

Chemical Process Utilities
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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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Topics covered previously

- Components of Steam generation unit
- Furnaces
- Pulverized coal system
- Draft System



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.

(Refer Slide Time: 01:09)

Topics to be covered

- Super heater
- Steam temperature control
- Reheater
- Leakage in air heaters



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.

(Refer Slide Time: 01:49)

Super heater

- The superheater consists of a superheater header and superheater elements.
- Steam from the main steam pipe arrives at the saturated steam chamber of the superheater header and is fed into the superheater elements.
- Superheated steam arrives back at the superheated steam chamber of the superheater header and is fed into the steam pipe to the cylinders. Superheated steam is more expansive.




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.

(Refer Slide Time: 02:18)

Super heater

One of the most important accessories of a boiler is a super heater. It effects improvement and economy in the following ways :

- The super heater increases the capacity of the plant.
- Eliminates corrosion of the steam turbine.
- Reduces steam consumption of the steam turbine.



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.

(Refer Slide Time: 03:35)

Types of Super heater

1. Plate Super heaters.
2. Pendant Super heaters.
3. Radiant Super heaters.
4. Final Super heaters.



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.

(Refer Slide Time: 04:01)

Steam Temperature Control

- The nominal control of **reheat steam** temperature is by tilting the burners.
- The **superheater steam** temperature is controlled by spraying water.



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.

(Refer Slide Time: 04:30)

Steam Temperature Control

Other control methods that are according to the need and design are:

- a) Excess Air Control
- b) Flue Gas Recirculation
- c) Gas by-pass Control
- d) Control of Combination Superheaters
- e) Adjustable Burner Control



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.

(Refer Slide Time: 04:58)

Excess Air Control in Superheater

- The steam outlet temperature of a convection superheater may be increased at partial load by increasing the excess air supply.
- The reduced gas temperature decreases the furnace heat absorption for the same steam production.
- The increased gas mass flow with its increased total heat content serves to increase the degree of superheat.



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 content serves to increase the degree of superheat.

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Excess Air Control in Superheater

- The steam outlet temperature of a convection superheater may be increased at partial load by increasing the excess air supply.
- The reduced gas temperature decreases the furnace heat absorption for the same steam production.

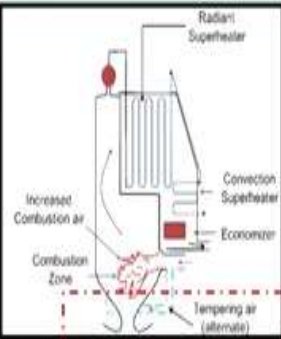



Fig: Convection superheater



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.

(Refer Slide Time: 06:06)

Flue Gas Recirculation

- The recirculation of some percentage of the combustion gases serves to control steam temperature in the same manner as does an increase in excess air.
- By introducing the hot gases below the combustion zone, relatively high efficiency may be maintained.

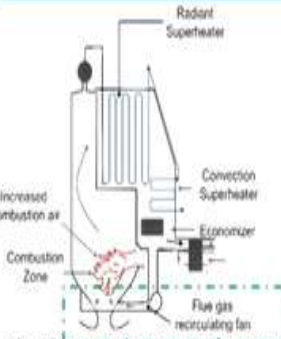



Fig: Convection superheater



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.

(Refer Slide Time: 07:00)

Gas Bypass Control

- The boiler convection banks can be arranged in such a manner that portion of the gases can be by-passed around the superheater elements.
- The superheater is oversized so that it will produce the required degree of superheat at partial load conditions. As the load increases, some of the flue gases are by-passed.



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.

(Refer Slide Time: 07:52)

Adjustable Burner Control

- With a multiple burner furnace it is possible to distribute the burners over a considerable burner wall height.
- This control is obtained by selective firing.
- Tilttable furnace may be adjusted to shift the position of the combustion zone.



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 tilttable furnace. So, the tilttable 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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Reheater

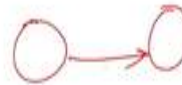
- The reheater functions similar to the superheater in that it serves to elevate the steam temperature.
- Primary steam is supplied to the high pressure turbine. After passing through the high pressure turbine, the steam is returned to the steam generator for reheating (in a reheater) after which it is sent to the low pressure turbine.
- A second reheat cycle may also be provided.



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.

(Refer Slide Time: 08:47)

Feed Water Heater



- Low pressure feed water heaters are used in the condensate system between the condensate pump discharge and boiler feed pumps, and utilize low pressure turbine extraction or auxiliary turbine exhaust steam for heating the condensate.
- High pressure feed water heaters are used in the feed water system between the boiler feed pump discharge and the boiler, and utilize high pressure turbine extraction steam for heating the feed water.



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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Feed Water Heater

- The condensate or feed water temperature increase for each feed water heater will be in the range of 28 to 56 degrees C with the actual value determined by turbine manufacturer's stage location of steam extraction nozzles.




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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Low Pressure Heater

- Use one or more low pressure feed water heaters to raise the temperature of condensate from condensate pump discharge temperature to the de-aerator inlet temperature.
- The heater drains are cascaded from the higher pressure heater to the next lower pressure heater with the lowest pressure heater draining to the condenser.



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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High Pressure Heater

- Use one or more high pressure feed water heaters to raise the temperature of feed water from de-aerator outlet temperature to the required boiler economizer inlet temperature.
- The heater drains are cascaded from heater to heater, back to the de-aerator in a fashion similar to the heater drain system for the low pressure heaters.



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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Advantages

- a) Fuel economy.
 - b) Longer life of the boiler.
 - c) Increase in steaming capacity.
- A feedwater heater is a power plant component used to pre-heat water delivered to a steam generating boiler.
 - Preheating the feedwater reduces the irreversibilities involved in steam generation and therefore improves the thermodynamic efficiency of the system.




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 involved in the steam generation and, therefore, improves the thermodynamic efficiency of the system.

(Refer to Slide Time: 12:30)

Advantages

- This reduces plant operating costs and also helps to avoid thermal shock to the boiler metal when the feedwater is introduced back into the steam cycle.
- In a steam power plant (usually modeled as a modified Rankine cycle), feedwater heaters allow the feedwater to be brought up to the saturation temperature very gradually.
- This minimizes the inevitable irreversibilities associated with heat transfer to the working fluid (water)



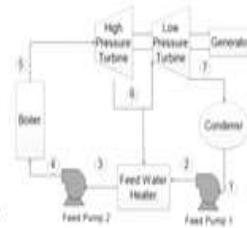
This reduces the plant operating cost, maximizes the efficiency or economy, etc. And also helps to avoid the thermal shock to the boiler metal when the feedwater is introduced back into the steam cycle because it minimizes the Δt . So, that is why the chances of thermal shock can be minimized. Now in 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.

(Refer Slide Time: 13:32)

Cycle Discussion and Explanation

- The energy used to heat the feedwater is mostly derived from a fraction of steam extracted from the stage between the high and low pressure steam turbine (point 6).
- This extracted fraction should not effect the efficiency of expansion work in the turbine.
- The extraction fraction should be carefully optimized for maximum power plant thermal efficiency since increasing it can cause a decrease in turbine power output.



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 fraction 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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Cycle Discussion and Explanation

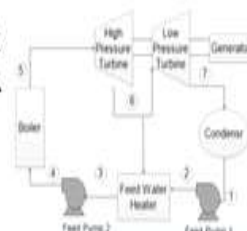
- This system can be explained by considering it as a two-steam turbine Rankine cycle unit.

Process flow:

1-2: Feed water is pumped from low to high pressure (isentropic process)

2-3: Heating of fluid at a constant pressure

3-4: heated fluid is pumped to the boiler (isentropic process)



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.

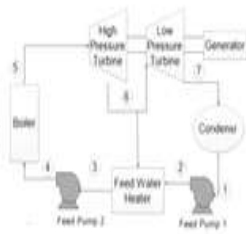
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Cycle Discussion and Explanation

4-5: Steam formation in a boiler (isobaric process)

5-6: High pressure superheated steam expands by doing work at the high pressure turbine, generating power. (isentropic process, partial condensation, temperature and pressure reduction)

6-3: Fraction of steam is extracted for the feedwater heater at same pressure (isobaric process)





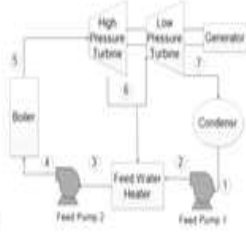
And from 4 to 5, steam formation in a boiler is an isobaric process. From 5 to 6, the high-pressure superheated steam expands by working at a high-pressure turbine generating power. That is an isentropic process, partial condensation temperature, and pressure reduction. It is quite obvious because it 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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Cycle Discussion and Explanation

6-7: The low pressure steam is reheated and used to generate more power at low pressure turbine (isentropic process)

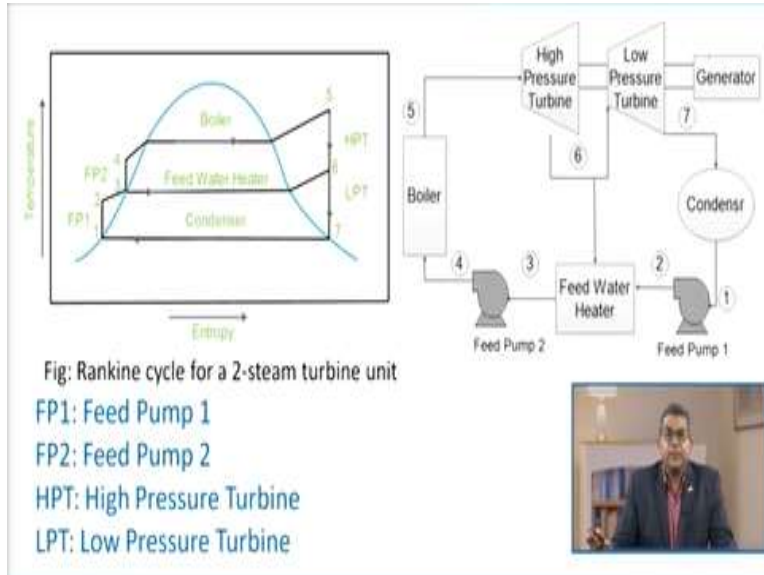
7-1: The wet vapor then passed through the condenser to condense it at constant pressure, forming saturated liquid.





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.

(Refer Slide Time: 16:07)




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.

(Refer Slide Time: 16:46)

Cycle Discussion and Explanation

- Feedwater heaters can function as both open and closed heat exchangers. An open feedwater heater is just a direct-contact heat exchanger that allows extracted steam to mingle with feedwater.
- 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.




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.

(Refer to Slide Time: 17:20)

Cycle Discussion and Explanation

- A deaerator is a type of open feedwater heater that is meant to remove non-condensable gases from the feedwater.
- Closed feedwater heaters are generally shell and tube heat exchangers in which feedwater is circulated through the tubes and heated by turbine extraction steam.
- As compared to an 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.



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.

(Refer Slide Time: 18:26)

Cycle Discussion and Explanation

- The extracted steam, however, must be throttled to condenser pressure. Many power plants have a number of feedwater heaters, which can be open or closed.
- Feedwater heaters are utilized in both fossil-fuelled and nuclear-powered power plants.
- Smaller versions are also used on steam locomotives, portable engines, and stationary engines.
- An economizer, like a feedwater heater, performs a similar goal but is technically distinct.



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.

(Refer Slide Time: 18:43)

Cycle Discussion and Explanation

- Instead of using real cycle steam for heating, it heats the water before it reaches the boiler with the lowest-temperature flue gas from the furnace.
- This enables heat transmission between the furnace and the feedwater to occur over a lower average temperature gradient.
- When the real energy content of the fuel is included, system efficiency is boosted even more.



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.

(Refer to Slide Time: 19:24)

Air Preheaters

- An air preheater or air heater is a general term to describe any device designed to heat air before another process (for example, combustion in a boiler) with the primary objective of increasing the thermal efficiency of the process.
- They may be used alone or to replace a recuperative heat system or to replace a steam coil.



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 Δt , 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.

(Refer Slide Time: 20:40)

Air Preheaters

- The purpose of the air preheater is to recover the heat from the boiler flue gas which increases the thermal efficiency of the boiler by reducing the useful heat lost in the flue gas.
- As a consequence, the flue gases are also sent to the flue gas stack (or chimney) at a lower temperature, allowing simplified design of the ducting and the flue gas stack.
- It also allows control over the temperature of gases leaving the stack (to meet emissions regulations, for example).



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.

(Refer to Slide Time: 21:22)

Types

- There are two types of air preheaters for use in steam generators in thermal power stations :
 - Tubular type: built into the boiler flue gas ducting
 - Regenerative air preheater
- These may be arranged so the gas flows horizontally or vertically across the axis of rotation.



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.

(Refer Slide Time: 21:55)

Tubular Air Preheaters

- Tubular preheaters consist of straight tube bundles which pass through the outlet ducting of the boiler and open at each end outside of the ducting.
- Inside the ducting, the hot furnace gases pass around the preheater tubes, transferring heat from the exhaust gas to the air inside the preheater.
- Ambient air is forced by a fan through ducting at one end of the preheater tubes and at other end the heated air from inside of the tubes emerges into another set of ducting, which carries it to the boiler furnace for combustion.



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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Limitations

- The tubular preheater ducting for cold and hot air require more space and structural supports than a rotating preheater design.
- Further, due to dust-laden 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 problem such as the use of ceramic and hardened steel.




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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Limitations

- Many new circulating fluidized bed (CFB) and bubbling fluidized bed (BFB) steam generators are currently incorporating tubular air heaters offering an advantage with regards to the moving parts of a rotary type.




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.

(Refer Slide Time: 23:44)

Dew Point Corrosion

- Dew point corrosion occurs for a variety of reasons. The type of fuel used, its sulfur content and moisture content are contributing factors.
- However, by far the most significant cause of dew point corrosion is the metal temperature of the tubes.
- If the metal temperature within the tubes drops below the acid saturation temperature, usually at between 88°C and 110°C, but sometimes at temperatures as high as 127°C, then the risk of dew point corrosion damage becomes considerable.




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.

(Refer Slide Time: 24:46)

Regenerative Air Preheaters

- There are two types of regenerative air pre-heaters:
 - Rotating-plate regenerative air preheaters
 - Stationary-plate regenerative air preheaters.



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.

(Refer Slide Time: 24:57)

Rotating-Plate Regenerative Air Preheaters

- The rotating-plate design consists of a central rotating-plate element installed within a casing that is divided into two (bi-sector type), three (tri-sector type) or four (quad-sector type) sectors containing seals around the element.

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.

(Refer Slide Time: 25:38)

Rotating-Plate Regenerative Air Preheaters

- The seals allow the element to rotate through all the sectors, but keep gas leakage between sectors to a minimum while providing separate gas air and flue gas paths through each sector.
- Tri-sector types are the most common in modern power generation facilities. In the tri-sector design, the largest sector is connected to the boiler hot gas outlet.

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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Rotating-Plate Regenerative Air Preheaters

- The third sector is the smallest one and it heats air which is routed into the pulverizer and used to carry the coal-air mixture to coal boiler burners.
- Thus, the total air heated in the air preheater provides:
 - heating air to remove the moisture from the pulverized coal dust.
 - carrier air for transporting the pulverized coal to the boiler burners and the primary air for combustion.



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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Stationary-Plate Regenerative Air Preheaters

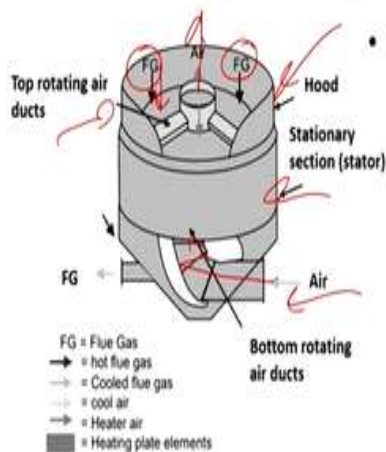
- The heating plate elements in this type of regenerative air preheater are also installed in a casing, but the heating plate elements are stationary rather than rotating.
- Instead the air ducts in the preheater are rotated so as to alternatively expose sections of the heating plate elements to the upflowing cool air.



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.

(Refer Slide Time: 28:04)

Stationary-Plate Regenerative Air Preheaters



- As indicated in the figure, there are rotating inlet air ducts at the bottom of the stationary plates similar to the rotating outlet air ducts at the top of the stationary plates.



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 stationary 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.

(Refer Slide Time: 28:38)

Leakage in air heaters



Sometimes you may experience leakage in air heaters.

(Refer Slide Time: 28:43)

Leakage in air heaters

- Leakage is a normal phenomenon in all air heaters. While leakage in a new recuperative air heater is essentially zero, leakage occurs with the passage of time and due to accumulation of thermal cycles.
- Nevertheless, leakage in a recuperative air heater can be restricted to 3% with regular maintenance.



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.

(Refer Slide Time: 29:46)

Leakage in air heaters

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

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

and;

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



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

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

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

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

(Refer to Slide Time: 30:18)

Leakage in air heaters

g : acceleration due to gravity (9.8 m/s²)

ΔP : pressure differential across gap, kg/m²

ρ : Density of leaking air, kg/m³

- The numerical average of the air heater's gas inlet, gas outlet and air inlet temperatures is calculated. Then the corrected air heater gas

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



g : acceleration due to gravity (9.8 m/s²)

ΔP : pressure differential across gap, kg/m²

ρ : Density of leaking air, kg/m³

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:

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

(Refer to Slide Time: 31:07)

Leakage in air heaters

Where,

$T_{g,ni}$: 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 $T_{g,ni}$

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 $T_{g,nl}$

(Refer to Slide Time: 31:22)

Leakage in air heaters

- **Gas side efficiency:** The gas side efficiency is defined as the ratio of the temperature drop, corrected for leakage, to the temperature head, expressed as a percentage.
- Temperature drop is obtained by subtracting the corrected gas outlet temperature from the gas inlet temperature.
- Temperature head is obtained by subtracting air inlet temperature from the gas inlet temperature.
- The corrected gas outlet temperature is defined as the outlet gas temperature calculated for 'no air heater leakage'



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.

(Refer to Slide Time: 32:16)

Leakage in air heaters

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

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

Where,

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



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

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

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

Where,

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

So, a gas inlet in temperature in degree Celsius.

(Refer to Slide Time: 32:43)

Leakage in air heaters

- **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 ($^{\circ}\text{C}$)



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)

(Refer to Slide Time: 33:24)

Leakage: Numerical Problem

□ While evaluating the performance of a boiler it is observed from flue-gas analysis that %O₂ content of flue gases entering and leaving a rotary air heater are 5.0% and 8%, respectively. Determine the percentage infiltration of ambient air.

Solution:



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,

$$\begin{aligned} \% \text{ Leakage} &= \frac{\%O_2 \text{ Leaving} - \%O_2 \text{ Entering}}{21 - \%O_2 \text{ Leaving}} \times 0.9 \times 100 \\ &= \frac{8 - 5.0}{21 - 8} \times 0.9 \times 100 = \mathbf{20.76\%} \end{aligned}$$

(Refer Slide Time: 33:54)

Leakage: Numerical Problem

- **Note:** In a rotary air heater, whose seals are in good condition, leakage of air should not exceed 10%. The above result reveals that the seals of the air heater are in bad shape and replacement and proper adjustment of seals should be done.



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.

(Refer to Slide Time: 34:12)

Leakage: Numerical Problem

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

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

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

- Solution:

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

$$T_{g,ni} = \frac{\{20.76 \times C_{p,a} \times (133.8 - 36.1)\}}{100 \times C_{p,a}} + 133.8 = 154.08^\circ\text{C}$$



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

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

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

- Solution:


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

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

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Leakage: Numerical Problem

- $GSE = \frac{T_{g,e} - T_{g,nl}}{T_{g,e} - T_{a,e}} \times 100$
 $= \frac{333.5 - 154.08}{333.5 - 36.1} \times 100 = \mathbf{60.32\%}$
- $X = \frac{T_{g,e} - T_{g,nl}}{T_{a,l} - T_{a,e}} = \frac{333.5 - 154.08}{288 - 36.1} = \mathbf{0.71}$



- $GSE = \frac{T_{g,e} - T_{g,nl}}{T_{g,e} - T_{a,e}} \times 100$
 $= \frac{333.5 - 154.08}{333.5 - 36.1} \times 100 = \mathbf{60.32\%}$

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

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.