Chemical Process Utilities
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Lecture - 22
Boilers

Welcome to the next lecture on boilers under the aegis of chemical process utilities. Before we start, let us have a brief outlook about the topics we covered in the last lectures.

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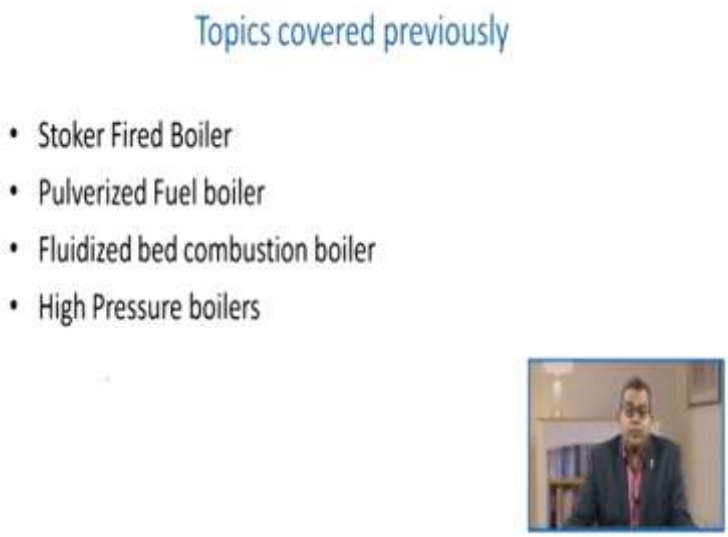

We discussed the stoker-fired boilers, in which we talked about the better combustion efficiency and the different parameters required for the proper maximization of the fuel efficiency of the boiler. That is the best size of the fuel coal than air supply and how we can manage or how we can configure the bed of the fuel over different types of grates. Then, we discussed the pulverized fuel boiler.

We talked about the fine particles polarization process, and we discussed that; what is the role of the size of the fuel particles in the boiler efficiency? We discussed the fluidized bed combustion boilers in this; we discussed briefly about the phenomena of fluidization and how this phenomenon of fluidization helps in boiler efficiency? We discussed two boilers under a high-pressure system, the Lamont boiler and the Benson boiler. And we discussed the various advantages associated with these kinds of boilers.

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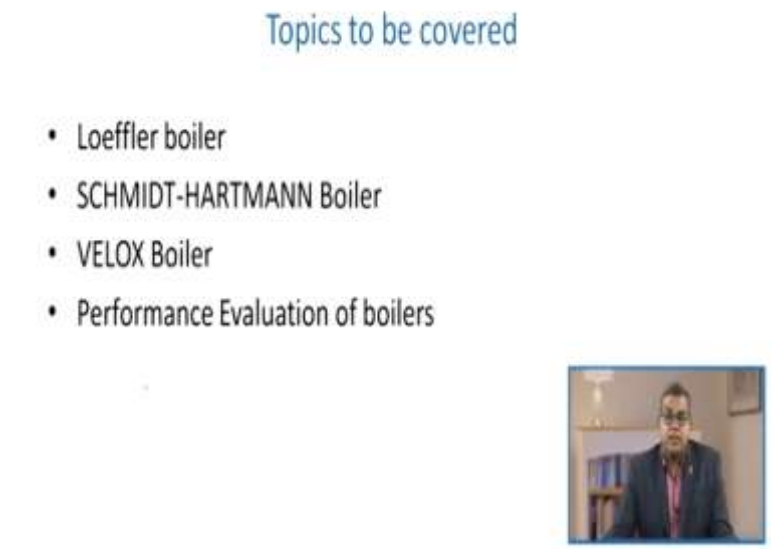

So, in this context, in this particular lecture, we will discuss the Loeffler type of a boiler, then Schmidt Hartmann boiler, Velox boiler, and then we will go for the concept of performance evaluation boilers.

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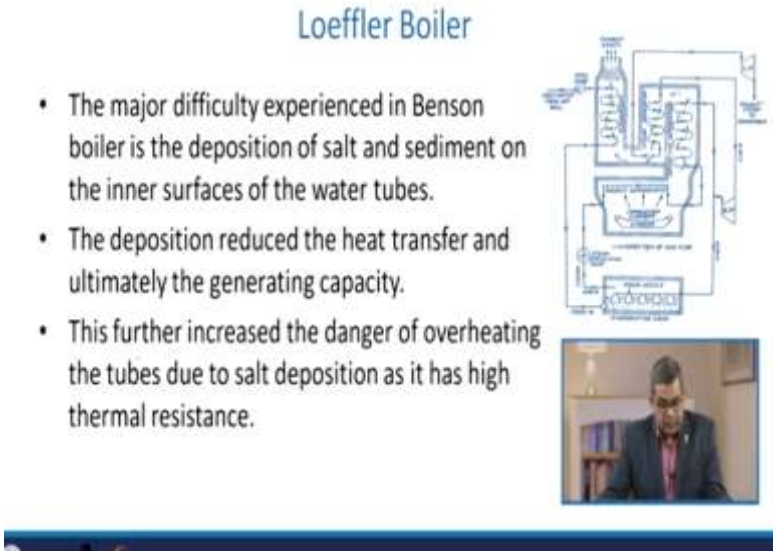

So, let us take up the first boiler of this lecture, the Loeffler boiler. See, when we discussed the concept and the basic anatomy of the Benson boiler. There are certain difficulties or disadvantages associated with the Benson boiler; although it is a high-pressure boiler, there are certain things associated with it. So, the major difficulty people experienced in Benson boiler is the deposition of the salt and sedimentation on the inner surface of water tubes.

Now, see if you recall that the Benson boiler, the tube's diameter was small. So, sometimes it is advantageous, but if any sedimentation, debris or salt may get deposited over time, there may be a chance of choking. So, if this deposition is there, it will reduce the heat transfer, and ultimately the power generation or steam generation capacity would be adversely impacted.

So, if you keep on bearing this thing, this further increases the danger of overheating the tubes because of this particular salt deposition and the high thermal resistance.

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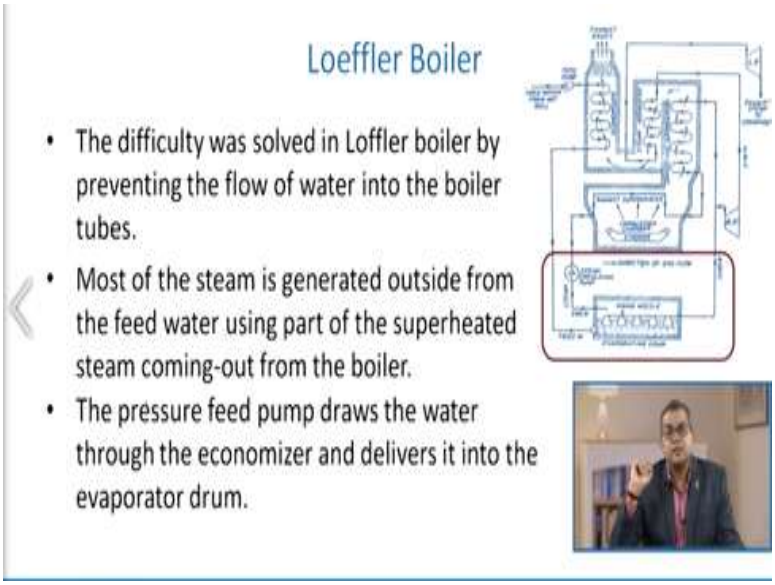

So, people thought about this particular aspect, and this particular difficulty was resolved in the Loeffler type of boiler by preventing the flow of water into the boiler tubes. So, most of the steam is generated outside from the feed water using part of the superheated steam coming out from the boiler. So, when you are carrying out this operation, you may require the pressure feed pump.

So, the pressure feed pump draws the water through the economizer and delivers it into the evaporator drum. So, in this way, you are also maintaining the boiler's energy efficiency.

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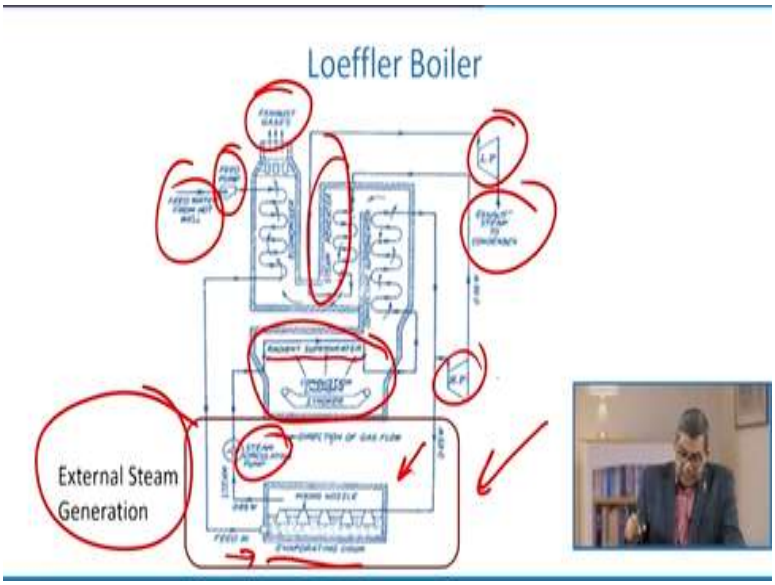

Now, is you can see the basic anatomy of the boiler or Loeffler boiler. Now, here again, I am repeating that the basic ingredient of our basic anatomy of all the boilers is similar; the only difference is the different types of parameters and configuration. Like here, you will see that exhaust, steam, high pressure, low-pressure pumps; this is the stoker type of combustion chamber. Here you will find the superradiant heaters.

Then steam preheaters, you also have the exhaust gas, feed pump, and feed water from the hot well. So, in the Loeffler- Benson type of boiler, all these Lamont types of boiler are similar. But the basic difference exists here: the external steam generation part. Now here, you have one evaporating drum supplying the continuous supply of a feed over here; these are the mixing nozzle and the steam circulating pump.

So, in this way, you are generating the steam externally and submitting it into the main boiler arena.

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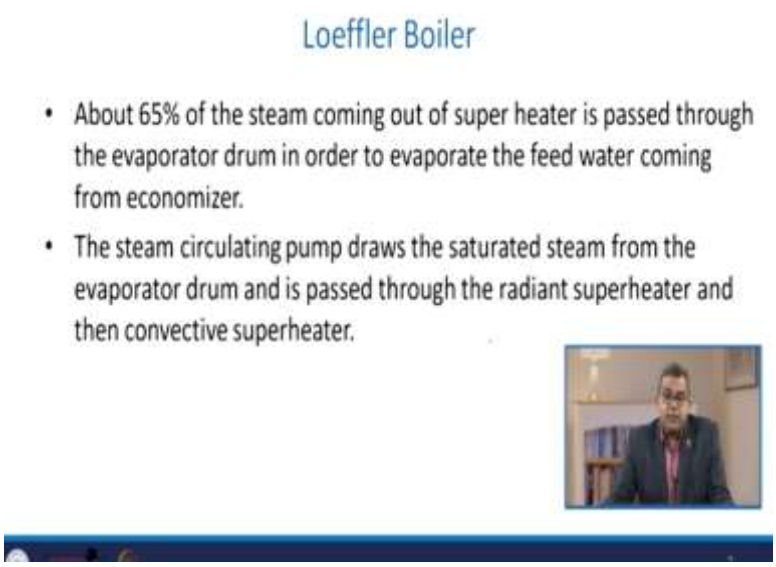

So, about 65% of steam is usually coming out of the superheater here and is usually passed through the evaporator drum to operate the feed water coming from the economizer. So, the steam circulation pump or steam circulating pump usually draws the superheated steam from the evaporator drum and is used to pass through the radiant superheater, which is situated here, the radiant superheater and the convective superheater. So, in this way, you are maximizing energy efficiency.

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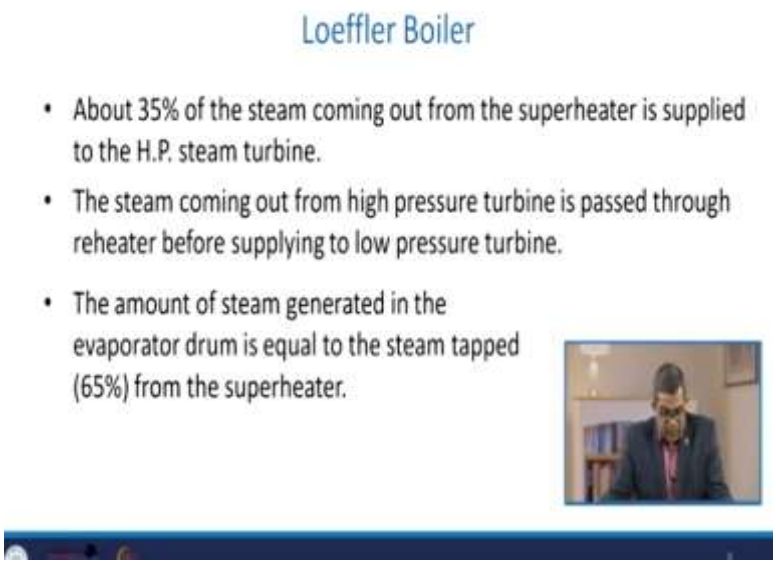

And it was remaining 35% of the steam. Usually, it comes out from the superheater and is supplied to the high-pressure steam turbine. So, the steam coming out from the high-pressure turbine is passed through a reheater before supplying to the low-pressure turbine. Here you see that this is

the low-pressure turbine, which is the high-pressure turbine. So, the amount of steam generated in the evaporator drum equals the steam tapped, which is 65% from the superheater.

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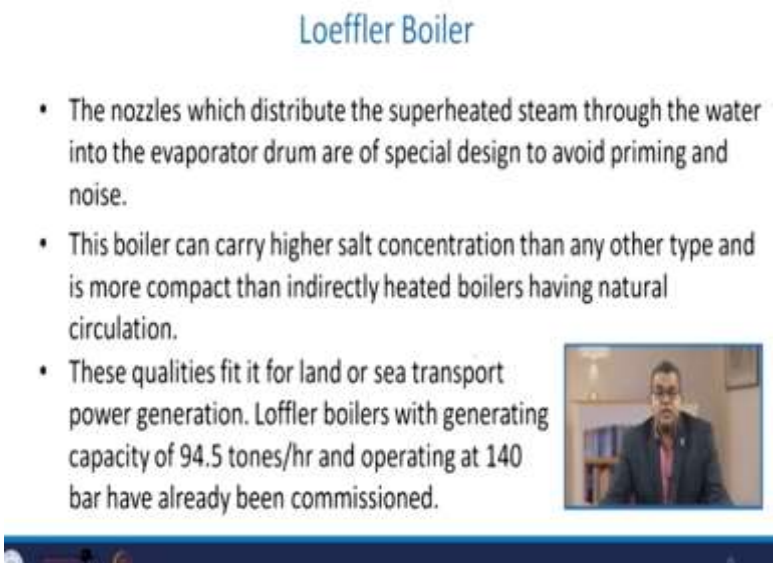

Now, the nozzle usually distributes the superheated steam through the water into the evaporator drum; they are of a special design to avoid priming and noise. Now, priming is again a very well-known and well-tested phenomenon in the boiler, just to remove any kind of air entrapment in the boiler system. Because, usually, air does not carry any kind of heat value, and obviously, it hinders the stream distribution and the water distribution network.

So, the priming is quite essential for any start-up of the boiler. This type of boiler, a Loeffler boiler, can carry high salt concentration than any other type of boiler. It is more compact than an indirectly heated boiler having natural circulation. So, these qualities fit it for land or sea transport power generation. The Loeffler boiler with a generating capacity of 94.5 tons per hour and operating at 140 bar has already been commissioned industrially.

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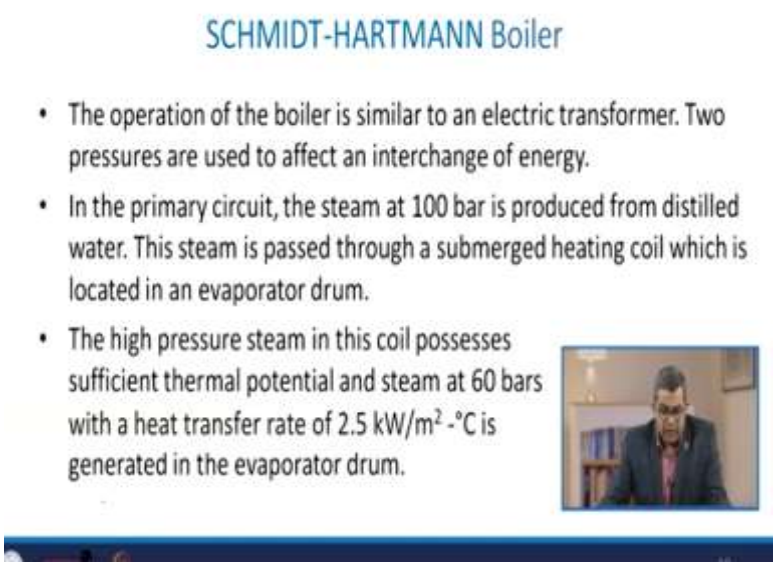

Now, let us talk about another type of boiler called the Schmidt- Hartmann boiler. Now, as I told you, the anatomy of all the boilers is almost similar. Now, here is the Schmidt- Hartmann boiler; the operation of the boiler is similar to an electric transformer. Now, the two pressures usually affect an interchange of energy. So, it is working on the concept of interchanging energy.

The steam at 100 bar is usually produced from distilled water in the primary circuit. So, when we use distilled water, the chances of scales or hardness are minimal. This steam is passed through the submerged heating coil located in an evaporator drum. The high-pressure steam in this coil possesses sufficient thermal potential and steam at 60 bars with a heat transfer rate of 2.5-kilo watt per meter square degree Celsius. Usually, it is generated in the evaporator drum.

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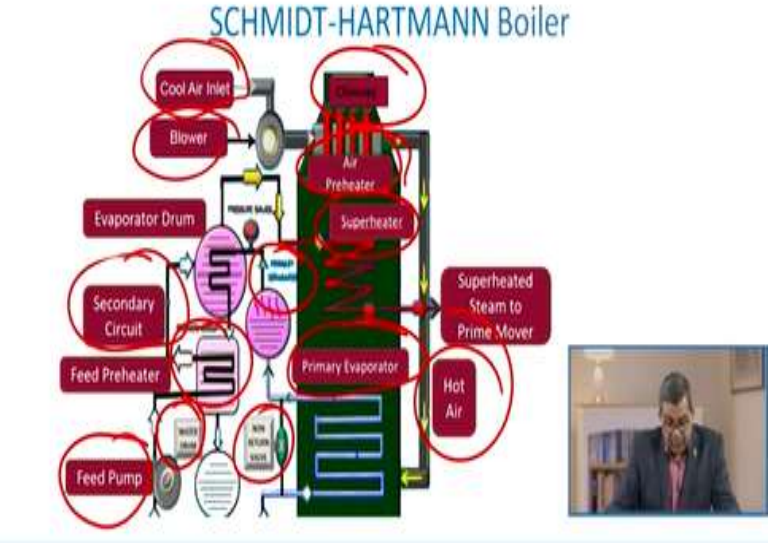

Here you see the anatomy or pictorial diagram of Schmidt- Hartmann boiler. Again, this is the chimney for exhaust gases; we have the cool air inlet, then the blower. We have the air inlet; obviously, there must be a blower. Here, you see that there are different types of secondary circuits, and this is the primary evaporator to maximize efficiency repeatedly; there is a superheated.

As you see here, this is the primary separator; apart from this, we have the NRV, which is a non-return valve and a water drum, and a feed pump to supply the continuous supply of water. But to maintain the water at the appropriate temperature, this is the feed preheater. So, that there may be in any thermal shock can be avoided apart from this the circulating hot air and this air preheater.

So, most of the accessories and mountings of these boilers are attributed to either safety or maximization of energy.

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So, the steam produced in the evaporator drum from impure water is further passed through the superheater and then supplied to the prime mover, as you can see in this particular figure. The high-pressure condensate usually forms in the submerged heating coils. This high-pressure condensate is circulated through a low-pressure feed heater to raise the feedwater temperature to its saturation temperature.

So, this knowledge is quite essential; what should be the saturation temperature of the given pressure? So, if we know all these things and perform this thing, optimize this thing. So, only latent heat must be supplied in the evaporator drum.

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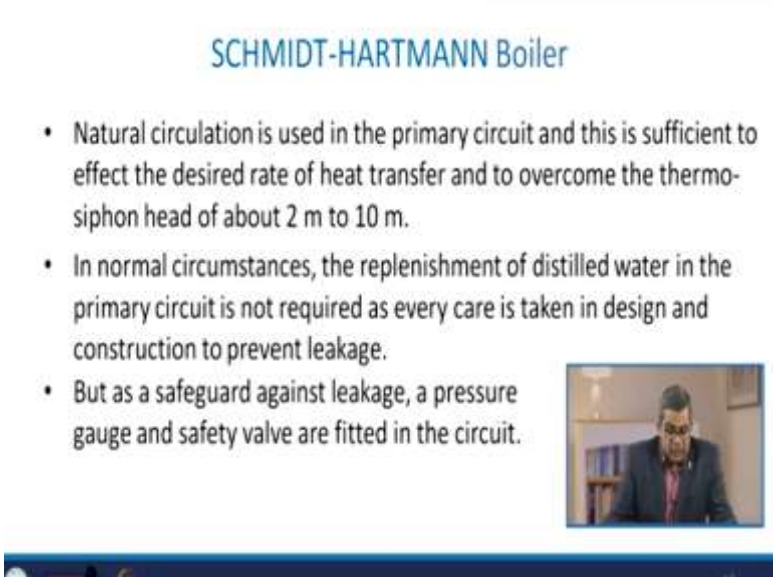

Now, natural circulation is used in the primary circuit. This is sufficient to affect the desired heat transfer rate and overcome the thermosiphon heat to about 2 meters to 10 meters. Again, in this aspect, optimization usually does occur. So, in normal circumstances, the replenishment of distilled water in the primary circuit is not required. Every care is taken in design and construction to prevent leakage. So, the proper water balancing is always there.

But as a safeguard or safety measure of a boiler with a safeguard against leakage. So, it is quite evident from the figure.

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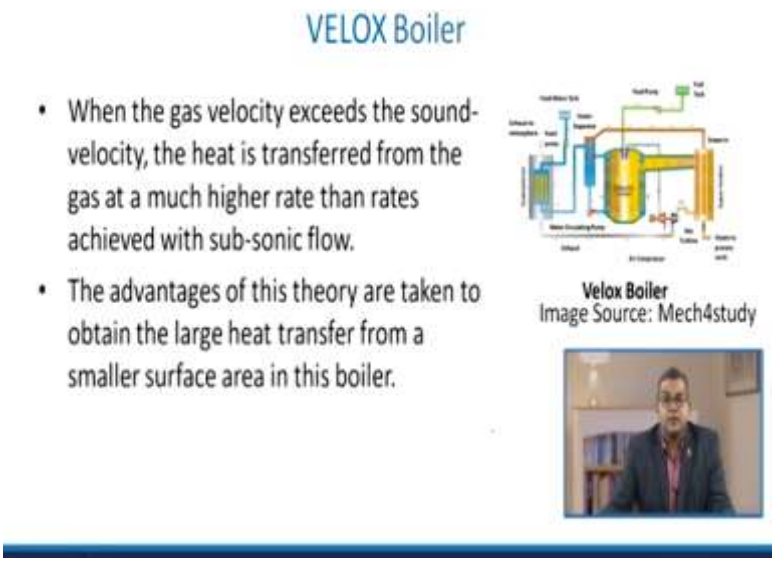

Now, let us talk about another type of boiler called the Velox boiler. Now, again it offers the same phenomena, now you see here we are having the economizer, we have a feed water tank, feed pump, fuel tank for the supply of energy, this is the combustion chamber, and there is a gas turbine over here, apart from air compression system, superheater. So, all these things are essential things are there.

The concept is that when the gas velocity exceeds the sound velocity, the heat is transferred from the gas at a much higher rate than rates achieved with the subsonic flow. So, this is the basic phenomenon. The advantages of this particular theory are that they are usually taken to obtain a large heat transfer from a small surface area in this type of boiler.

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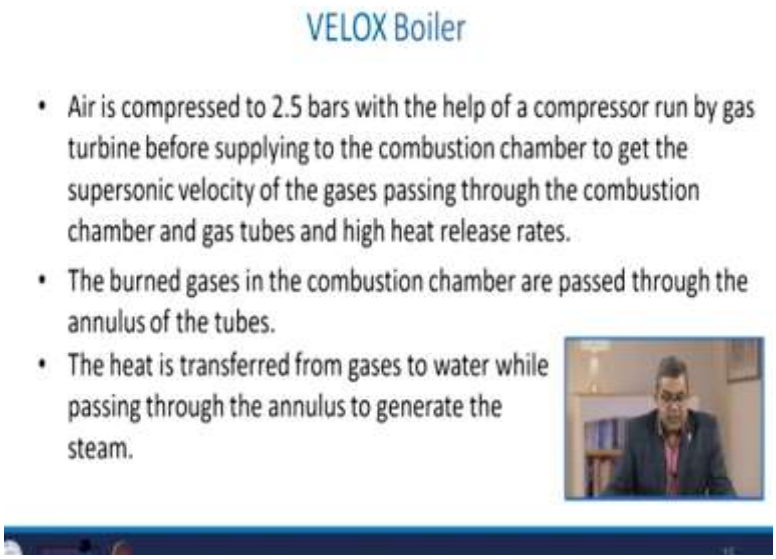

Now, the air is usually compressed to say 2.5 bars with the help of a compressor run by a gas turbine before supplying to the combustion chamber to get the supersonic velocity of the gases passing through the combustion chamber and gas tubes apart from the high heat release rates. So, you need to create the supersonic velocity. Now, the burned gas after the combustion or burn gas in the combustion chamber is passed through the annulus of the tube.

So, the heat is transferred from gases to water while passing through the annulus to generate steam.

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Now, the mixture of water and steam is being formed over time. They then passed this into a separate so designed that the mixture enters with a spiral flow like this. The centrifugal force they

are being produced causes the heavier water particles to be thrown outward on the walls. Now, this effect separates the steam from water. See, this is again a very crucial phenomenon, let me tell you.

Because you see that when we were discussing the different types of boiler, there is a steam chest and of course, water level and all these things are well you can say optimized. So, separation of steam from the water is quite essential. Otherwise, the entire system will get collapsed. So, the separation of steam from the water is again a very crucial phenomenon. The separated steam is further passed through the superheater and supplied to the prime mover. So, you may get the superheated steam from this particular juncture.

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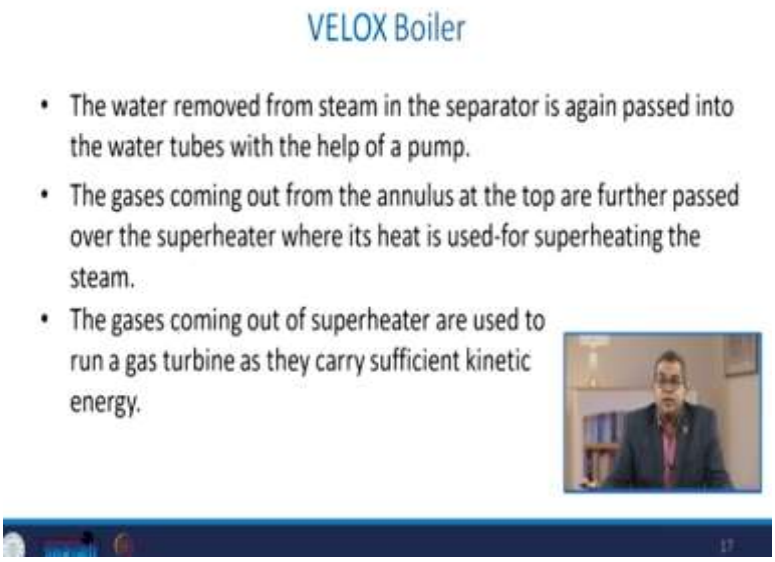

The water is removed from the steam in the separator, which is again passed into the water tubes with the help of a pump. You cannot say that let the water go, but the thing is that whenever you are using, as I told you in the previous lectures, every drop of water costs. So, you need to conserve the water at this juncture also, and also, the water possesses a significant heat value.

So, the gases coming out from the annulus at the top are further passed over the superheater. Its heat is used for superheating the esteem, which we have already circulated and discussed in the previous slides. Now, the gas coming out of the superheater is used to run a gas turbine as they

carry sufficient kinetic energy. So, it would help if you played with the dynamics or thermodynamics to get sufficient kinetic energy.

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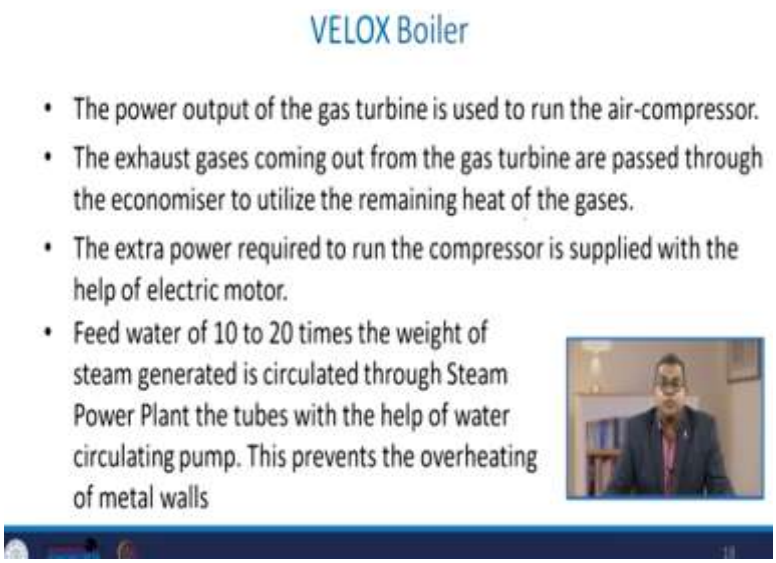

The gas turbine's power output is used to run the air compressors. And the exhaust gases whatever been coming out from the gas turbine are passed through the economizer to utilize the remaining heat of the gases. So, sometimes you may require some extra power to run the compressor. Usually, it is supplied with the help of an electric motor. Feedwater of say 10 to 20 times the weight of steam generated is circulated through the steam power plant, the tube with the help of water circulating pump.

So, this phenomenon usually prevents the overheating of metal walls. And trust me, the overheating of these metal walls is an extremely common phenomenon in the boiler system.

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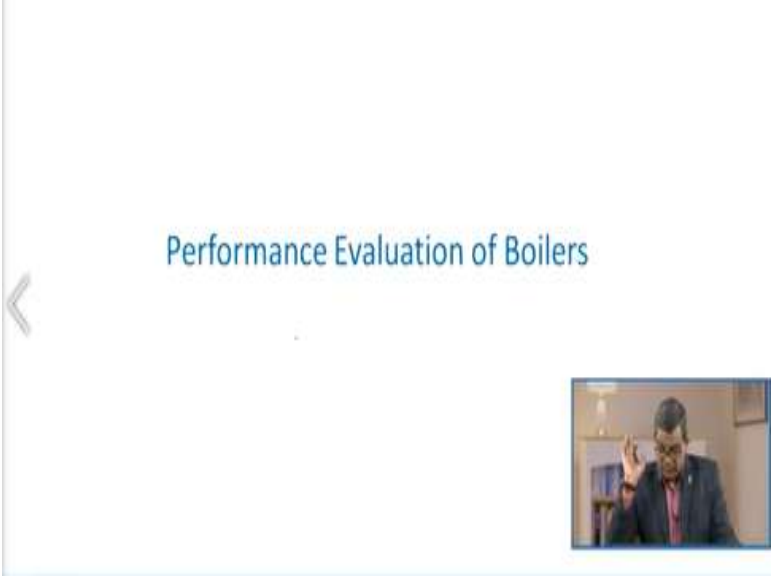

Now, let us come to the remaining part of this particular boiler concept, which is crucial for the performance evaluation of boilers.

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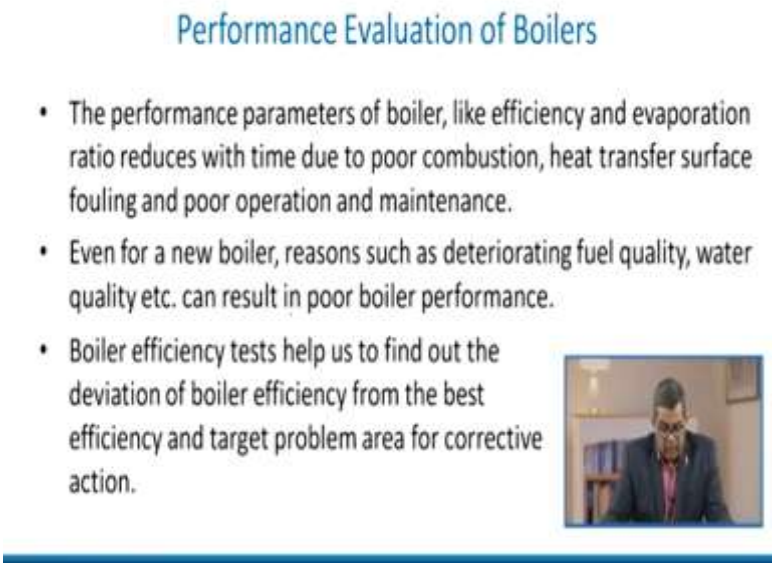

Now, during the entire course of your time, we always talked about efficiency. The efficiency of a boiler, efficiency of the fuel, efficiency of concerning the economics, efficiency concerning the environment. So, all these things must be evaluated properly. In this way, we can object that the boiler performance and the boiler routine evaluation of boiler performance are again very important phenomena.

Because this particular diagnosis gives you an idea of whether your boiler is functioning well or there is some malfunctioning or something goes wrong within the boiler system. So, the performance parameters must be analyzed first, under what category and parameters would like to evaluate the boilers. So, the boiler's performance parameter is like the efficiency evaporation ratio.

Now, these things they reduce over time, due to sometimes poor combustion, maybe because of the wrong choice of the fuel, maybe because of the low circulation or high circulation of air, etc. Then, there may be certain problems associated with the heat transfer surface, which may be attributed to falling, scaling, etc. This may be attributed to poor operation, very rapid load fluctuation may sometimes be leakage or condensate recovery, malfunctioning the preheater.

So, all these things are attributed under the edge of maintenance. Even if you see that for a new boiler, the reason for such deteriorating fuel quality, water quality is again very important to say if you have the water with a high level of turbidity, high level of total solid TDS, or high level of hardness, it can result in all these things can attribute to poor boiler performance. So, the boiler efficiency tests usually help us determine the deviation of boiler efficiency from the best efficiency.

And always you can assess that, what are the problematic area, and this way, you can perform some corrective measures, which are essential for the boiler's smooth functioning.

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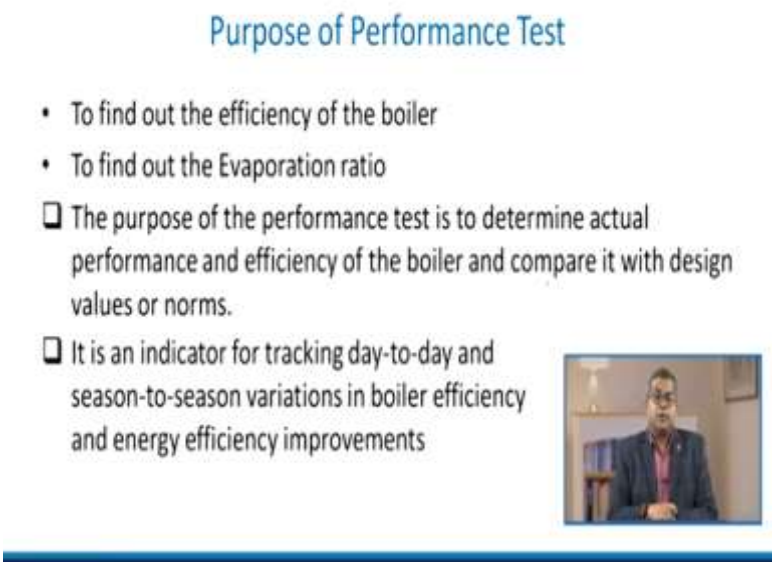

Now, again I am repeating that the purpose of the performance test is that, what is the boiler's efficiency, and you need to find out the evaporation rate ratio of the boiler because all these things we discussed in the previous slide are embedded in it. So, the purpose of the performance test is to determine the actual performance and efficiency of the boiler and compare it with the design, values, or norms.

You know, you see the different government organization attributes various norms. Sometimes, if you are not getting the proper efficiency, that may be one reason for the unburned fuel. And this may create an environmental problem, and of course, if you do not have the proper evaporation ratio, that means your tubes are not functioning properly. I mean, this is you can say the pressure vessel and any kind of a choking any kind of a malfunction of the tube may create a severe problem to the boiler's safety.

So, that is why every government or state government has its design values or norms. So, usually, these norms or the values are an indicator for tracking day to day and season to season variation of the boiler efficiency. Of course, energy and economic efficiency are also very important. You need to improvise all these things.

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Definition

- $Boiler\ efficiency = \eta = \frac{Heat\ Output}{Heat\ Input} \times 100$

$$= \frac{Heat\ in\ Steam\ Output\ (kCal.)}{Heat\ in\ fuel\ input\ (kCal.)} \times 100$$

- $Evaporation\ Ratio = \frac{Quantity\ of\ Steam\ Generation}{Quantity\ of\ Fuel\ Consumption}$

So, when we talk about the boiler efficiency and evaporation ratio, there are set mathematical formulas. Say, if you talk about the boiler efficiency, it is calculated using the following formulae:

$$Boiler\ efficiency = \eta = \frac{Heat\ Output}{Heat\ Input} \times 100$$

$$= \frac{Heat\ in\ Steam\ Output\ (kCal.)}{Heat\ in\ fuel\ input\ (kCal.)} \times 100$$

$$Evaporation\ Ratio = \frac{Quantity\ of\ Steam\ Generation}{Quantity\ of\ Fuel\ Consumption}$$

Now, when we talk about the evaporation ratio, that is the quantity of steam generation over fuel consumption. So, these two things are important.

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Reference Standards

British standards, BS845 : 1987

- The British Standard BS845: 1987 describes the methods and conditions under which a boiler should be tested to determine its efficiency.
- For the testing to be done, the boiler should be operated under steady load conditions (generally full load) for a period of one hour after which readings would be taken during the next hour of steady operation to enable the efficiency to be calculated.

As I told you, every state government and country has its norms, standards, codes, etc. And the reason is quite obvious that the boiler is a pressure vessel as well as it may create the problem of environment, it may create based on the other parameters, it may create the problem of safety. So, every country has its own codes standards for the smooth functioning of the boiler, like Indian boiler regulations, etc.

Similarly, we have British standards, and they are referred to as BS845:1987. This describes the method and condition under which a boiler should be tested to determine its efficiency. Because there must be some characterization, there must be some standards. So that we can use our protocols to determine the efficiency. Now the testing is to be done, and the boiler should be operated under steady load conditions and generally full load, which is based on the rating.

For a period of, say, one hour, the reading would be taken during the next hour of study operation to calculate the efficiency.

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Reference Standards

- The efficiency of a boiler is quoted as the % of useful heat available, expressed as a percentage of the total energy potentially available by burning the fuel. This is expressed on the basis of gross calorific value (GCV).

Now, usually based on the mathematical relationship, the boiler's efficiency is quoted as the percentage of the useful heat available, expressed as the percentage of the total energy potentially available by burning the fuel. This is usually expressed based on gross calorific value, sometimes called GCV.

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Reference Standards

- This deals with the complete heat balance and it has two parts :

(a) Part one deals with standard boilers, where the indirect method is specified.

(b) Part two deals with complex plant where there are many channels of heat flow. In this case, both the direct and indirect methods are applicable, in whole or in part.

Now, when we talk about the various standards, especially the British standards, this deals with the complete heat balance, and it usually has two parts. One is that part one deals with the standard boilers, where the indirect method is specified. Whereas part two deals with the complex plant, where there are many channels of heat flow. In this case, both the direct and indirect methods are applicable either partially or in total.

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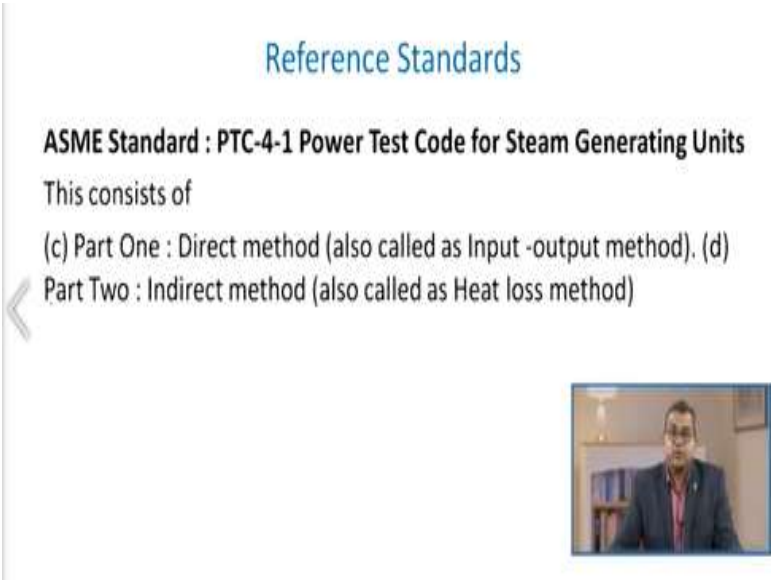

Another standard is again very common in practice: ASME, that is, the American Society for mechanical engineers, their standard PTC-4-1 power text code for steam generating units. This usually consists of part one, the direct method, and is sometimes called the input-output method. Another thing is that part two, the indirect method, is also called the heat loss method.

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In the Indian context, we also have our BIS code, the bureau of Indian standard BIS code. IS 8753 that is an Indian standard for boiler efficiency testing. Usually, the most standards for boiler efficiency computation include IS 8753 and BS 845; they are designed to spot the measurement of

boiler efficiency. These standards invariably do not include blowdown as a loss in the efficiency determination process.

Now, I am telling you this because it also carries the heat value when we go for the blowdown. It also carries because it is normally when it discharges from the boiler, usually has the temperature equivalent to the boiler and a significant quantity of water. So, if you do not include this blowdown, there is a flow in the standard.

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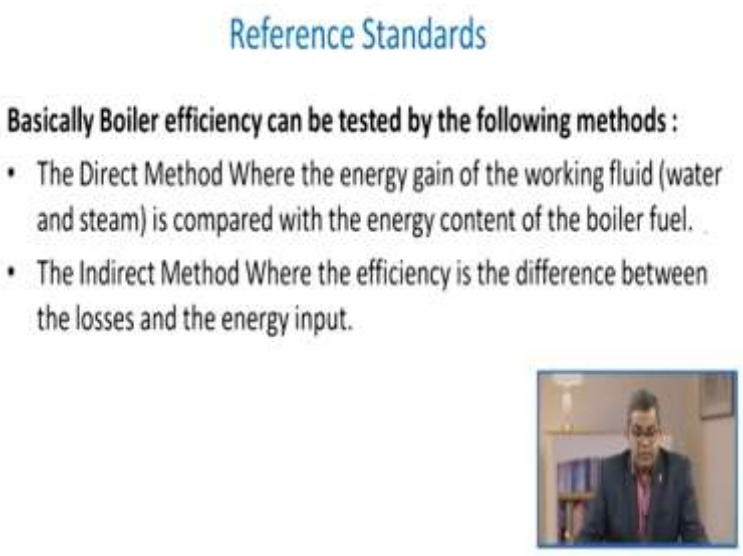

Now basically, boiler efficiency can be tested by different methods; one is the direct method where the energy gain of the working fluid, water, and steam, is compared with the energy content of the boiler fuel, maybe oil, maybe gas, or maybe coal. The indirect method where the efficiency is the difference between the losses and energy input.

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Direct Testing Method

This is also known as "input-output method" due to the fact that it needs only the useful output (steam) and the heat input (i.e. fuel) for evaluating the efficiency.

This efficiency can be evaluated using the formula :

- $Boiler\ Efficiency = \eta = \frac{Heat\ Output}{Heat\ Input} \times 100$
- $Efficiency = \frac{Heat\ addition\ to\ the\ Steam}{Gross\ heat\ in\ fuel\ input} \times 100$

When we talk about the direct testing method, it is also known as the input-output method. This is because it needs only the useful output, that is, the steam and the heat input that is fuel for evaluating the efficiency. Now, this efficiency can be evaluated using the formula

$$Boiler\ Efficiency = \eta = \frac{Heat\ Output}{Heat\ Input} \times 100$$

$$Efficiency = \frac{Heat\ addition\ to\ the\ Steam}{Gross\ heat\ in\ fuel\ input} \times 100$$

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Direct Testing Method

- $Boiler\ efficiency = \frac{Steam\ flowrate(Q) \times (steam\ enthalpy(h_g) - feed\ water\ enthalpy(h_f))}{Fuel\ firing\ rate\ (q) \times Gross\ Clorific\ Value\ (GCV)} \times 100$

So, when we talk about the boiler efficiency under the edges of the direct testing method, it is referred to as

$$Boiler\ efficiency = \frac{Steam\ flowrate(Q) \times (steam\ enthalpy(h_g) - feed\ water\ enthalpy(h_f))}{Fuel\ firing\ rate\ (q) \times Gross\ Clorific\ Value\ (GCV)} \times 100$$

the steam flow rate Q is team enthalpy hg. Of what is feed water enthalpy hf, that is a fluid enthalpy, over fuel firing rate q and GCV, the gross calorific value multiplied by the 100.

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Now, there are various advantages associated with the direct testing method that plant people can quickly evaluate the boiler's efficiency. They require very few parameters for computation, quite evident from the previous mathematical relationship. And they need very few instruments for monitoring. So, these are the advantages associated with this particular slide.

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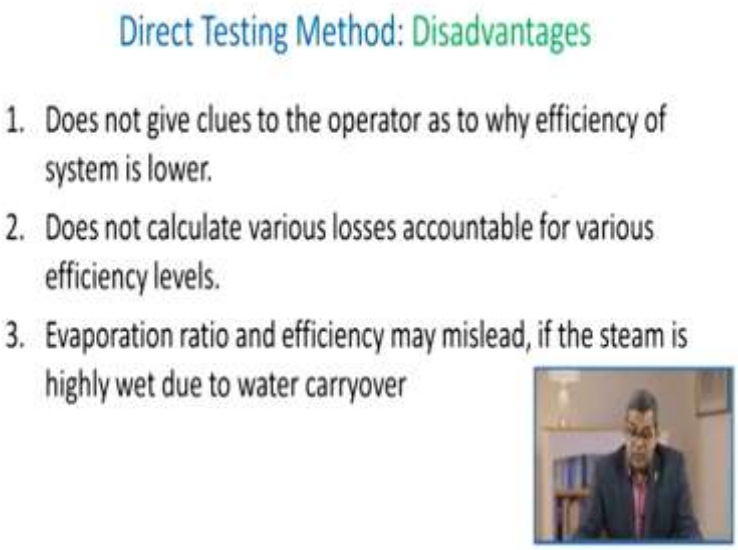

But when there are advantages obviously, you cannot overlook the importance of disadvantages. So, one disadvantage is that it does not give a clue to the operator as to why the system's efficiency is lower. Again, it is a major disadvantage and does not calculate various losses accountable for various efficiency levels. Again, evaporation ratio and efficiency may sometimes mislead if the steam is highly wet due to the water carryover.

Water carryover is again a very important phenomenon, which we will discuss in time. So, at last, in this particular lecture, we discussed the various parameters attributed to the performance of the boiler and discussed that, what the major parameters are required for the performance evaluation of the boiler, as well as discussed a couple of high-end boilers at the start of this lecture.

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References

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- Buecker, Brad - Fundamentals of steam generation chemistry-PennWell Corp (2000)
- S. C. Stultz, J. B. Kitto - Steam_ Its Generation and Use (41st Edition)-Babcock & Wilcox Company (2005)
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Again, you may look for different references. Apart from this, we have discussed a couple of standards, BIS code, British standard code, American standard codes, etc., for them as reference material. So, in case you are facing any difficulty, you may look to all these references. Thank you very much.