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

Lecture - 25
Steam Generation Unit - Heaters

Welcome to the next aspect of the steam generation unit under the aegis of chemical process utilities. Before we go into the next stage, let us have a brief outlook about the topics we covered previously. We discussed the various components of steam generation units in which, if you recall, we discussed the fuel preparation segments.

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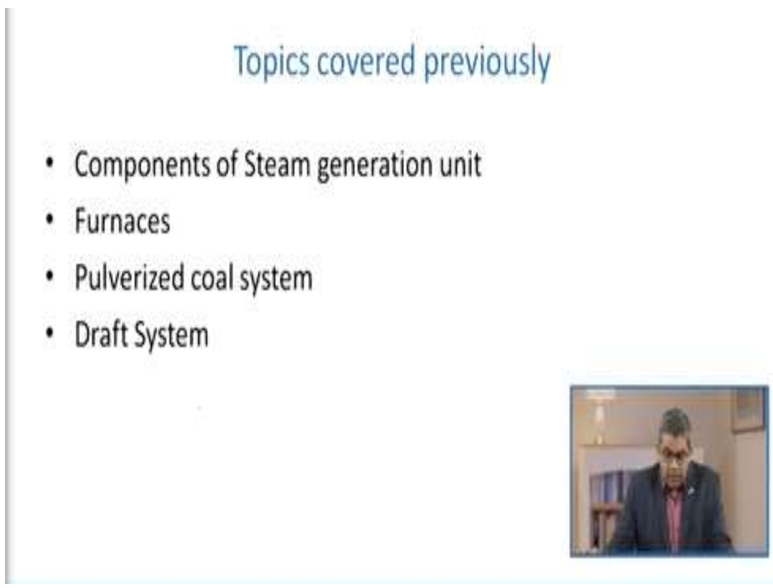

We discussed the environmental aspect, especially with the stake and another thing. And then steam generation and power output etc. We discussed the various aspects of furnaces, pulverized coal system, and a draft system.

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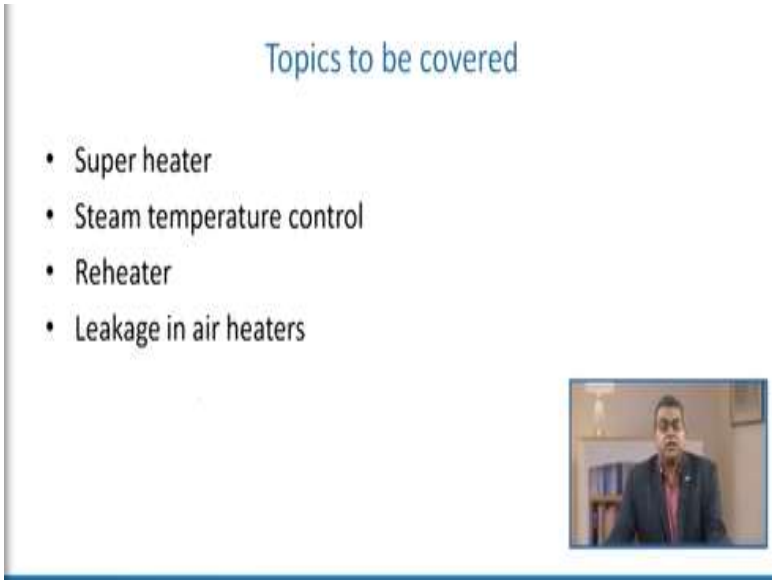

In this lecture, we will discuss the other accessories and mountings of this steam generation unit. This includes superheaters, steam temperature control, reheaters, and leakage in the air heaters. So, let us discuss all these things one by one. First is the superheater. This superheater usually consists of superheater headers and superheater elements. Because sometimes we need the steam in the superheated mode, these superheaters are quite useful devices to get the same.

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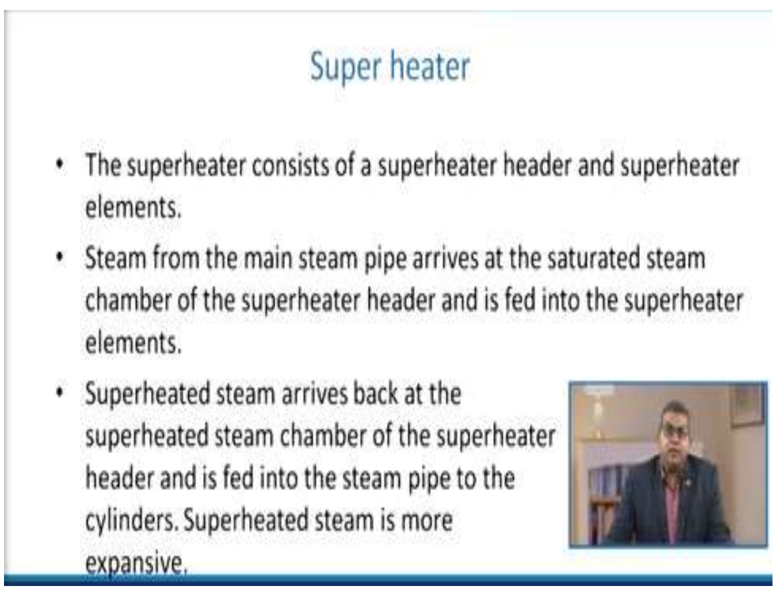

Now steam from the main steam pipe usually arrives at the saturated steam chamber of the superheater header and is fed into the superheater element. This superheated steam usually arrives back at the superheated steam chamber of the superheater header and is fed into the steam pipe to the cylinder.

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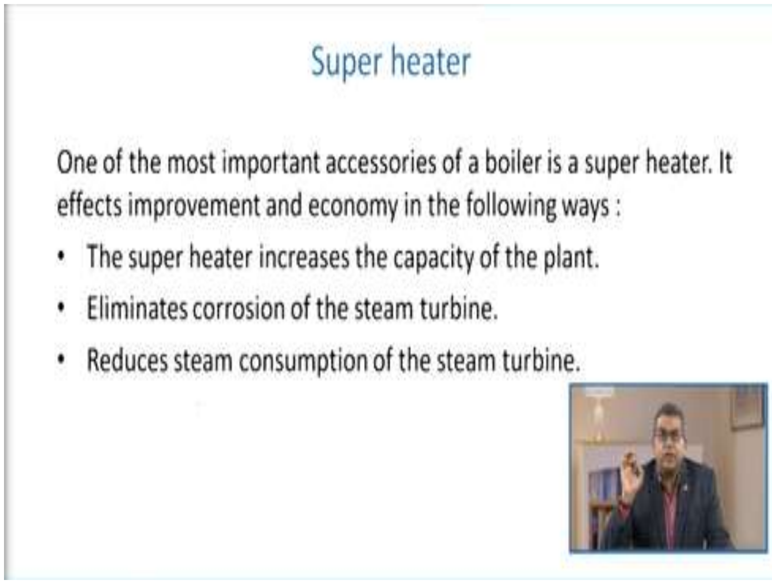

So, the superheated steam is expensive compared to the saturated one. One of the most important accessories of a boiler is a superheater. It affects the improvement and economy of the boiler or a steam generation unit in different ways. One way is that a superheater increases the plant's capacity. Sometimes, one basic example is if you are using the saturated steam and passing from one station to another station.

There may be a chance that the saturated steam may get condensed, thereby creating the problem of pressure drop. Because of the condensation, the segment's volume may be drastically reduced. You may not get the desired effect with respect to the temperature and the pressure. That is why the superheaters increase the capacity of the plant. This superheater eliminates the chances of corrosion in the steam turbines.

They reduce the steam consumption of the steam turbine because the higher temperature and the pressure are always desirable in the steam turbine.

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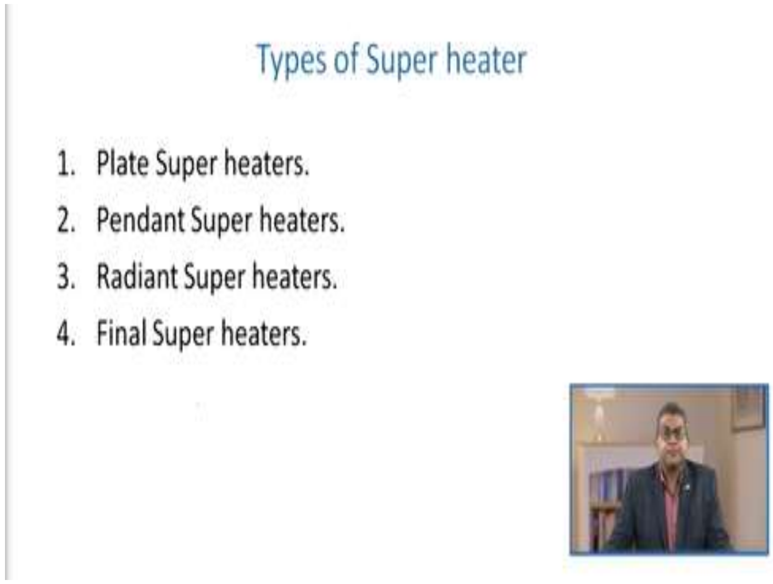

When you see that superheater, if they are so important, there are various types of superheaters. We need to address; one is the plate superheater. Another is the pendant type of a superheater, then the radiant type of a superheater, and the other is the final superheater.

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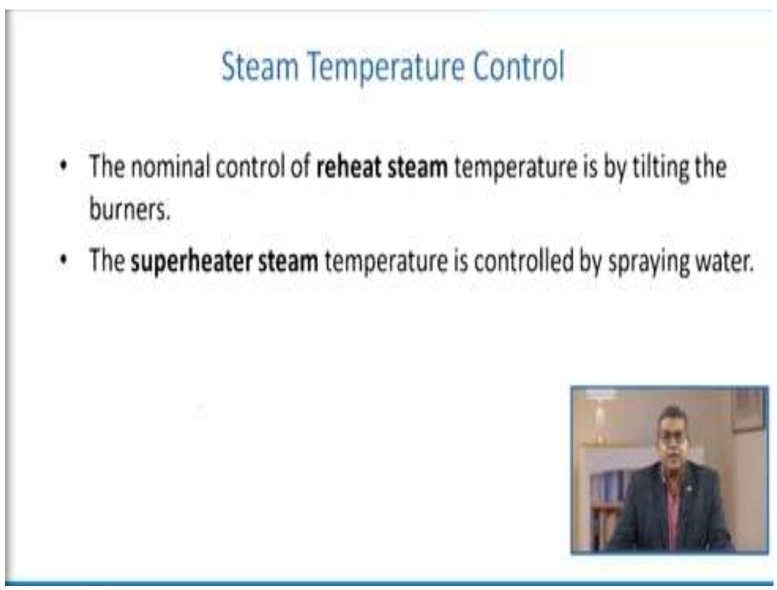

Apart from this, there are certain steam temperature control devices, and usually, nominal control of reheat steam temperature is by tilting the burners. And the superheated steam temperature is usually controlled by the spraying water because it is always attributed to the consumption and combustion aspect. So, you can control it by spraying water.

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Sometimes, some designs are attributed to excess air control when we talk about the control methodology according to the need. Sometimes you may go for the flue gas recirculation aspect, sometimes gas bypass control, control of combination superheaters, and adjustable burner controls. All these are steam temperature control devices.

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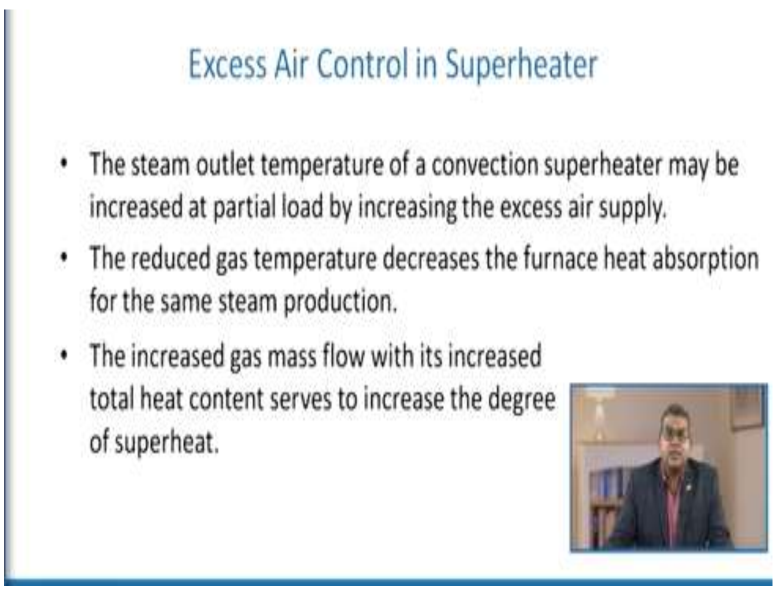

Let us talk about the excess air control in the superheater. The steam outlet temperature of a convective superheater may be increased at partial load by increasing the excess air supply. The reduced gas temperature usually decreases the furnace heat absorption for some, for we can say the same for steam production. The increased gas mass flows with its increased total heat condensers to increase the degree of superheat.

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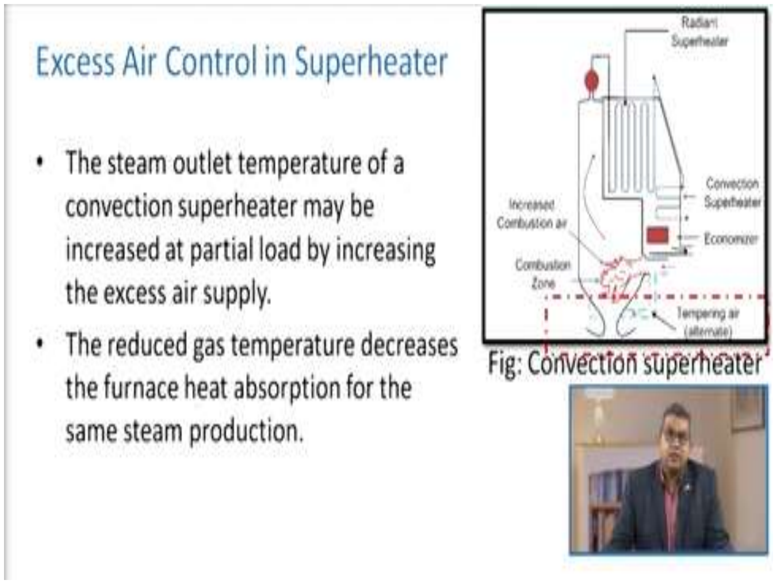

Now the; steam outlet temperature of a convective superheater. This may be increased at partial load by increasing the excess air supply. Here you can see that sometimes we need to go for the tempering here. The reduced gas temperature decreases the furnace heat absorption of the same steam production.

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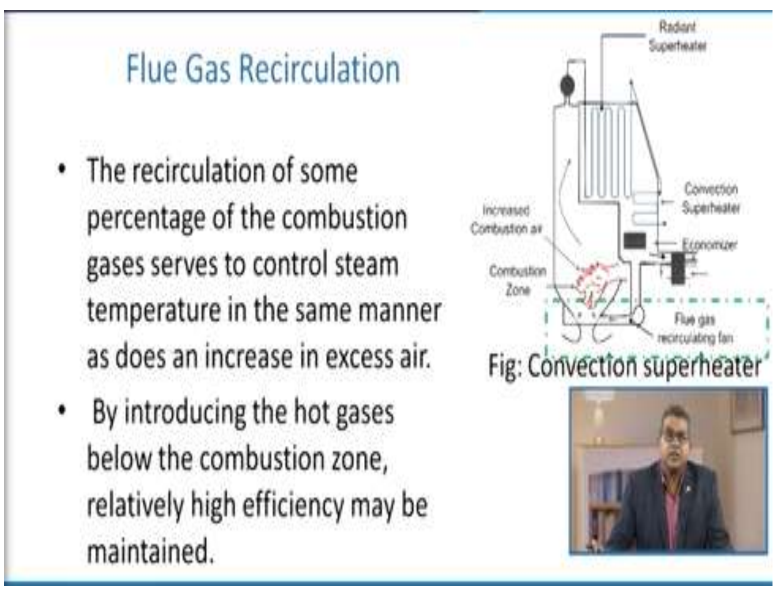

Let us talk about flue gas recirculation. The recirculation of some percentage of combustion gas serves to control the steam temperature in the same manner as does an increase in excess air. Now here you see that this is the flue gas recirculating fan. Now, by introducing the hot gas below the combustion zone, you see this is the combustion zone. And if you here we have the hot gas gases supply. Now, this introduction relatively increases the high efficiency.

So, you can say that high efficiency can be maintained by introducing hot gases below the combustion zone.

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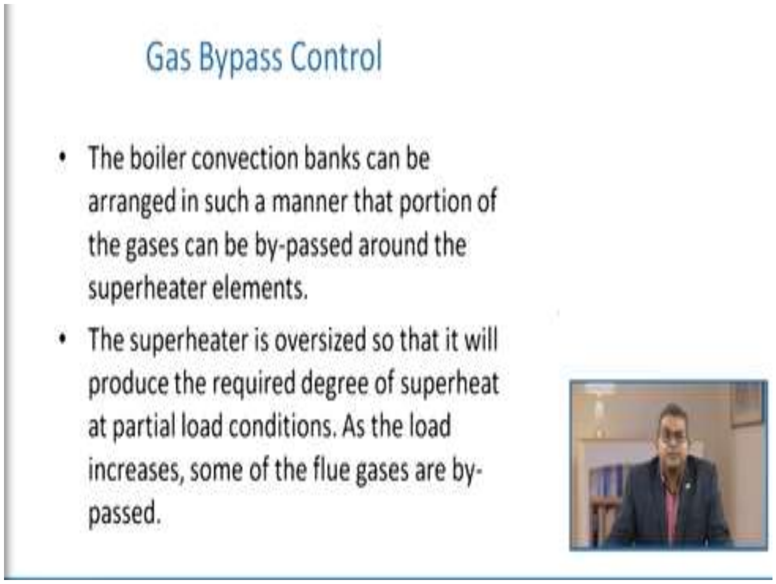

Now let us talk about gas bypass control. Now the boiler convection banks can be arranged so that the portion of the gas can be bypassed around the superheater elements. So, the superheater is oversized to produce the required degree of superheat at partial load conditions. As the load increases, some of the flue gases are bypassed. Another important aspect is the adjustable burner control. Sometimes, in the furnace, we used multiple burners to maximize efficiency.

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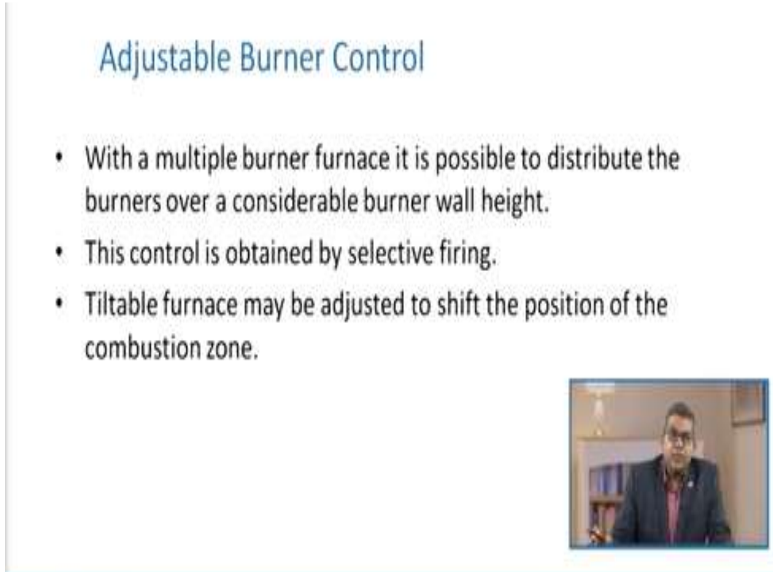

So, it is possible to distribute the burners over a considerable burner wall height with a multiple burner furnace. Now, this control is obtained by selective firing. Sometimes we use a tiltable furnace. So, the tiltable furnace may be adjusted to shift the position of the combustion zone: Reheaters, the reheater function is similar to the superheater in that it serves to elevate the steam temperature. Now usually, the primary steam is supplied to the high-pressure turbine.

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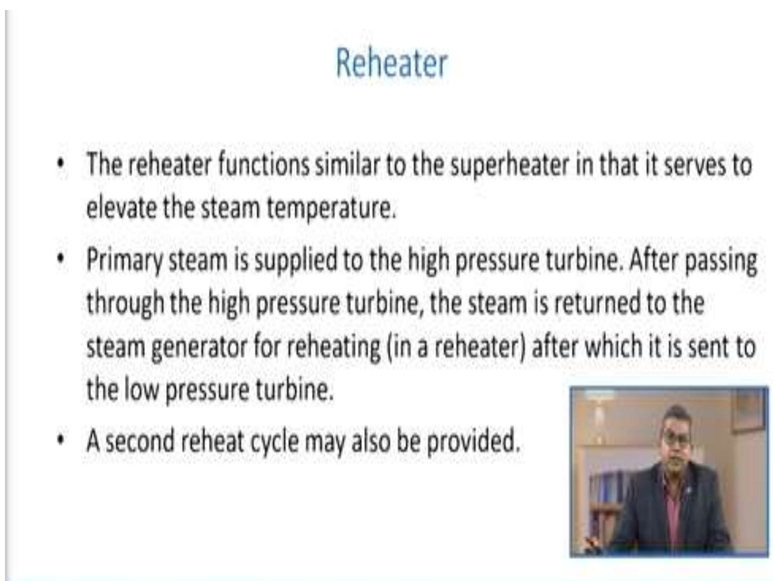

After passing through the high-pressure turbine, the steam is returned to the steam generator for reheating. Obviously, in a reheater, it is sent to the low-pressure turbine. Sometimes a second reheat cycle may also be provided to improvising the efficiency.

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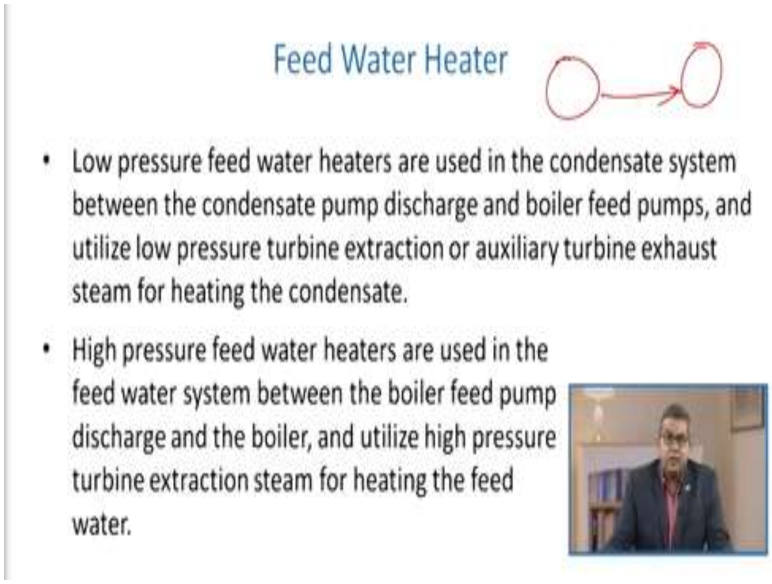

Feedwater heater. Low-pressure feedwater heaters are sometimes used in the condensate system between the condensate pump discharge and the boiler feed pump. So, this is the condensate pump discharge, and this is the boiler field system. So, sometimes you need to have heating to maintain the appropriate temperature. This way utilizes the low-pressure turbine extraction or auxiliary turbine exhaust system to heat the condensate.

High-pressure feed water heaters are used in the feedwater system between the boiler feed pump discharge and the boiler. And utilize high-pressure turbine extraction steam for heating the feedwater.

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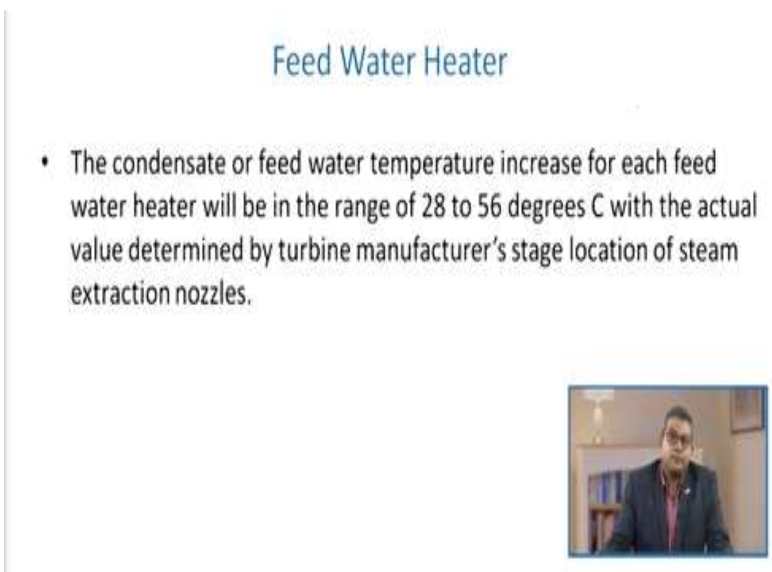

The condensate or feedwater temperature increase for each feedwater heater will be almost 28 to 56 degrees Celsius, with the actual value determined by the turbine manufacturer stage location of the steam extraction nozzle. So, depending on the turbine size, some turbines say they offer an alternate number of extraction nozzles with usually a choice of using the highest pressure extraction nozzle.

The selection in this case of the total number of feedwater heaters to use should be based on an economic evaluation of economic feasibility. Let us talk about low-pressure heaters because we use this term in so many ways. Now use one or more low-pressure feedwater heaters to raise the condensate temperature from condensate pump discharge temperature to the deaerator inlet temperature.

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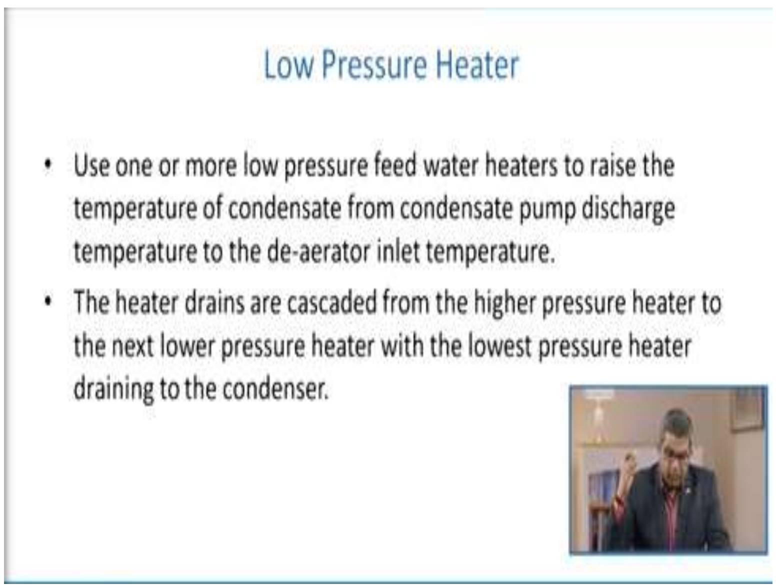

Now deaerator is sometimes used to eliminate the entrapped air in the feedwater line. Just because this entrapped air has no heat value, it may cause the corrosion problem, cause the foaming problem, and alter the system's better heat efficiency. The heater drains are cascaded from the high-pressure heater to the next low-pressure heater, with the lowest pressure heater draining to the condenser.

Let us talk about the high-pressure heater. You may use one or more high-pressure feedwater heaters to raise feedwater temperature from deaerator outlet temperature to the required boiler economizer inlet temperature.

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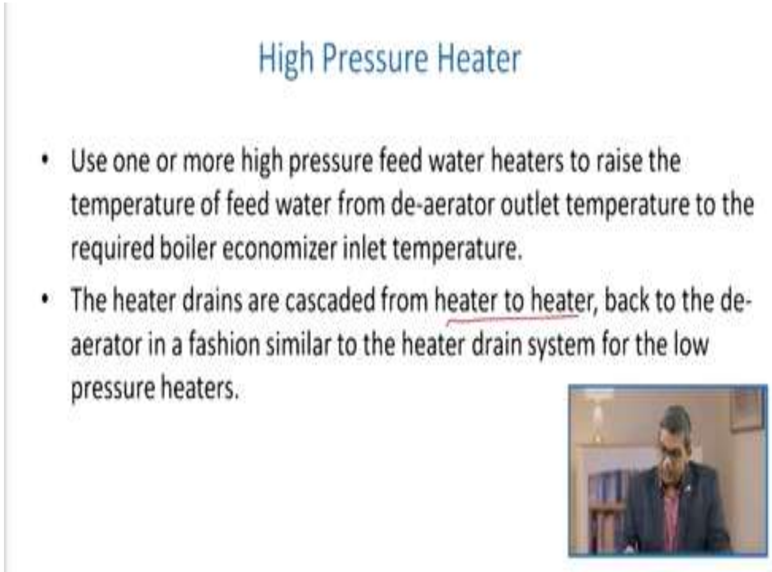

Now, these heat or drains are cascaded from heater to heater back to the deaerator in a fashion similar to the heater drain system for the low-pressure heaters.

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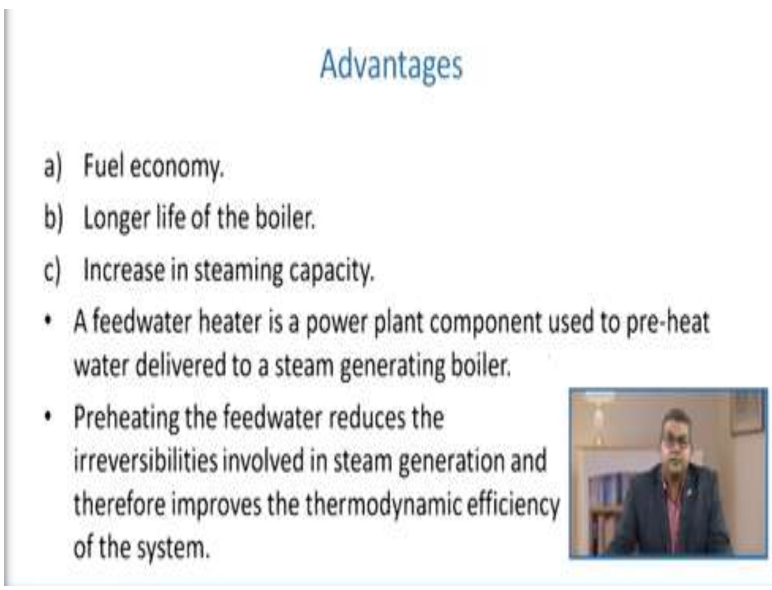

Now there are various advantages attributed to this type of system. One is the fuel economy; they have a longer life or are the attributes of the longer life of the boiler. They are increasing the steaming capacity. So, a feedwater heater is a power plant component using preheated water delivered to the steam-generating boilers. Now, the preheating of feedwater reduces the irreversibility is involved in the steam generation and, therefore, improves the thermodynamic efficiency of the system.

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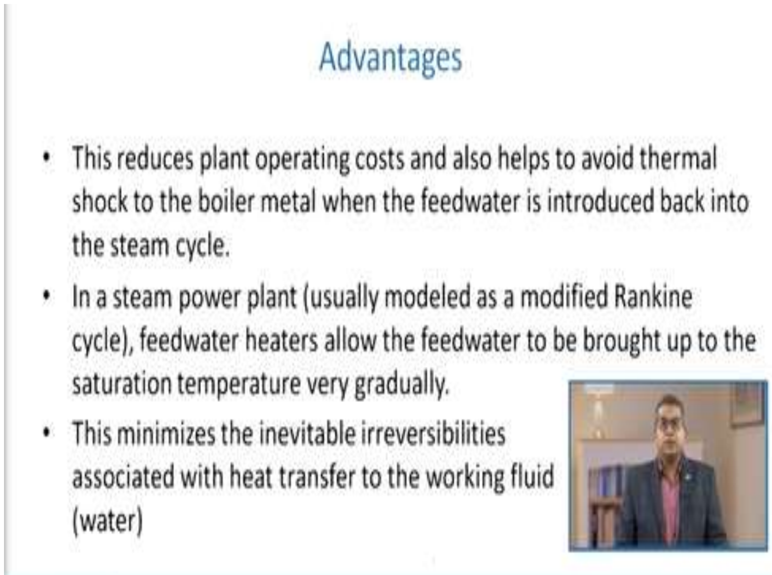

This reduces the plant operating cost, maximizes the efficiency or economy, etc. And also helps to avoid the thermal shock to the boiler metal when the feedwater is introduced back into the steam cycle because it minimizes the delta t. So, that is why the chances of thermal shock can be minimized. Now in a steam power plant usually modeled as a modified Rankine cycle, we have already discussed this Rankine cycle.

Now the feedwater heaters allow the feedwater to gradually be brought up to the saturation temperature. This minimizes the inevitable irreversibility of heat transfer to the working fluid. We are using the working fluid in the water now since we are using different cycles like the Rankine cycle, Carnot cycle, etc.

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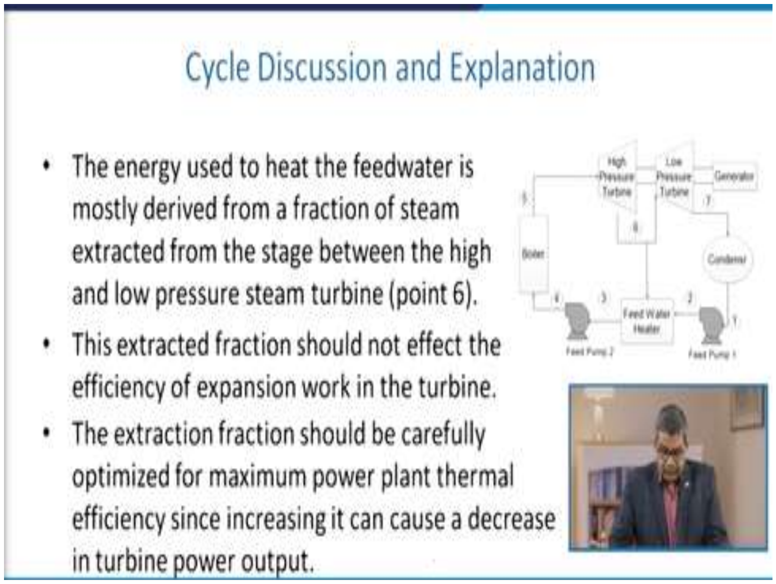

So, let us have a brief discussion about the cycle and explanation. Here, the energy used to heat the feedwater is mostly derived from the fraction of steam extracted from the stage between the high and low-pressure steam turbine. Now here you see, this is the high and low-pressure turbine. This extracted fraction should not affect the efficiency of expansion work in the turbine.

The extraction faction should be carefully optimized for maximum power plant thermal efficiency since increasing it can cause a decrease in turbine power output.

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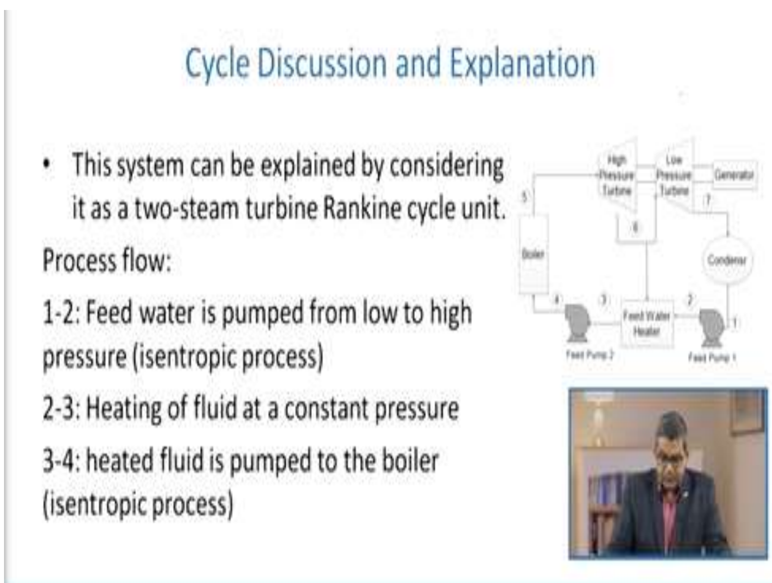

This system can be explained by considering it a two steam turbine Rankine cycle unit. Here, we can discuss the process flow from station 1 to station 2. The feedwater is pumped from low to high pressure, which is an isentropic process. Now from stations 2 to 3, the heating of the fluid is at constant pressure, and from 3 to 4, the heated fluid is pumped to the boiler, which is again an isentropic process.

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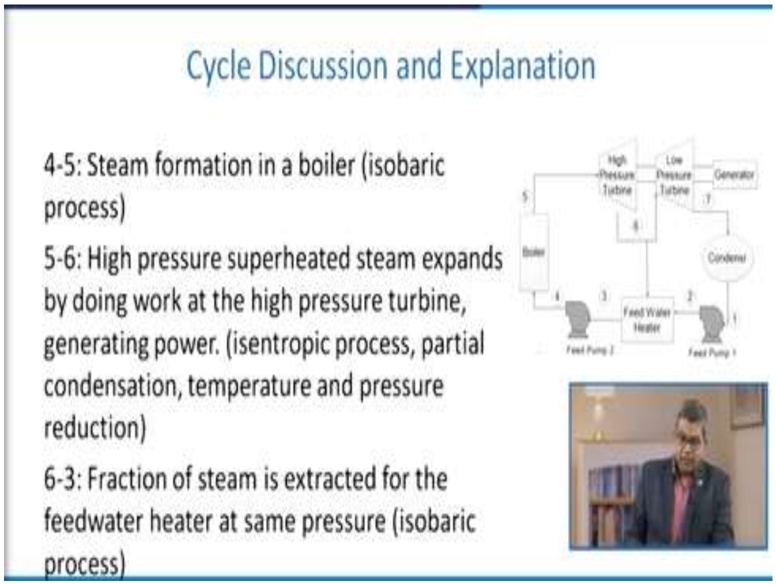

And from 4 to 5, steam formation in a boiler is an isobaric process. From 5 to 6, the high-pressure superheated steam expands by working at a high-pressure turbine generating power. That is an isentropic process, partial condensation temperature, and pressure reduction. It is quite obvious because it is a turbine. Then this segment that is 6 to 3 is a fraction of steam, which is extracted for the feedwater heating system at the same pressure. That is an isobaric process.

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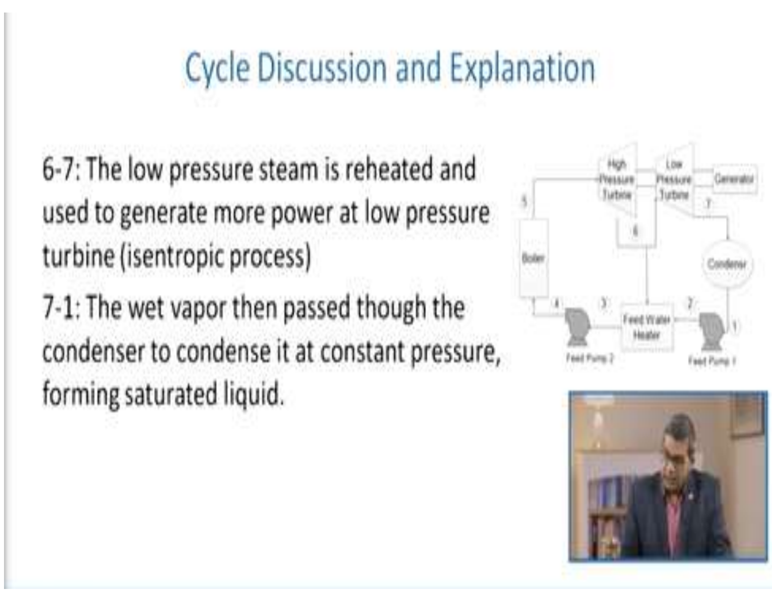

And from 6 to 7 here. The low-pressure steam is reheated and used to generate more power at low pressure, which is an isentropic process. And from 7 to 1, the wet vapor then passes to the condenser to condense it at constant pressure forming the saturated liquid.

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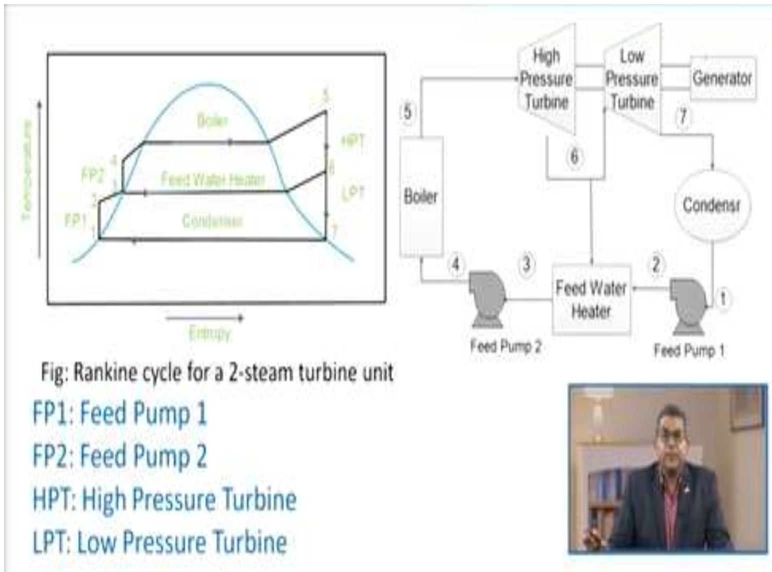

If we convert the entire thing into the temperature entropy diagram, that is the Rankine cycle for two steam turbine units. Now here you see that this is the feed pump one, so FP1 here isentropic operation. Then it goes to feed pump 2 and high-pressure turbine. Here we are using the isentropic operation again and a low-pressure turbine. This is the isentropic operation.

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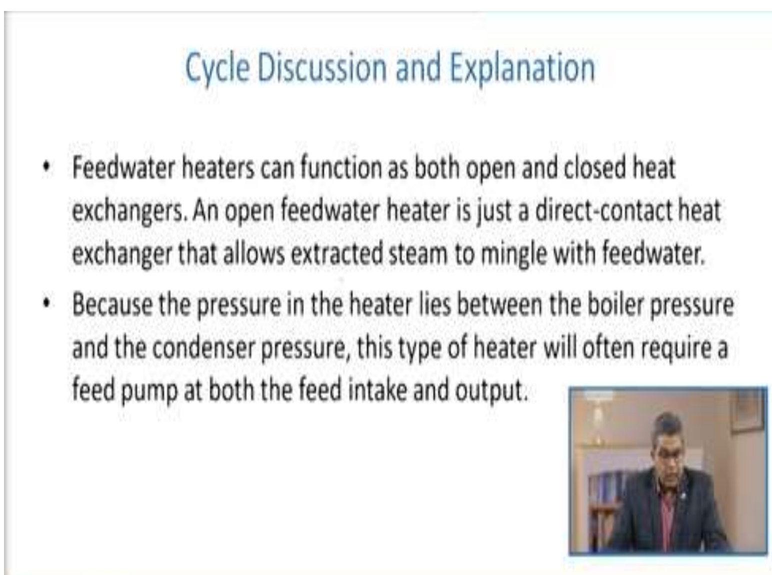

Now feedwater heaters; can function as both open and closed heat exchangers. An open feedwater heater is a direct contact heat exchanger that allows extracted streams to mingle with the feedwater. Now because the pressure in the heater lies between the boiler pressure and the condenser pressure, this type of heater will often require a feed pump at both the feed intake and output.

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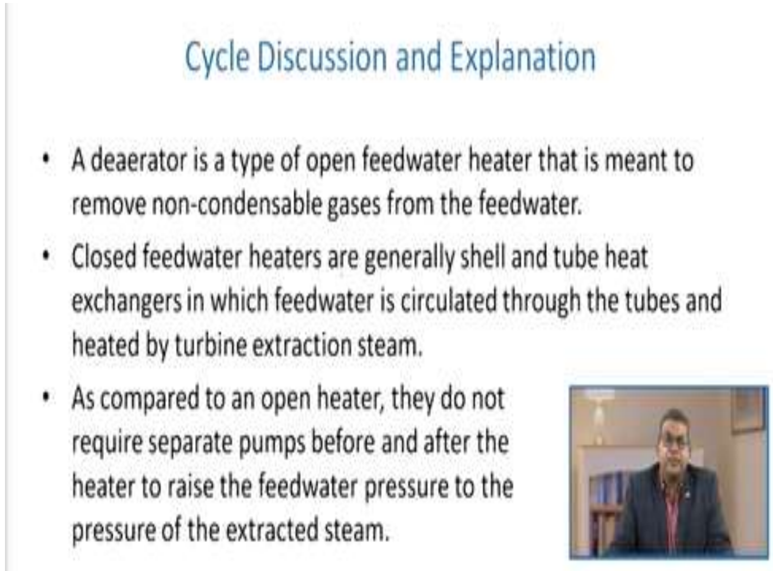

Deaerator is a different type of open feedwater heater system. This is meant to remove the non-condensable gases from the feedwater and air. So, the closed feedwater heaters are generally shell and tube heat exchangers in which the feedwater is circulated through the tubes and heated by the turbine extraction steam. If you compare it with the open heater, they do not require separate pumps before and after the heater to raise the feedwater pressure to the pressure of the extracted steam.

However, the extracted steam must be throttled to a condenser pressure, and many powers plants have several feedwater heaters that can be open or closed. So, the feedwater heaters are utilized in both fossils fuelled or nuclear-powered plants.

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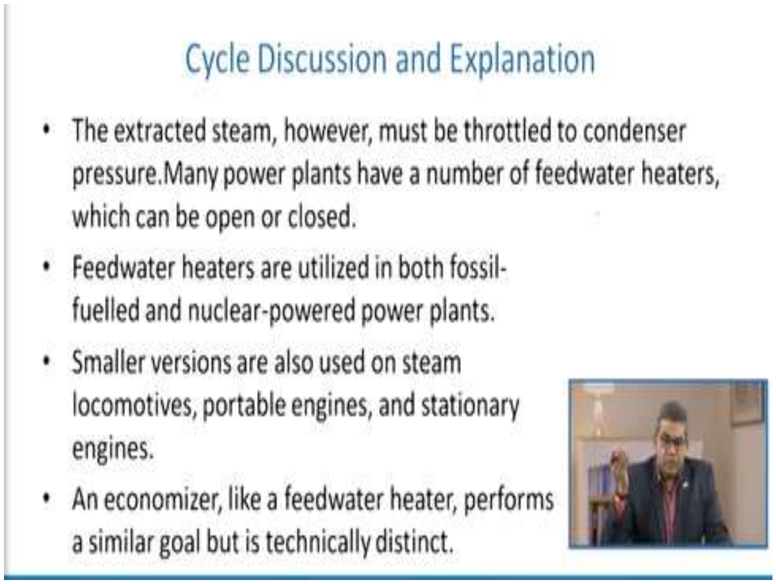

Small versions are also available, and they are used for steam locomotives, portable engines, stationary engines, etc. Now, an economizer like a feedwater heater performs a similar goal but is technically distinct.

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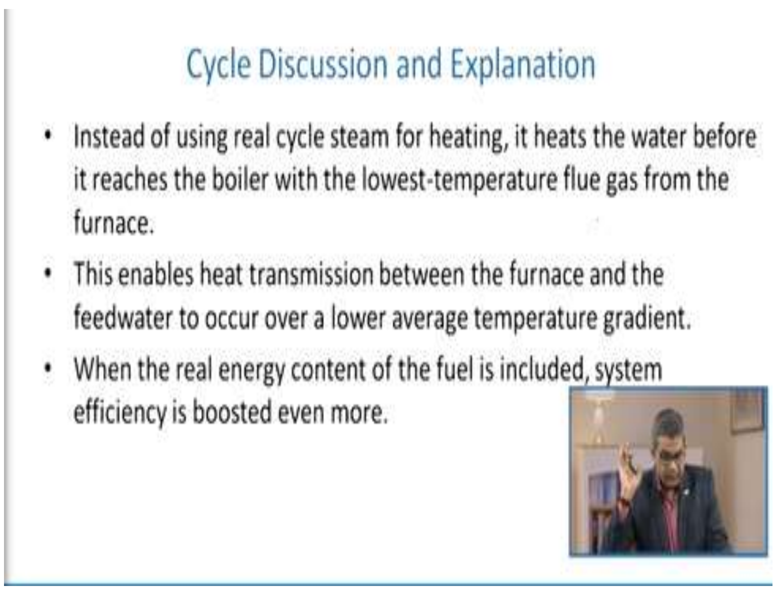

Instead of using real cycle steam for heating, it heats the water before reaching the boiler with the lowest temperature flue gas from the furnace. So, this is the slight difference between the superheater and the economizer. Now this enables the heat transmission between the furnace and the feedwater. So, flue gases, excess heat, economizer, and water preheating. When fuel's real energy content is included, the system efficiency is boosted even more.

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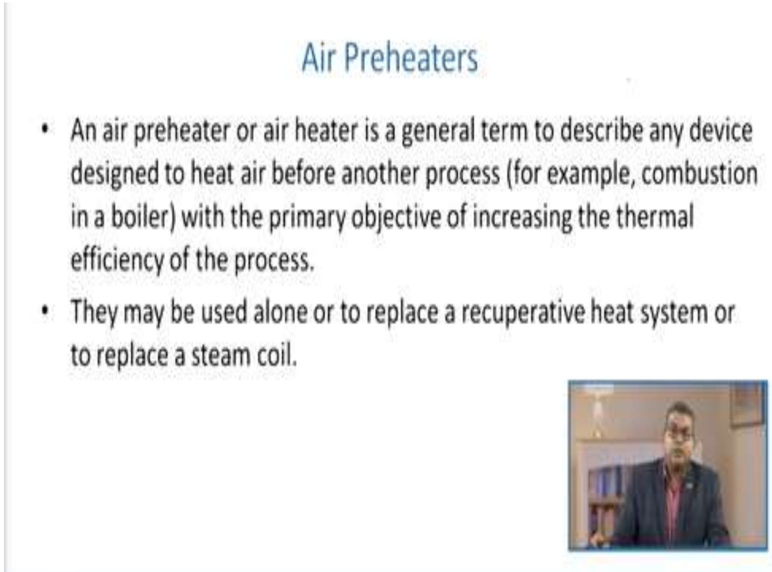

Let us talk about the air preheaters. Now an air preheater or air heater is sometimes referred to as an air heater. This is a general term to describe any device designed to heat air before another process. Let us take an example of combustion in a boiler with the primary objective of increasing the thermal efficiency of the process. See, when we are talking about the combustion process, the temperature is at an optimum level.

All the raw materials or ingredients must achieve a particular temperature zone. And if there is a drastic difference concerning the delta t, there may be chances of a thermal shock and a non-efficient system. So, that is why the air preheater because air is an integral part of the combustion process; air preheaters are quite important in any kind of steam generation unit.

Sometimes they may be used alone or replaced with a recuperative type of heat system or to replace a steam coil.

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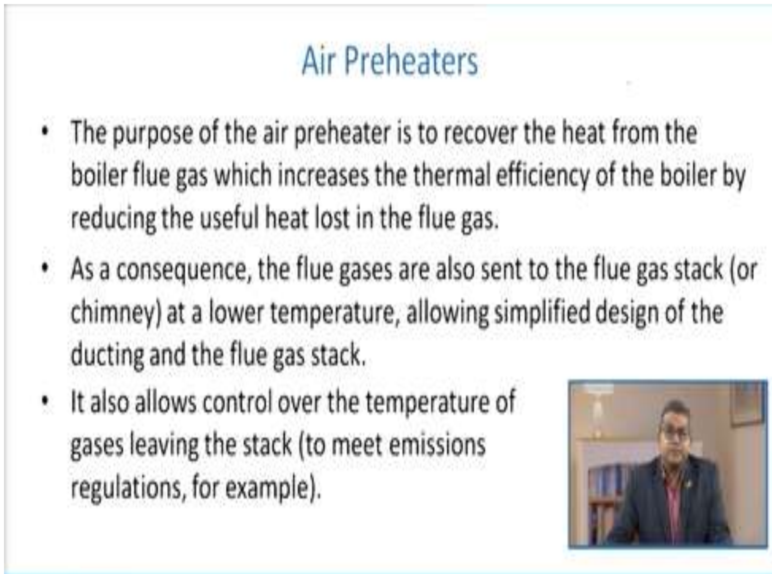

The air preheater aims to recover the heat from the boiler flue gas, which increases the boiler's thermal efficiency by reducing the useful heat lost in the flue gases. Consequently, the flue gases are also sent to the flue gas state, for example, the chimney, at a lower temperature allowing the simplified design of the ducting and the flue gas to stay. It also allows control over the temperature of gases leaving the stake. This is to meet the emission regulations etc.

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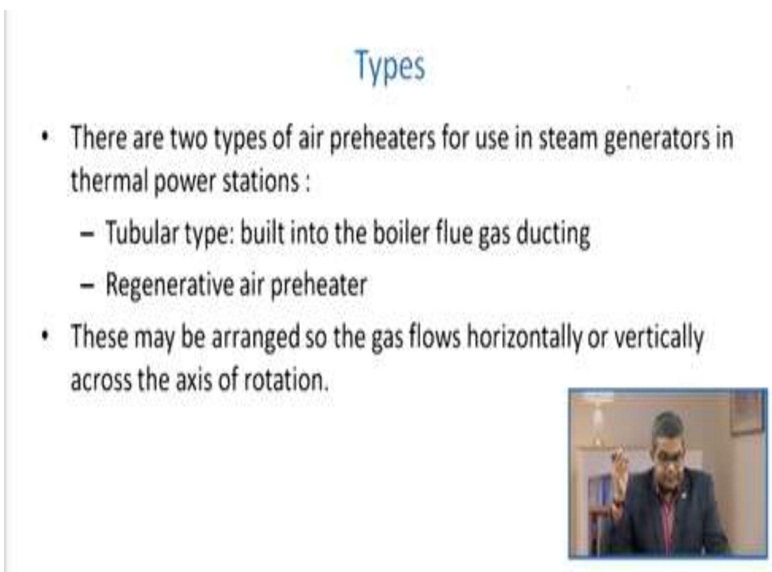

There are two types of air preheaters. One is the tubular type of preheater. This is built into the boiler flue gas ducting. Maybe like this, you may put over here this is the chimney. And another is the regenerative type of a preheater. Now, these may be arranged so that the gas flows horizontally or vertically across the axis of rotation. So, it all depends on the configuration.

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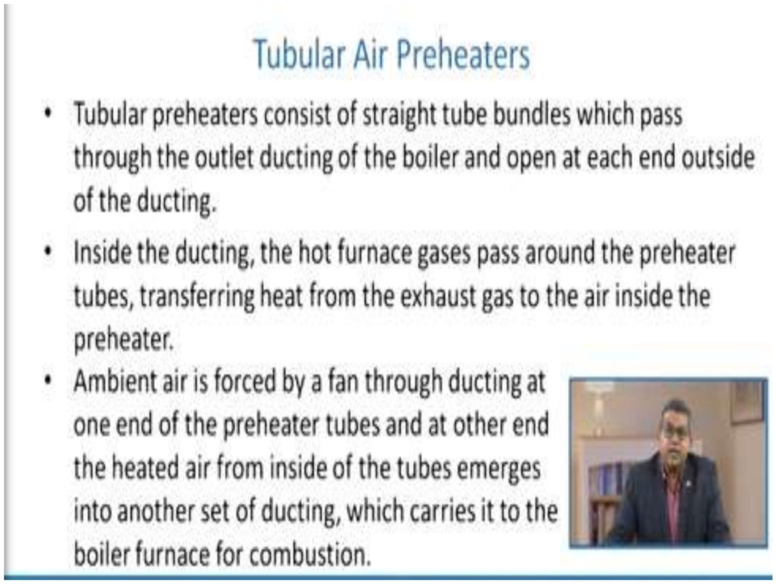

Let us talk about the tubular type of preheaters. Now tubular preheater consists of straight tube bundles that pass through the boiler's outlet ducting and open at each end outside the ducting. Now inside the ducting, the hot furnace gases pass around the preheater tubes transferring heat from the exhaust gas to the air inside the preheater. And ambient air is forced by a fan through ducting at one end of the preheater tubes.

And the other end of the heated air from inside the tube emerges into another set of ducting, which carries it to the boiler furnace for combustion purposes.

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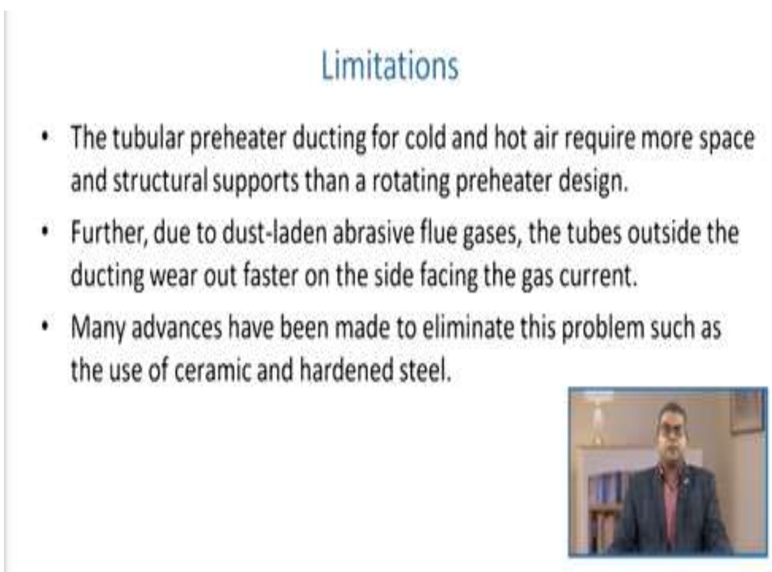

There are various limitations; one can talk about these tubular preheaters. Now the tubular preheater is ducting for cold and hot air. This requires more space and structural support than a rotating preheater design. Further, due to dust still and abrasive flue gases, the tubes outside the ducting wear out faster on the side facing the gas current. Many advances have been made to eliminate this particular problem, such as ceramic or hardened steel.

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Many new circulating fluidized bed or CFB or bubbling fluidized bed BFB type of system or steam generators are currently incorporating tubular heat preheaters offering an advantage with regards to the moving part of a rotary type.

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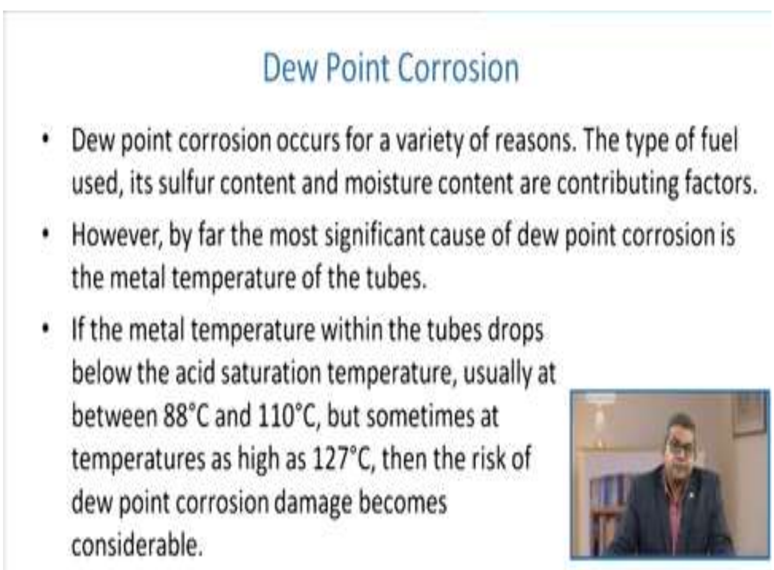

Another important phenomenon in this steam generation unit is the dew point corrosion. Now, this dew point corrosion usually occurs for a variety of reasons. The fuel used, sulfur content, and moisture content contribute to dew point corrosion. However, by far the most significant cause of dew point corrosion is the metal temperature of the tubes. Now, if the metal temperature within the; tubes drop below the acid saturation temperature, usually at between say 88 and 110 degree Celsius.

But sometimes, at temperatures as high as 127 degrees Celsius, the risk of dew point corrosion damage becomes considerable—the regenerative type of air preheaters.

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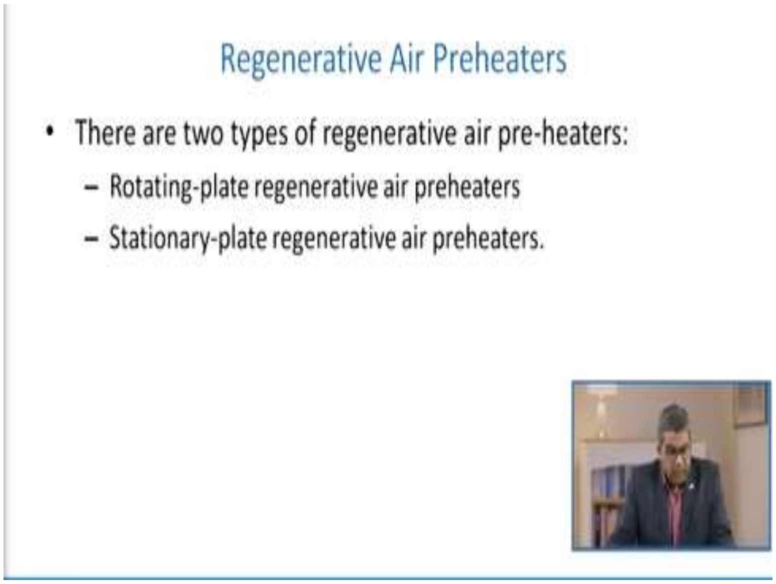

Usually, there are two types of regenerative air preheaters one is the rotating plate regenerative air preheaters, and the second one is the stationary plate regenerative air preheaters.

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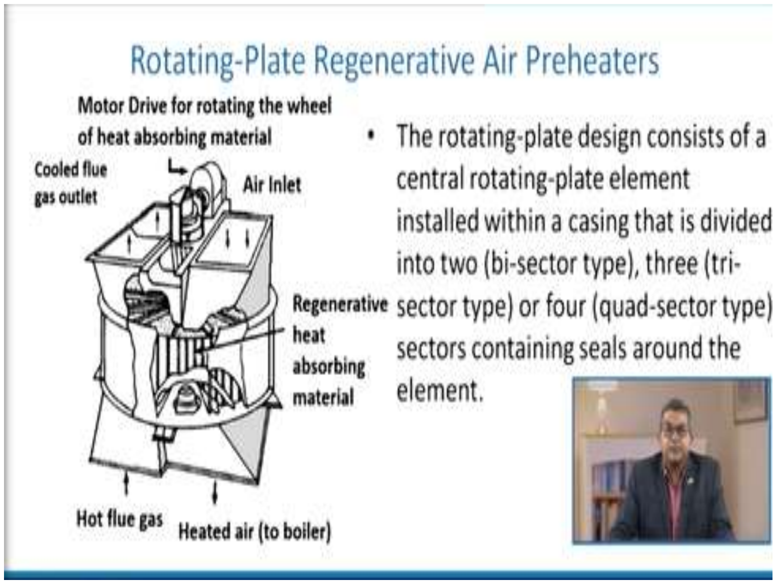

Now let us talk about the rotating plate regenerative air preheaters. This rotating plate design consists of a central rotating plate element installed within a casing divided into two bisector types or three tri-sector types or four quad sector type sectors containing the seals around the element. Here you see that this is an air inlet and a cooled flue gas outlet, the regenerative heat absorbing material.

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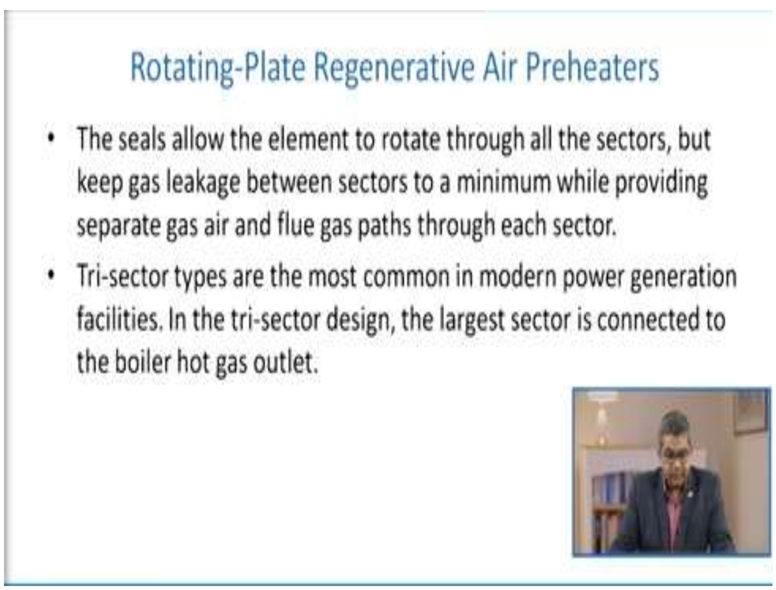

This seal allows the element to rotate through all the sectors but keeps gas leakage between the sectors to a minimum while providing a separate gas air and flue gas path through each sector. Sometimes tri-sector types are the most common in modern power generation facilities. The largest sector is connected to the boiler hot gas outlet in tri-sector design. When we talk about the other integral part of rotating regenerative plate preheaters, the hot x exhaust gas flows over the central element.

Thereby transferring some of its heat to the element and then ducted away for further treatment in dust collectors and other equipment before being expelled from the flue gas state. The second smaller sector is usually fed with the ambient air by a fan, which passes over the heated element as it rotates into the sector and is heated before being carried to the boiler furnace for combustion.

The third sector is the smallest one, and it heats air routed into the pulverizer and used to carry the coal air mixture to the coal boiler burners.

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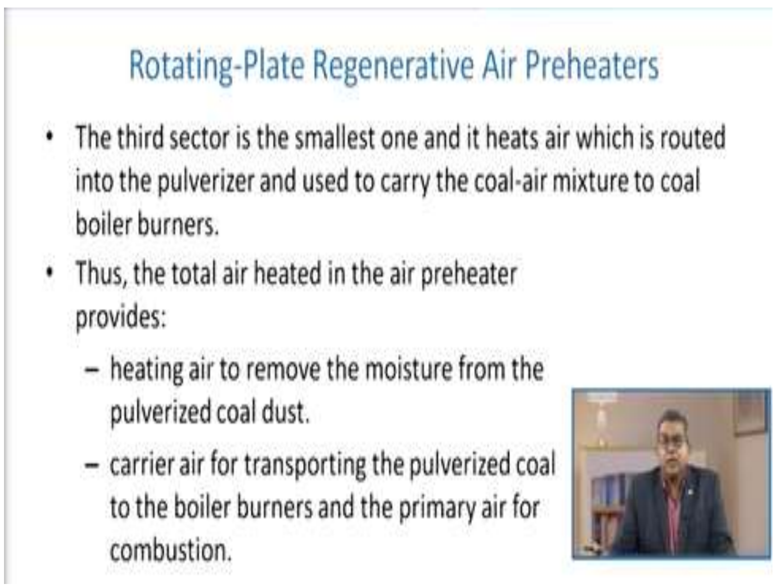

Thus, the total air heated in the air preheater provides the heating air to remove the moisture from the pulverized coal dust. And the second thing is the carrier air for transporting the pulverized coal to the boiler burners and the primary air for combustion.

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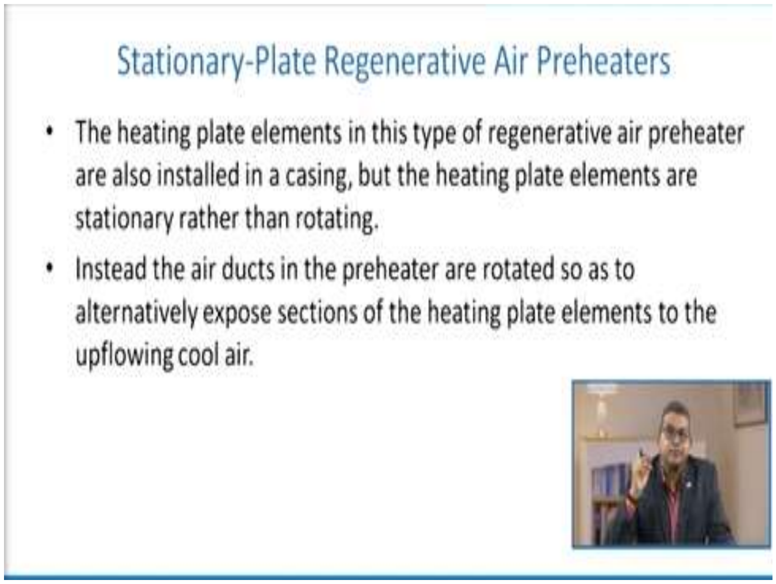

Let us talk about the stationary plate regenerative air preheaters. The heating plate elements in this type of regenerative air preheater are also installed in the casing, but the heating plate elements are stationary rather than rotating. Instead, you can say that air ducts in the preheater are rotated to alternatively expose a section of the heating plate elements to the up-flowing cool air.

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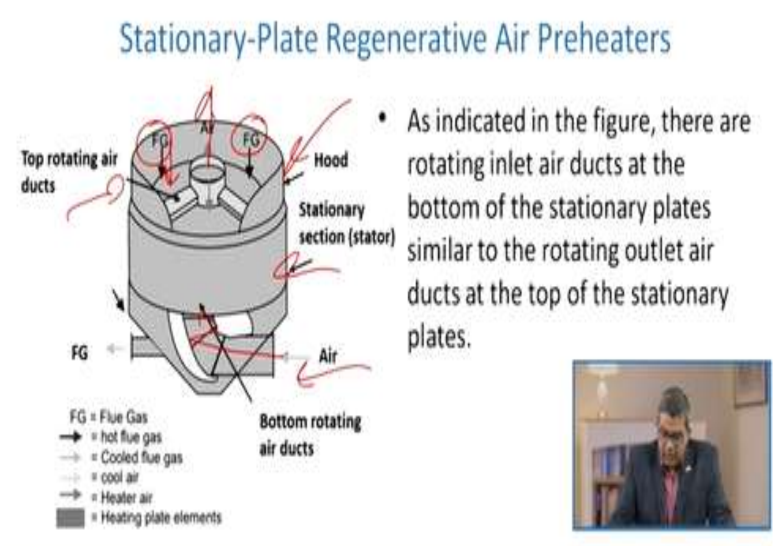

Now here, you can see the stationary plate regenerative air preheaters. This is the flue gas, and the air is coming out. This is the top rotating air. Here you are supplying the air, enclosed with the hood and stationery section. So, there are rotating inlet air ducts are at the bottom you can see here of the stationary plate. And similar to the rotating outlet air ducts at the top of the stationary plates.

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Sometimes you may experience leakage in air heaters.

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Now leakage is a common or normal phenomenon in all air heaters. At the same time, leakage in a new recuperative heat air heater is essentially zero. Leakage occurs with time and due to the accumulation of various thermal cycles. Nevertheless, leakage in recuperative air heaters can be restricted to 3% with regular maintenance. With the rotary regenerative type of air heaters, air leakage is inherent, and its design value ranges from 5 to 10%, which increases further over time as seals wear.

So, when the higher pressure air side passes to a lower pressure gas side, leakage occurs through gaps between the rotating and stationary parts. Sometimes we need to calculate the rate of such leakage.

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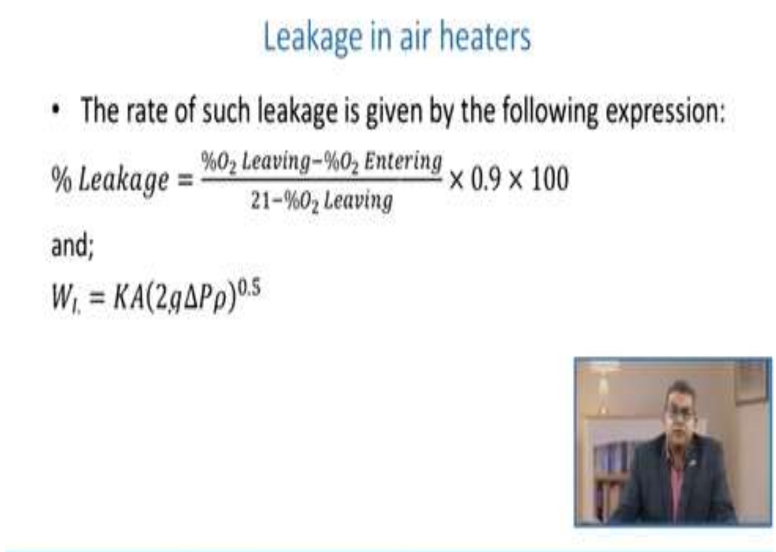

So, this particular mathematical expression usually gives the rate of such leakage.

The rate of such leakage is given by the following expression:

$$\%\ Leakage = \frac{\%O_2\ Leaving - \%O_2\ Entering}{21 - \%O_2\ Leaving} \times 0.9 \times 100$$

and;

$$W_L = KA(2g\Delta P\rho)^{0.5}$$

Where,

W_L: Leakage flow rate, kg/s

K: Discharge coefficient (generally 0.4-1.0)

A: Flow area,m^2

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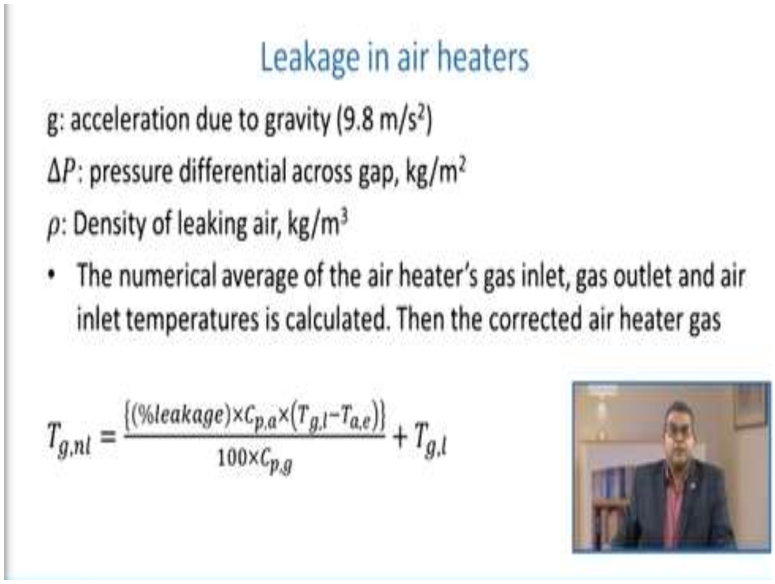

g: acceleration due to gravity (9.8 m/s^2)

ΔP: pressure differential across gap, kg/m^2

ρ: Density of leaking air, kg/m^3

The numerical average of the air heater's gas inlet, gas outlet and air inlet temperatures is calculated. Then the corrected air heater gas outlet temperature is calculated using the following formula:

$$T_{g,nl} = \frac{\{(\%leakage) \times C_{p,a} \times (T_{g,l} - T_{a,e})\}}{100 \times C_{p,g}} + T_{g,l}$$

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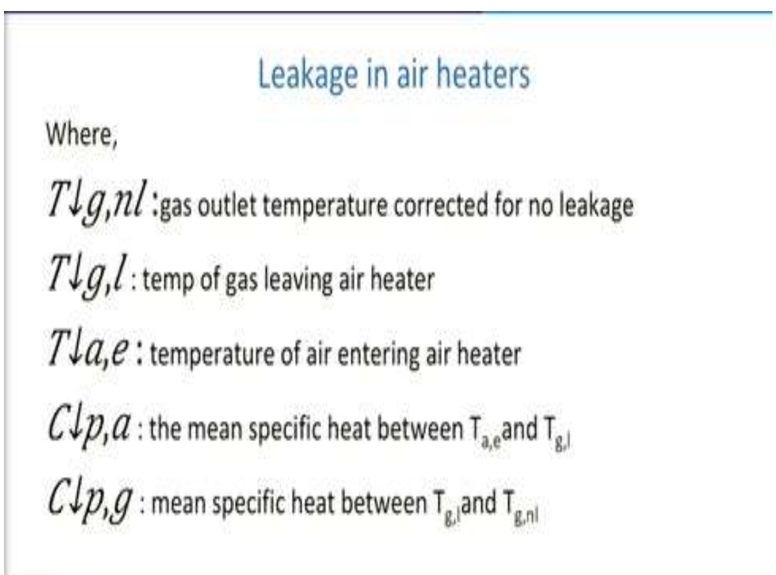

Where,

$T_{g,nl}$:gas outlet temperature corrected for no leakage

$T_{g,l}$: temp of gas leaving air heater

$T_{a,e}$: temperature of air entering air heater

$C_{p,a}$: the mean specific heat between $T_{a,e}$and $T_{g,l}$

$C_{p,g}$: mean specific heat between $T_{g,l}$and $T_{g,nl}$

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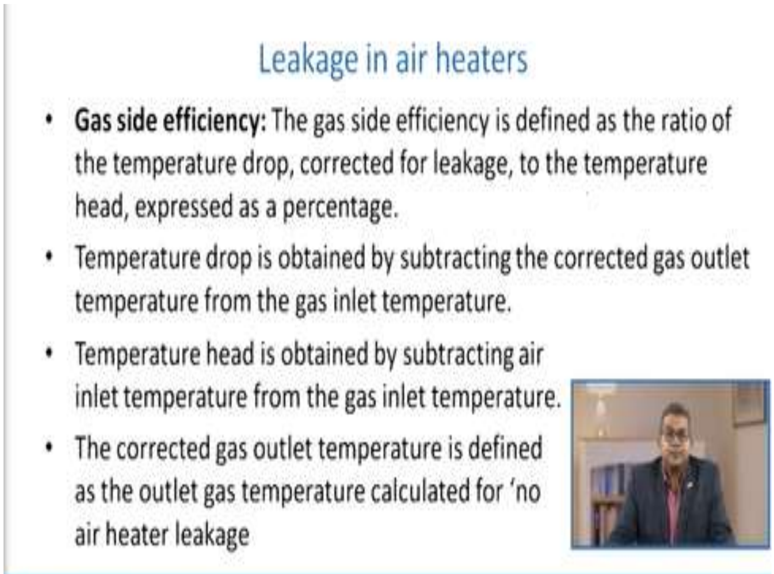

When we talk about the leakage in the air heaters, you cannot overlook the importance of gas side efficiency. The gas side efficiency is usually defined as the ratio of the temperature drop corrected for leakage to the temperature head, expressed as a percentage. Now temperature drop is obtained by subtracting the corrected gas outlet temperature from the gas inlet temperature. Now temperature head is obtained by subtracting the air inlet temperature from the gas inlet temperature.

And corrected gas outlet temperature is defined as the outlet gas temperature is calculated for no air heater leakage.

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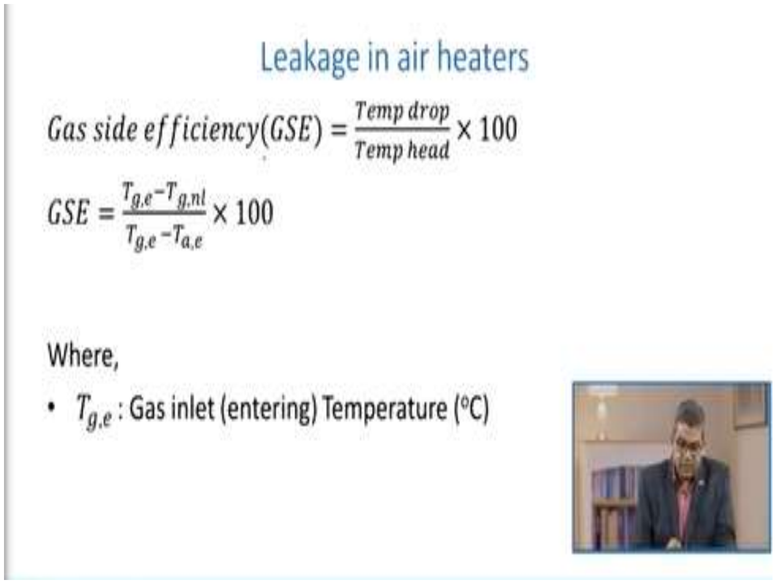

So, this is the mathematical expression where the gas side efficiency GSE referred to as

$$Gas\ side\ efficiency(GSE) = \frac{Temp\ drop}{Temp\ head} \times 100$$

$$GSE = \frac{T_{g,e} - T_{g,nl}}{T_{g,e} - T_{a,e}} \times 100$$

Where,

- $T_{g,e}$: Gas inlet (entering) Temperature (^{o}C)

So, a gas inlet in temperature in degree Celsius.

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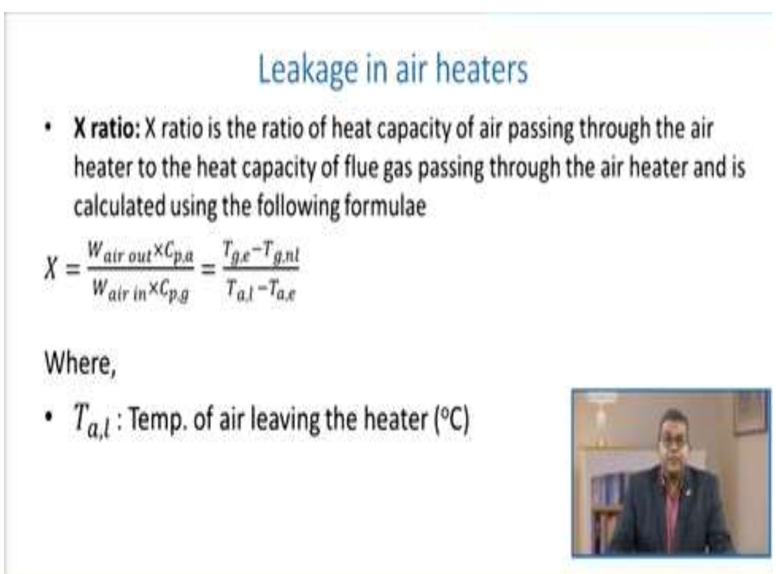

X ratio: X ratio is the ratio of heat capacity of air passing through the air heater to the heat capacity of flue gas passing through the air heater and is calculated using the following formulae

$$X = \frac{W_{air\ out} \times C_{p,a}}{W_{air\ in} \times C_{p,g}} = \frac{T_{g,e} - T_{g,nl}}{T_{a,l} - T_{a,e}}$$

Where,

- $T_{a,l}$: Temp. of air leaving the heater (°C)

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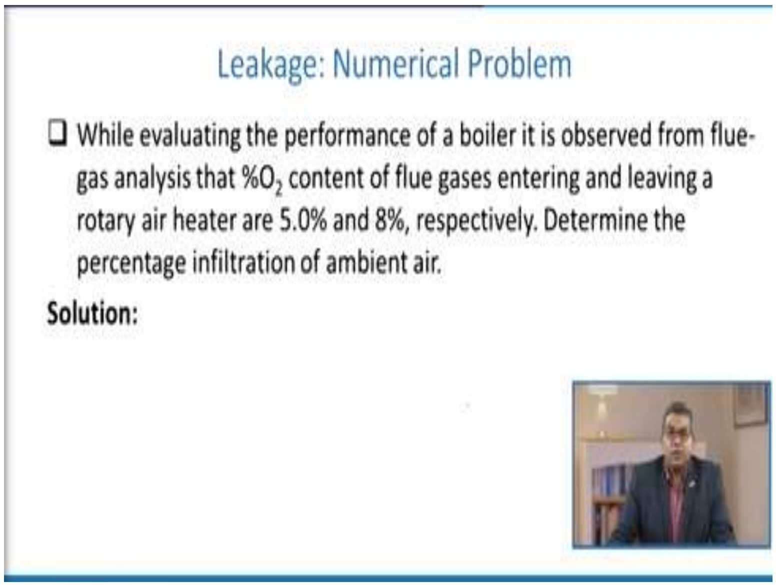

Now because leaking is an important phenomenon, we thought we should have a numerical problem. Now here is one numerical problem while evaluating the performance of a boiler; it is observed from flue gas analysis that the percentage oxygen content of the flue gas entering and leaving a rotary air heater. They are 5% and 8% respectively. So, you need to determine the percentage infiltration of ambient air.

So,

$$\%\ Leakage = \frac{\%O_2\ Leaving - \%O_2\ Entering}{21 - \%O_2\ Leaving} \times 0.9 \times 100$$

$$= \frac{8 - 5.0}{21 - 8} \times 0.9 \times 100 = \mathbf{20.76}\%$$

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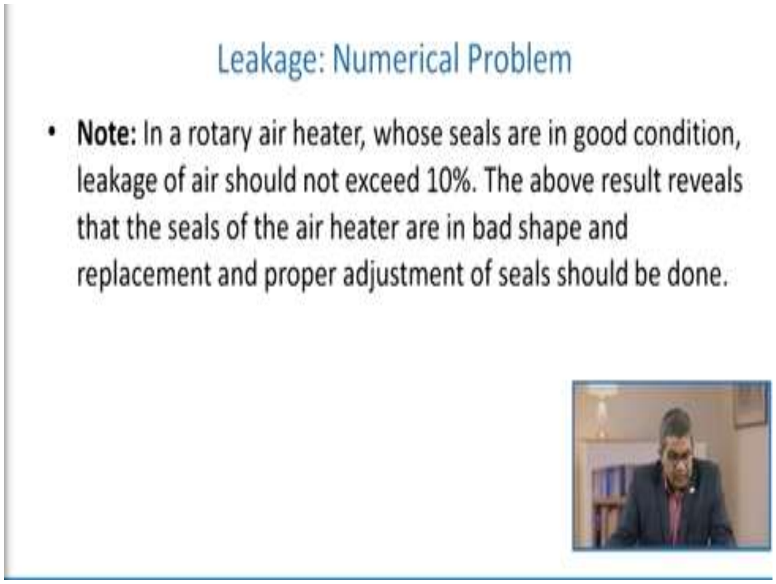

Now in a rotary air heater, whose seals are in good condition, air leakage should not exceed 10%. So, the result reveals that the seal of the air heater is in bad shape, and a replacement in the proper adjustment of the steel should be done.

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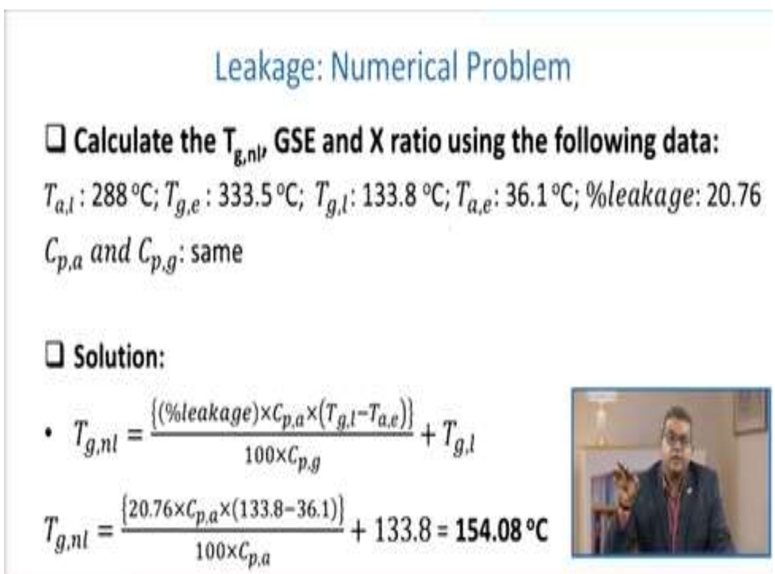

- **Calculate the $T_{g,nl}$, GSE and X ratio using the following data:**

$T_{a,l}$: 288°C; $T_{g,e}$: 333.5 °C; $T_{g,l}$: 133.8 °C; $T_{a,e}$:36.1°C; $\%leakage$: 20.76

$C_{p,a}$ and $C_{p,g}$: same

- **Solution:**

- $$T_{g,nl} = \frac{\{(\%leakage)\times C_{p,a}\times(T_{g,l}-T_{a,e})\}}{100\times C_{p,g}} + T_{g,l}$$

$T_{g,nl} = \frac{\{20.76 \times C_{p,a} \times (133.8 - 36.1)\}}{100 \times C_{p,a}} + 133.8$ = **154.08°C**

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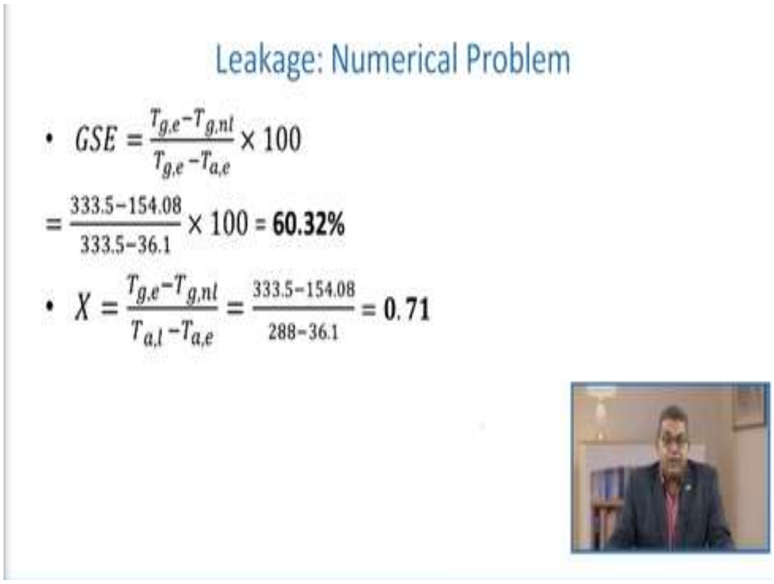

- $GSE = \frac{T_{g,e} - T_{g,nl}}{T_{g,e} - T_{a,e}} \times 100$

$= \frac{333.5 - 154.08}{333.5 - 36.1} \times 100$ = $\mathbf{60.32\%}$

- $X = \frac{T_{g,e} - T_{g,nl}}{T_{a,l} - T_{a,e}} = \frac{333.5 - 154.08}{288 - 36.1} = \mathbf{0.71}$

So, in this particular lecture we had discussed about the various aspects attributed to the preheating system different type of systems superheaters etc.

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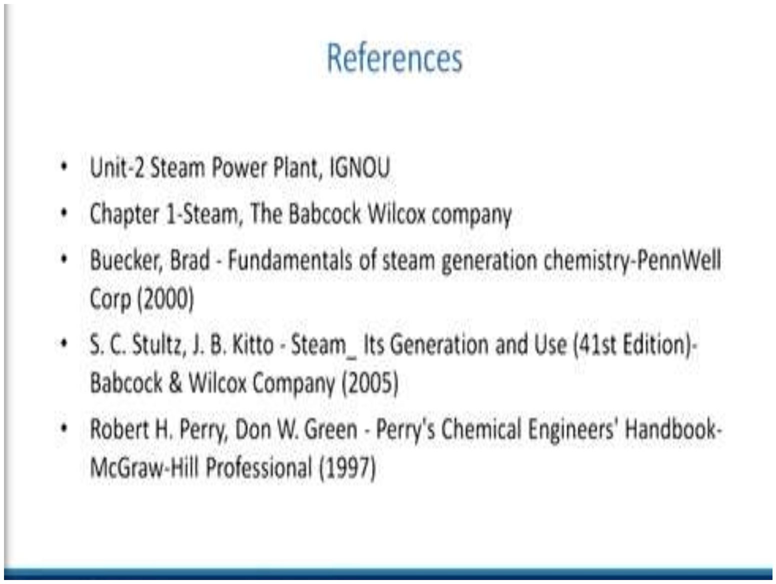

And for your convenience, we have enlisted a couple of references. If you wish to have further reading, you can utilize these references. Thank you very much.