Chemical Process Utilities
Prof. Shishir Sinha
Department of Chemical Engineering
Indian Institute of Technology, Roorkee

Lecture - 15
Boiler Water Treatment

Welcome to the boiler water treatment concept under the aegis of chemical process utilities. Before we discuss this boiler water treatment, you know that we have covered the topic in the previous lecture related to the different types of inhibition.

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Introduction to microfiltration, ultra-filtration, nanofiltration, reverse osmosis, and we discussed the mechanism of filtration.

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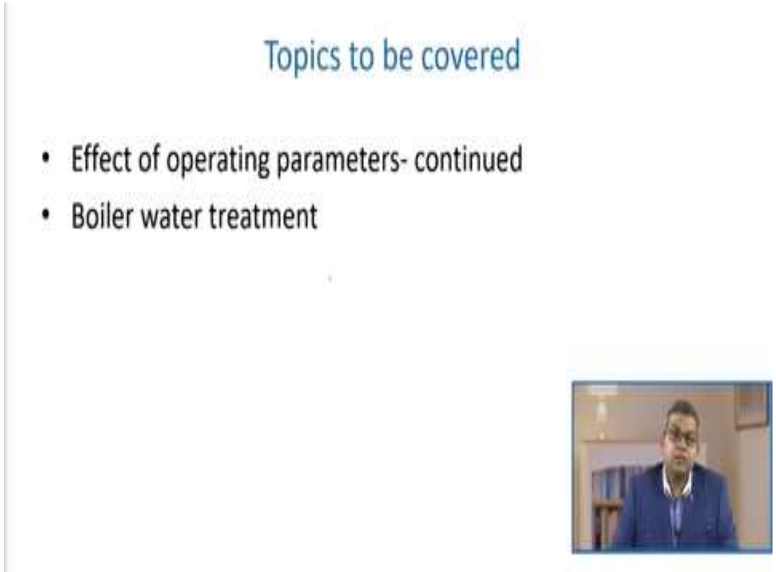

In continuation with the filtration mechanism, we will discuss if various effect of operating parameters will be continued in this particular segment. The later part will discuss the boiler water treatment, which is also an integral part of these operating parameters. So, let us have a look at the effect of salt concentration. Usually, osmotic pressure is a function of the type and concentration of salts or organic contained in feed water. As salt concentration increases, so does osmotic pressure.

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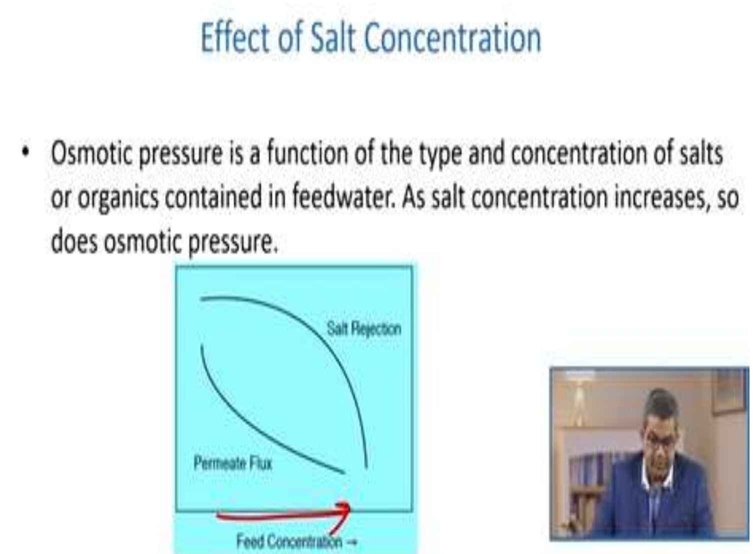

So, you can see over here.

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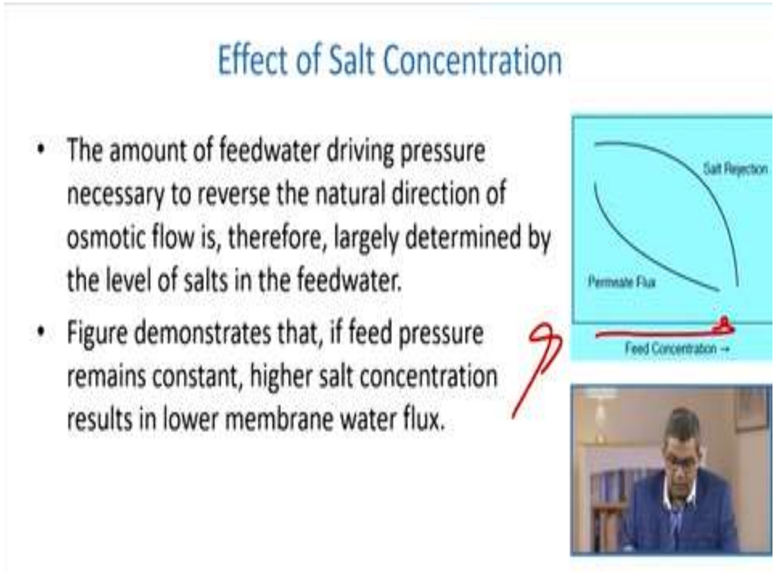

The amount of feed water driving pressure necessary to reverse the natural direction of osmotic flow is largely determined by the level of salt in the feed water. This figure demonstrates that if feed pressure remains constant, the higher salt concentration results in lower membrane water flux.

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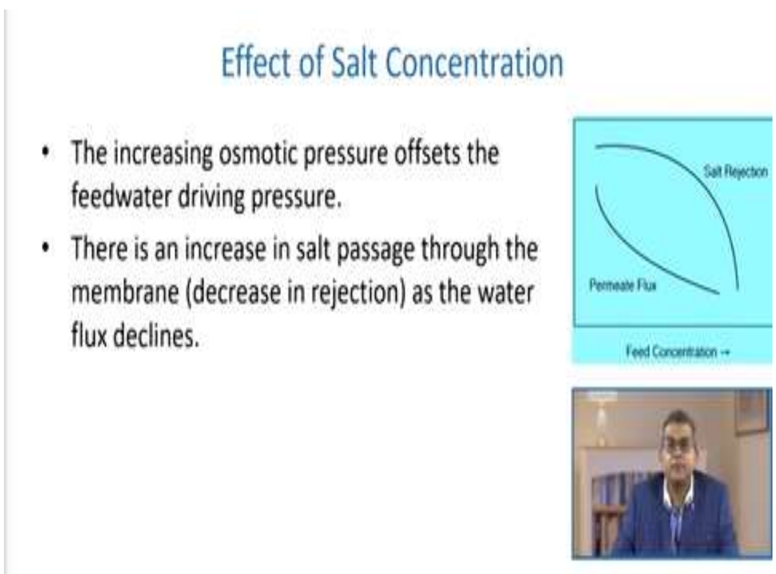

So, the increased osmotic pressure offsets the feed water driving pressure. There is an increase in salt passage through the membrane, or we can say that there is a decrease in rejection as the water flux declines.

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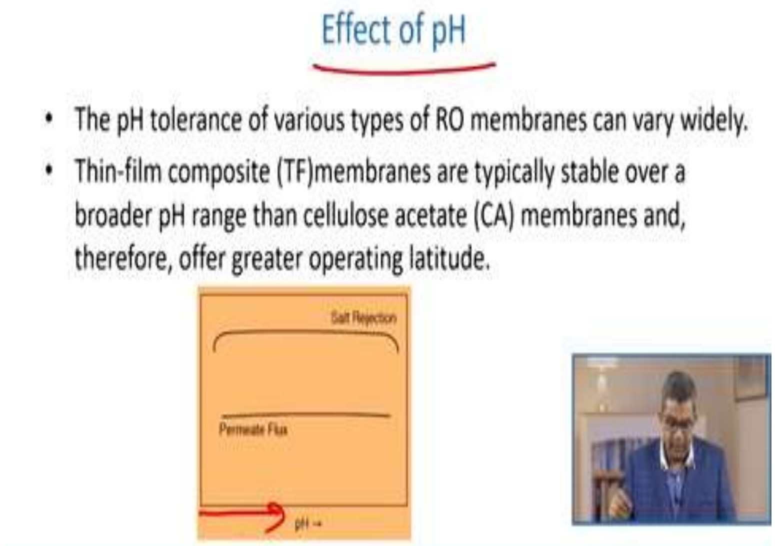

Let us have discussion on the effect of pH; the pH tolerance of various types of reverse osmosis membranes can vary widely. Thin-film composites membranes are typically stable over a broader pH range than cellulosic acetate membranes or CA membranes. Therefore, offer the greater operating latitude you can see, or it can be visualized over here.

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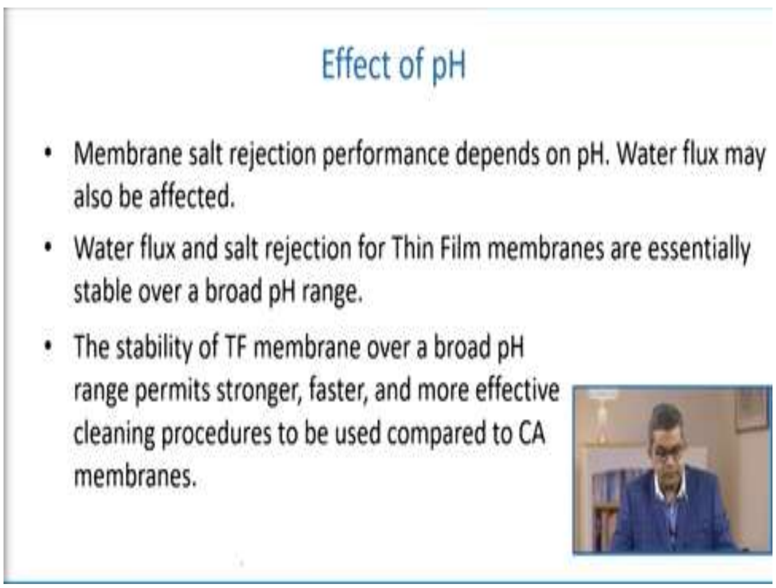

The membrane salt rejection performance depends on pH, and water flux may also be affected. So, thin-film membranes' water flux and salt rejection are essentially stable over a broad pH range. The stability of TF membrane over a broad pH range permits a stronger, faster, and more effective cleaning procedure to be used compared to cellulosic acetate membrane.

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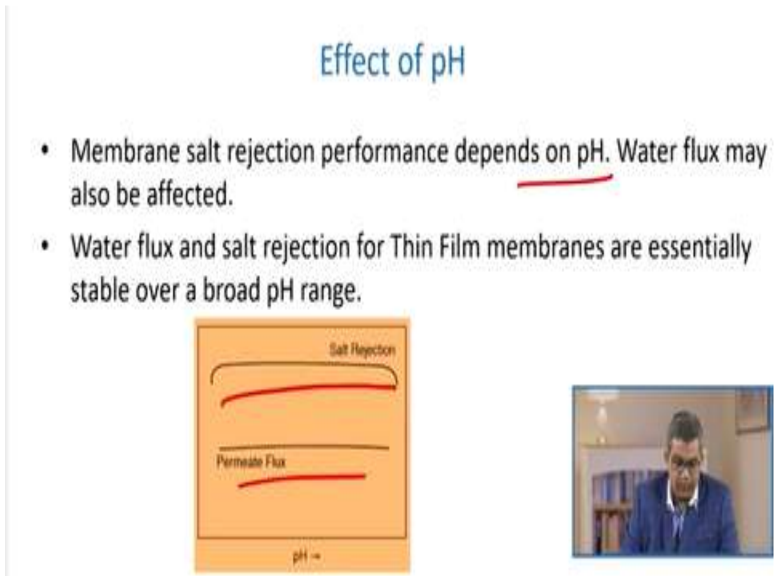

Membrane salt rejection performance usually depends on pH. Water flux may also be affected. Water flux and salt rejection for thin-film membranes are essentially stable over a broad range of pH.

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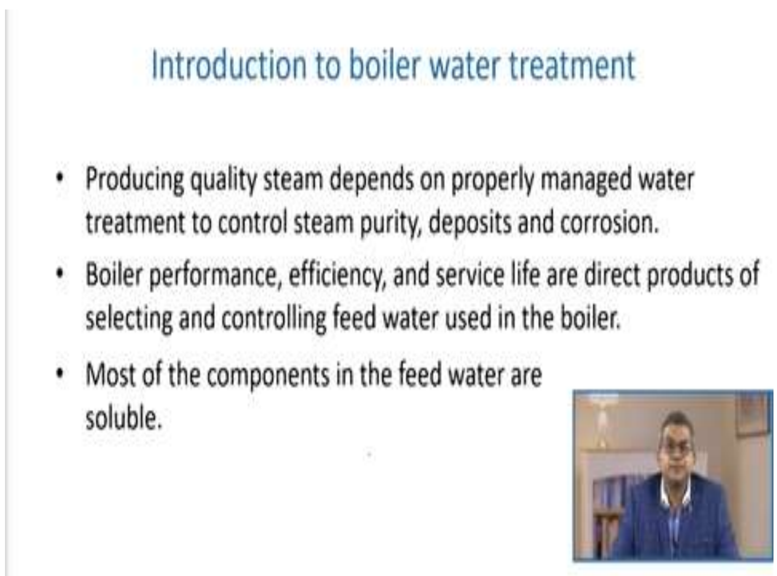

As the start of this particular lecture, we discussed the title of this particular lecture, called the boiler water treatment. Previously, we discussed the quality feed water requirement for the boiler because there may be certain impurities attributed to the vegetation, debris, hardness, etc. This may create the problem of the proper operation of the boiler. Scales may form within the tubes of the boiler.

This may corrode the tubes, and the pressure build-up and the boiler may explode. Similarly, if scales are usually narrow down the tubes' inner diameter, the flow may get fluctuated. So, and moreover, these scales do not have any heat value. Therefore, the efficiency of the boiler may go down. Therefore, it is an utmost requirement for boiler feedwater treatment.

Because ultimately, producing quality steam depends on properly managed water treatment to control the steam purity, deposits, and corrosion. So, when we talk about the various scaling parameters, when we talk about the flow fluctuation, when we talk about the corrosion attributed to the scales and damage to the tubes so, the boiler performance, efficiency, and service lives are direct products of selecting and controlling feed water used in the boiler.

Sometimes the iron, sometimes the dissolved gases, etc may produce the scales forms, and these forms, etc, do not have any kind of heat value. So, again the efficiency performance, etc may go down, and you may not get the steam as desired. So, therefore in view of all these, most of the components in the feed water are soluble.

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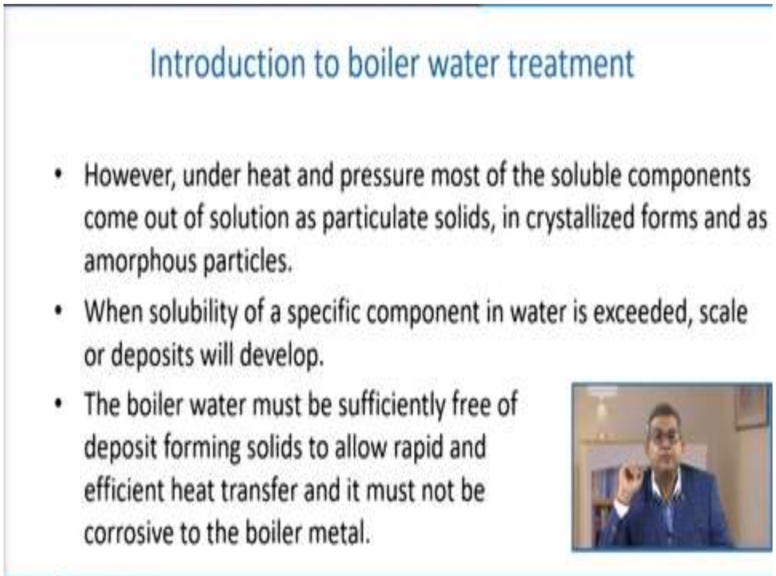

Under heat and pressure, most soluble components come out to the solution as particulate solid in crystallized form or as amorphous particles. Remember all these things we have already discussed. The heat and pressure may alter the concentration of all these soluble components within the boiler feed water. So, when the solubility of a specific component in water is exceeded, the scale or deposits will develop.

So, you have to look into this aspect too. The boiler water must be sufficiently free of deposits forming solid to allow rapid and efficient heat transfer, and it must not be corrosive to the boiler metal. We have already discussed this because all these solids or deposit-forming solids may form the scale. It may become corrosive, thereby impacting the boiler badly.

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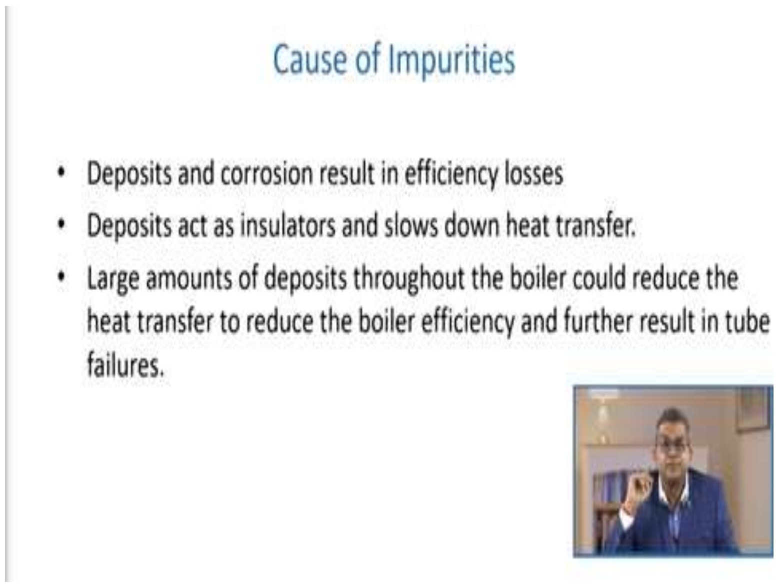

There are various causes of impurities. The deposits and corrosions result in efficiency losses. Deposits may act as insulators and slow down the heat transfer. And ultimately, the energy efficiency of your boiler may go down, and ultimately the performance of your boiler may go down. Large amounts of deposits throughout the boiler could reduce the heat transfer to reduce the boiler efficiency and further result in tube failure.

It affects in two ways. One is the efficiency or performance of the boiler may go down, and the second is boiler may explode to it, may create a safety hazard. There are various causes of impurities like hardness salts.

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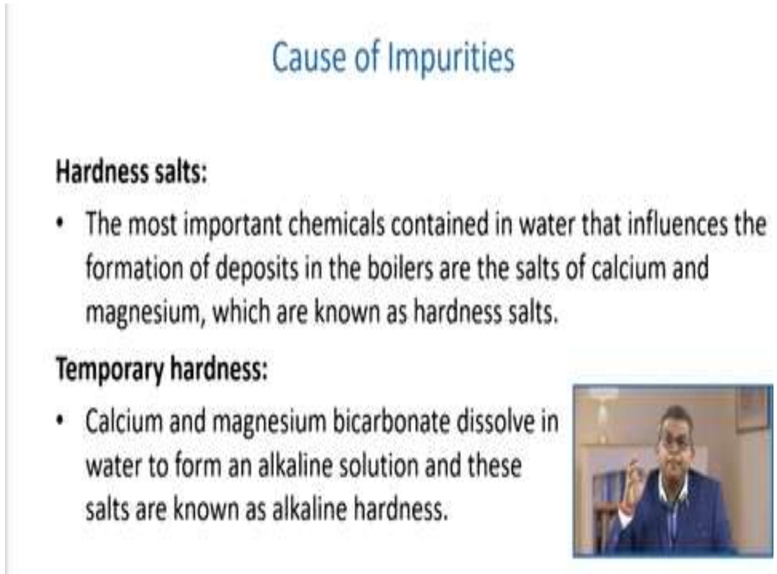

Hardness salts: The most important chemicals in the water that influence the formation of deposits in the boiler are the salts of calcium and magnesium, known as the hardness salt. Remember all these are temperature and pressure depending. So, sometimes, if repeated reuse of water occurs, the concentration of these salts may go up. There is temporary hardness, the calcium and magnesium bicarbonate is dissolved in water to form an alkaline solution, and these salts are known as alkaline hardness.

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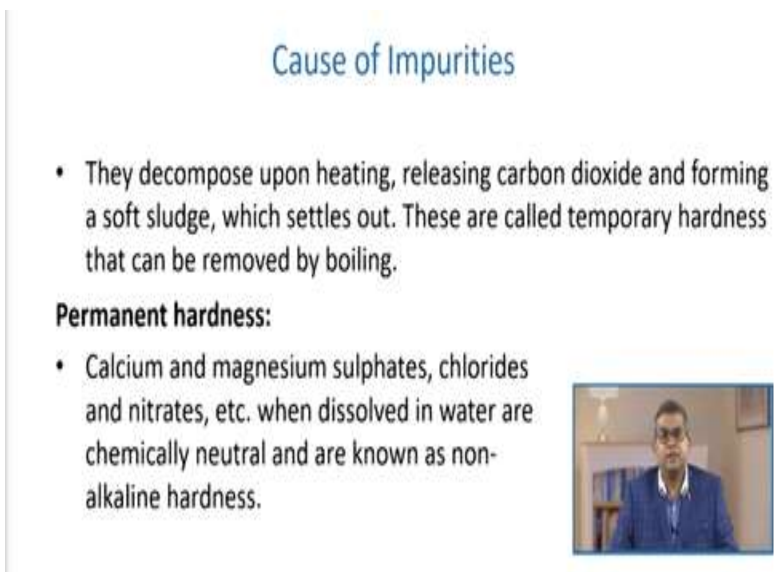

They decompose upon heating, releasing carbon dioxide and forming a soft sludge that settles out. These are called temporary hardness that can be removed by boiling. There are permanent hardness. When dissolved in water, the calcium and magnesium sulfates, chlorides, nitrates, etc when dissolved in waterare chemically neutral and known as non-alkaline hardness.

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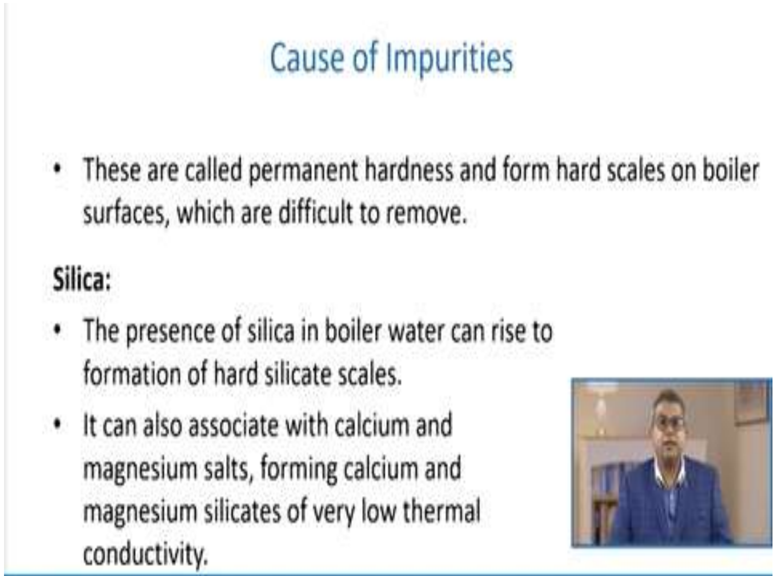

And these are called the permanent hardness to form the hard scale on boiler surfaces which are difficult to remove. Silica, we had a discussion in the previous lectures. The presence of silica in boiler water can rise to the formation of hard silicate scales. It can also associate with calcium and magnesium salt, forming calcium and magnesium silicates at very low thermal conductivity. Silica can give rise to deposits on steam turbine blades.

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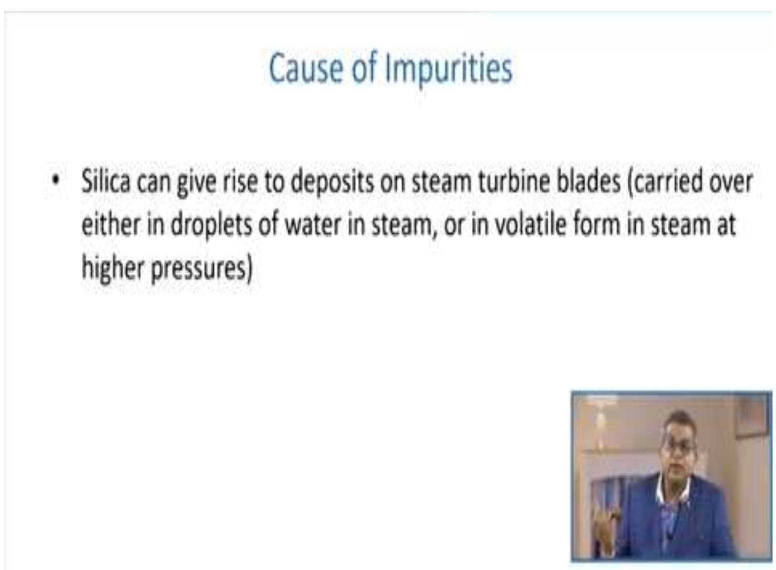

They carried over either in droplets of water in steam or in a volatile form in the steam at high pressure. See, steam is being produced in the boiler, and it is being used as the turbine for the production of electricity or for the movement of various mechanical pumps, etc. So, any kind of deposition over the steam turbine blades may cause lower efficiency as well as wear and tear to all these turbine blades.

So, that is why silica is again an undesired impurity in the boiler feedwater. Other is the iron. Either soluble or insoluble iron can deposit on boiler parts and tubes, damaging the downstream equipment and affecting the quality of certain manufacturing processes. Iron may enter the boiler as a result of corrosion in the pre-boiler section or maybe re-deposited as a result of corrosion in a boiler or condensate steam.

Sometimes iron oxide will be deposited and retired the heat transfer within the boiler tube at a time, resulting in tube failure. And sometimes, if we neglect the importance of iron, it may become part and parcel of his steam. And once it becomes part and parcel of the steam because it is a very good catalytic agent, it may create a problem if steam is being used as a direct heating media in a different chemical reaction.

So, when we were talking about iron oxide deposition, this usually occurs in high heat transfer areas i.e. screening tubes is the nearest to the frame. When the iron is not present in the raw feed water, or its presence in the boiler indicates active corrosion within the boiler system itself.

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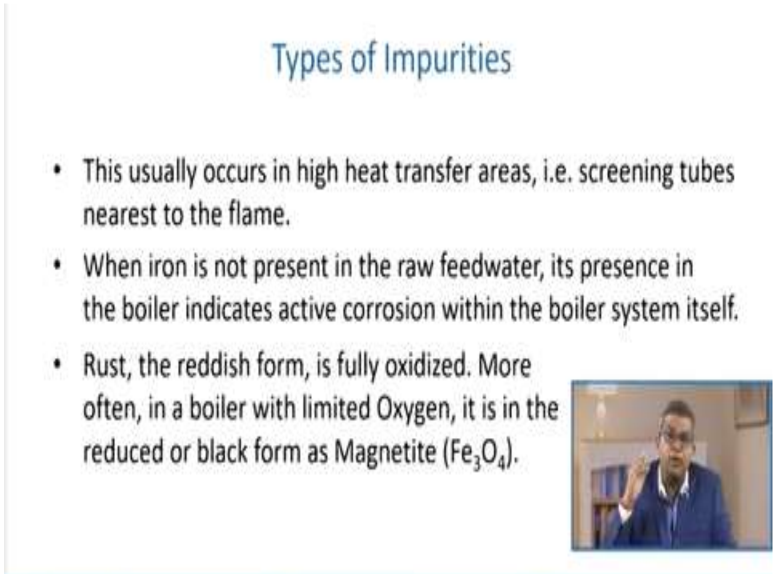

Rust, the reddish form of fully oxidized more often in a boiler with limited oxygen, it is in reduced or black form as magnetite Fe 3 O 4.

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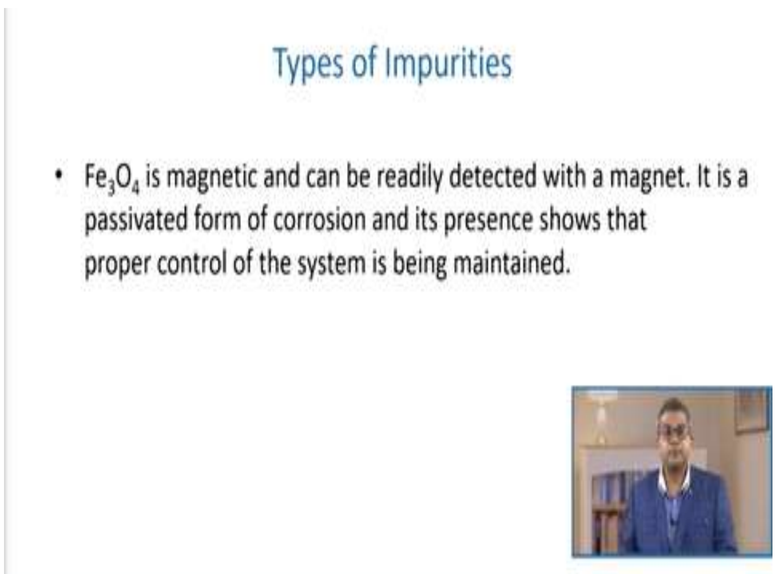

this magnetite it can be readily detected with magnet. it is passivated form of corrosion and its presence shows that proper control of the system is being maintained.

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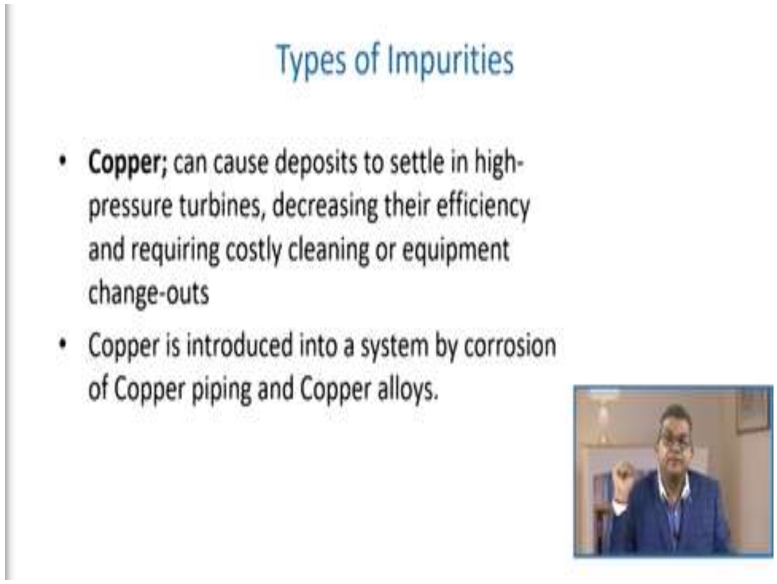

Another part of impurity is copper. It can cause deposits to settle in high-pressure turbines, decreasing their efficiency, sometimes requiring costly cleaning or equipment change-outs. So, the copper is introduced into a system by corrosion of copper piping and copper alloy, and sometimes when we are repeatedly using the steam with respect to the condensate water recovery system. So, copper may become part and parcel of the condensate water system.

So, it needs to be addressed because otherwise, it may create a problem. Again, copper is a very good catalytic agent. So, if the contamination of copper is not addressed properly, then again, if the direct steam is being used in any kind of chemical reaction, then definitely it may create a problem, it may cause the formation of undesired product, it may form the formation of certain by-product even it may create a problem of a thermal runaway reaction.

In the boiler, the source of corrosion could be either dissolved gases in the boiler water or excessive use of hydrogen, which can corrode the copper and copper alloy, allowing copper to be carried back to the boiler.

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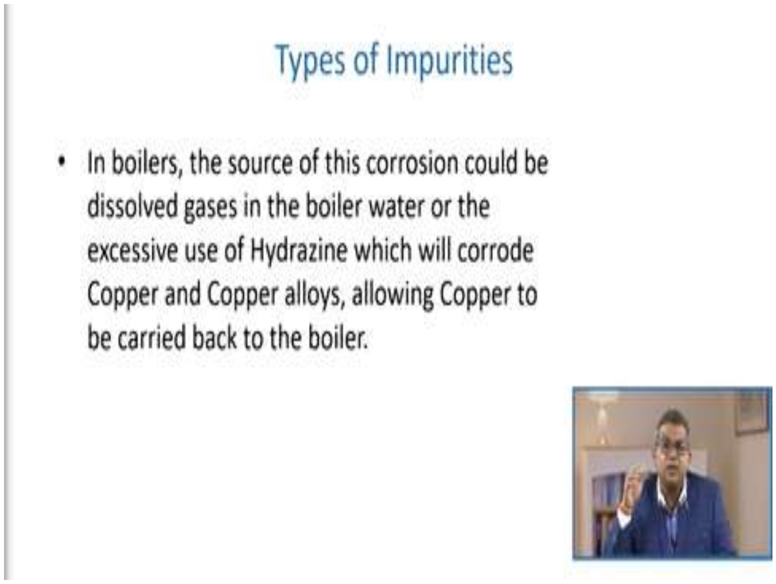

So, sometimes these hydrogen or certain chemicals are being used to clean the tube system to clean the steam network system. This creates a problem because the inner coating may get destroyed, and the surface or metallic surface of the tube can be exposed. And repeatedly, the copper particles or other metal particles may become part and parcel of the steam, which may create a problem.

Silica: If it is not removed to a low level, especially in the high-pressure boiler, this can cause hard scaling. Calcium can cause the scaling in several forms depending on the chemistry of the boiler feed water, maybe the calcium silicate, calcium phosphate, etc.

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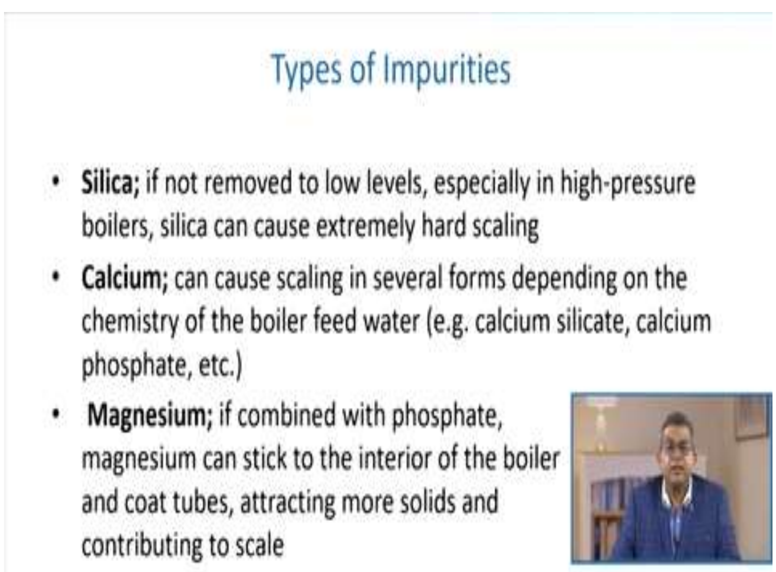

If combined with the phosphate magnesium, magnesium can stick to the interior of the boiler and coat tubes, attracting more solids and contributing to scale.

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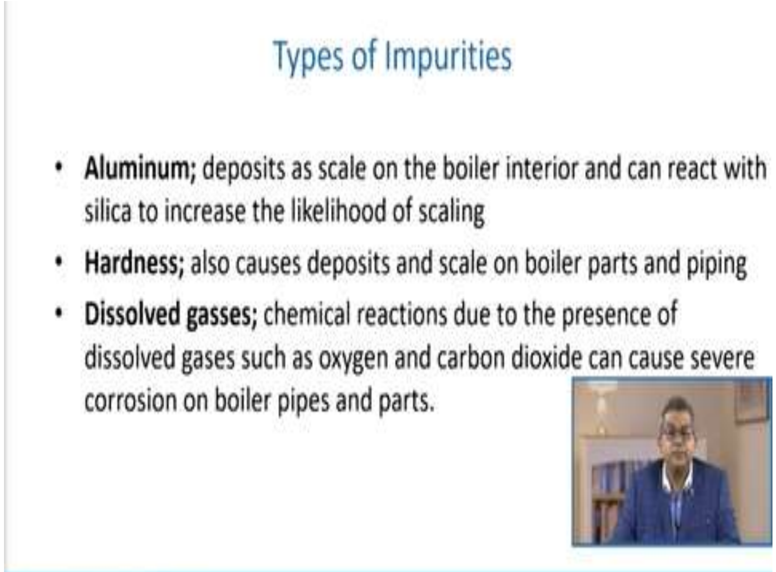

Aluminum again these deposits as scale on the boiler interior. And it can react with the silica to increase the likelihood of scaling. Hardness also causes the deposits and scale on the boiler part and piping. So, it is not necessary that, but it is this hardness causing an adverse effect on the boiler. But it may deposit at the steam distribution network, it may deposit in the piping network, it may deposit in the various walls, it may get deposited in the various parts where steams are being used.

So, it has to be addressed properly. Dissolved gases, the chemical reactions due to dissolved gases such as oxygen and carbon dioxide, can cause severe corrosion on boiler pipes and parts. other impurities are oil. To prevent oil from entering the condensate and feedwater systems, certain safety equipmentsare generally being incorporated to detect, remove, and rest such kinds of contamination.

The question may arise is how this oil can enter into the steam network or in the piping network or steam generation aspect.

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This may occur either through the mechanical failure of any equipment like faulty oil deflectors at turbine glands passing lubricant oil to gland seals condensers and main condensers and undetected leaks at tank heating coils, etc. So, there may be a variety of ways through which this oil can get contaminated by the steam network.

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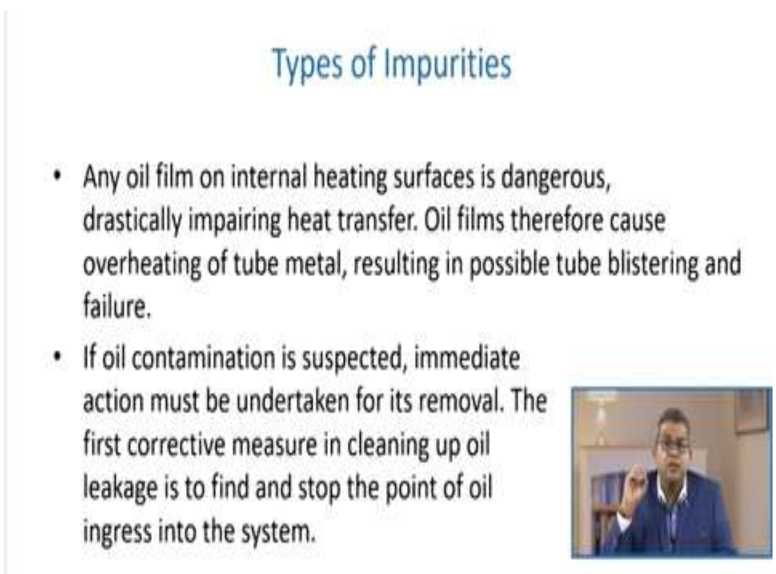

Any oil film on the internal heating surface is extremely dangerous, drastically impairing heat transfer. Oil film, therefore, may cause overheating of tube metal, resulting in the possibility of blistering and failure. if oil contamination is suspected, immediate action must be taken for its removal. The first corrective measure is cleaning oil leakage to find and stop the point of oil ingress into the system.

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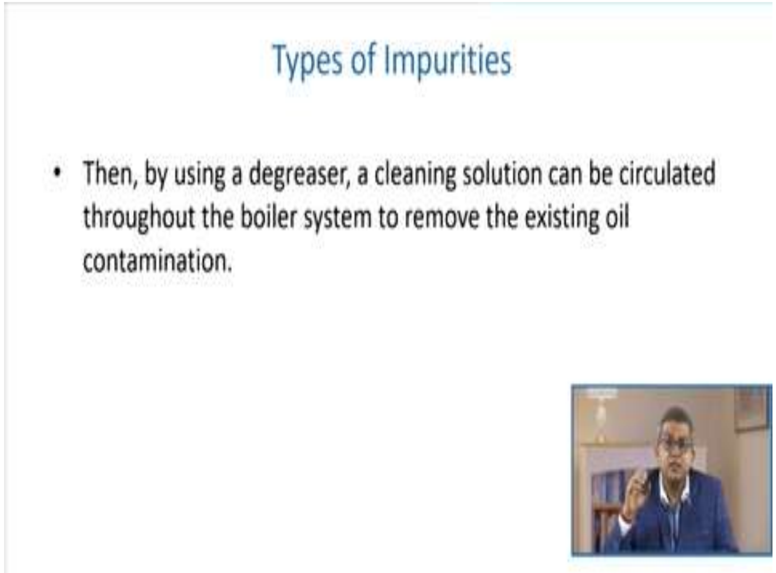

Apart from this, the oil may create a problem if again the steam is used in the direct chemical reaction, then it may create a problem. So, by using the degreaser, a cleaning solution can be circulated throughout the boiler system to remove the existing oil contamination.

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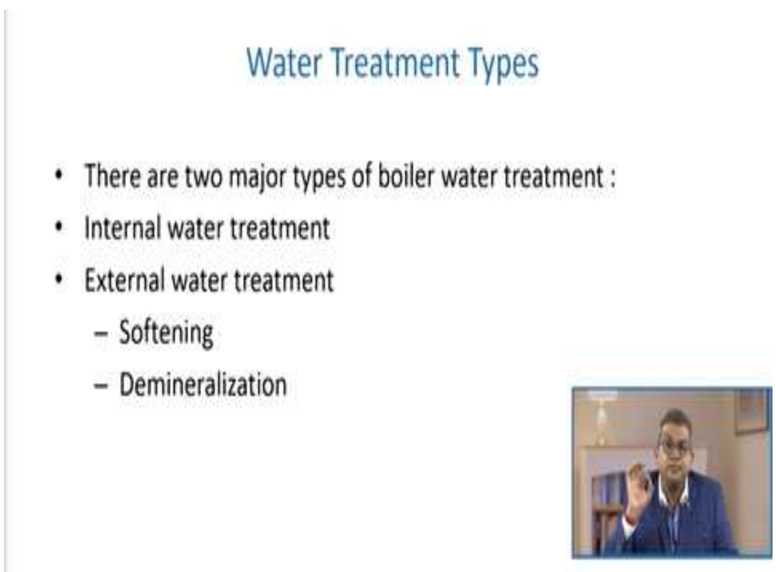

Let us discuss the water treatment type. In the previous slides, we discussed the various kinds of negative effects and may incorporate if the various kinds of contaminants is there. Then the question arises. We have discussed the various kind of contaminants. But how do we treat it? How do we remove these contaminants? Because if we are not treated this water well. Remember in the boiler, there are two types of systems.

Direct nascent feed water, after treatment, can go directly, and second is the condensate water recovery system because, the condensate carries precious value or economic value. So, you cannot let it go. So, the treatment protocol calls for a very strong intervention and it invites the proper care. So, there are two major types of boiler water treatment, one is the internal water treatment, and the second is the external water treatment maybe by the softening, demineralization etc.

We will discuss them one by one. Internal water treatment, the internal treatment is carried out by adding certain chemicals to the boiler to prevent the formation of scale by converting the scale-forming compounds to free-flowing sludge, which can be removed by blowdown. So, it can get deposited, and intermittently this can be, blown it down. Different waters require different chemicals sodium carbonate, sodium aluminate, sodium phosphate, sodium sulfite, and compounds of vegetable and inorganic origins.

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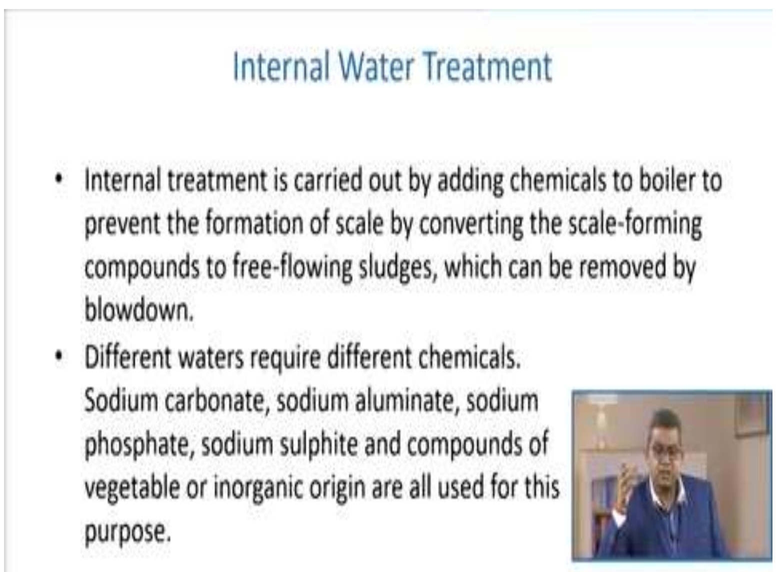

They are all used for this kind of purpose.

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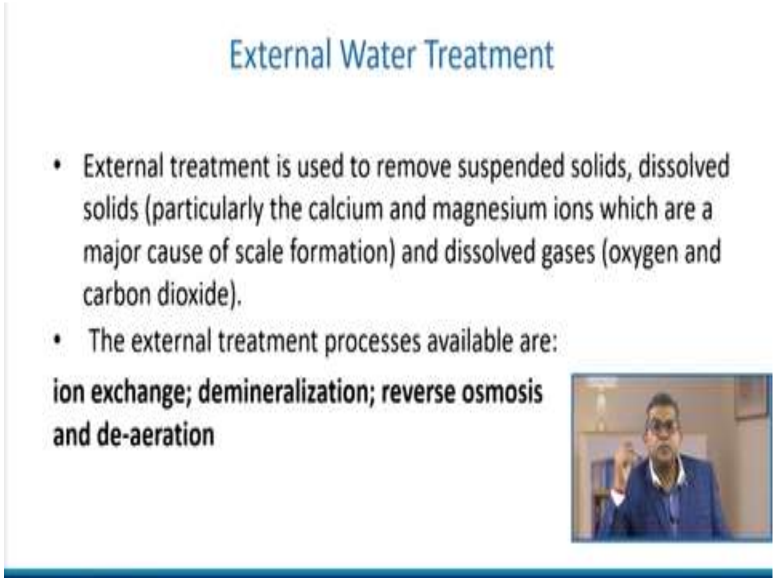

There are certain external water treatments. External water treatment is used to remove the suspended solids in which the water may contain dissolved solids, particularly the calcium and magnesium ion, which are the major cause of scale formation. We have already discussed the effects of dissolved gases, oxygen, and carbon dioxide on the boiler feed water. So, the external treatment processes whatever available for this boiler feed water are iron exchanges, demineralization, reverse osmosis, and deaeration.

So, remember that whenever we adopt any protocol for this external water treatment, one thing is very important: economics. We will discuss this thing in due course of time.

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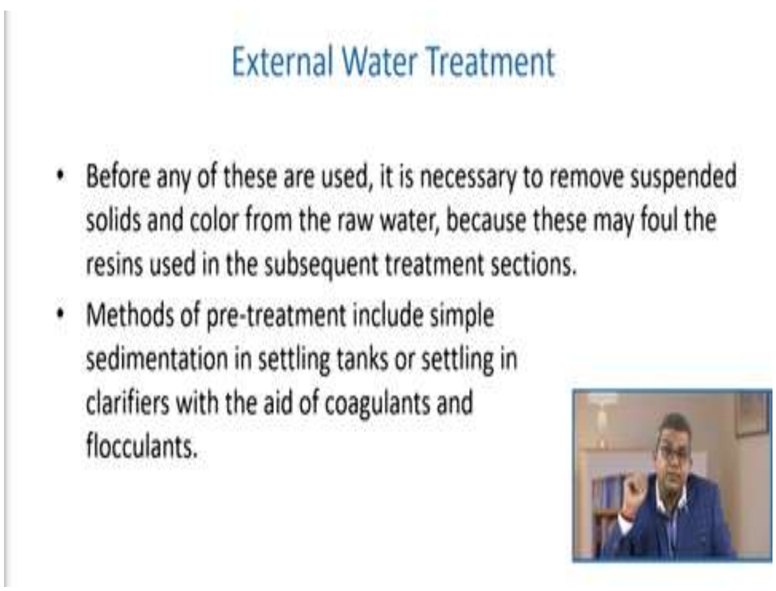

Before any of these are used, removing the suspended solids by screening color from the raw water is necessary. Because these may foul the resin used in the subsequent treatment section, all these things may get deposited over the raising surface, and the efficiency of these raisings may come down. The method of pre-treatment includes simple sedimentation in the settling tank or settling in the clarifier with the aid of coagulation and flocculants, sometimes screening.

Another thing is that the pressure sand filters with spray aeration to remove carbon dioxide and iron. These may be used to remove the metal salts from the bore well water.

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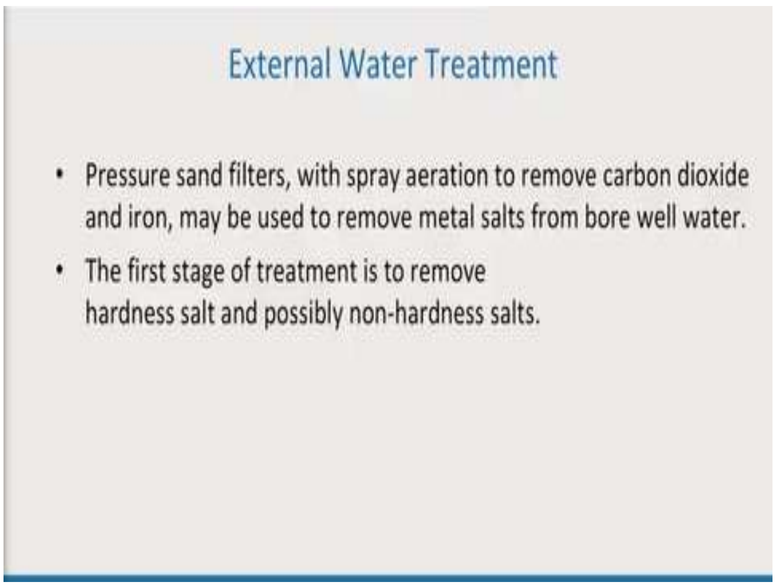

The first stage of treatment is to remove hardness salt and possibly non-hardness salt.

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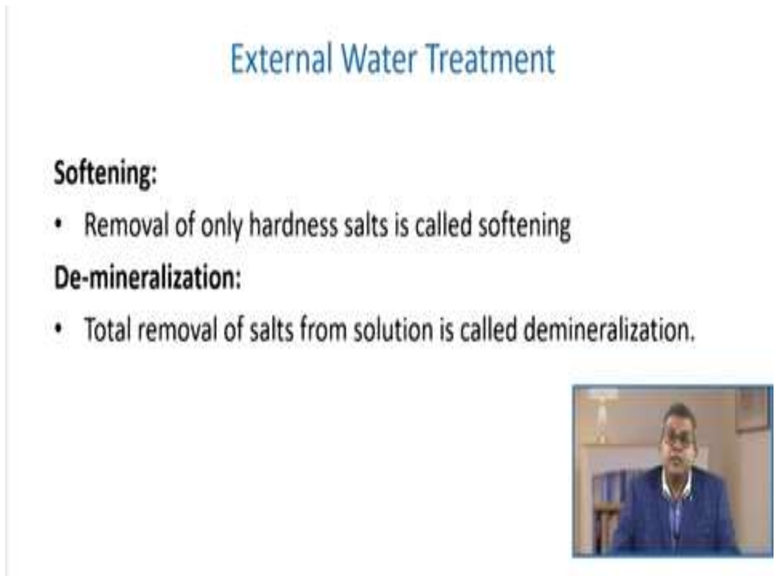

Next is softening which is the removal of only hardness salt is called softening. Demineralization, the total removal of salts from solution, is called demineralization.

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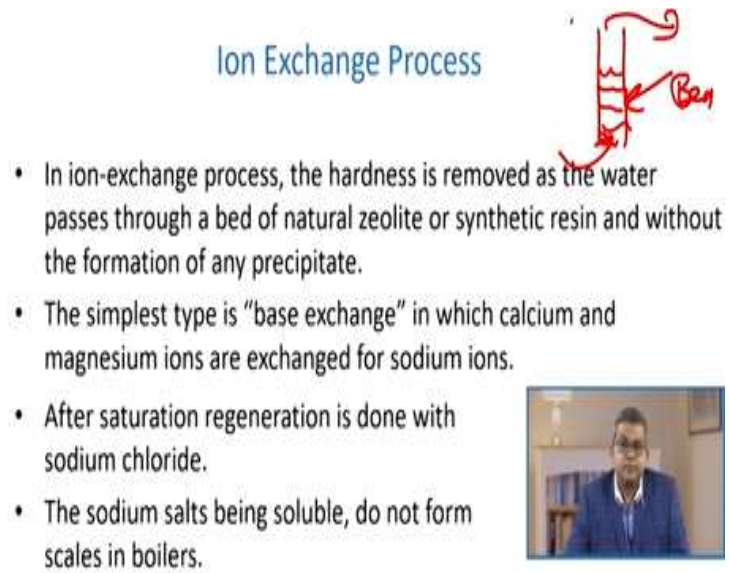

Let us briefly discuss brieflythe ion exchange process. In the ion exchange process, the hardness is removed as the water passes through the bed of natural zeolite or synthetic resin without any precipitate formation. So, it may be like column structure you have this bed and water may go like this or and you may get the pure water. The simplest type is the base exchange in which calcium and magnesium ions are exchanged for sodium ions.

After saturation usually, the regeneration is carried out with the help of sodium chloride. To maintain the economics, the regeneration aspect is again very important. So, it is understood that these ion exchangers must have a stipulated regeneration cycle. So, the sodium salts being soluble do not form a scale in the boilers. Since base exchangers only replace calcium and magnesium with sodium.

It does not reduce the TDS content and the blowdown quantity. So, it also does not reduce the alkalinity. So, they are very specific in nature.

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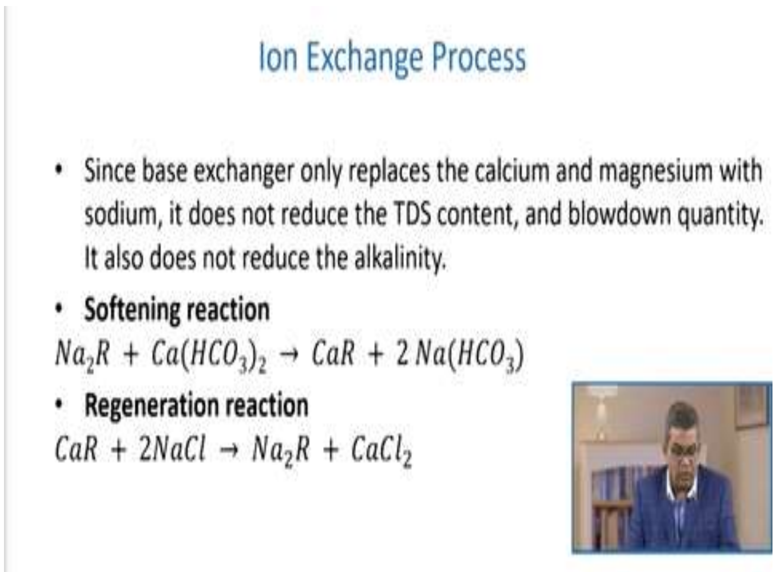

This is the softening reaction

$$Na2R + Ca(HCO3)2 \rightarrow CaR + 2\,Na(HCO3)$$

Regeneration reaction

$$CaR + 2NaCl \rightarrow Na_2R + CaCl_2$$

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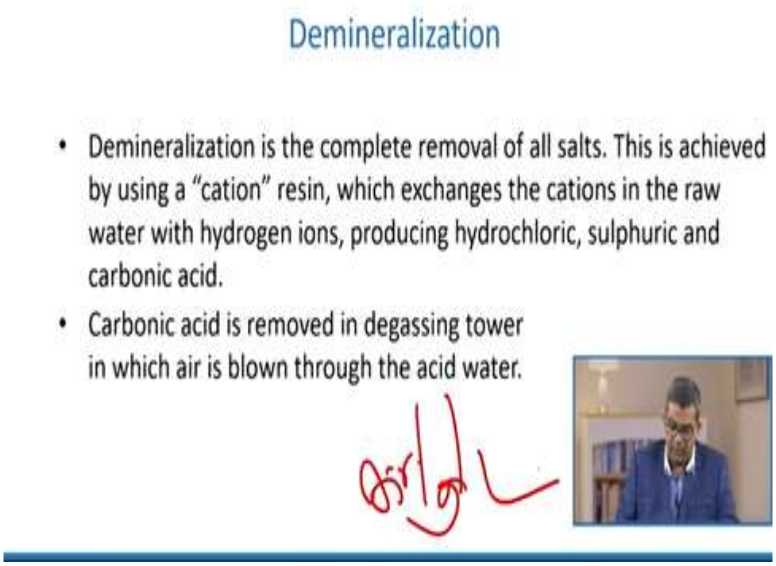

The demineralization, demineralization is the complete removal of all salts. This is achieved using a cation resin that exchanges the cation in raw water with hydrogen ions producing hydrochloric, sulphuric, and carbonic acid. Carbonic acid can be removed in degassing tower in which air is blown through the acid water-like. From here, the air is blown, and remaining you can collect it here.

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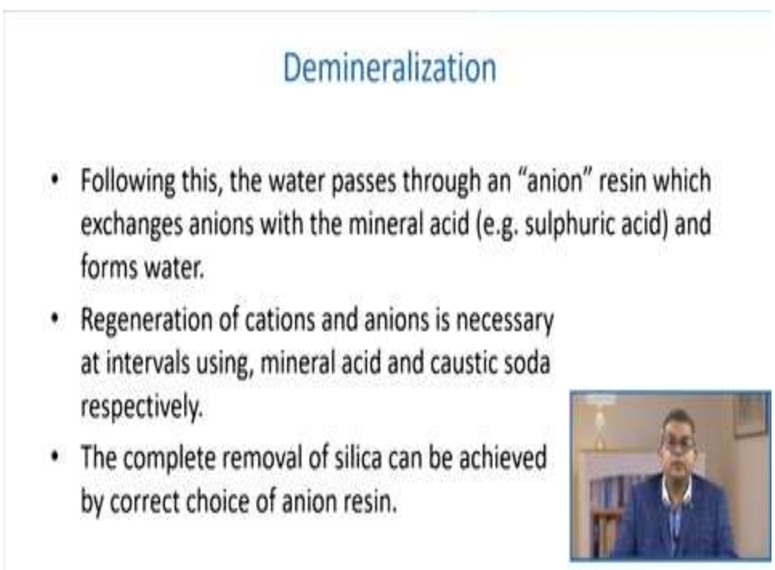

Following this, the water passes through an anion exchange resin which exchanges anions with the mineral acid and sometimes sulphuric acid, and it forms the water. Regeneration of cation and anion is necessary at intervals using mineral acid and caustic soda. Because all the active sites of these cations and anions may get blocked during the course of water treatment, it is necessary that to maintain to maintain the efficiency you need to regenerate these sides. The correct choice of anion resin can achieve the complete removal of silica.

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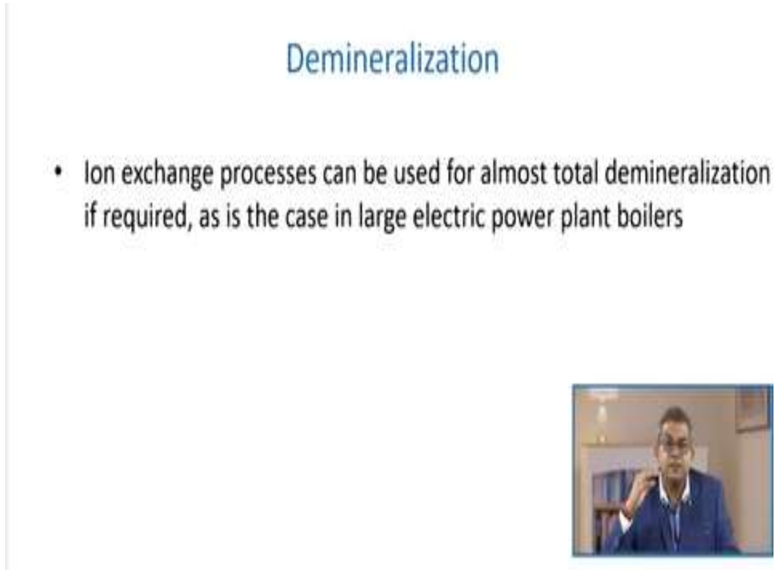

Ion exchange processes can be used for almost total demineralization if required, as is the case of large electric power plant boilers because it is a mandatory requirement. In order to remove the dissolved gases or to overcome the problem of the dissolved gases, deaeration is carried out. These dissolved gases may be like oxygen, carbon dioxide are usually removed by preheating the pre-feed water before it enters the boiler system.

Natural water contains dissolved gases in solution. It is practically impossible to have natural water without these dissolved gases.

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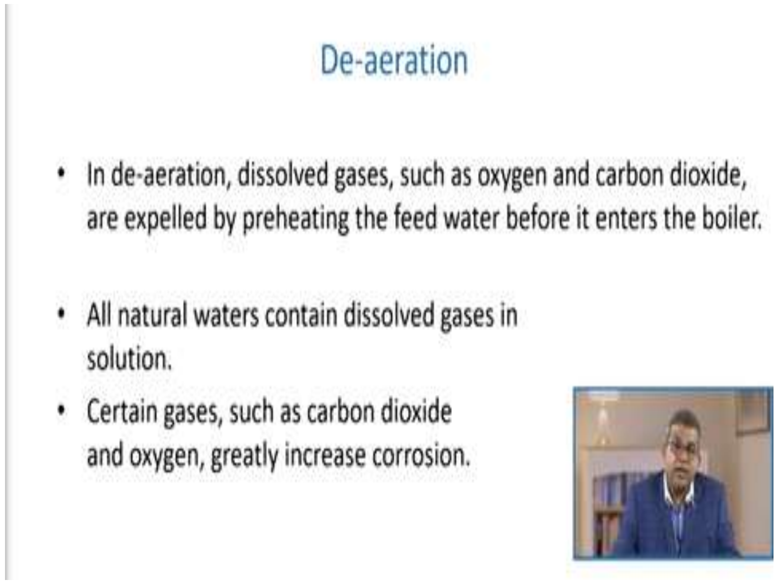

Certain gases such as carbon dioxide and oxygen greatly increase corrosion and may impart the problem of foaming. When heated in boiler systems, carbon dioxide (CO_2) and oxygen (O_2) are released as gases and combine with water (H_2O) to form carbonic acid (H_2CO_3).

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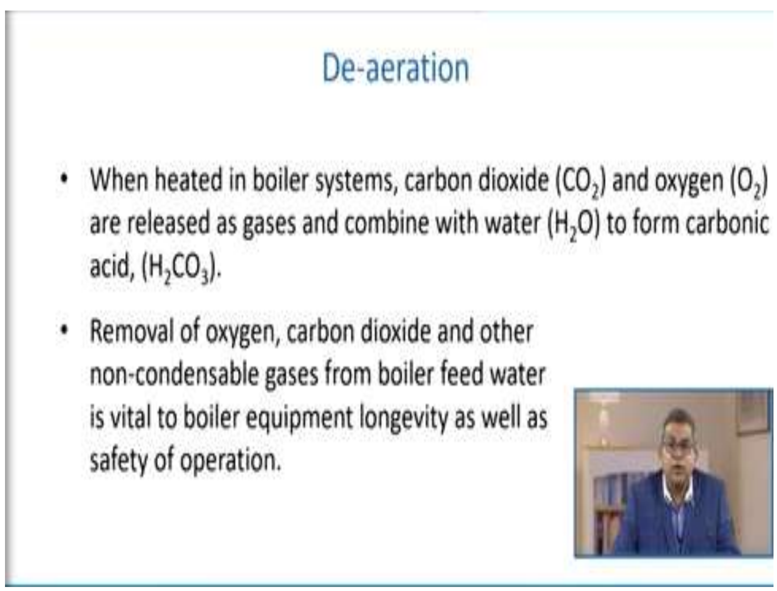

Removal of oxygen, carbon dioxide, and other non-condensable gases from boiler feedwater is extremely important for the boiler equipment longevity as well as the safety of operation.

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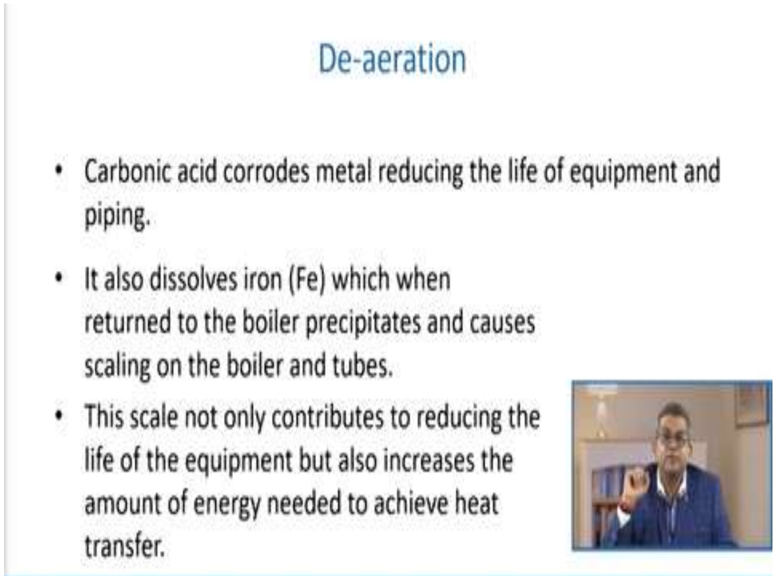

Carbonic acid corrodes metal, reducing the life of the equipment and the piping, and thereby the metal may get exposed, and it can become part and parcel of the steam. It also dissolves iron which returns to the boiler, precipitates, and causes scaling on the boiler and tubes. This scale contributes to reducing the life of the equipment and increases the amount of energy needed to achieve heat transfer.

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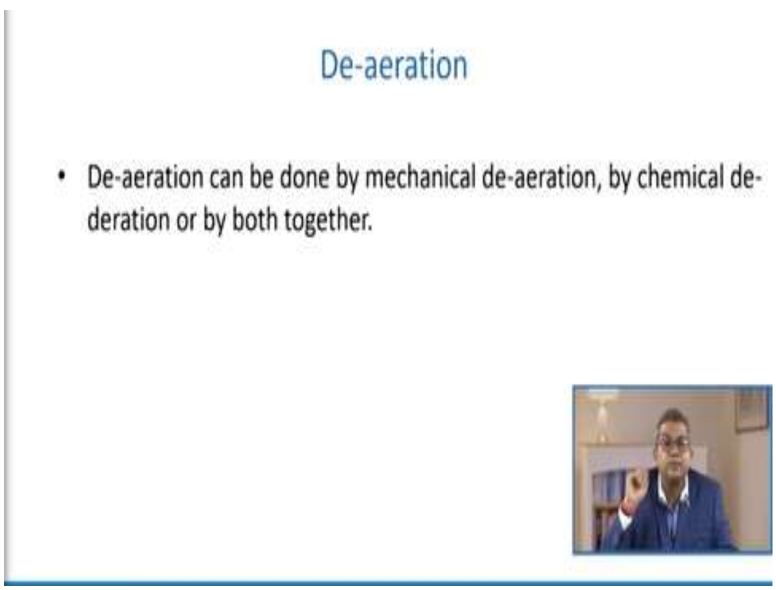

So, deaeration can be done by mechanical de- aerators, by chemical deaeration process, or a combination of these two.

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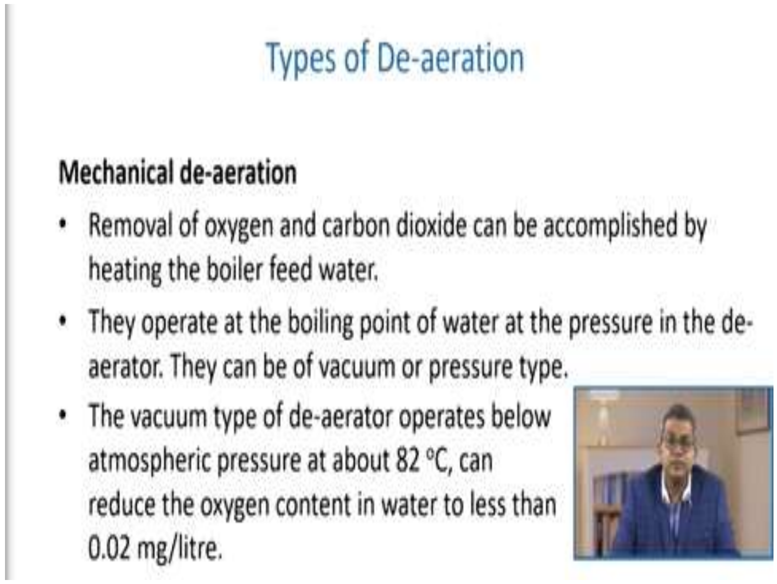

There are different types of de aeration like mechanical de aeration, that is the removal of oxygen and carbon dioxide can be accomplished by heating the boiler feed water. Operate at the boiling point of water at the pressure in the de-aerator. It can be of vacuum pressure type, vacuum type, or a pressure type. The vacuum type of deaerator operates below atmospheric pressure at around 82 degrees Celsius and can reduce the oxygen content in water to less than 0.02 milligram per liter.

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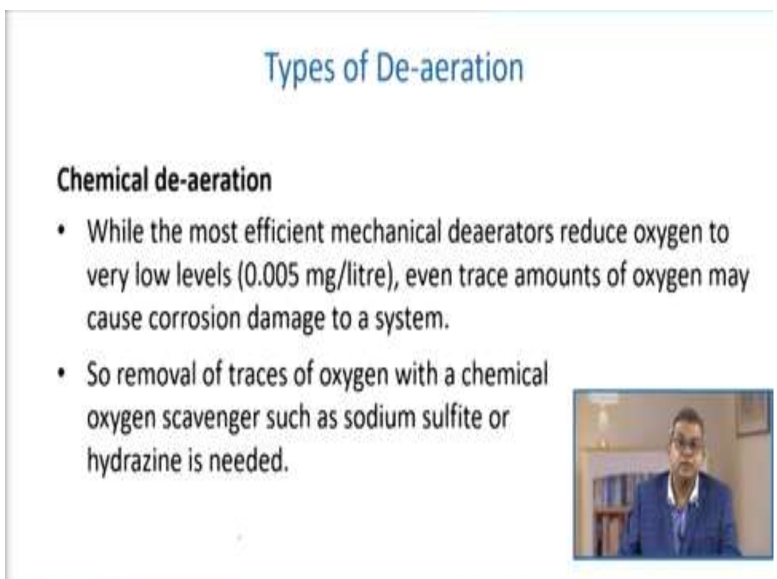

Chemical deaeration, the most efficient mechanical deaerators, reduces the oxygen to a very low level. Even trace amount of oxygen may cause corrosion damage to a system. Therefore, sometimes the chemical deaeration is also applied. So, to remove the traces of oxygen, this is being carried out with the help of chemical scavengers such as sodium sulfite or hydrogen.

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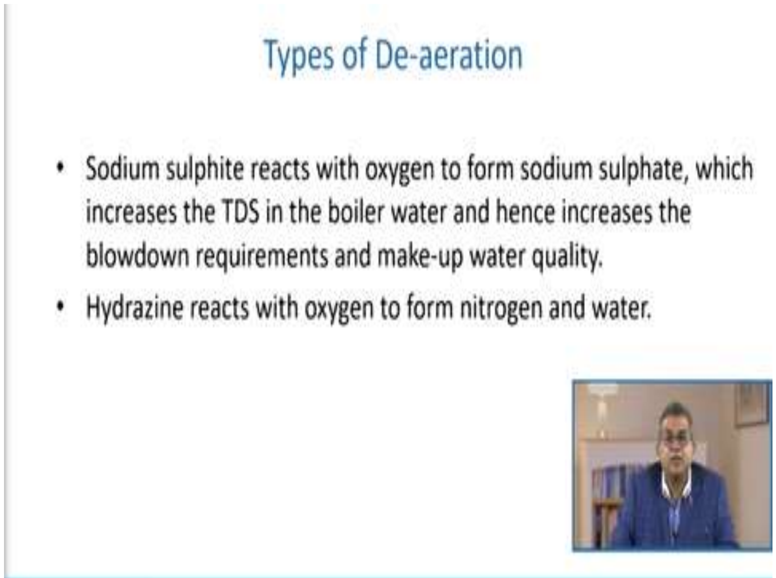

Sodium sulfite reacts with oxygen to form sodium sulfate, increasing the TDS in the boiler water and increasing the blowdown requirement and making up water quality. Hydrogen reacts with oxygen to form nitrogen and water. Sometimes reverse osmosis is also being used. We have discussed the concept of reverse osmosis and nanofiltration in the previous lectures, which are often used down the line in the boiler feedwater treatment system.

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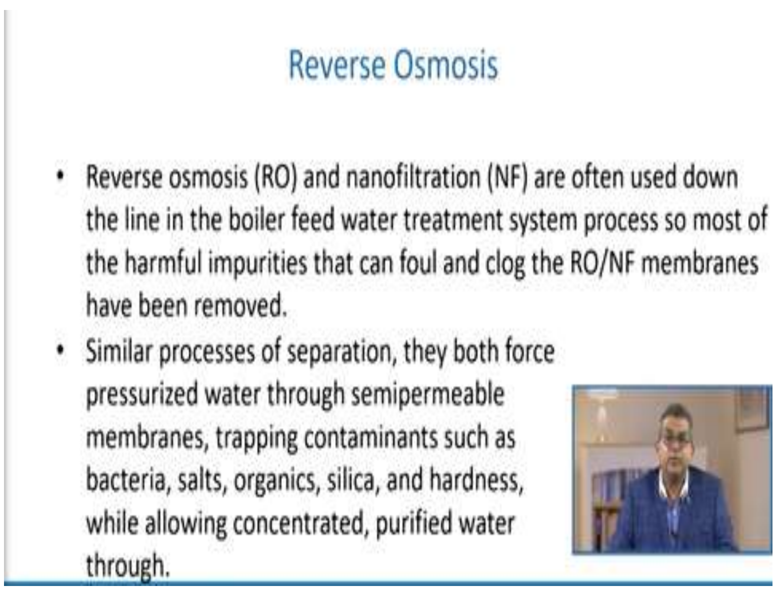

So, most harmful impurities that can foul, and clog on the reverse osmosis or nanofiltration membranes have been removed. Similar separation processes force pressurized water through the semipermeable membrane, tapping the contaminants such as bacteria, salt, organic, silica, and hardness while allowing the concentrated purified water through. Not always required in a boiler feed water treatment because these are the costly affairs.

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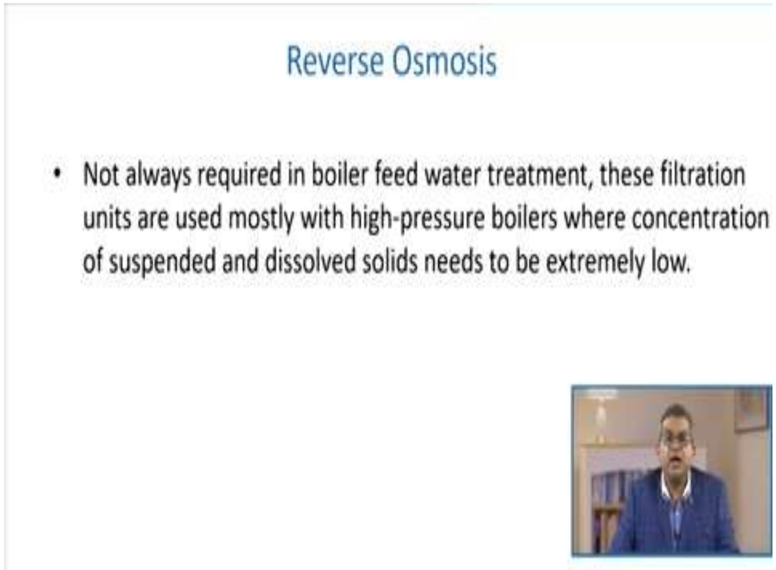

These filtration units are used mostly with the high-pressure boiler when the concentration of suspended and dissolved solid needs to be extremely low. So, in this particular lecture, we had discussed the various contaminations in the boiler feed water and there are certain methodologies through which we can purify these, boiler feed water.

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In case if you wish to have further reading, we have enlisted several references in this particular slide. Thank you very much.