Chemical Process Utilities
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Lecture - 19
Boilers

Welcome to the new lecture on boilers under the aegis of steam in chemical process safety. Before discussing the other aspects of the boiler, let us look at what we studied in the previous lecture.

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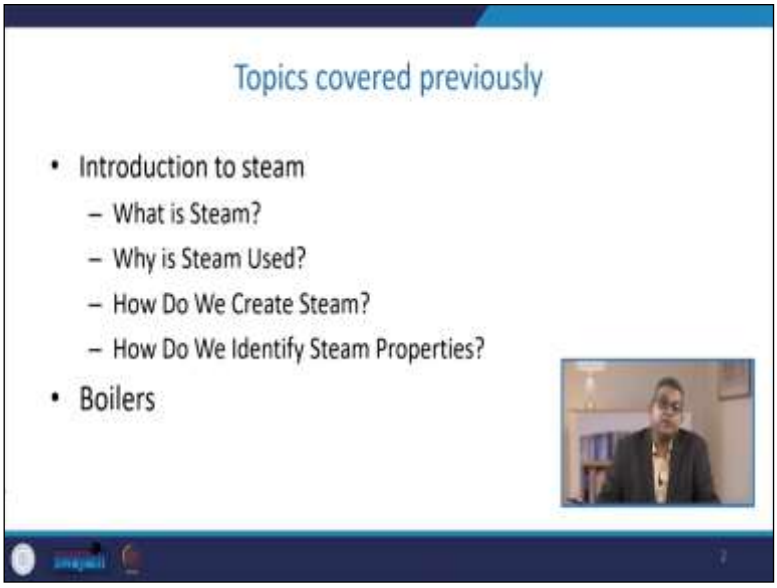

We had the introduction of steam, the importance of steam, and discussed why steam is used and how we create the steam in; theoretically, we had discussed what an integral part of a steam generation plant is. How do we identify the steam properties? We started with the boiler concept in which the basic anatomy of the boiler we were discussing. In this lecture, we will discuss the broad spectrum of the boiler concerning the classification and other issues about the boilers.

Now see, because steam has a wide choice of various uses, we have a wide spectrum or wide choices of boilers. So, when we have the n number of choices, the concept of the classifications does occur again. So, various boiler classification has been suggested by the various workers. One classification is based on the flow of water and hot gas.

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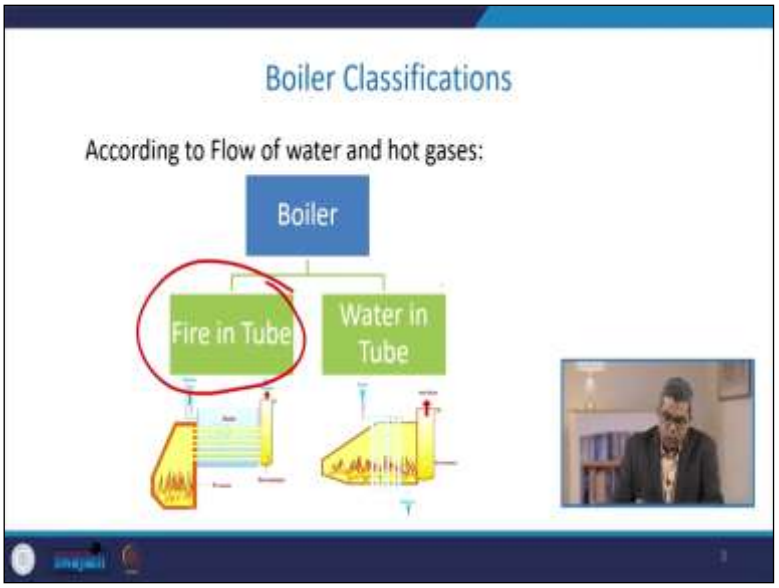

So, this may be the fire in the tube and water in the tube because the boiler is the assembly of tubes and shells. Now here you see that fire is or the flue gases they are within the tube system, and these two bundles of the tube are submerged with the water. Now upon heating, you can produce the steam. So, fire is in the tube side. Now in this boiler where the water is in the tube, the water is inside the tube, and the fire surrounds this bundle of tubes. So, the heat transfer can take place.

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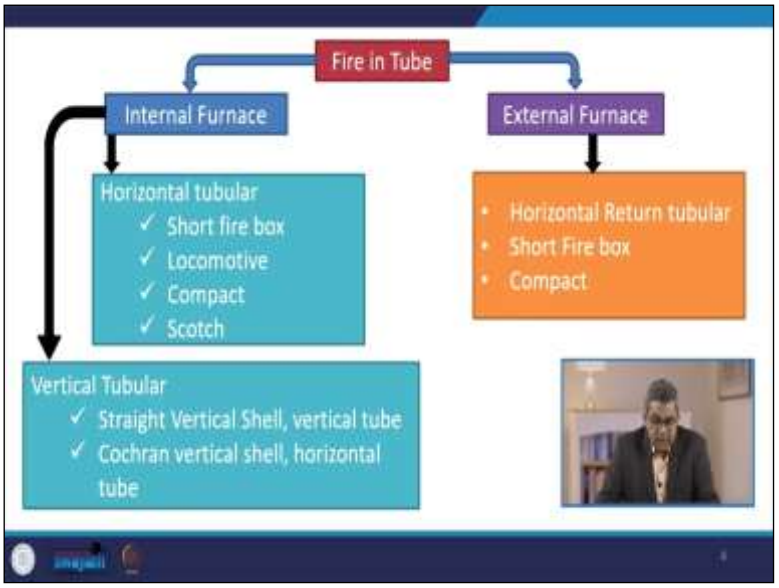

So, based on the use, one can use any boiler. Another is when we talk about the firing tube type of boiler, and they are again classified into two categories: the internally fired boilers and the externally fired boilers. There may be horizontal tubular boilers or vertical tubular boilers when

we talk about internal fire boilers. So, they have the like short firebox locomotive type of boiler compact in nature scotch.

And the vertical tube boilers are the straight vertical shell vertical tube-like Cochrane vertical shell horizontal tube boiler. This is one of the examples externally fired boiler that is a horizontal return tubular type of boiler. They have a short firebox, and they are very compact.

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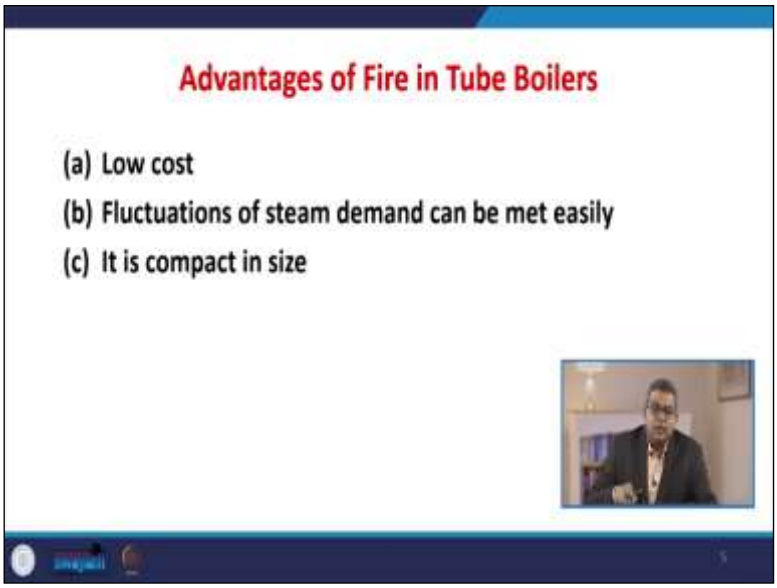

There are certain advantages attached to the fire in tube boilers: they are low cost. The fluctuation of steam demand can be met easily and is, as we discussed, it is compact.

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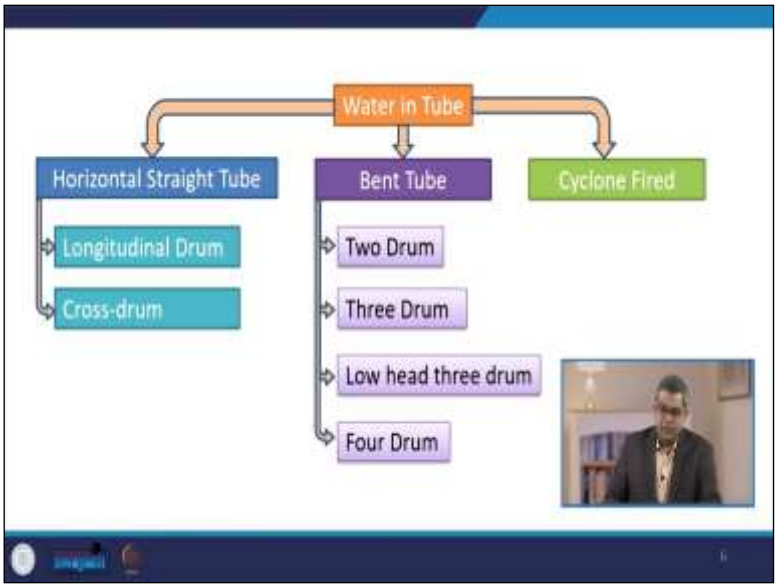

When we talk about the water and tube type of boiler, they are again divided into three categories. One is the horizontal straight tubes. This may be the longitudinal drum or a cross drum. There may be a bent tube, maybe two drums, three-drum, low head, three drums, or four drums, even they can have four drums, and a cyclone fired boilers.

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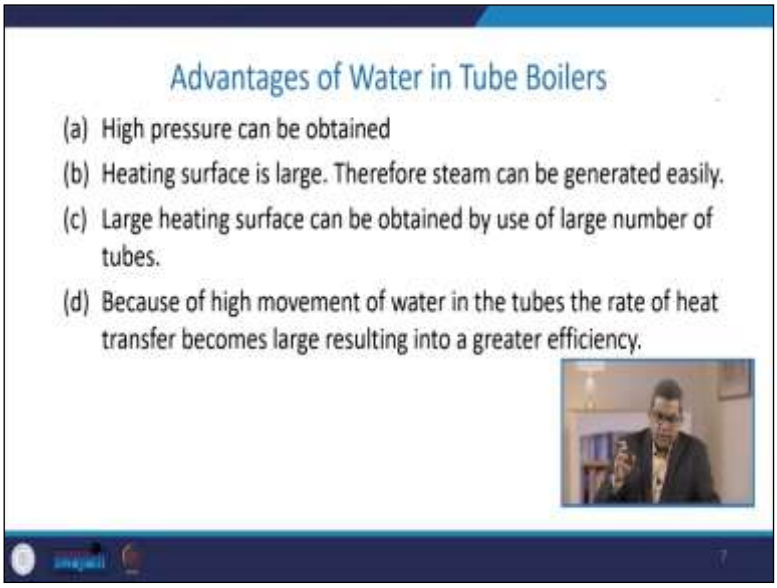

Now again there are certain advantages associated with the water in tube type of boiler you can obtain the high pressure the heating surface is quite large therefore steam can be generated the larger heating surface area easily this can be obtained by the use of a large number of tubes. So, you can embed the tubes accordingly, but obviously, you need to look at the heat transfer aspect.

Now because of the high movement of water in the tube, the heat transfer rate becomes large, resulting in greater efficiency.

Again one may classify the furnace position may be externally or internally. The internally fired boilers of the great combustion chambers are usually enclosed within the boiler shell.

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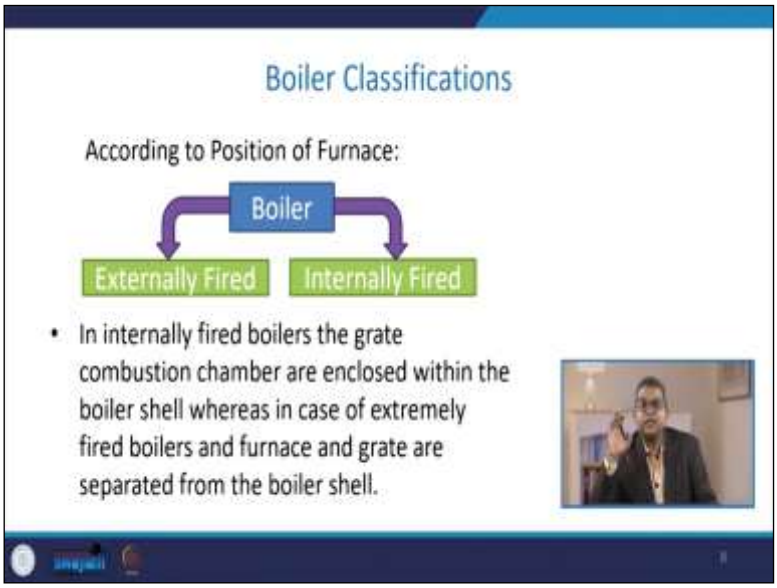

Whereas in the case of an extreme external fire boiler, the furnace and grates are separated from the boiler shell. So, suppose this is the boiler shell. So, they are separated over here in the externally fired boiler.

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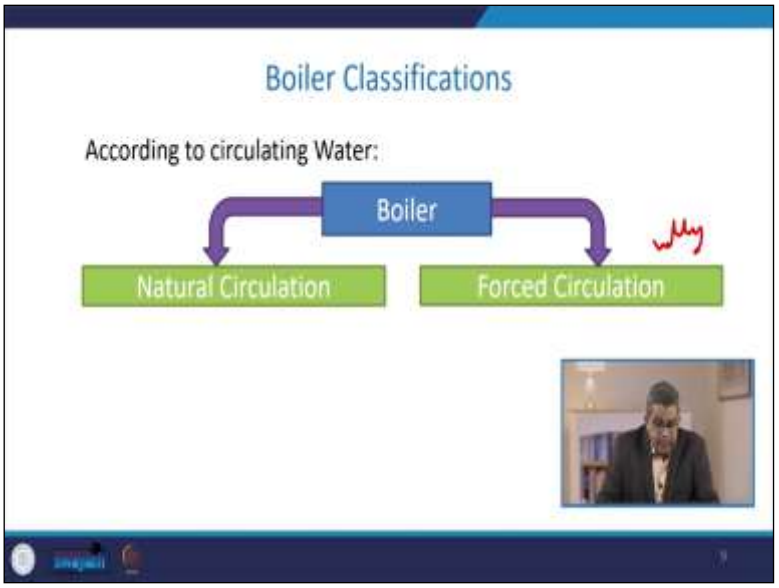

Then sometimes, people do classify based on the circulation of water concept. This boiler can now be classified in two categories: natural circulation or forced circulation. Then again, one classification may be based on the position of the principal axis. This may be either vertical horizontal, or sometimes inclined like this. Then steam pressure, we discussed the various steam classification based on the pressure.

So, according to the application, it may be low pressure, medium pressure, high-pressure, etc. So, see, we discussed a lot about the various application of the steam in situ the boiler but broadly based on the application the broadly the boiler can be classified in two ways one is the stationary another one is the mobile stationery, or more common mobile may be the marine locomotive type of boiler.

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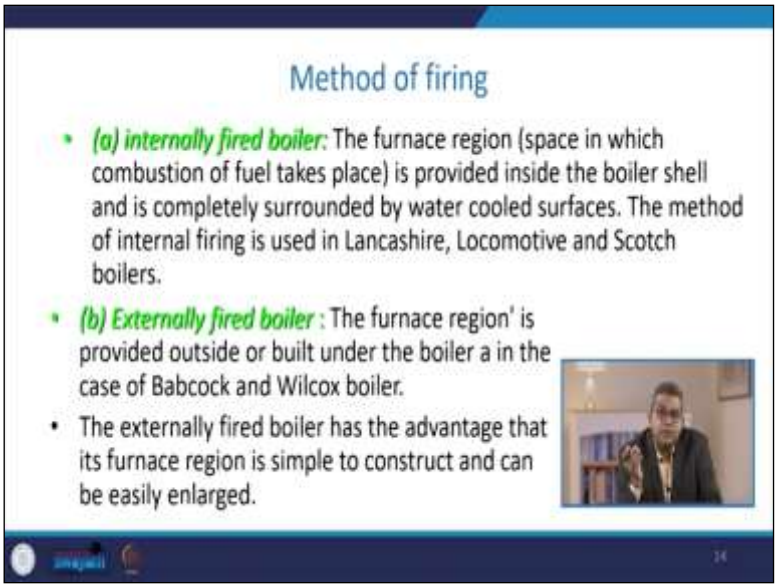

When we talk about the internal fire boiler in detail, the furnace region space in which fuel combustion takes place is provided inside the boiler shell. So, if this is the boiler shell, the firing is provided inside, and the water-cooled surface surrounds this. Now the method of internal firing is used in Lancashire, locomotive scotch type of boiler. There are externally filed boilers we discussed previously; the furnace reason we discussed this is at the outside or built under the boiler in the case of Babcocks and Wilcox boiler.

The externally fired boilers have the advantage that their furnace region is simple to construct and can be easily enlarged. So, based on the capacity requirement, you can have various choices for the firing.

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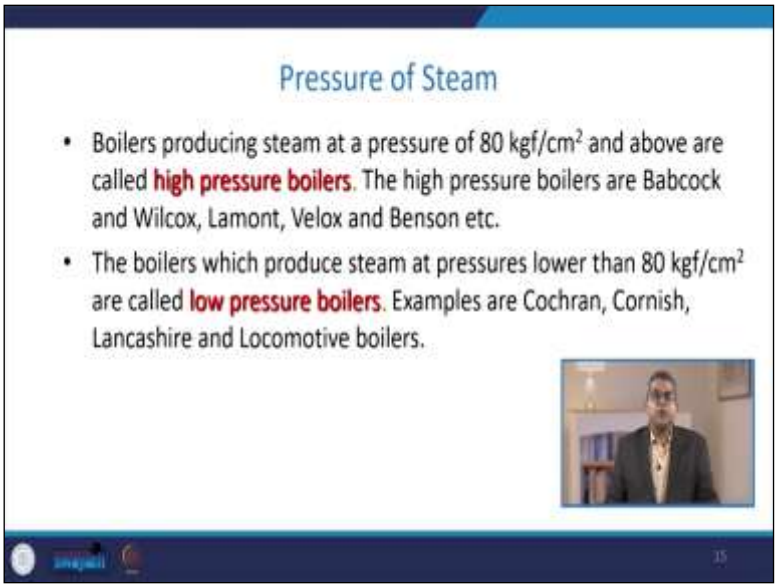

Now see the boiler usually producing steam at 18 kilogram-force per centimeter square pressure. So, one classification may be based on the pressure system, maybe high-pressure boiler, low-pressure boiler medium pressure boiler, etc. So, one is that 80-kilogram force per centimeter square and above are called high-pressure boilers. So, high-pressure boilers are called Wilcox, Lemon well Ox Benson boilers, and low pressure when sometimes, in the broad spectrum, you say that the pressure requirement is less than 80-kilogram force per centimeter square.

You may embed one more category, low-pressure high pressure, between medium pressure. So an example of this is the Cochrane, Cornish, Lancashire locomotive boiler. All these are an example of low-pressure boilers. So, when we talk about the method of circulation of water.

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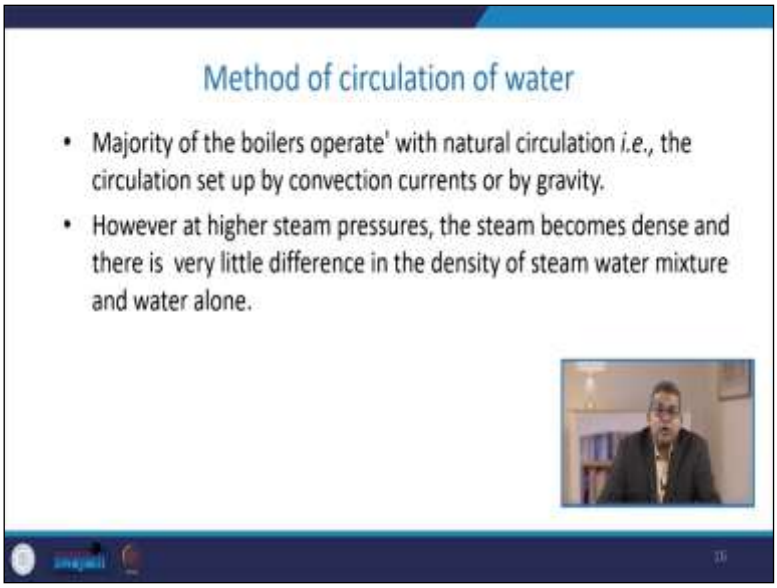

So, the majority of the boilers operate with the natural circulation, that is, the circulation set up by the convection current of gravity. Sometimes density difference is also attributed to this one. However, at higher steam pressure, the steam becomes dense, and there is very little difference in the density of the steam-water mixture and water alone.

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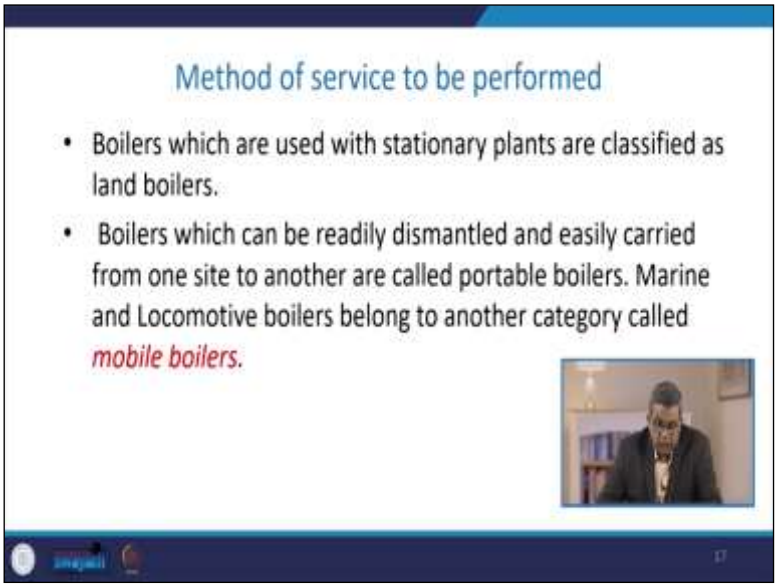

Again, we would like to discuss more this one is the service method. So, the boiler used for the stationary plant is classified as land boilers and boilers that are readily dismantled and easily carried from one side to another. They are called portable boilers, marine and locomotive boilers; we have already discussed them.

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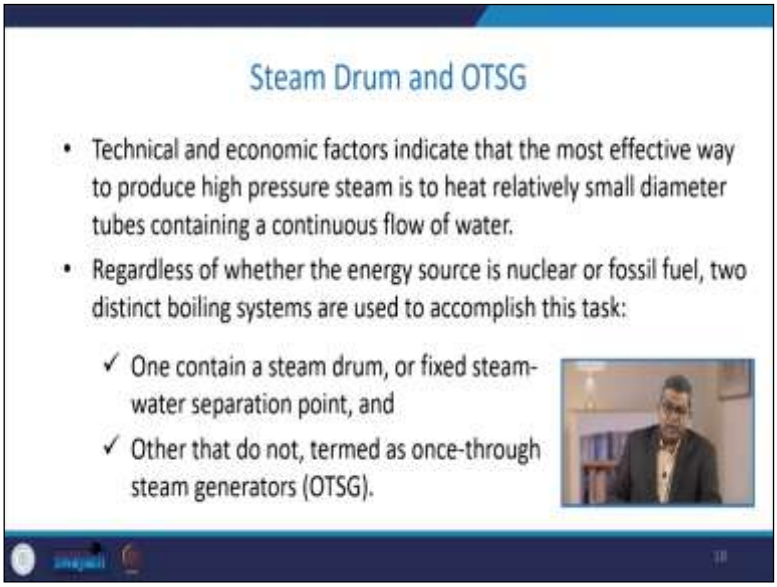

Let us talk about the steam drum and once-through type of steam generator. Now technical and economic factors indicate that the most effective way to produce high-pressure steam is to heat relatively small diameter tubes containing a continuous water flow. Whether the energy source is nuclear or fossil fuel or something else, two distinct boiling systems are used to accomplish the task.

One is contained in a steam drum or fixed steam water separation point other is not termed a once-through steam generator or is sometimes referred to as OTSG.

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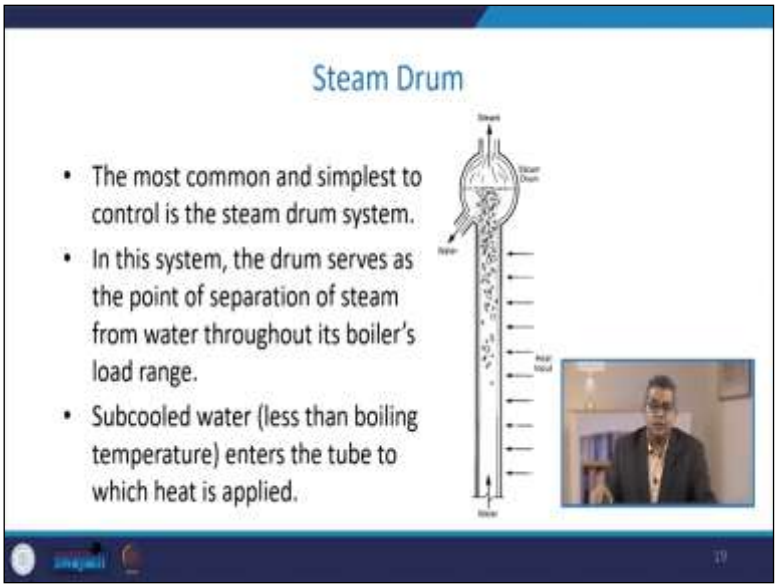

Now let us talk about the steam drum. The most common and simplest control is the steam drum type of system. Here you see that this is the steam drum in this system drum serves as the point of separation of steam from water throughout its boiler load range. We previously discussed that the water and steam both enjoy the same chamber. So, there must be a clear-cut separation system through which you can separate the steam.

Now subcooled water that is less than the boiling temperature enters the tube to which heat is applied, and nowhere you see that water is input heat is applied here, you may have the steam out.

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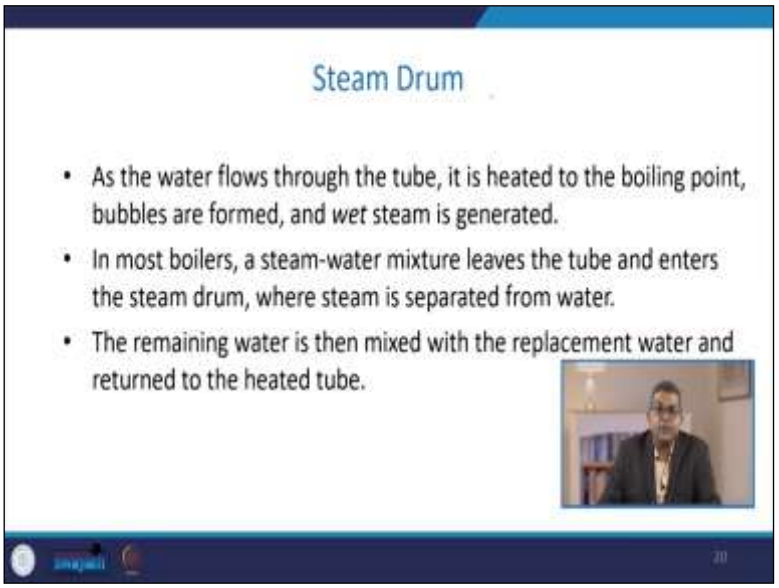

As the water flows through the tube, it is heated to the boiling point, bubbles are formed, and wet steam is generated in the boiler. The steam-water mixture leaves the tube and enters the steam drum, where steam is separated from the water. The remaining water is usually mixed with the replacement water and returned to the heated tube.

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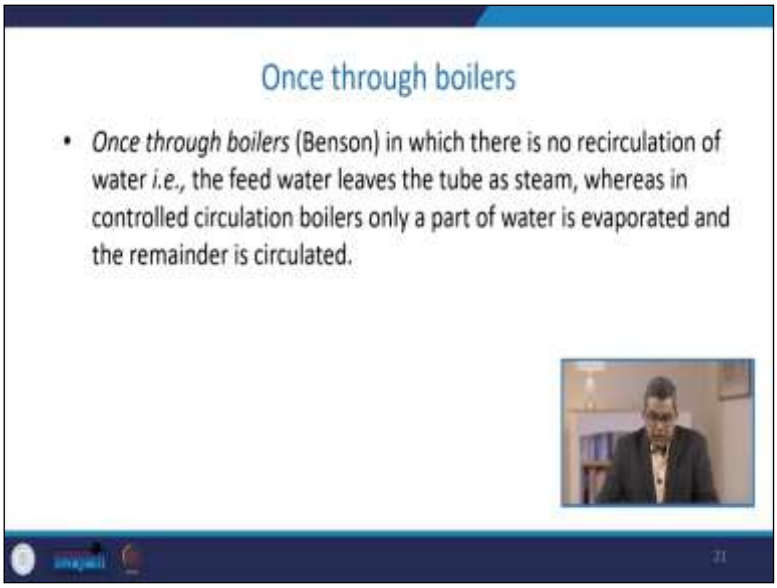

Once through boilers, the common ones to a type of boiler are the Benson boiler, in which there is no recirculation of water. The feed water leaves the tube as steam, whereas in the controlled circulation boiler, only a part of the water is evaporated, and the remainder is circulated. So, when we further elaborate on the ones through steam generators without a steam drum, you require the steam drum for other types of boilers apart from this OTSG.

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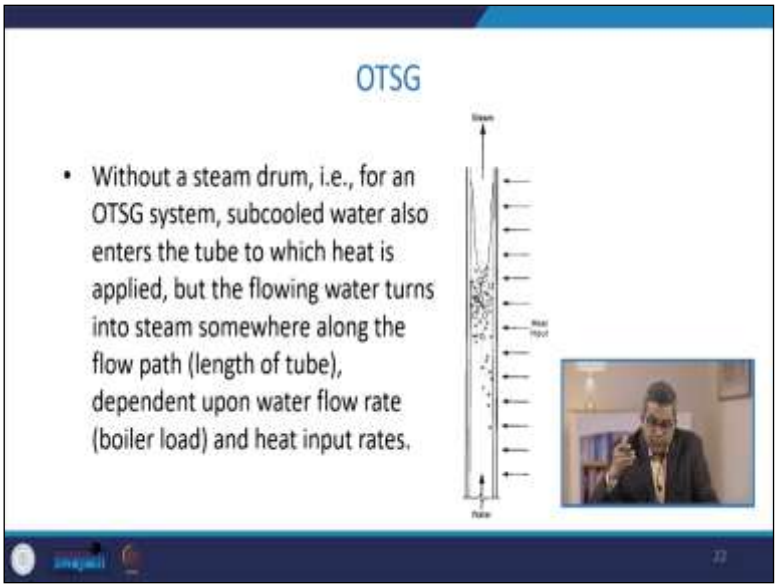

So, without a steam drum for an OTSG system, sub-cooled water also enters the tube to which heat is applied, but flowing water turns into steam somewhere along the flow path. So, this is the flow path, and you can experience the steam depending upon the water flow rate and heat input rate. So, these two are the variables for this OTSG.

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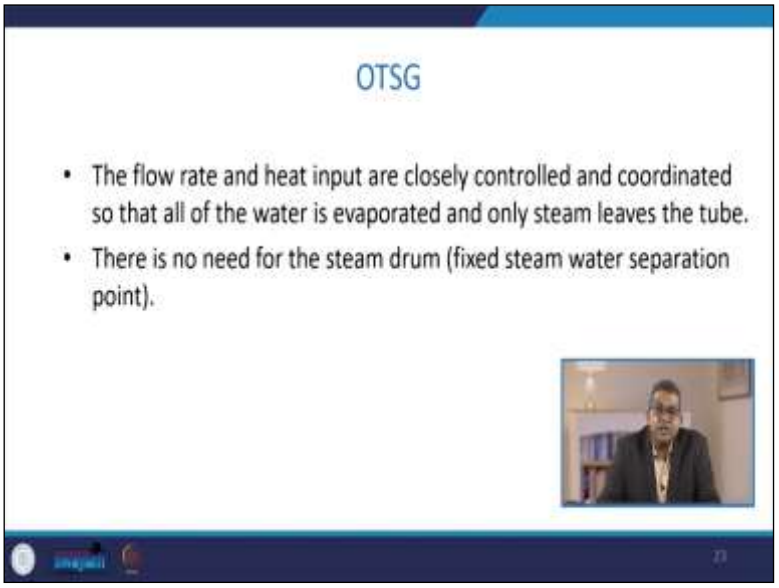

The flow rate and heat input are closely controlled and coordinated. So, all the water is evaporated, and only steam leaves the tube. So, there is no need for any kind of steam drum. Fixed steam-water separation points are there.

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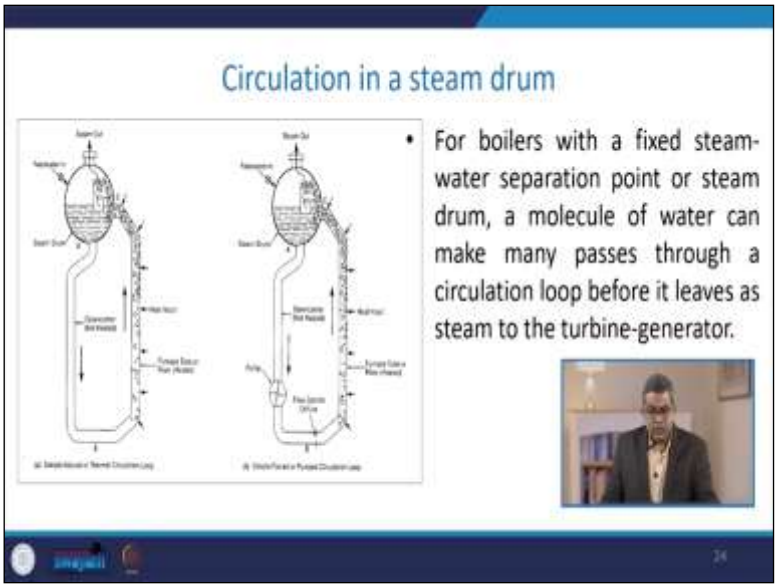

Now let us talk about the circulation in the steam drum. Now here you see that this is the steam drum steam is coming outflow water in, and here you have to have the heat input risers. This is a simple natural. Now for a system for a boiler with a fixed steam-water separation point or steam drum, a molecule of water can make many passes through a circulation loop before it leaves as steam to the turbine generator.

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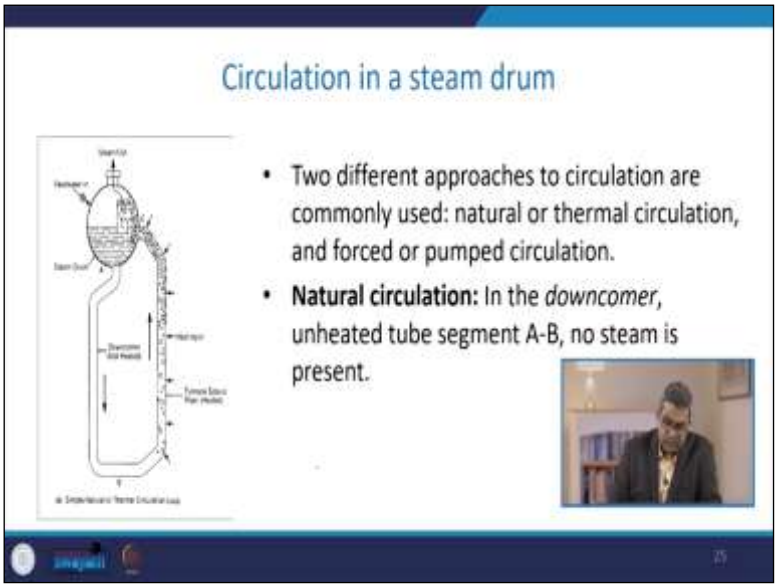

Now, two different types of approaches for circulation are attributed natural or thermal circulation and force or pump circulation. The natural circulation is the downcomer. This is the downcomer unheated tube segment. Now, this is from A to B; no steam is present; there is no steam.

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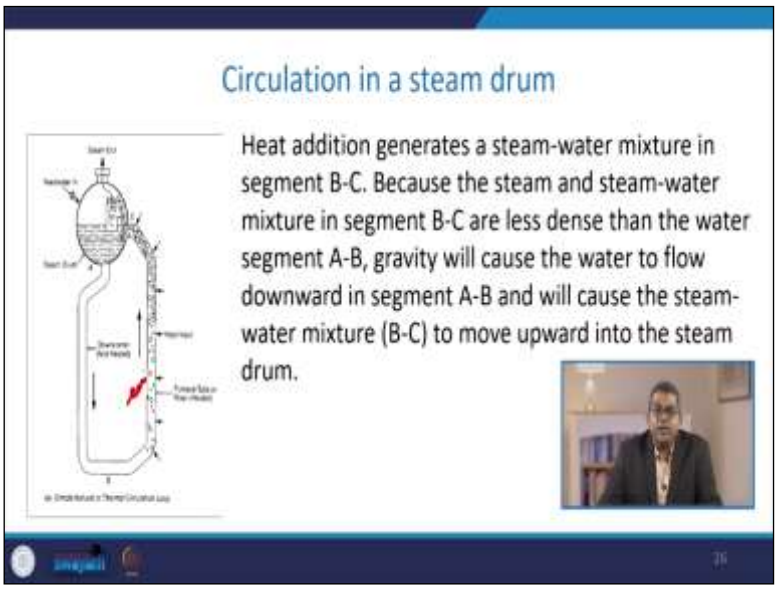

Now heat addition generates a steam-water mixture. So, you are providing the heat input at this juncture and this segment from B to C. Now because the steam and steam-water mixture in the segments b to care less dense than the water in segments A to B, gravity will cause the water to flow downward in the segment A to B in this because of gravity aspect, and this is called the steam-water mixture in between this is to move upward into the steam drum.

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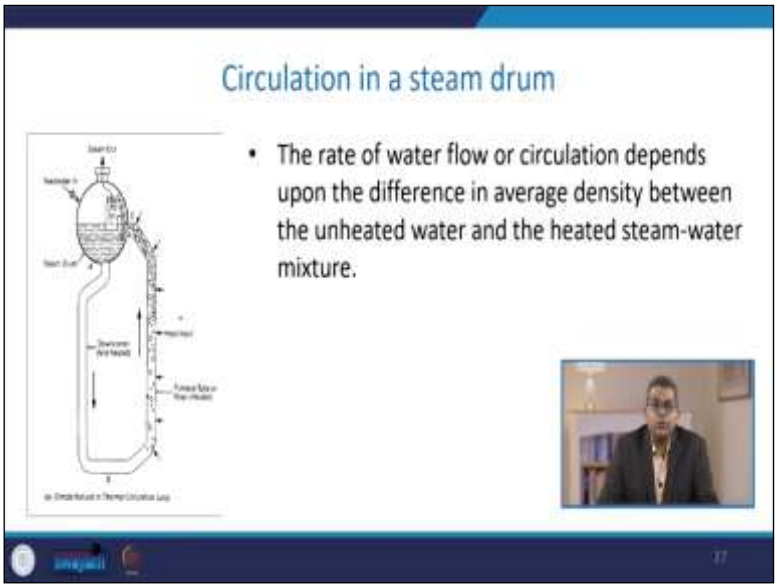

The water flow rate or circulation depends on the difference in average density between the unheated water and the heated steam-water mixture.

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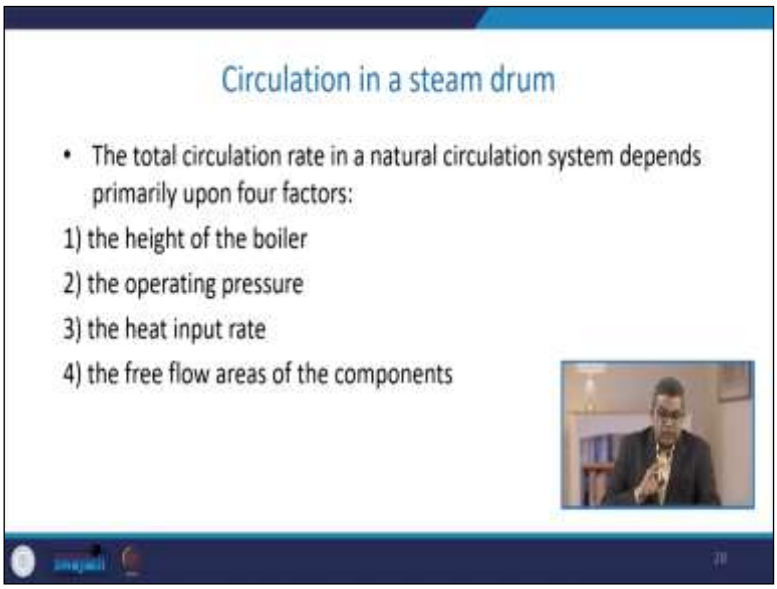

The total circulation rate in the natural system of circulation depends primarily upon four factors: what is the height of the boiler, the what is operating pressure, the third is the heat input rate, and the third is free flow area of the component.

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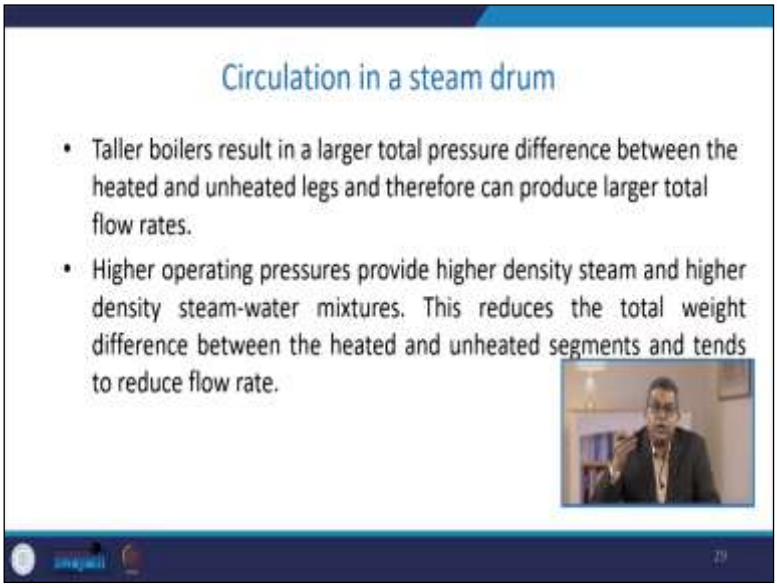

The Taylor boilers sometimes result in a large total pressure difference between the heated and unheated legs, which can produce a larger total flow rate. Sometimes higher operating pressure provides high-density steam and high-density steam-water mixture. This reduces the total weight difference between the heated and unheated segments and reduces the flow rate.

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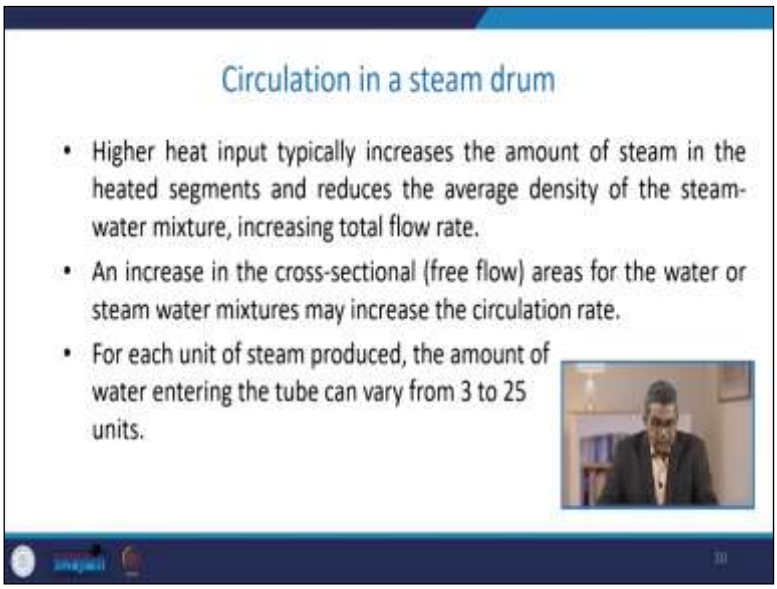

The higher heat input typically increases the amount of steam in the heated segment and reduces the steam-water mixture's average density, increasing the total flow rate. So, in this way, the total flow rate and altered. An increase in the cross-sectional, free flow area for the water or steam-water mixture may increase circulation. So, for each unit of steam produced, the amount of water entering the tube can vary from 3 to 25 units.

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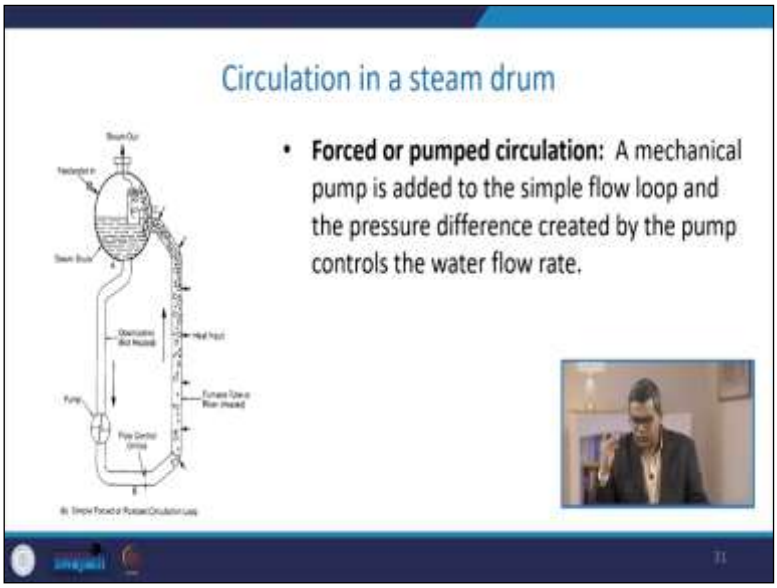

Let us talk about forced or pumped circulation. Here you see a small difference that we are using the pump. A mechanical pump is added to the simple flow loop, and the pressure difference created by the pump controls the water flow rate; it is quite simple.

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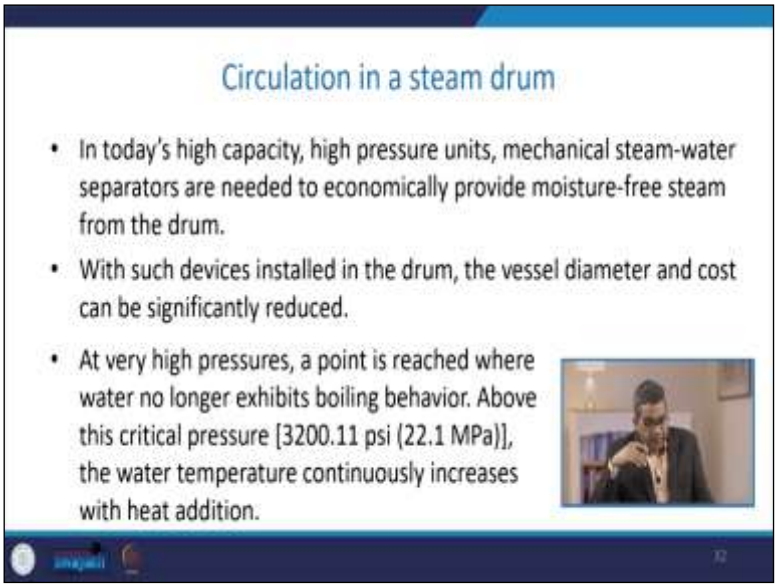

Now in today's high capacity, high-pressure units, mechanical steam-water separators are needed for the economical operation of any system where you require moisture-free steam from the drum. With such devices installed in the drum, the vessel diameter and the cost can be significantly reduced. So, a point is reached at a very high pressure where water no longer exhibits boiling behavior.

Above this critical pressure, around 22 22.1 megapascal, the water temperature continuously increases with the addition of heat.

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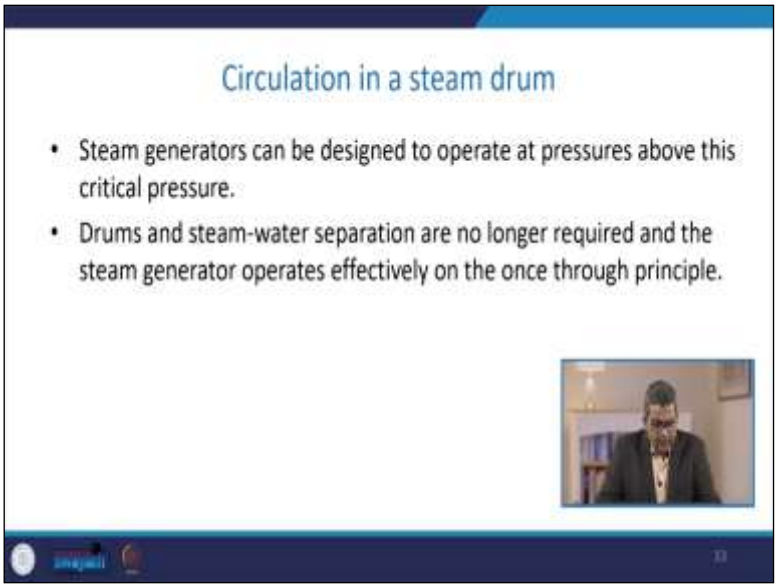

Now steam generators can be designed to operate at pressures above this critical pressure. Drums and steam-water separation are no longer required, and the steam generator operates effectively on the once-through principle.

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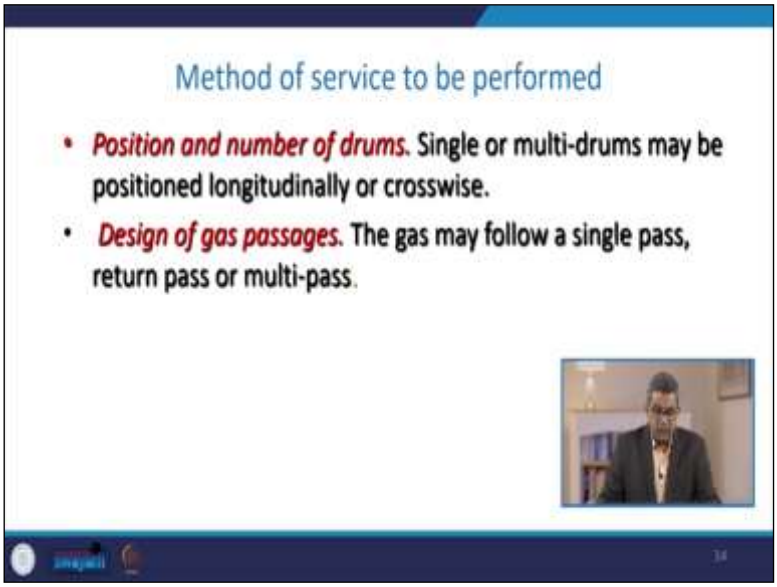

When we are talking about the classification, another classification is based on the position and number of drums. These may be either single or multi drum. This may be positioned longitudinally or crosswise. Another classification is steam; this steam is based on the design of gas passage. The gas may follow a single pass, return pass, or multi-pass.

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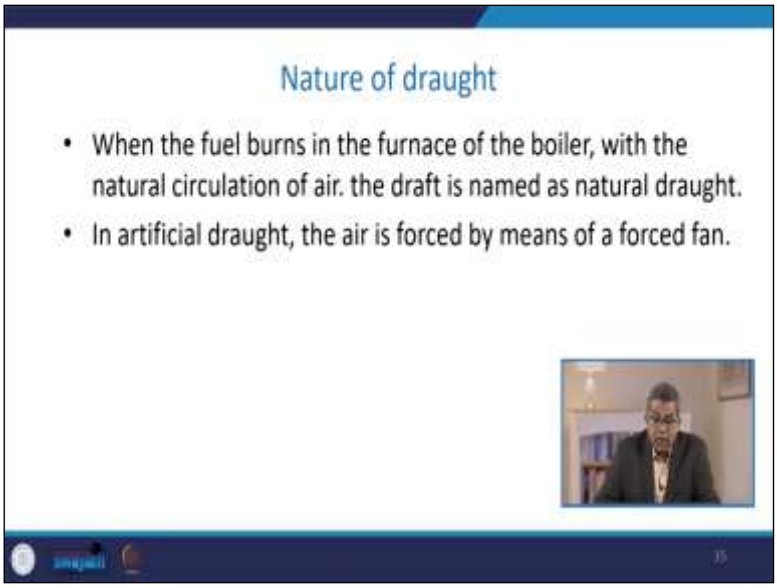

One more classification is based on the nature of drought. So, when the fuel burns in the boiler's furnace with the natural air circulation, the draught is named natural drought. In the artificial drought, the air is forced using a forced fan. So, you require some mechanical approach to remove the drought. The knowledge about the heat source can give another classification. So, as we know, heat energy utilized to convert fluid into vapor can be derived from either the combustion of solid-liquid or gaseous fuel.

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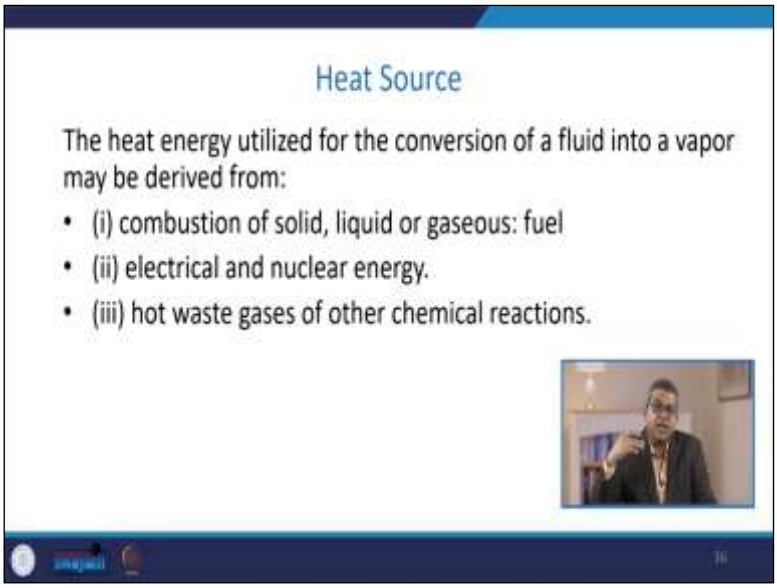

It may come from electrical and nuclear sources or sometimes hot waste gases or other chemical reactions—those that are exothermic in nature or some of the combustion of other allied processes.

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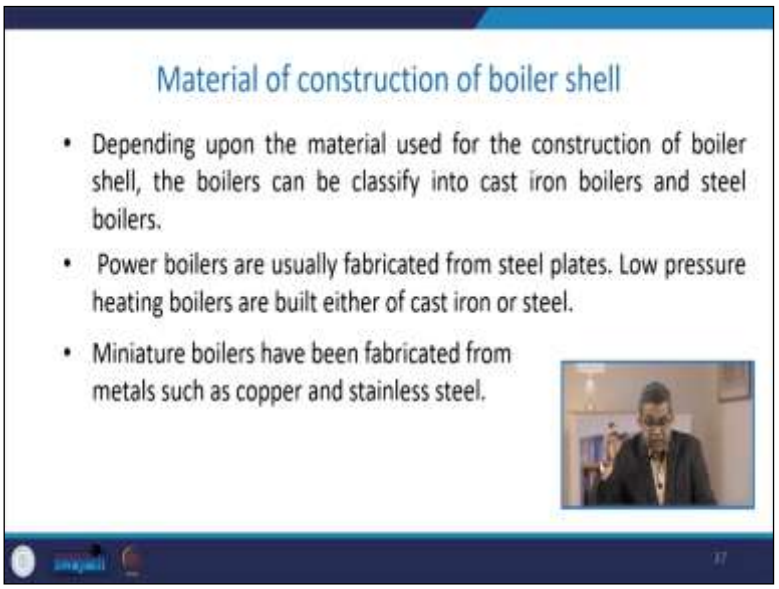

Another classification is based on the material of construction of the boiler shell. So, depending upon the material used for the construction of the boiler shell, the boilers can be classified into cast iron boilers and steel boilers. So, power boilers are usually fabricated from steel plates. Low-pressure heating boilers are built either of cast iron or steel. Sometimes miniature boilers have been fabricated from metals such as copper or stainless steel.

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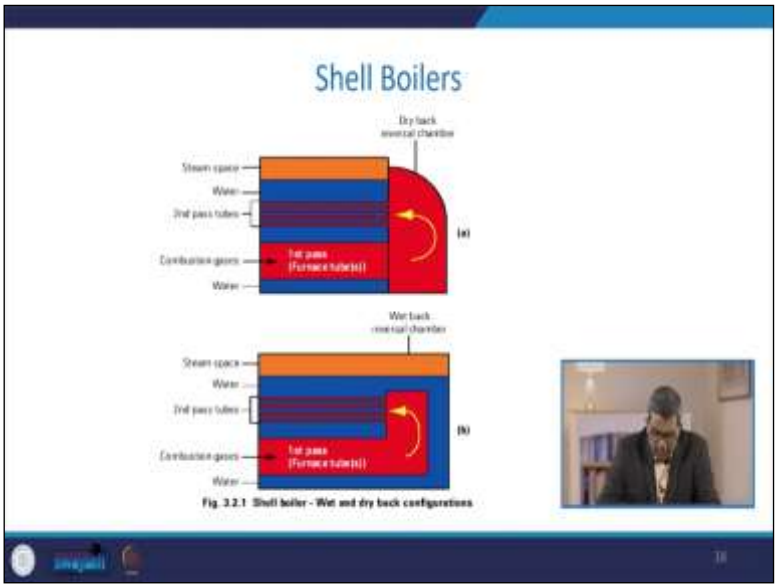

So, that is purely based on the requirement. Now let us talk about the shell boilers here; we were talking about the few fuels circulating to the tube side. Now here is the basic anatomy of a boiler.

This is the steam space water, and the water surrounds the tube bundles. Now here you see that whatever combustible gas is come in the first past the furnace to impart the energy to the water, and then again, there is a reversal.

So, dry back reversal chamber and second pass tube, and by this way, they can come to go out and generate the steam. Another configuration is the wet back reversal chamber. Here the combustion gases are always submerged in the water, coming out during the second pass. So, this is the difference between a dry back reversal chamber and a wet back reversal chamber.

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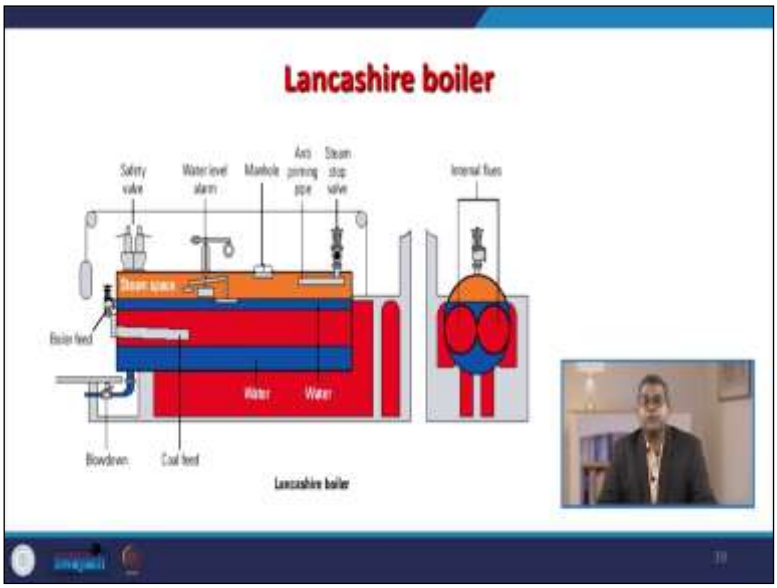

Now here we are talking about the various boilers. This is again the anatomy of the boiler called the Lancashire boiler. It is very popular in various textile plants where you require the wettest steam. So, the basic purpose of this Lancashire boiler figure is that you can become acquainted with the different accessories and mountings that are attributed to the boiler. Now here you see the fire tube boiler, which is submerged in the water.

Now here is the steam space. Now for any boiler, the water is an integral part. Now the maintenance of the water level is quite essential because if the water level is low, then there may be a chance that tubes may get destroyed, and if water level is high, you may not get the steam at the desired properties. So, there must be a water level alarm. As I told you, since it is a pressure vessel, it should be equipped with a safety valve.

So, if pressure rises to the stipulated rating, it can open, or it can be actuated, and excess pressure can be relieved to the point in question. Then sometimes, you may need to regulate the steam. So, every boiler must equip with a steam control wall, or sometimes you may need to have some steam stop wall so that the equipment can be prevented from further damage. There must be some anti priming pipe to remove the air entrapment between the water and the fire tube because air does not carry any kind of heat value.

So, if the start of the boiler, you need to overcome the air entrapment. Another thing is that the boiler must have one manhole. So that all the internal mountings can be cleaned easily, we said that accessibility of this is extremely important. There must be a line for the feed. I told you about the blowdown in which the sludge can be removed intermittently because the water is continuously being heated. Over time, scales may get formed, and this can be accumulated if it does not carry any heat value. So, intermittently they can be removed.

So, for this, there must be a blowdown. Now, this is the source of coal here. This is the coal-fired boiler. So, you need to supply the coal. So, there must be a chamber for this firing. Here you can see the front view of this boiler. Here this is the internal flues. You can see the tubes because this is the fire-tube type of boiler. So, you can see that these are the tubes. Through this pulley, you can control the passage of flue gases because flue gases have a substantial quantity of heat intake.

So, if you wish to enhance the efficiency of the boiler, you can control the passage so that they can have some retention time over there and pass the excess amount of energy to the water.

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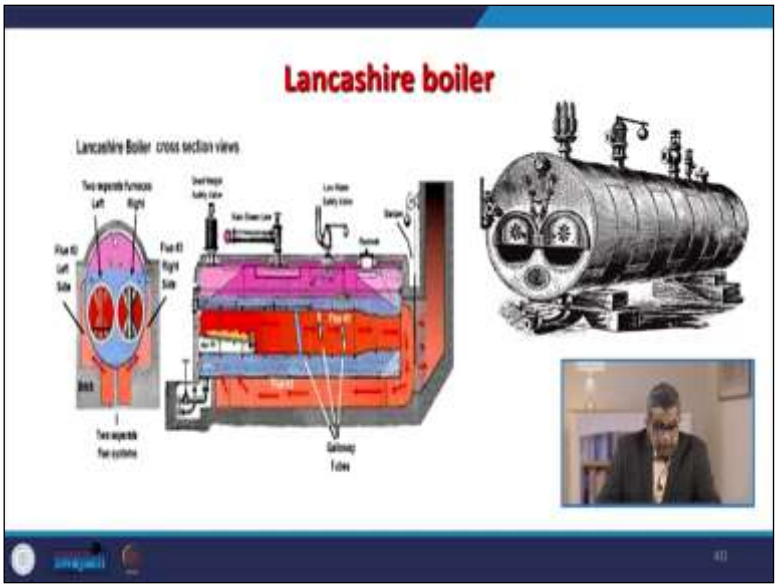

Now here you see that this is the typical photograph of a Lancashire boiler. We have already discussed these things.

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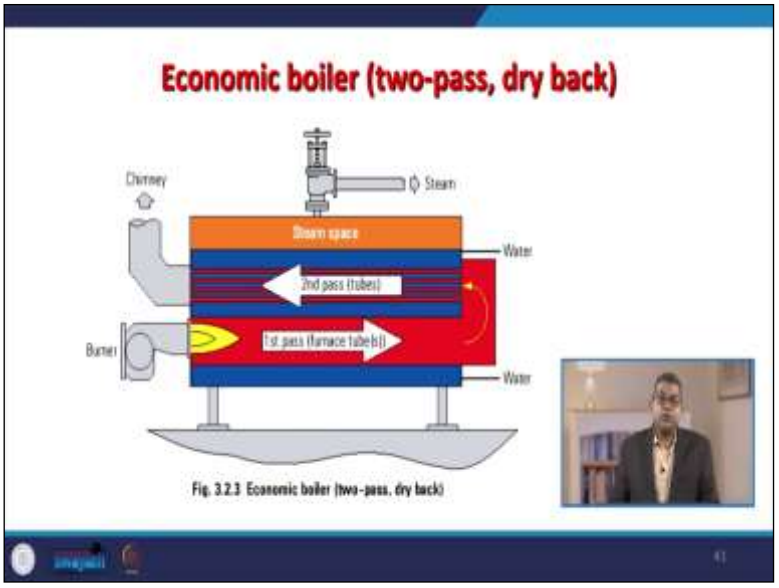

Another is the economic boiler two-pass dry back boiler. Dry back boiler we have already discussed in the previous slides. Now here you see that there is an externally fired burner and the chimney to discharge a flue gas. Here, to achieve maximum efficiency, the flue gases are passed in two passes for getting more and more efficiency.

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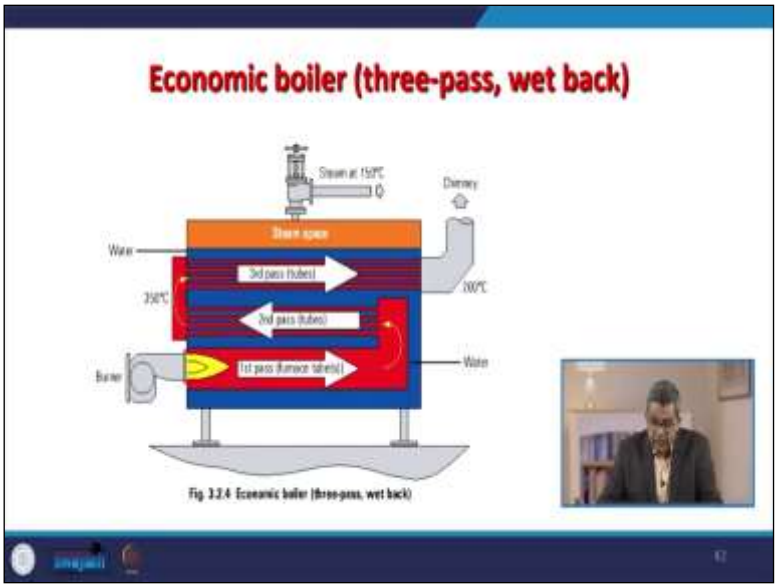

Similarly, we may have a wet back type of a three-pass system. Here you see the burners burner imparts the heat energy one pass, two passes, and three passes for the maximization of this thing, and you may get the steam at the desired temperature.

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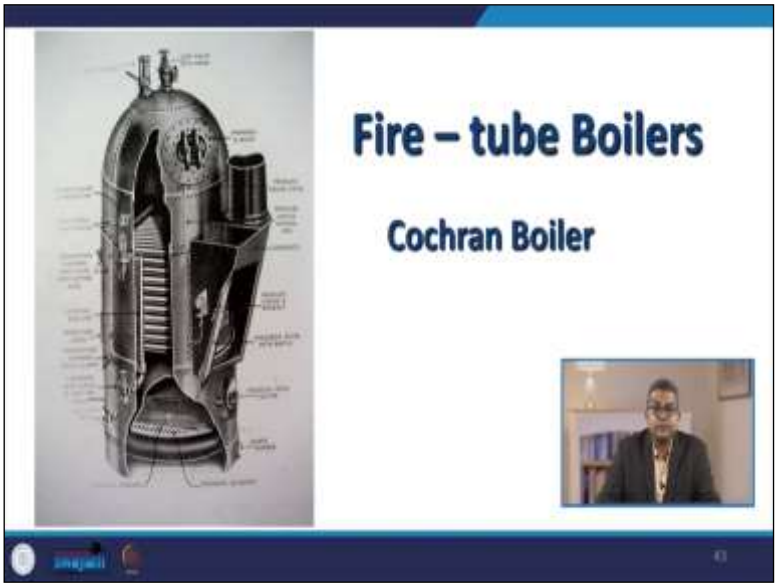

Now, this is the basic anatomy of the Cochran boiler. This is the fire-tube type of wire. You can easily see the tubes and various other mountings for this particular boiler water gauge and other types of mountings. We will discuss all these mountings in due course of time. Stop wall the steam distribution network, and This is the manhole, etc.

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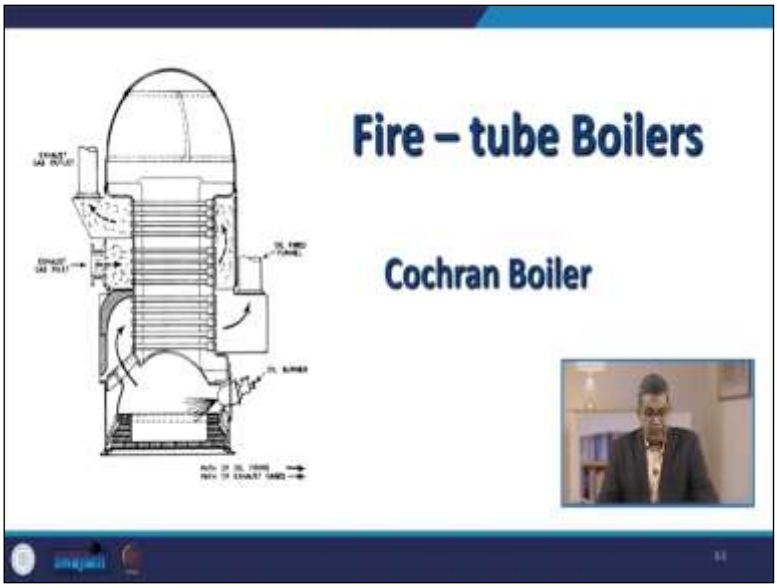

The basic points of this Cochran boiler are here this is the oil for the fired boiler. Now here is the gas inlet and gas outlet. You can see the tubes. This is the fire inside the tube, submerged in the water. So, you can produce the steam, and you can discharge the steam from here.

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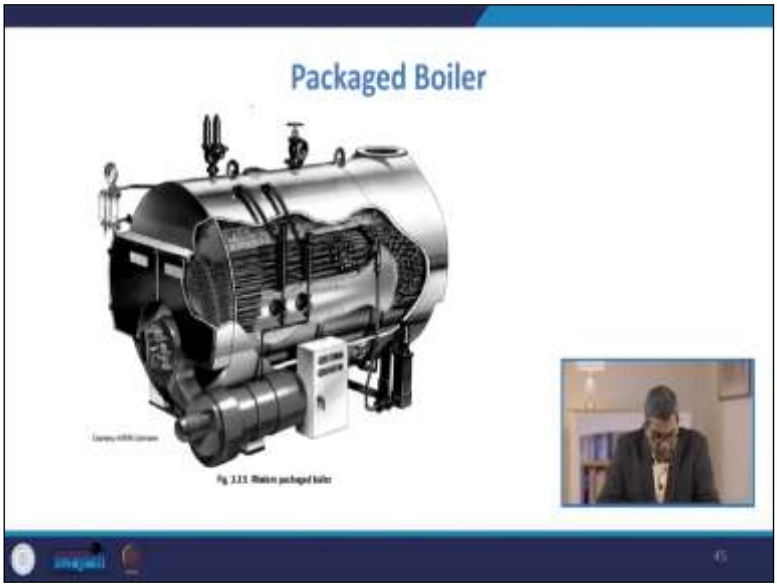

We are always looking for a compact assembly to minimize the space requirement in the modern-day. So, the packaged boiler came into existence. You can see that everything is housed in this particular boiler. You can see the tubes, steam distribution wall manhole water level indicators firing media, etc. All these things are there.

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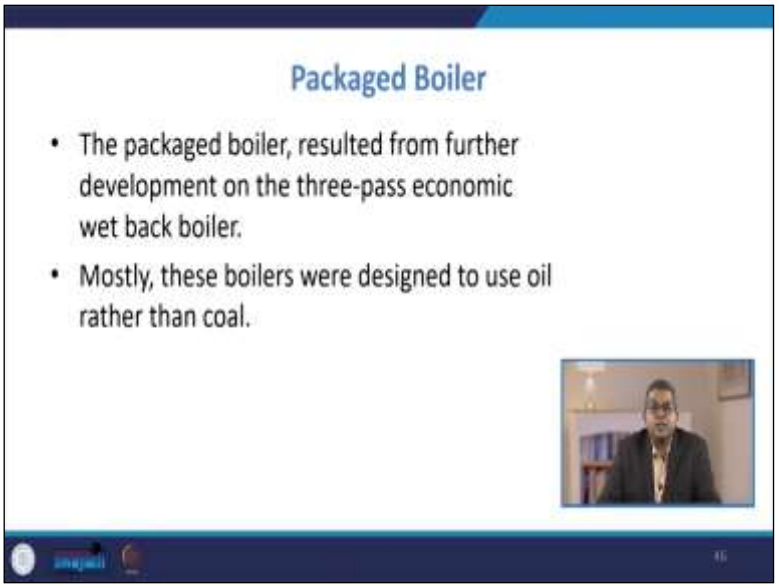

So, the packaged boiler resulted from the further development of the three past economic wet boilers mostly, and these boilers were designed to use oil rather than coal.

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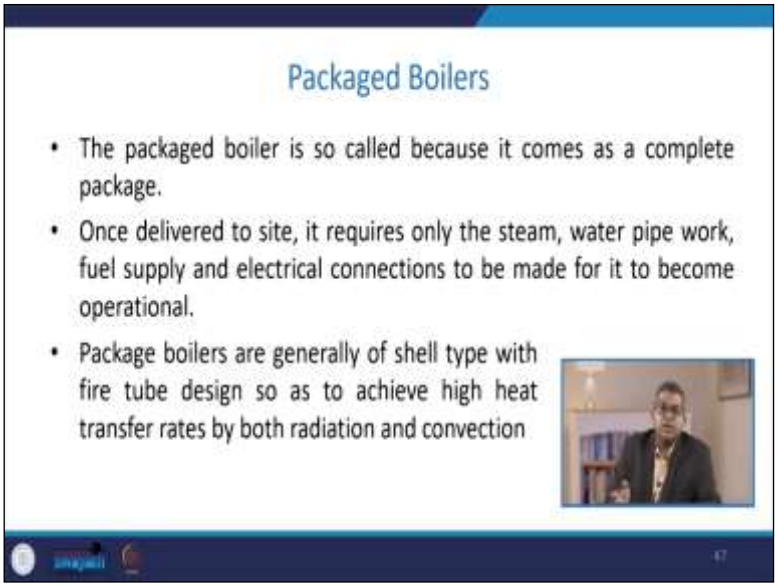

They are so-called package boiler because it comes as a complete package. So, once you deliver to the site, it requires only the steam. The water pipe piping network supply of fuel electrical connections, and you can start things. So, these boilers are generally of shell type with the fire tube design. So as to achieve a high heat transfer rate by both radiation and convection.

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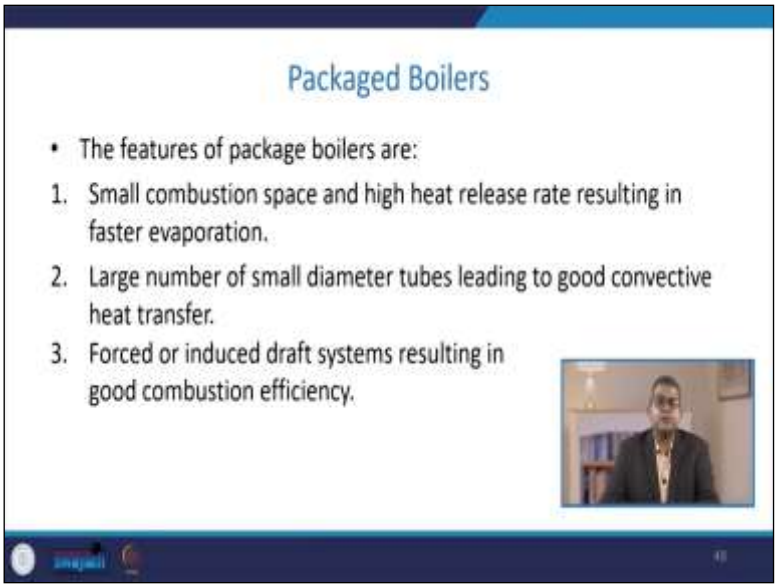

There are certain features of these packaged boilers: small combustion space and high heat release rate resulting in faster evaporation. A larger number of small diameter tubes leading to a good convective heat transfer forced or induced drop system may result in good combustion.

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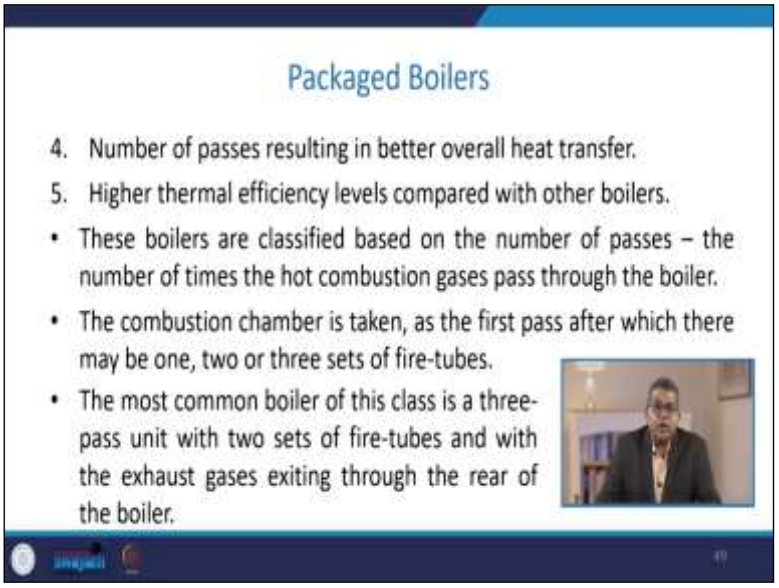

Now, with fewer passes resulting in a better overall heat transfer, you may experience a higher thermal efficiency level than other boilers. So, these boilers are classified based on the number of passes, the number of times the hot combustion gas passes through the boiler, maybe two-pass three passes, etc. So, the combustion chamber is taken as the first pass, after which there may be one or two three-set of fire tubes.

The most common boiler of this class is three pass units with two sets of fire tubes and exhaust gases that can exit through the rear of the boiler.

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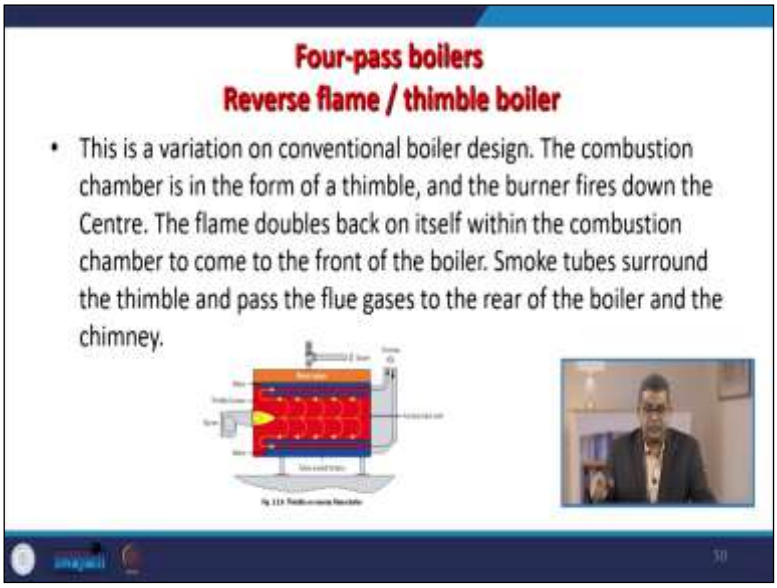

Another category is called the four-pass boiler or reverse flame or thimble type of boiler. Now, is you can see the variation in conventional boiler design. The combustion chamber is in the form of a thimble. You can see the various thimbles and the burner fire down the center. So, you can see the profile of flue gas. The flame doubles back on itself within the combustion chamber to come to the front of the boiler. Smoke tubes usually surround the thimble and pass flue gases to the rear of the boiler and chimney.

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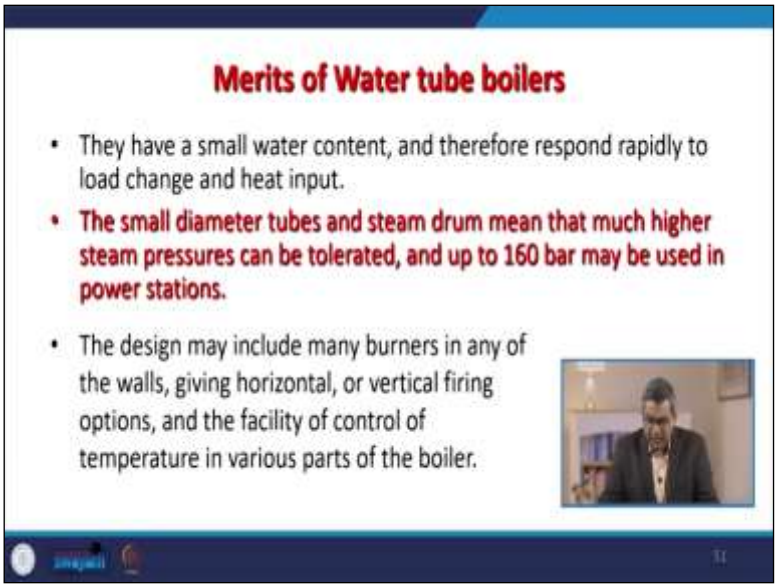

There are various merits associated with the water tube boiler. Therefore, they have small water content and respond rapidly to the load change and heat input. The small diameter tube steam diameter means much higher steam pressure. This can be tolerated, and up to 160 bars may be used in the various power station. So, the design may include many burners in any wall, giving horizontal or vertical firing options and the facility of temperature control and various parts of the boiler.

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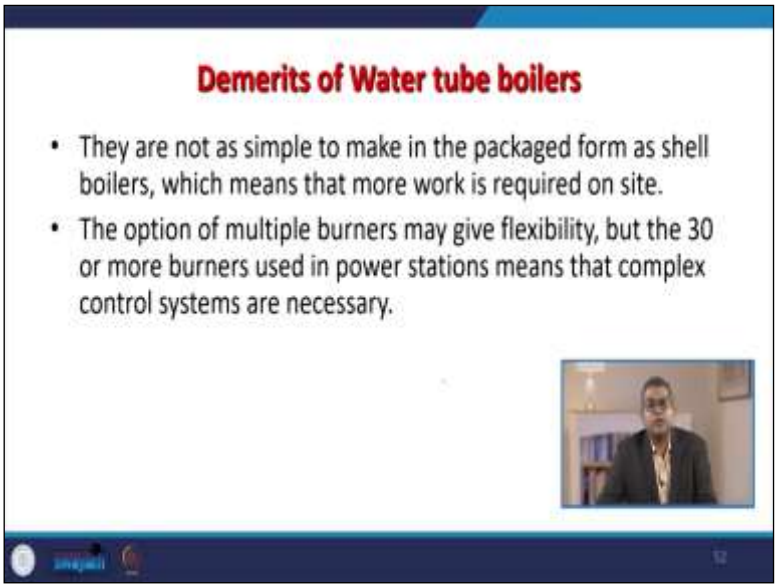

Now let us talk about some demerits of water tube boilers because when merits are there, you obviously cannot overlook the damage. Now they are not as simple to make in the packaged form

as shell boilers, which means more work is required. So installation time cost etc., may be phenomenal. The option of multiple burners may give flexibility, but the 30 or more burners used in the power station means complex control systems are necessary. Because when more burners, then obviously more chances of clogging wear and tear may occur.

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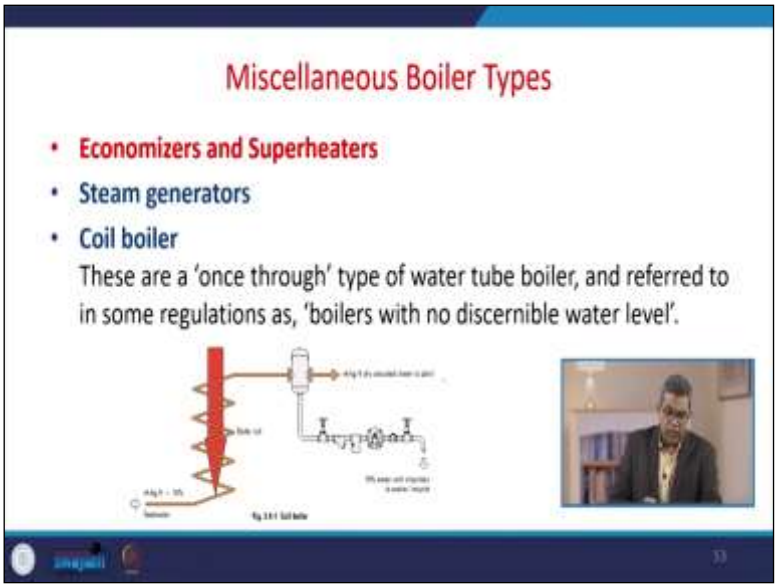

Another is the miscellaneous boiler type like coil boilers. They are a once-through type of boiler, which we have already discussed, and they are referred to some regulations with the boiler with no disclaim water level.

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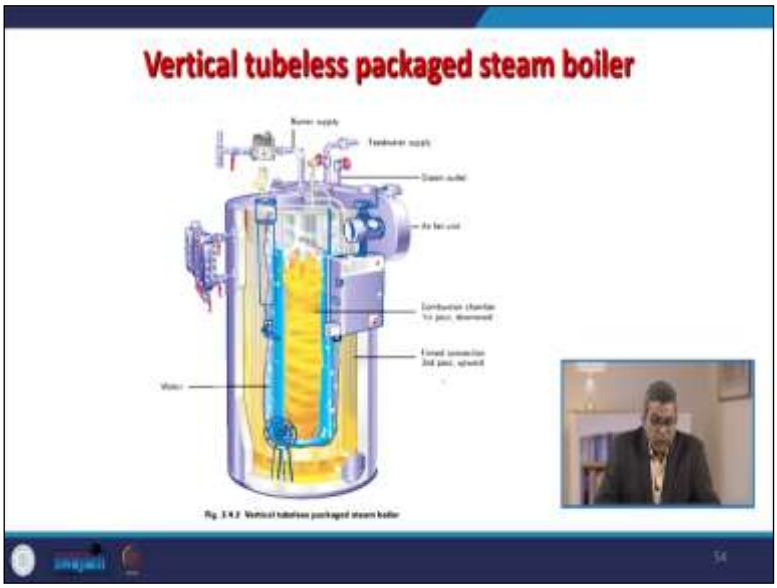

There is a certain vertical tubeless packaged steam boiler, the domestic type of facing thing here there is no tube the only thing is that you have the burner supply feed, water supply. You get the tubeless package steam system, and here you see that the steam chest is there.

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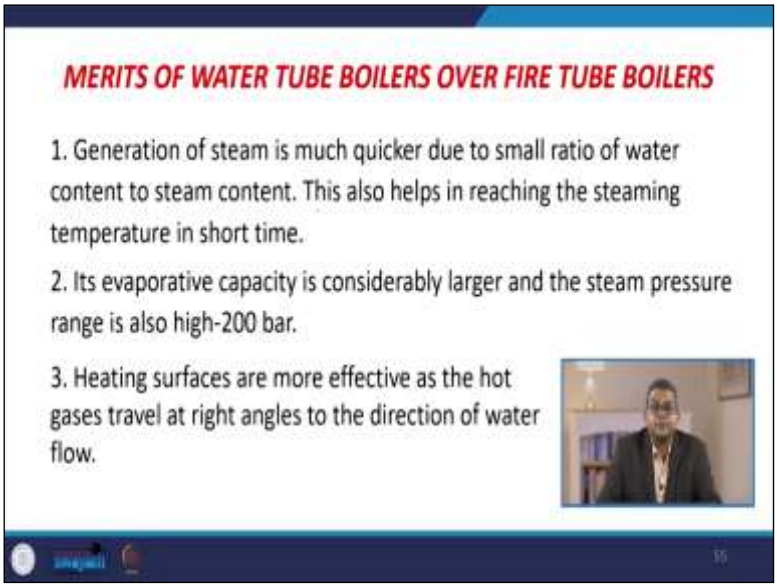

So, we have, I mean, if we go to the classification of boilers in the broad spectrum, there are two types of boiler water tube boiler and a fire tube boiler. So, let us talk about the merit of a water tube boiler over fire tube boilers. Now the generation of steam is much quicker due to the small water content ratio to steam content. This also helps in reaching the steaming temperature in a short time. Its evaporative capacity is considerably larger, and the steam pressure range is also high, around 200 bar. The heating surfaces are more effective as the hot gases travel at a right angle to the direction of water flow.

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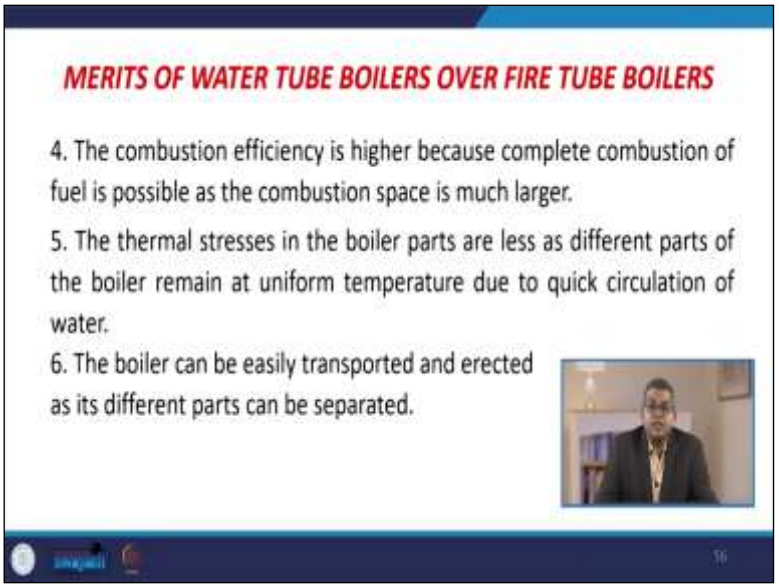

The combustion efficiency is higher because complete combustion of fuel is possible as the combustion space is much larger. The thermal stresses In the boiler parts are less as different parts remain in uniform temperature due to the quick circulation of water. The boilers can be easily transported and erected in different parts and can be separated as quickly as possible. The damage due to the bursting of a water tube is less serious; therefore, water tube boilers are sometimes called safety boilers, and safety, you know that this is a pressure vessel.

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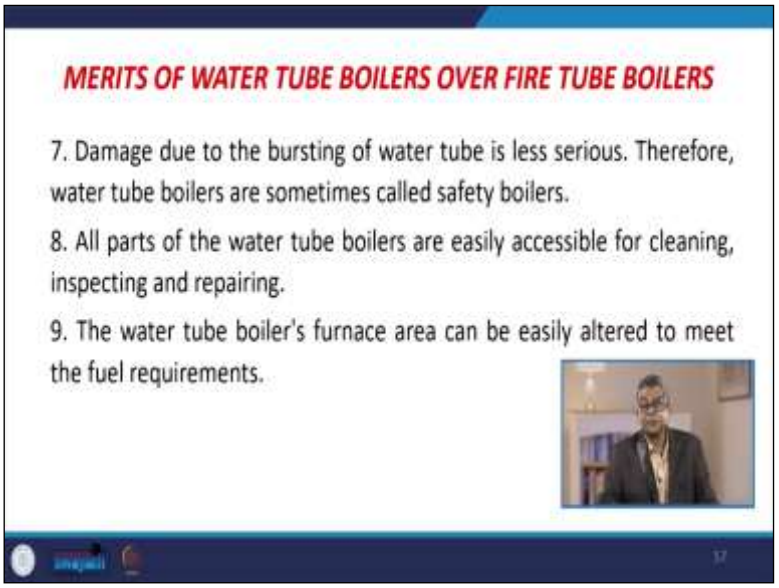

So, safety is very important. All parts of the water tube boilers are easily accessible for cleaning, inspecting, and repairing. The water tube boilers furnace area can be easily altered to meet the fuel requirement.

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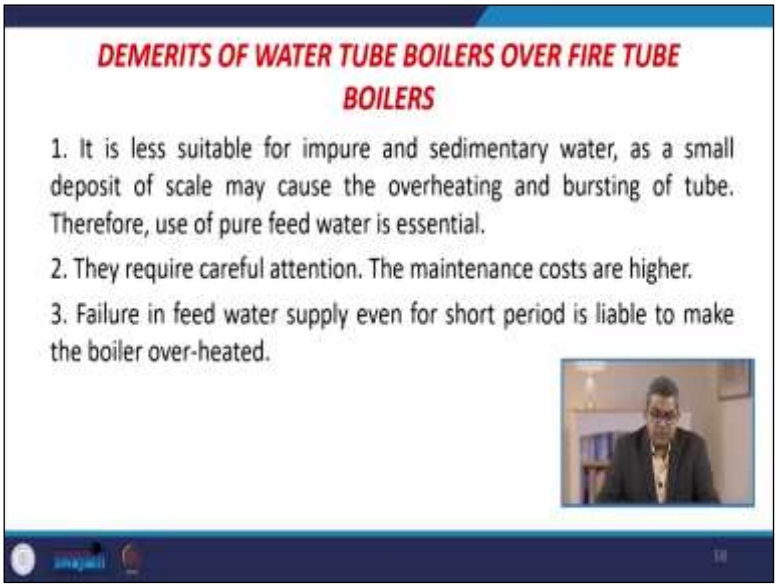

There are certain demerits of water tube boilers over fire tube boilers. They are less suitable for impure and sedimentary waters. So, the purest form of water is needed. Now, as a small deposit of scale may cause the overheating and bursting of the tube, safety may be at stake. Therefore you need to use pure feed water, which is again, you can say the economic aspect is always in there while using the purity of while considering the purity of the feed water.

Now they require careful attention. The maintenance costs are a high failure in feed water supply even for a short period is liable to make the boiler overheated. So, at the end of this particular lecture, we discussed the various aspects of the boiler, including the classification. We had discussed that n number of classifications could be given for the boiler classification based on the n number of uses attributed to the boiler. We discussed the merit and demerit of the water tube boiler and the fire tube boiler.

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If you wish to further study, then we have enlisted a couple of references for your convenience. You can go through it, thank you very much.