nearest to the division wall to reduce the run of expensive reheat steam piping. But with high capacity modern power plants, the reheat section is built into the main boiler and involves the same run of piping as the main turbine steam lead. If steam reheating is used, the steam reheater is generally located adjacent to the high pressure turbine in the turbine room.

21.5. ONE-ROOM ONE-FLOOR STATION

The arrangement of this system is shown in Fig. 21.3. This new type of arrangement is developed to achieve maximum economy of design. In this arrangement, the division wall between turbine room and boiler room is totally omitted. This arrangement has been used successfully for several small stations.

In this arrangement, the boiler operating floor is level with the furnace floor. The draught fans (I.D. and F.D.) and feed pumps are also placed on this floor. The turbine is located above on an island, but all controls are brought down to the main floor level. The switchgears for the generator and outgoing circuits are also placed on the same floor. All the piping is placed below the turbine gallery and practically hidden from view.

The outstanding features of this arrangement are listed below :

1. The operation of all boilers and turbines is controlled from one central group located on one floor level.

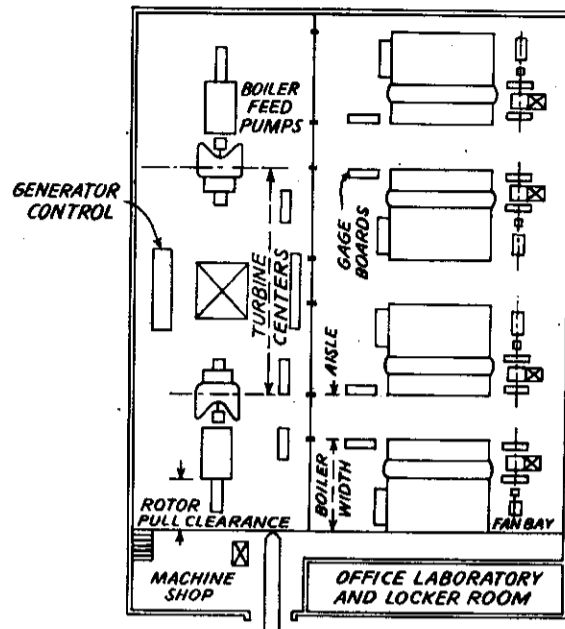


Fig. 21.2. Units parallel to division wall.

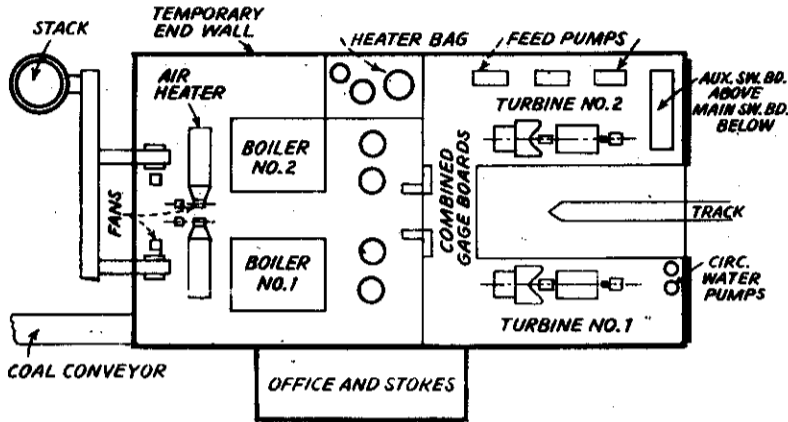


Fig. 21.3. Single floor-station.

2. There is centralization of generator and outgoing feeders.
3. Separate switch-room facilities are not required.
4. The firing axle is located between the boiler and turbine room without curtain wall between them.
5. All heaters and pumps are located in close grouping according to heat cycle arrangement.

21.6. UNIT PLAN STATION

With all modern developments in thermal sciences, materials and design, it has become customary to use unit plan even for high capacity power plants. This is because, the single-boiler and single-turbine power plant is less expensive than multi-boiler units. Presently unit-boiler of 1000 to 2000 tons of steam per hour generating capacity and turbine generator sets of 100 to 500 MW capacity are available.

Such arrangement permits the placement of turbine on the exact centre line of the boiler and facilities for expansion of the power plant. With this arrangement, one section does not extend beyond the other in normal growth of the station. This also permits the duplication of units from identical design drawings.

The arrangement of the plant is shown in Fig. 21.4.

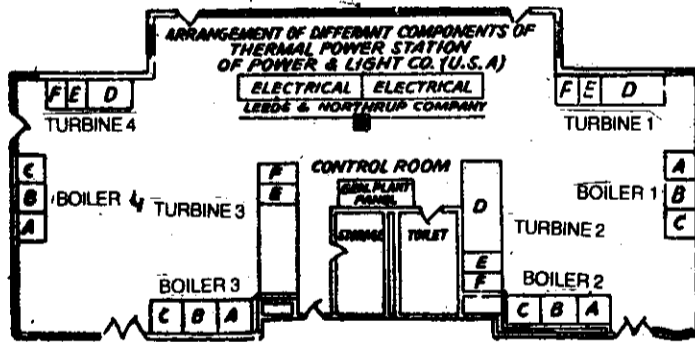


Fig. 21.4. Unit plan station.

21.7. OUT-DOOR TYPE STEAM ELECTRIC STATION

Another type of arrangement which is commonly used in modern power plant layout is the out-door design. It is possible to save considerable cost of the plant building by an out-door layout.

The outdoor type of boiler arrangement was a natural development because the steel cased unit is equally satisfactory either indoors or outdoors. The out-door boiler arrangement was first used in the South and Gulf States of U.S.A. The next development was to place certain portions of the electrical plant and heat cycle equipment of the turbine plant out of doors. Finally, the turbine generator unit has been placed out of doors either on deck or on foundation under a gantry crane.

Boilers, turbine-generator sets, tanks, fans and other bulky equipments are normally enclosed by a fairly weather-tight casing, even when located indoors. Therefore, the modifications necessary to weather proof such equipments are not expensive.

The physical size of the building is considerably reduced when outdoor layout is used. It is established fact that the cost of plant is reduced by 50 to 100 rupees per kW capacity by adopting out-door arrangement.

The greatest saving is achieved in building cost where the fuel used is oil or gas and most outdoor stations use these fuels only. The prospect of outdoor layout is more attractive in the areas where the rainfall is not severe because rainfall is the only weather obstacle to maintenance. This type of layout is also not suitable in cold seasons such as Utah and Kansas in U.S.A. Certain amount of inspection and maintenance becomes out-door work for operators of this kind of plant which is one of the major drawbacks of this layout.

The layout of the system is shown in Fig. 21.5.

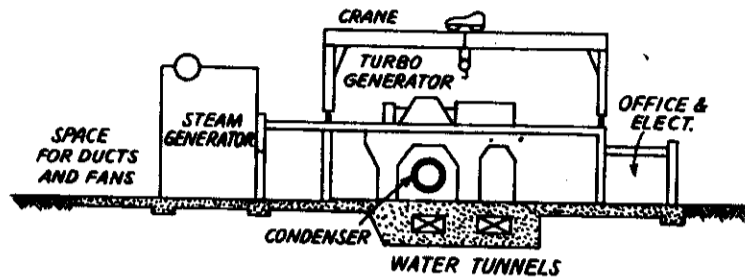


Fig. 21.5. Building arrangement for an out-door type steam electric station.

21.8. LIGHTING OF STEAM POWER PLANTS

The problem of illumination in power stations is somewhat specialized and installations are totally different from industrial lighting system for the reasons listed below :

- (1) It is not necessary for the operator to examine the product closely.
- (2) Intensive local illumination is essential for instrument panels, gauge glasses and control boards.
- (3) High ceilings eliminate consideration for indirect lighting.
- (4) Fumes and moisture may corrode the lighting units.
- (5) Separate emergency lighting is absolutely essential because the power plant is the source of lighting service.

- (6) The coal handling and draught equipments make it difficult to illuminate the boiler room from above.

A power station operates 24-hours a day and 365 days a year and daylight is available only for about one-third of the running period. The sunlight is also not available in night time, therefore, a provision for good artificial lighting should be made.

The lighting provided should be adequate, steady, evenly distributed and correctly diffused. The number of lighting points should be as few as possible, they should be evenly distributed for ensuring uniform lighting. In addition to this, the lighting system must ensure reliability of operation, safety, economy and ease of maintenance.

The choice between mercury, tungsten, sodium and general arrangement is often governed to some extent by local conditions and economics.

The lighting details in different parts of the power plants are discussed below.

1. Turbine House. The turbine house is considered as show place of the power station, therefore, very good lighting arrangement should be provided in this house. The common methods used for lighting the turbine house are overhead lighting and side lighting systems or combination of both.

If the roof is flat and unglazed, then the lighting should be chosen so that it will illuminate both the floor and the roof. With flat and unglazed roof, the desired lighting is obtained by mounting the units on the face of the crane girders and continuing round the end walls at the same level. In this system of lighting, the crane does not obstruct the lighting as is the case with overhead mounting.

The average service illumination required in turbine house is 120 to 150 lumens per metre square.

2. Boiler House. The lighting of boiler house is most difficult as the galleries, platforms and ducts present problems in fitting the lights. Therefore, special fittings designed for that purpose are generally used.

Discharge lamps are used for general lighting over certain sections of the boiler house though lighting is used on a boiler firing floor. Four lamps each of 500 kW capacity are generally used per trough. All the lights are generally provided with protection to prevent damage.

An adequate number of low voltage plug points are also provided to facilitate the boiler inspection.

3. Control Room. The design of control room is very important in modern power plants and, therefore, deserves careful thought throughout an early stages of the station design and layout.

Control room, its layout, design and lighting has become an important feature as the control of mechanical and electrical equipments is undertaken from this room.

It is essential to provide an even diffused light, both natural and artificial, of adequate intensity but with a total absence of glare. Well designed ceiling light is used which provides natural illumination in day time and lighting units housed provide illumination during night. This system consumes large amount of energy and the illumination falls off considerably if clean conditions are not maintained.

Care should be taken to eliminate reflections from instrument faces. With the use of proper intensities, the control engineer should be able to look up from white paper on his desk and see the control board immediately without waiting for his eyes to become accustomed to a different intensity.

The fluorescent tube lighting is commonly used as it closely approaches that of daylight and this reduces the possibility of eye strain compared with the point type lighting. The fluorescent lighting is costly but energy consumption is considerably less than tungsten filament lamp.

The lighting control panel is mounted on the desk of the control engineer together with all switches for the colour combinations which can be varied to provide the desired effect.

Outdoor Services. Adjustable flood lighting equipments are used for outdoor transformer and switchgear layouts as well as for yards, roadways and sidings. These lights do not give satisfactory performance unless relatively high mounting heights are employed due to glaring character.

The lighting on coal handling plant is supplied at 110 V. This safety voltage is also used for plug boards for portable tools.

Where power stations are in the vicinity of aerodromes, it is advisable to provide suitable neon lights on chimneys.

The possibility of providing suitable advertising features should not be lost sight of, particularly where special buildings can be used for the purpose. For example, where large reinforced concrete cooling towers are installed and if the site is favourable, it is possible to floodlight these towers with great effect. At night, a wonderful spectacle is presented and can be seen for miles around. The main buildings can be designed to give effect to flood-lighting.

EXERCISES

- 21.1. What are the basic requirements of steam piping used in thermal plants ?
- 21.2. Draw different joints. Mention one use of each in power plants.
- 21.3. Draw 5 different piping supports and mention use of each in the power plant.

- 21.4. What are different materials used for steam piping ? Mention the materials used to carry (1) very high pressures steam (2) steam for regenerator and (3) exhaust steam.
- 21.5. Why insulation is necessary ? Mention the names of insulators used for steam piping.
- 21.6. What factors are considered in locating the components of a big thermal power plant ?
- 21.7. Draw a line diagram of inline unit arrangement and list out its special features.
- 21.8. Draw the components of one room, one floor station and list out the outstanding feature of this arrangement.
- 21.9. What do you understand by out-door type steam station ? Draw a line drawing of such an arrangement and list out its merits.
- 21.10. Draw the layout of a big thermal power station of 2000 MW capacity showing all necessary components.



