Steam Power Engineering

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Lecture - 18
Boiler Accessories

Welcome to the class. Till time we had seen that there is Rankine cycle and Rankine cycle has different components. Among that we had started seeing the steam generator in last class. We had also seen that the steam generator has basically different types and those types were essentially based upon to start with the application.

The types like industrial steam generator, utility steam generator or marine steam generator. The types of steam generator also based upon the flow of water and steam or water or steam and the flue gas. So there is type like fire tube boiler or water tube boiler. Now in today's class we are going to see the some essential details of water tube boil. So basically in a water tube boiler we had seen that there will be a drum.

We had seen types like straight tube boiler or bent tube boiler like Stirling boiler where there will be drum, boiler drum and boiler drum would have some tubes connected and those tubes, some of those we are calling them as down comer and some of those we are calling it as a riser. So water essentially in the saturated state comes down from the down comer and then it would get heated in the riser.

And then it gets circulated in the loop of down comer, riser, and drum. In the space it will receive the heat from the flue gases. And this loop or this flow of water in this circuit is called as circulation.

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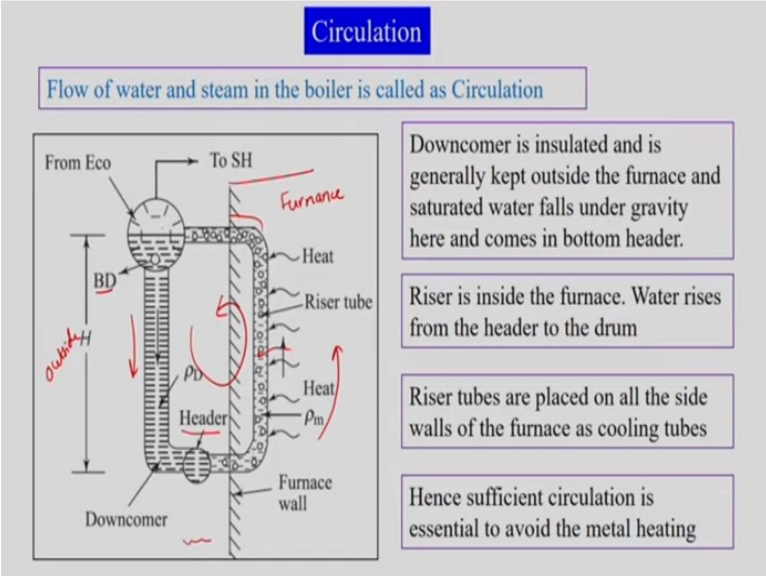

So flow of water and steam in the boiler is called as circulation. This is what we were talking about that we have boiler drum means BD and then it has a down comer where water is coming down in saturated format. It comes to the header and then it comes to the riser where it is flowing actually in the presence of the flue gases. And flue gases give the heat to the water and then water will change its state from the liquid to vapor and again it goes to the boiler drum.

These riser tubes are essentially inside the furnace. So this is the part of furnace and here we are outside the furnace. The down comer is sometimes outside of the furnace or it can be inside the furnace as well. So down comer is basically if it is outside the furnace it would be an insulated tube, which would allow the liquid water to come down in the presence of gravity towards the bottom header.

And riser tubes are essentially the tubes inside the furnace and which would receive the heat from the flue gases. Riser tubes are also called as cooling tubes since those tubes are the tubes which are associated with the furnace walls or which are the tubes inside of the furnace walls. Then we need to provide sufficient amount of circulation. Here we mean that there is mass of water which is going in this circuit.

And then that mass of water has to be of certain quantity. Certain kg per second mass need to be provided in this circuit, so that we can get efficient and essential heating of the water. So if here we have seen that water is coming down in the presence of gravity. So this is a gravity based circulation, but it is not guaranteed that we will always get assistance of gravity.

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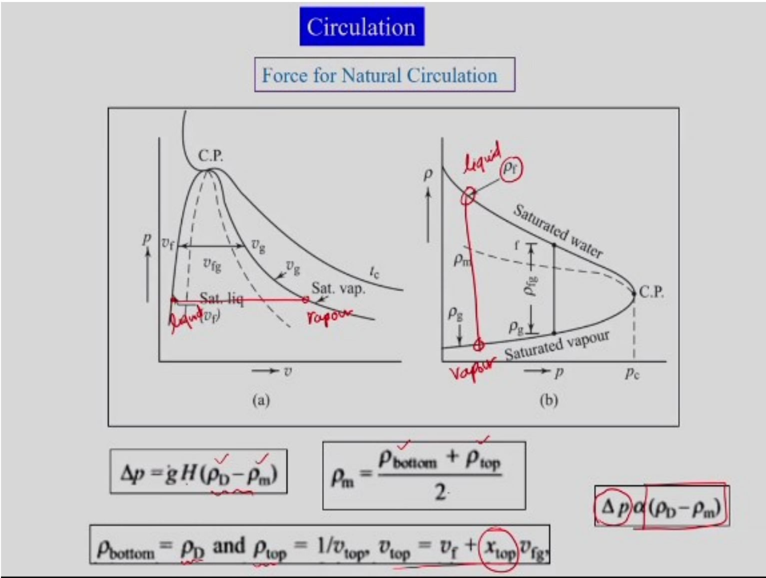

In the case where we are getting assistance of gravity we can see here from the P-v diagram or $P-\rho$ diagram, that this is a point where we have very large density. This is the point where we have very low density at a constant pressure line. So this large density is liquid and low density is gas or is vapor. So we have liquid here and we have vapor here.

And then we can see equally in P-v diagram, that small density, we can see here that the large density corresponds to small specific volume, which is liquid here. And then we have large specific volume means the small density, so we have vapor here. And we have liquid here. So this difference is huge. So we get at lower pressure, large density difference for the help towards the natural circulation of water inside the same loop.

So here the necessary buoyancy force or the circulation is based upon the density difference and head provided in by the circulation tubes. But here we need two densities. One density is the density of the down comer and one density is the mean density in the riser. This mean density is the density from the bottom of the riser and the density from the top of the riser divided by 2.

The bottom density is necessarily the density of the saturated liquid water. But we do not know the density at the top. So that can be found out using the expression which needs dryness fraction at the top. Essentially, we mean here that the necessary force for natural circulation is proportional with the density difference.

So we can design or we can define the necessary circulation criteria or system for water to get circulated in the loop. And if this density difference is high then we can go for gravity based or natural circulation. And then if it is less then we have to go for forced circulation.

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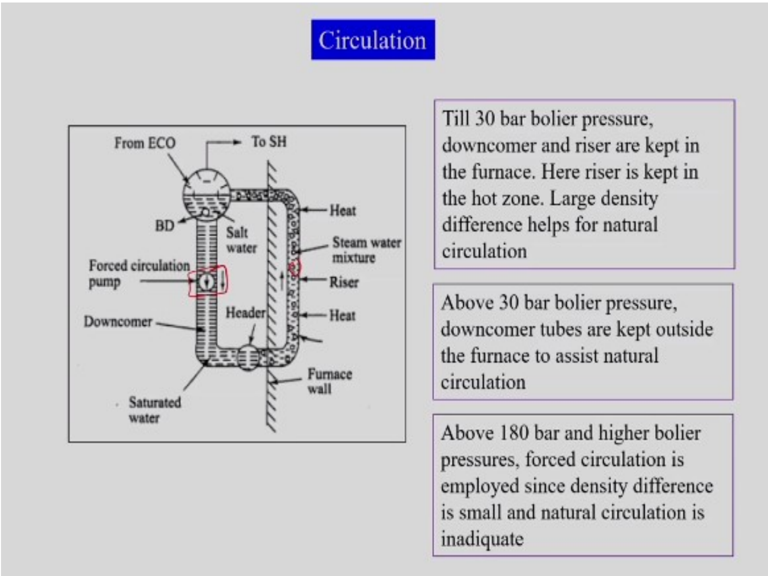

So this is an example of forced circulation, where we would not have sufficient density difference to assist the minimum required circulation. So for that we can employ a pump for circulation of water into the circuit. So till 30 bar there is no problem, we can have the down comer and riser tubes inside the furnace where down comer tubes will be little aside from the burner but the riser tubes will be close to the hot zone.

This would create the necessary density difference for natural circulation since there is large difference in density. So we can go ahead without any pump's assistance for the forced circulation and we can go ahead with the natural circulation. But if we go with the pressures which are above 30 bar then down comer tubes will be kept outside the furnace.

And here the riser tubes will be inside the furnace which will get the necessary heating from the flue gases and which will rise the water in them and create the sufficient density difference between the down comer and riser tube. Here as said earlier, this down comer tubes will be insulated. So keeping the down comer tubes outside the furnace actually helps to assist the natural circulation.

But if we go to the pressure levels above 180 bar, then forced circulation is essential since density difference becomes small and we cannot employ natural circulation into this circulation loop.

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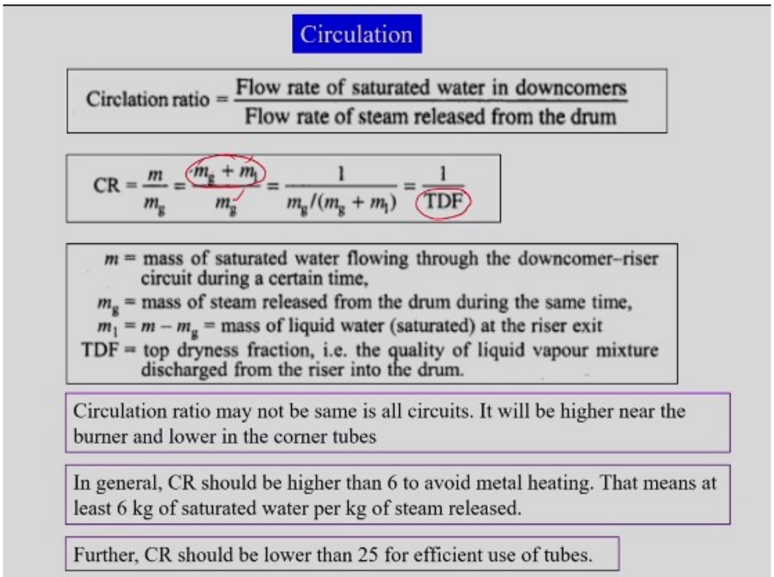

Here the whole this circulation can be defined or quantified on the basis of circulation ratio, which is defined as flow of water, saturated water in the down comers divided by rate of steam released from the drum. Basically circulation ratio by means, we say that x or y kg of water, saturated water coming down from the down comer for 1 k g of steam released from the drum.

So this we can again represent in terms of masses from the down comer. We are getting total mass coming which is the mass of liquid plus mass of steam divided by mass of steam. And if we rearrange the term, we get it in terms of TDF, which is called as top dryness fraction or the dryness fraction of the water at the exit of the riser.

Essentially this circulation ratio will not be same or may not be same in all the loops. Some loops would have higher circulation ratio. The loops or tubes which are near to the burner would encounter higher circulation ratio. But the loops or the tubes, which are away from the burner would face lower circulation ratio. But whatever it is, we need to provide minimum circulation ratio of six into the circulation loop.

Since if we cannot provide the minimum circulation ratio, then instead of water getting heated, we would have the metallic tubes getting heated from the flue gases. So as to avoid it, we need to provide minimum circulation ratio which is around six into the circuit. Further, we should have an upper limit of the circulation ratio and that is said to be around 25 such that if we provide the circulation ratio more than 25 then we would have to heat the water through many passages.

Or we need to pass the water many times into the loop since water will not be residing for longer amount of time into the tubes. Hence to avoid this and to make the water's heating efficient, we have to provide the circulation ratio lower than 25.

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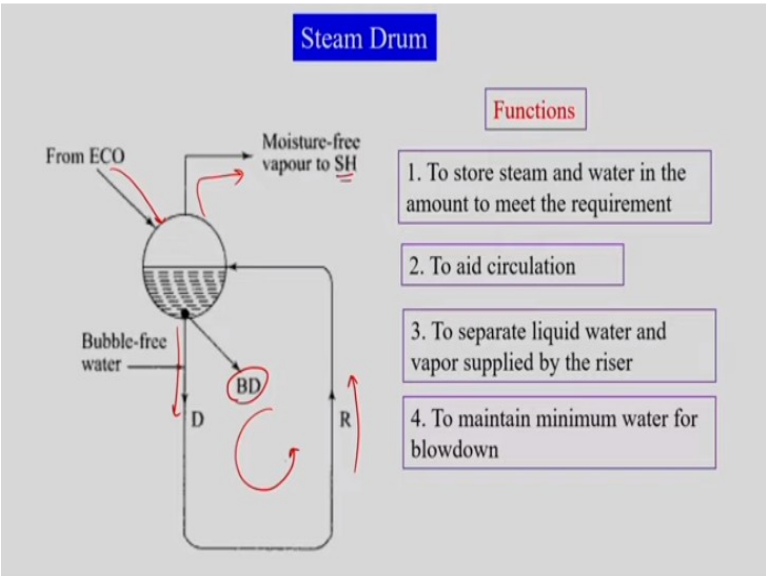

Now having seen the circulation we are talking about the steam drum. So steam drum here is the, or the boiler drum, basically receives the water from economizer. Once it receives the water from economizer it lets the water go from the down comer either by natural circulation or by forced circulation and then water goes up into the riser. In this case of circulation of the water it gets heated and it attains a state which is essential so as to let it go towards the super heater.

So this is the overall schematic of a steam drum. But there are some functions of the steam generator and among those, it basically stores the steam and water in the desired quantity which is required to basically cater or handle the said load of the steam power plant. It also helps for the circulation.

We need a means of circulation where we need some water to be maintained at certain place so that it can come into the round comer so it helps or aids to the process of circulation. It separates, we are going to see after few slides that these are called as drum essentials. Within the drum there are certain attachments which are required to help the separation of the liquid water from the vapor so that, that vapor should be passed over the superheater.

Then it also has to maintain minimum amount of water for blow down or stopping the power plant.

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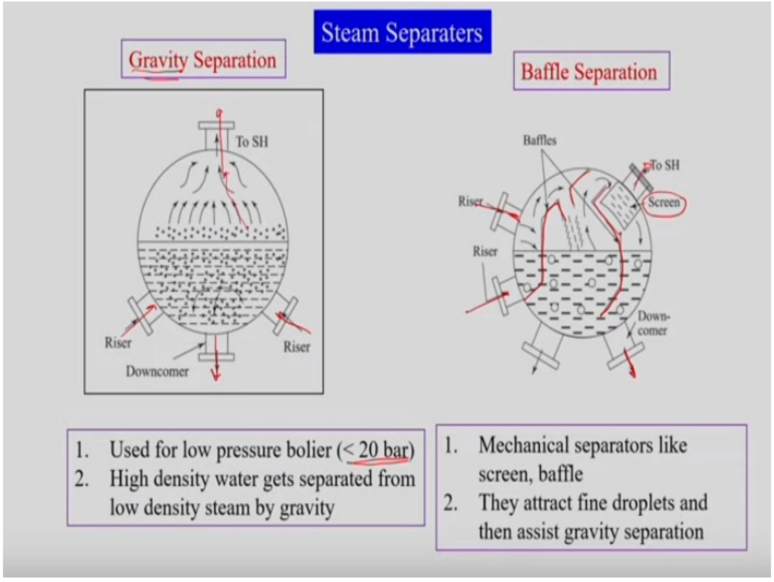

Now we are going to see the steam separators. Steam separator is a gravity separator. In this gravity separator we are seeing that there is drum and in the drum, we are having water in liquid plus vapor state. Basically this drum is receiving water from the riser and then there is round comer and then this riser would pass the steam plus liquid plus vapor mixture of water.

But we are operating on the basis of gravity means we are working with low pressures such that the vapor are lighter than the liquid water so they will automatically go toward the top and pin the top part of the drum such that they can be passed towards the superheater. So this kind of gravity based separation is used if we are working with the pressures lower than 20 bar.

And here we basically get high density water getting settled down and low density vapor going towards the top part of the drum. Then we have baffle based separation. Here basically, we are working with moderate pressures and at those pressures, we are not having sufficient density difference such that the water and vapor can be completely separated. So as two separate them, this is a riser.

This is a round comer and then there is a riser. So when the flow comes from the two risers, we have baffles or screens which are placed inside the drum and these baffles guide the water which is coming from the riser. And in this phase the water droplets would get settled on the baffles and then they will settle down in due course of time into the drum and then only vapor will get passed toward the exit.

But at the exit we will have some more screens placed which will again capture the fine droplets of the water and only steam or which is vapor which is going toward the superheater. So this is also called as mechanical separation system, which is basically helping the natural circulation or gravity along with the mechanical separation of the liquid water and the vapor.

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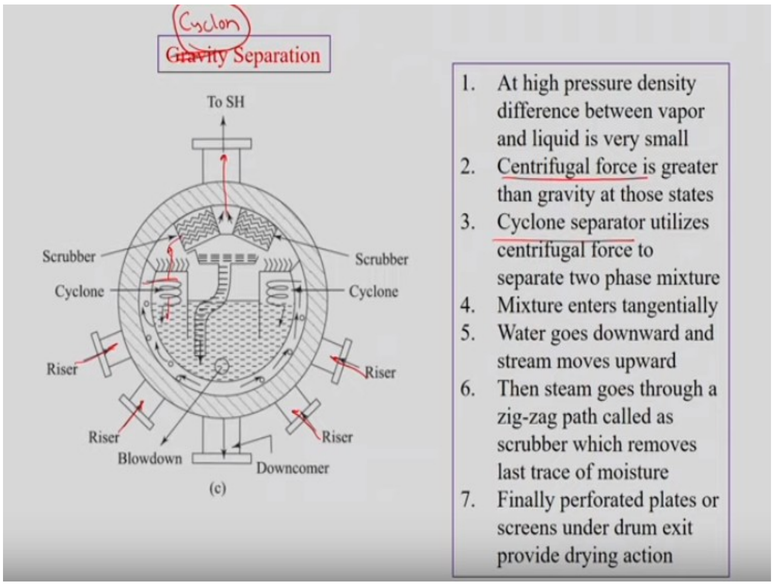

But if we go towards the, this is cyclone separator, if we go towards the further high pressure then we cannot employ the baffle or gravity based separator. So we have to use cyclone separator. So what do we mean by cyclone separator here, we basically are at very high pressure and at those high pressures as we can see toward the as we go close to the critical point the specific volumes or densities of vapor and liquid water try to become same. So density difference is small.

So we practically are not able to distinguish between vapor and the liquid. In such case the gravity or the mechanical separation would not be helping centrifugal force become the prominent way to separate the two small density states of water, one is liquid and one is vapor. So basically from the riser, we will get steam plus liquid vapor, liquid vapor, liquid plus vapor mixture and this mixture will tangentially enter into a cyclone unit.

And then in this case, this due to centrifugal force in this spiral unit, the steam will get separated, since it is little lighter, but water will get settled down. And in this phase steam will go further up and it will go through the screens or scrubbers which will capture the small droplets of water and then some rest of the steam will go to the superheater.

So cyclone separators are essentially employed when we are having very high pressure of the boiler and salient feature is here we are trying to make use of centrifugal force in the cyclone separator to separate liquid water and the steam vapor.

So now we are going to see the other parts of this boiler or steam generator like economizer, then we will see superheater, reheater and air preheater.

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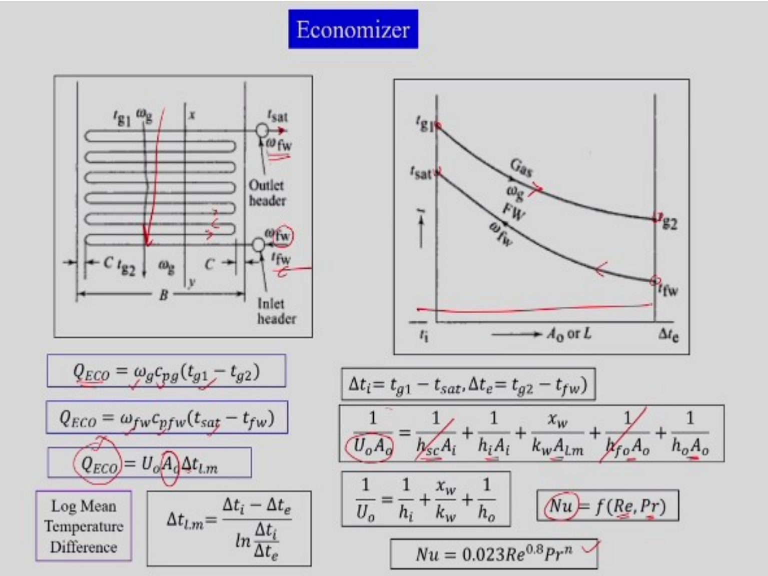

So economizer, this is a typical schematic of the economizer where we can see economizer is supplying feed water heater or water from feed water heater or feed water from the inlet at the inlet to the steam generator and then it will get passed through the tubes or through the loop and then it will become saturated and then it will go into the evaporator. So this is the path of water in the economizer.

However, we can see that we have gas of flue gas which is coming down, coming in this direction and heating the water. Our idea in this schematic is to design the number of coils required for the economizer in the water tube boiler. Basically this is a counter flow heat exchanger, where we are having the heating of the feed water from the low temperature to high temperature along this length.

And in this phase, the gas which is a flue gas will lose its temperature from this to this and then it will get cooled but at the expense that it will heat the feed water. We know that the heat exchange in the economizer is mass flow rate of flue gas and the specific heat or flue gas into temperature change $mC_p\Delta T$. This is mass flow rate into C_p into delta T for flue gas. But same heat is earned by the feed water.

So mass flow rate of feed water, specific heat of feed water into temperature change of feed water. So here the same thing can be denoted in terms of the $U\ A\ \Delta T$. Here U

is the coefficient of heat transfer, but here ΔT is the log mean temperature difference. This log mean temperature difference has terms which are related to temperature of liquid water and temperature of flue gas at their inlets and at their outlets.

Then we know this we can measure the temperatures using the thermocouples at the inlet and outlet. We know flow rates and we know specific heats. So basically we know this Q and we should know the area and if we know area then we can find out the number of turns. So for that this is a resistance or U A, $\frac{1}{UA}$can be said as their total resistance for heat transfer.

And it is summed over different resistances out of which first resistance is inside the water tubes. We will have certain amount of scaling and that would lead to certain resistance for heat transfer. Then inside film will lead to certain resistance. The metal or tube would have resistance for heat transfer outside or gas side of the tube will have certain foreign elements.

They will resist for the heat transfer and outside gas film would have resistance for heat transfer. So these all resistances would basically sum up towards the total resistance of for heat transfer. However, we can neglect these two residences and this with certain assumption becomes a formula in this case where we have $\frac{1}{U_0}=\frac{1}{h_i}+\frac{x_w}{k_w}+\frac{1}{h_0}$; x is thickness of wall and k is thermal conductivity of wall.

Necessarily, here we have Nusselt number of heat transfer as a function of Reynolds number and Prandtl number and this is a expression for the heat transfer. So using this we can find out the area and knowing the area, we can find out the total number of turns required in the economizer to get the desired heat transfer rate and rising temperature from t_{fw} to t_{sat}

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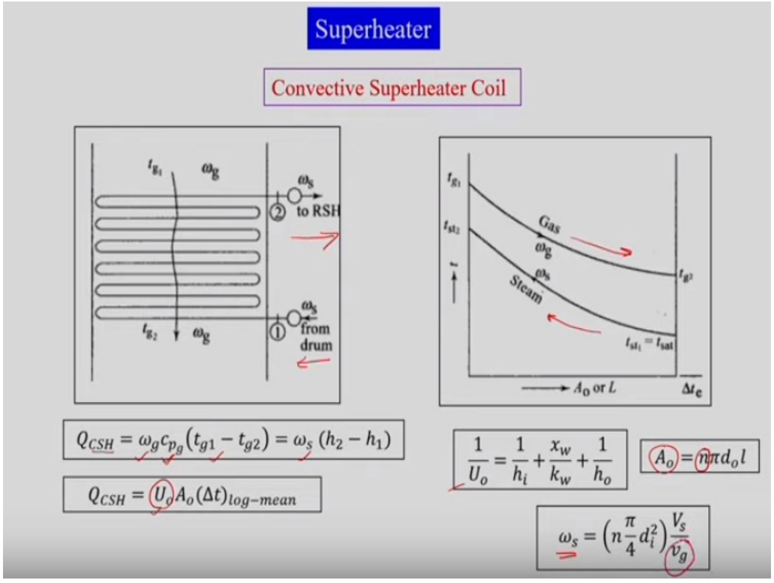

After economizer we are seeing the superheater. There are two types of superheaters. One superheater is called as convective superheater and other superheater is called as radiative superheater. In the convective superheater major amount of heating is basically done using the convective heat transfer. This type of superheater is kept away from the furnace burner or flame.

But radiant superheaters basically have heating of the water by radiation. And this superheater is kept very close to the burner. Initially, the steam from the evaporator would enter into the convective superheater and then it would go to the radiant superheater. Again, we can use the similar philosophy for the superheater where we have superheater.

Again water coming as the steam coming from the drum will enter the superheater which is a convective superheater and it will go to the radiative superheater. In this phase, the steam would rise the temperature since it is receiving the sensible energy and sensibility and then gas, flue gas will reduce its temperature.

We can again, convective superheater will have heat exchange which is mass of water, mass of flue gas, mass flow rate of flue gas into C_p of flue gas into temperature change which is equal to change in enthalpy into mass flow rate of the steam. And then we can as well represent here the total heat transfer rate $U_0 A_0 (\Delta t)_{\log-mean}$

Similarly log mean temperature difference will have temperatures at different inlets and outlets of the heat exchange media's. The total resistance required over here or U required over here can be found out from the total resistance in this case, where essentially each resistance is would be found out from the Nusselt number expression and $A_0 = n\pi\, d_0 l$ where we are trying to find out number of coils required for the heat transfer.

This is mass flow rate of the steam, which is going through n number of coins and which have d diameters and we have $\rho A v$ as the mass flow rate where the ρ is defined as $\frac{1}{v}$, v is velocity into area.

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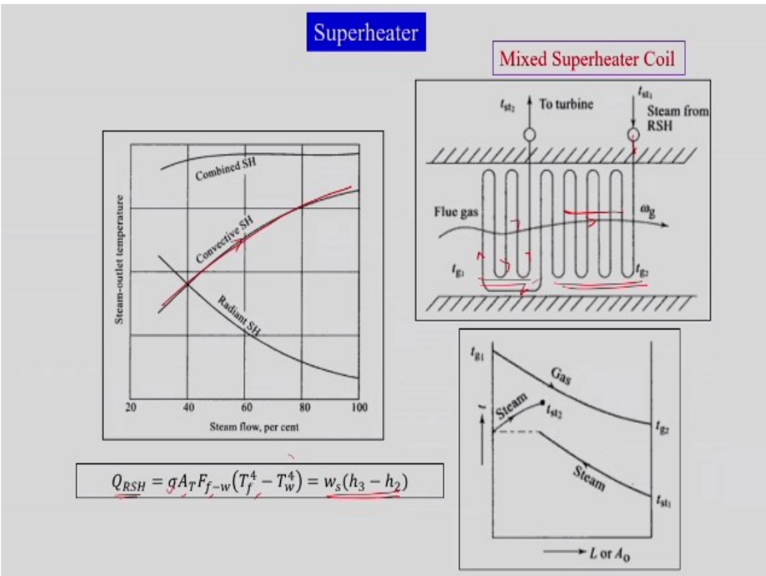

As what we have said if we increase the steam flow rate, then convective heat transfer rate will increase in this fashion, but radiant heat transfer rate, radiant superheater will have lower heat transfer rate with the increasing steam flow rate. But we have one more type of superheater which is called as combined which will take both forms of heat. So such superheater is called as combined superheater.

In case of radiant superheater we are basically receiving radiant energy and radiant energy is $Q_{RSH} = \sigma A_T F_{f-w}(T_f^4 - T_w^4)$. So we have this as the temperature difference, temperature raised to 4. That difference as the driving potential for the heat in the radiation case.

This heat will be used by the steam so as to go from the low enthalpy to high enthalpy. The mixed superheater is also existing and an example for it is called as pendant type of superheater where we can see here that initially we have steam which is coming out from the radiant superheater and then this will go in counter way for the gas. But after some time this steam is going in the direction along the gas.

For some distance, we have the counter flow and in some distance we have the parallel flow heat exchange. This is a necessity arrangement so far as construction of the steam generator is concerned. And this is corresponding temperature chain diagram along the length of the superheater. So this is how we can define the different dimensions of the superheater as well.

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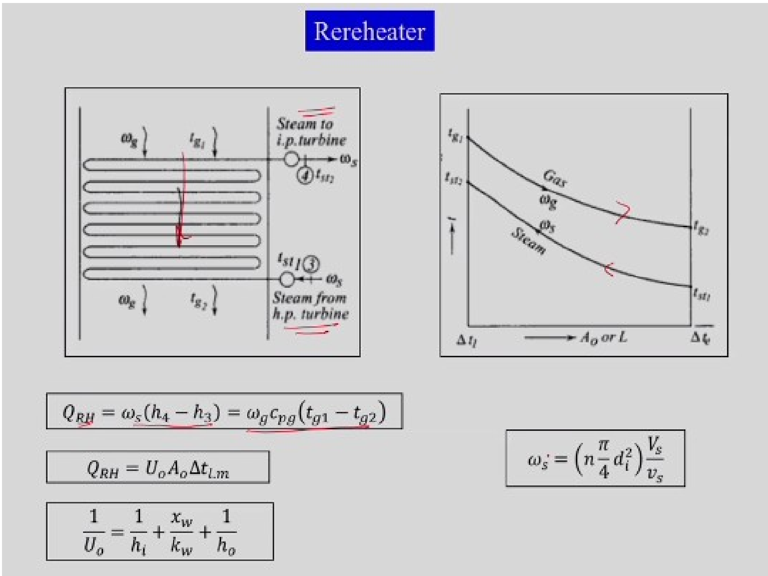

Then on the same line, we can define for the reheater, where again we will have reheater as the entry of the steam from the high pressure turbine and then it will exit to the low pressure or intermediate pressure turbine. In this phase it will get heated from the flue gas and then this is the heating pattern of the steam. This is the lowering of the enthalpy of the gas.

We again have heat transfer in the reheater as increase in enthalpy of the steam and lower enthalpy of the gas. Again we are interested in finding out area and number of turns of the reheater. So for that we can represent this heat transfer as $UA(\Delta t)_{l-m}$.

Here again, we have total resistance as sum of the three resistances and this is the mass flow rate of the steam into the reheater, air preheater.

As what we had seen that the flue gas was heating the water in the economizer. Then it was heating the two phase mixture in the evaporator. It is heating the superheater and it is also heating the reheater. After having all these heat exchanged, what the flue gas will still have certain amount of heat in it. And that heat we want to get utilized.

But we do not have that heat to be passed to the water or the working medium of our Rankine cycle. But we need that heat for the air which will be passed for the furnace as an oxidizer. So that kind of heating is called as air preheater. So we basically would supply air to burn the coal and then that air will be heated into the air preheater using the gas or using the flue gases which are getting exited from the steam generator.

Further, we also need these air heating so that this air will have lower and lower amount of moisture while entering into the cold zone for the burning.

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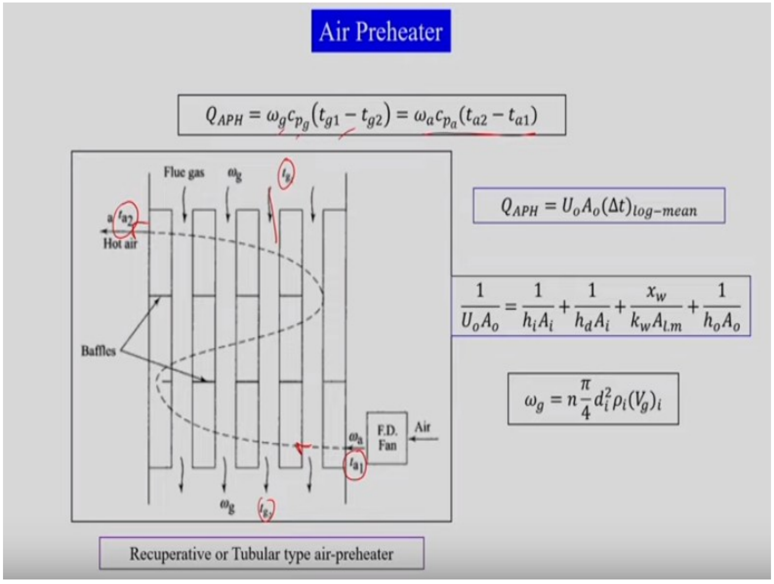

So there are two types of air preheater. One air preheater is called as recuperative or tubular type of heater where we again will have tubes in which air will be passing and across which air will be passing and then through which we will have gas which is flue gas which will be passing.

So we will have flue mass of air as air is coming from this fan and this air will go towards the furnace and then this is the direction of flue gas which are coming from the tubes, they are at higher temperature. They will lose the heat and come at lower temperature. By that all means air's initial temperature t_{a_1}goes to t_{a_2}. This is a conventional tubular or recuperative air preheater where we have mass flow rate of gas C_p of gas and temperature change of gas and this will be heating the air.

So again total heat transfer is $UA(\Delta t)_{l-m}$ and this is the total resistance. Again we can neglect the terms and then accordingly we can find out the number of tubes and diameter of the tubes required for air preheating which is efficient so as to get the hot air towards the furnace.

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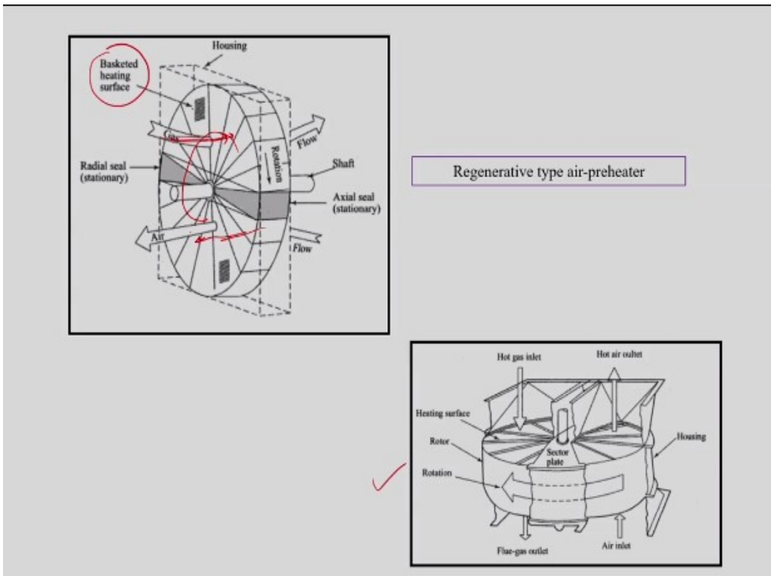

But there is one more type of air preheater, which is called as regenerative type of air preheater. In this air preheater, there is an assistance taken from matrix, which will store the heat from the hot gas, which is a flue gas and then it will pass that heat to the air. And then we can see over here that there is air which is coming from here, there is flue gas going from here.

When the flue gas goes from here, this thing will get heated and in this case, once it comes down and then when air passes these things will heat the air. So this is what is called as basketed heating surface. So these heating surfaces will get heated when they are exposed to the gas. But these will give heat to the air when they are exposed to the low temperature air. Similar is the concept over here.

So regenerative type of heat exchangers basically are used for the air heating when we are interested in supplying hot air to the furnace or we are interested this to have efficient combustion of the coal or also to have dry air to be present while combusting the coal. So these topics covered in this class were dealing with the steam generator and its parts.

Now we have dealt with the most of the components of the steam generator, function of the drum, different parts of the steam generator. Here we end the topic of discussion of steam generator. Thank you.