Thermal Engineering: Basic and Applied
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Lecture - 26
Characteristics of Convective and Radiant Superheaters; Steam Temperature Control

I welcome you all to this session of thermal engineering, basic and applied and today we shall discuss about the characteristics of radiant and convective superheaters. And finally, we shall discuss about the important issue that is the steam temperature control. So if we try to recall, in the last class we have discussed about the classification of superheaters.

And we have seen that the superheaters can be principally classified based on the modes of heat transfer into two subclasses. What are those? One is the convective superheater, and other one is the radiant superheater. So from their name itself, we can understand that convective heat transfer is dominating for the convective superheater and the radiative mode of heat transfer is the dominating mode for the radiant superheaters. And further we also could you know classify the superheaters based on the flow configuration and geometrical configuration.

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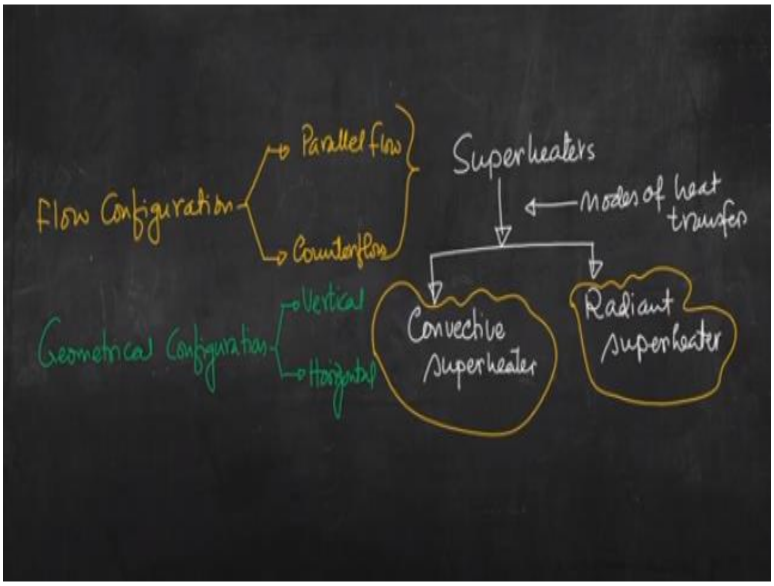

So just to recall exactly what we have discussed in the last class so superheaters are classified into convective superheater and radiant superheater. And this classification that we have discussed is based on the modes of heat transfer. Whether it is a convective superheater or radiant superheater, this class of superheaters can also be sub classified depending on the flow configuration and the geometrical configuration. See, I mean we can now see this particular convective superheaters in which the dominating mode of heat transfer is the convective heat transfer. So long as the convective heat transfer is there we can see that the fluid flow will play an important role. So naturally the flow configuration can also be taken into account while classifying the convective superheater. And that is why this particular class of superheater can be again classified into two different categories depending on the flow configuration.

So this particular classification depending on flow configuration is based on the direction of flow, that is parallel flow and counter flow that we have discussed in the last class. So basically there are two streams, one is the steam and another stream is the flue gas. If these two streams are allowed to pass in the same direction then that is called parallel flow. In other case, if stream is allowed to pass in the direction which is opposite to the direction of the flue gas or combustion products, then it is counter flow. So you can understand this particular classification that is counter flow and parallel flow is very important for this particular class that is convective superheater.

When you are talking about flow configuration, it is not like, there is no flow of the steam in radiant superheater. Even for the radiant superheater, there is a flow of steam through the superheater. But in that case, the combustion product flow is not that much important. Because radiative mode of heat transfer is the dominating one as the superheaters are placed in a zone which is very close to the combustion chamber of the boiler. And it is because of this position of the superheaters, the radiative mode plays an important role. So to clarify this particular issue here, I have discussed this.

So when you are talking about flow configuration, that means we are indirectly trying to understand that the performance of the convective superheaters is based on the arrangement of the flow because these two streams that are combustion gases and steam will be allowed to pass through the superheater and while they are passing they will exchange heat, and we will be getting superheated steam.

Now next one is the geometrical configuration. We have discussed that this is applicable to both the cases, whether it is convective superheater or radiant superheater.

And this is sub classified into vertical superheaters or horizontal superheaters. That means, this particular classification depends whether you are placing the superheater in the horizontal plane or vertical plane. Depending on that we can design a particular superheater whether it is convective or radiant superheaters. So these aspects we have discussed in the last class.

What we could understand from the discussion we had in the last class is that superheaters are basically very important element for the efficient operation of the boiler. Though they are not the mandatory components, but still these components are attached to the boiler to have the maximum performance or best performance of the boiler.

The reason is that the steam, we are getting in a boiler is either saturated steam or dry saturated steam that we have discussed in the context of Babcock Wilcox boiler. So whether it is saturated steam or dry saturated steam, to increase the performance of the cycle, and also not to have poor quality steam at the exit of the turbine, steam which will be taken to the turbine should be superheated from the boiler. And that is why the steam which is being produced in the boiler will be taken through these superheaters, either convective or radiant, essentially to increase the temperature of the steam. Now today we shall be discussing about the characteristics of the convective and radiant superheaters.

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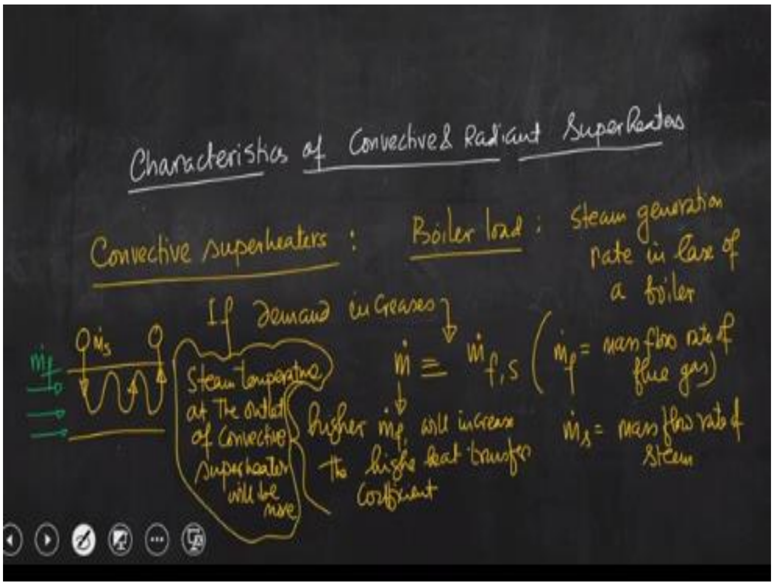

Characteristics of the convective and radiant superheaters.

So why it is important to study this in the course? Because our only the objective is to increase the steam temperature before it leaves the boiler. There are two reason for that. One is if we do not get the superheated steam at the exit of the boiler, then the performance of the cycle would be compromised. Not only that, the quality of steam at the exit of the turbine can affect the health of the blades and rotor.

So steam will be taken to the turbine and there it will be allowed to flow. While it is flowing through the turbine, it does work on the rotating part of the turbine that is the turbine runner. And finally steam comes out from the turbine and taken to the condenser.

So rather whoever is designing the system, he or she must be careful to check whether quality of the steam at the exit of the turbine is less or high. So if the quality falls below a threshold value, then the moisture content of steam will try to create several other problems that we have discussed. And that is very much problematic considering the smooth as well as cyclic operation of the turbine for a long time.

So, we can understand when you are taking steam through the superheater its temperature will increase. But whether the increase in temperature is linear with the boiler load or not linear, whether the temperature at the exit of the superheater will be increasing or decreasing with increasing or decreasing the load of the boiler; that aspect is very important.

Superheaters will always run at the design condition. Sometimes depending on the requirement, we may have to go for the mass flow rate of steam from the boiler higher than the design value. Sometimes, we also have to consider the mass flow rate of steam through the boiler lesser than the design value. So that means, it is not always possible to run the boiler at its design condition.

Now considering this aspect, if the steam flow rate through the boiler increases, then what would be the performance of the superheater? Because our entire objective is to get superheated steam from the turbine exit. With increasing steam flow rate, if the performance of the superheaters is not at par with the design condition then what will be the consequence?

So now let us first look at the characteristics of the convective superheaters. So I have already introduced one terminology that is boiler load. So what is boiler load? Boiler load is very important. This is the steam generation rate in case of a boiler. That means, if you would like to have high boiler load that means boiler is loaded, and we are trying to have maximum steam generation from the boiler. So if the boiler is designed to produce certain amount of steam, sometimes we may have to go off design condition. That means, the steam generation rate which is expected from the boiler should be increased depending on the requirement. So if the boiler load increases, what would be the characteristics of the convective superheater?

If demand of power increases, then we need to have more amount of steam generation. So mass flow rate of both flue gas is $\dot{m}_f$ and mass flow rate of steam is $\dot{m}_s$. That means, if we need to have high steam generation inside the boiler, then $\dot{m}_s$will increase. If you need to have higher amount of $\dot{m}_s$, then we need to circulate higher amount of feedwater. And if we need to have conversion of that higher amount of feedwater into the steam, then we should have higher mass flow rate of the flue gas.

So now question is if $\dot{m}_f$ is increasing and $\dot{m}_s$ is increasing then I can write mass flow rate $\dot{m}$ will increase. What would be the consequence? See, we have studied that $\dot{m}_f$ of flue gas needs to be increased to have higher amount of $\dot{m}_s$. If $\dot{m}_f$increases the convective heat transfer coefficient will increase. And the temperature of stream at the outlet of the superheater will be increased. That you have studied in the heat transfer course in heat exchanger.

So if we consider the superheater as the parallel flow superheater then basically we can understand that to meet the demand as needed by the system, we should have higher amount of mass flow rate of steam and to get that we should supply higher amount of feedwater. Naturally, the flow rate of flue gas or combustion products should be increased, to increase the combustion rate. So when this $\dot{m}_f$ is increasing the convective heat transfer coefficient will increase and that will eventually result in the higher temperature of the steam at the outlet of convective superheater. So this is the convective superheater characteristics. What about radiant superheater?

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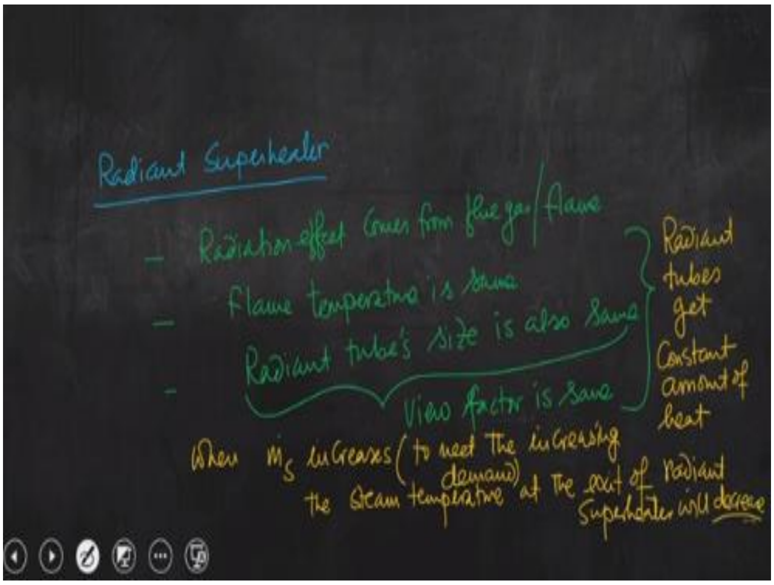

Basically radiant superheaters are placed in a zone which is very close to the combustion chamber. Now radiant superheater characteristics means that radiation effect comes from flue gas or flame but flame temperature is remaining the same. We are increasing the mass flow rate of flue gas, but that does not indicate that the flame temperature will increase. As I told today that whether it is radiant superheater or convective superheater, steam will be allowed to flow through the radiant tubes. Moreover, the radiant tube size is also remaining same. Everything is remaining same, but we are increasing the load or demand. With increase in demand $\dot{m}_f$ will increase but the flame temperature is remaining same. Radiant tube size is also remaining same. So you have studied in heat transfer course that if the size is remaining same that means view factor is remaining same. View factor or shape factor is remaining same. So if the view factor is remaining same and flame temperature is remaining same, then it is because of these two reasons, radiant tubes get constant amount of heat.

We have understood that radiation effect will come from flame or flue gas and flame temperature is remaining same. Maybe we have increased the mass flow rate of flue gas, but that does not indicate the flame temperature will be increased. On the top of that, the size of the radiant tube is also same. So the view factor or shape factor will be the same. Now if we place that radiant superheater for a case, where demand has increased, then also the radiant tubes will get constant amount of heat.

So steam should be allowed to pass through convective superheater and then radiant superheater or reverse maybe true. But the radiant tubes will be getting constant amount of heat. If $\dot{m}_s$ increases then what would be the consequence? So when $\dot{m}_s$ increases to meet the increasing demand then the steam temperature at the exit of radiant superheater will decrease. So this is very important.

So what you have understood? We have understood that if demand increases steam temperature increases when it is passing through the convective superheater. And if demand increases, steam temperature will decrease when it is passing through the radiant superheater. So these are the characteristic of the convective and radiant superheater.

So in the same boiler and same tubes only $\dot{m}_s$ has increased to meet the higher demand. And to get higher $\dot{m}_s, \dot{m}_f$ will increase. Because of this increase in both $\dot{m}_s$ & $\dot{m}_f$, the temperature of steam at the exit of the convective superheater will increase, but since the view factor is remaining same and flame temperature is also remaining same, the steam temperature at the exit of the radiant superheater will decrease.

Our objective is to get a fixed temperature at the exit of the superheater. So when steam is passing through the convective superheater its temperature increases, but when passing through the radiant superheater its temperature decreases. The entire purpose of placing the superheater was to get superheated steam. It is because of this different characteristics of these two different superheaters, the convective and radiant superheaters are placed in series.

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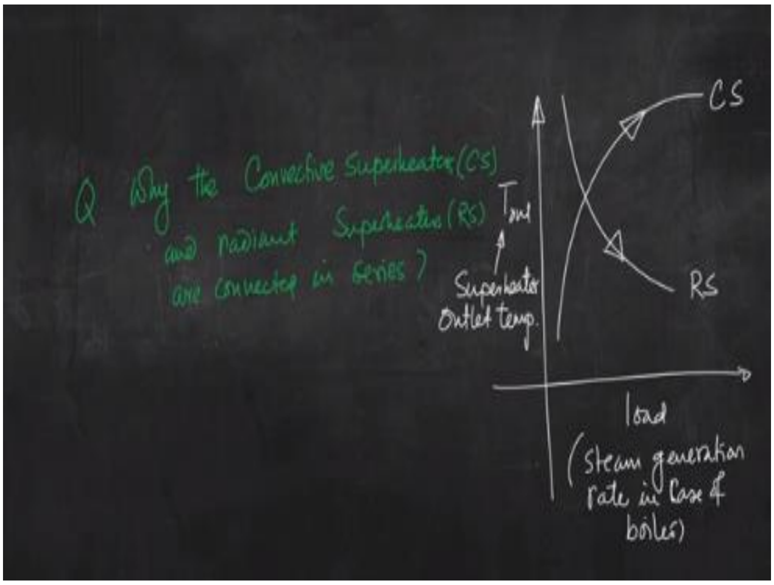

So one question should be why the convective superheater (CS) and radiant superheater (RS) are connected in series? Let me try to explain by drawing the load versus temperature curve. So X-axis is the load, which is nothing but the steam generation rate in case of the boiler. And Y-axis is T_{out} that is the superheater outlet temperature. So if we increase the load, then changes in outlet temperature in case of CS & RS are represented in the slide. With increasing load, the temperature of steam increases for convective superheater and temperature of steam will decrease for the radiant superheater.

So these two are contradicting each other considering the fact that the sole objective of placing superheater is to increase the steam temperature. But our objective is also to maintain the constant temperature of steam at the exit of the superheater or at the exit of the boiler, attributed primarily to the metallurgical consideration of the turbine blades. So the steam temperature should not be excessively high, otherwise turbine blade material will fail. Thermal crack will be generated and it is not desirable one. So to maintain a constant temperature at the exit of the boiler, these two superheaters are placed in series. The underlying reason is in one case, steam temperature increases if you increase the load and in other case, steam temperature decreases if we increase the load.

So you have understood that the sole purpose of placing the superheaters is to get superheated steam. Now from today's discussion, we have understood that the characteristics of CS & RS are not same. In one case steam temperature will increase, and in other case temperature will decrease, if we increase the load. And this increasing load is not impractical. The most realistic case is that the load should increase depending on the demand of the system. So whenever a boiler is placed in a power plant, it is very unlikely that the boiler will operate always at the design condition. Boiler needs to operate at off design condition very often. So the practical situation is that load will increase. If load increases then because of the different characteristics of these two different types of superheaters, these are placed in series, only to ensure that the steam temperature at the exit of the boiler should be constant.

You know we all are discussing about mechanical components. And mechanical devices and mechanical components, after being used for a long time, will start malfunctioning. And even after having the proper design or proper placing of these two superheaters, it may not be possible to get the temperature of steam, which is most desirable. That means, even if we place these two superheaters in series, nobody can ascertain that the temperature of steam at the exit of the boiler should be the one which is suitable for the turbine blade. The steam temperature may be higher than the temperature, which the turbine blade can withstand. So considering this, there is a particular aspect which very important and is called steam temperature control.

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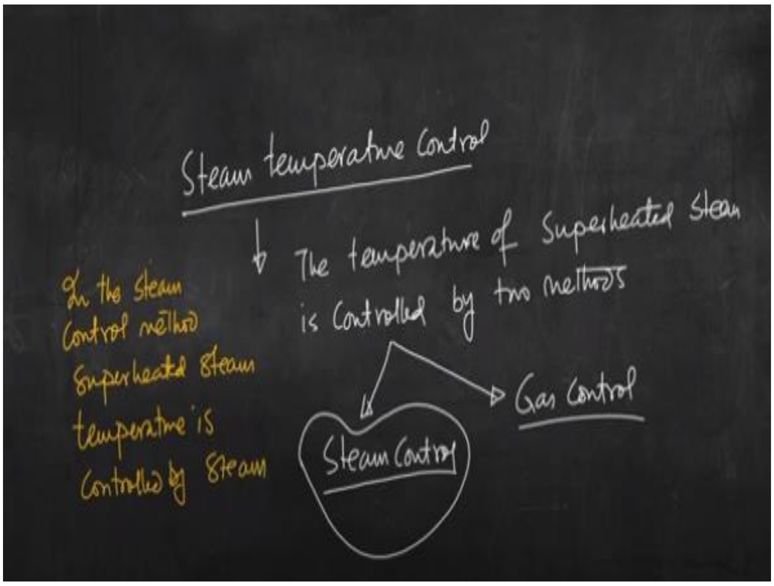

So you know this is kind of very contradicting. We have generated stream and only to increase the temperature of steam, we had to pass the steam through the superheaters. And placing superheaters is again not an easy task and then we also had to place superheaters in series. But what we have understood that even after having proper placing or proper arrangement of the superheaters, it is not possible to get the actual temperature of steam, which the turbine blade can withstand. So that means, we are trying to increase the temperature of steam after its generation inside the boiler and for that we are passing it through the superheaters and finally we can see that even after passing through the superheater, its temperature may become so high that again we need to have a control over its temperature. So I think that is very contradicting.

So till now, we have understood that we need to increase the temperature of steam, because if we do not increase the steam temperature, performance will deteriorate. But now we can understand that when we are trying to increase the steam temperature, we may not have enough control to increase the steam temperature up to the desirable limit. Sometimes the temperature may go beyond the desirable limit and that is why we need to have control of the steam temperature, otherwise turbine blade material fail.

Steam temperature control

Essentially the temperature of superheated steam is controlled by two methods. So superheated steam which is produced that steam should be taken through again some mechanical arrangements essentially to have a control of its temperature, before it enters into the turbine. And this is done by two methods. One is known as steam control, another is known as gas control. In this particular course, I shall briefly discuss about the steam control method.

So temperature of superheated steam is controlled by these two methods; steam control and gas control. So in the steam control method, superheated steam temperature is controlled by steam. So what is the process? Let us briefly look into it.

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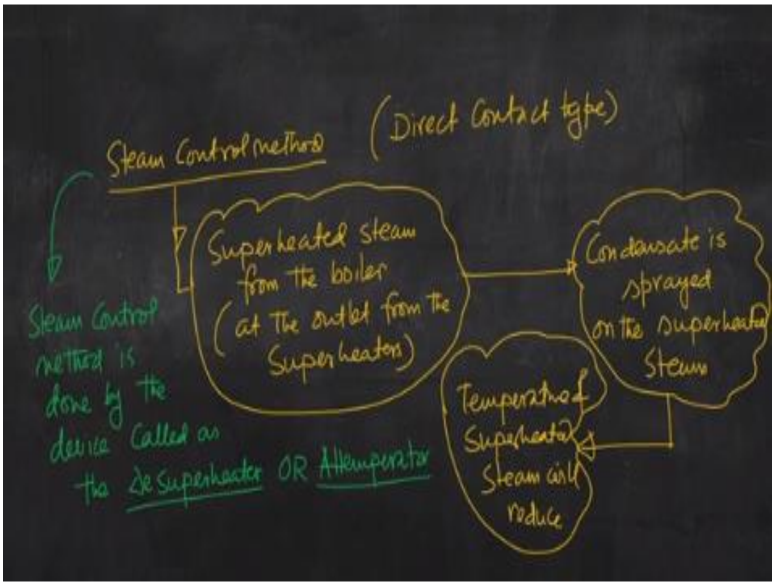

Steam control method

So you know that the temperature of superheated steam should be controlled, to be precise, the temperature of the superheated steam should be reduced to some extent, which the turbine blade can tolerate. This method is shown in slide by the block diagram. So in this method, we are getting superheated steam from the boiler precisely at the outlet from the superheaters. Then the condensate is sprayed on the superheated steam. So if we spray the condensate, the temperature of superheated steam will reduce. So this is the idea of the steam control method.

So we are getting superheated steam, then we are trying to spray the condensate on the superheated steam essentially to reduce its temperature. So this is the method what we can understand from this block diagram. So this method is known as direct contact type.

So the sole objective is to get the steam temperature which will be taken to the turbine and the turbine blade can safely withstand that temperature. But again we may have indirect contact type. Because we have discussed in the context of regenerative cycle, there was open type feedwater heater and closed type feedwater heater. So in the open type feedwater heater, bleeding steam is now taken to one chamber and in that chamber the feedwater is mixed with the steam which is extracted. And these two streams mix together, increasing the feedwater temperature. But in case of the closed type feedwater heater the feedwater is allowed to pass through the tube and the extracted steam is allowed to spray over the tube. And while passing over the tube, the steam releases heat and that heat is taken by the feedwater and feedwater temperature increases.

So similar to that here also there can be another type. Till now we have discussed about direct type, but let us discuss about indirect type steam control method.

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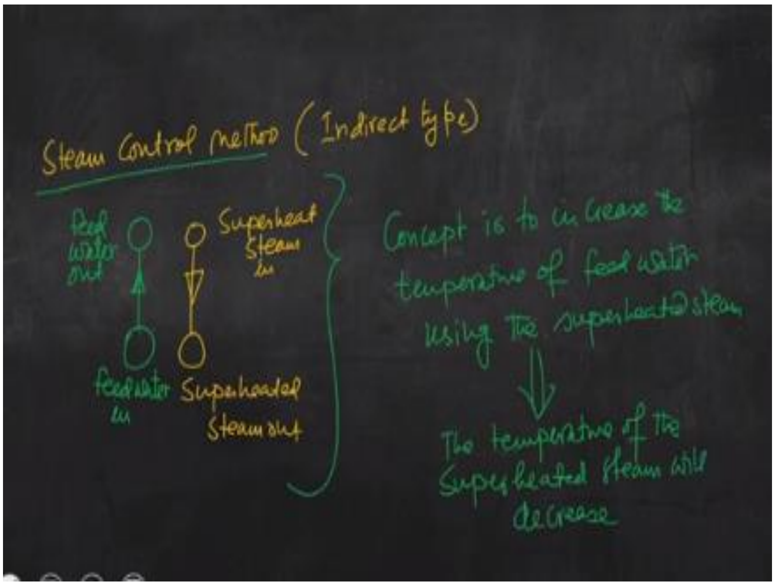

So now the question arises that why not to the use temperature of superheated steam to increase the temperature of feedwater. Because, essentially we have tried our best to take heat from the flue gas to increase the superheated steam. So now, if we need to reduce the temperature of superheated steam to make it suitable for the turbine blade material, then why not to utilize that heat to increase the temperature of feedwater which will be supplied to the boiler.

So the diagram for indirect type is drawn in slide. The direction of superheated steam in and superheated steam out is shown along with the direction of feedwater in & out. So while these two streams are passing and as we are trying to reduce the temperature of superheated steam so that temperature can be taken by the feedwater. So that means, these two are basically a kind of heat exchanger just like economizer.

If you can recall, in the economizer, the objective was to increase the temperature of feedwater using the flue gas. So the combustion product before leaving from the boiler, is taken through the coil and the feedwater is taken through the pipe and the combustion product is allowed to pass over the pipe. So we can extract some amount of heat from the combustion product, which otherwise will be leaving from the boiler, to increase the temperature of the feedwater.

The similar concept is applied here in indirect type steam control method. The superheated steam and feedwater will be close to each other while passing. And when feedwater is passing, we may allow steam to pass over the feedwater line. And while doing this, the feedwater itself will try to reduce the temperature of steam by taking some amount of heat. So feedwater will take some amount of heat from the flowing steam, which in turn will reduce the temperature of superheated steam and that will serve the purpose.

So this is the concept of indirect type steam control method. The concept is to increase the temperature of feedwater using the superheated steam. And in due course, the temperature of the superheated steam will decrease.

Now let me briefly discuss here that whether it is a direct contact type or indirect contact type, we have seen that we have taken steam after its generation in the boiler through the superheater to increase the temperature, but at the exit from the superheater, again we need to reduce the temperature because of several reasons that we have discussed. So, this is called as De superheater or Attemperator. So the steam control method is done by the device called as the De superheater or Attemperator. That means, we had superheated the steam and now we have we are trying to de superheat.

So finally, we will the placing of superheaters and attemperator using the block diagram. So let us show the block diagram.

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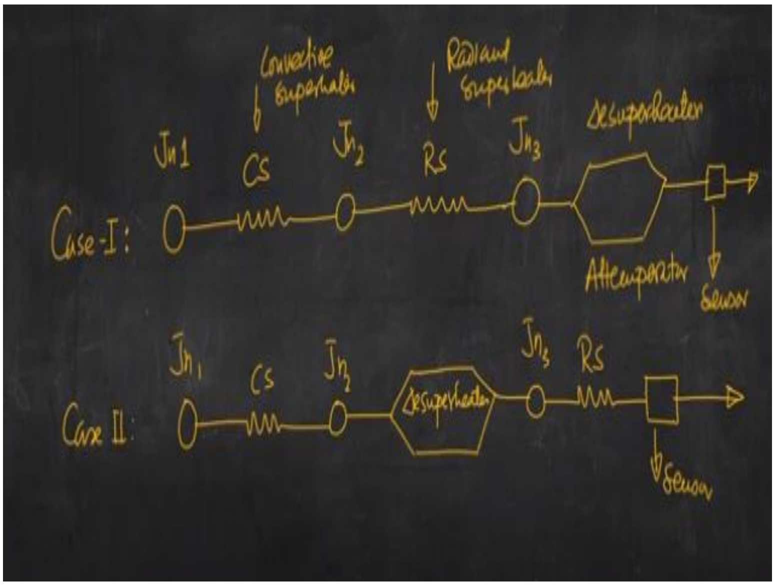

Case-I

I told that these two superheaters are connected in series. Through the block diagram we can show that. So in case-I we have shown that there are 3 junctions namely, junction 1, junction 2, junction 3. In between junctions, there is first convective superheater, then radiant superheater and then attemperator or De superheater. And finally, there is a sensor to measure the temperature. The sensor will measure the temperature at the exit of the attemperator to make sure that the temperature of steam is suitable for the turbine blade material. Then finally steam is going. So this is case I, What we can understand that there is convective superheater and radiant superheater these two superheaters are placed in series.

Case II

Say there is the junction 1, then there is convective superheater. After that we have junction 2. And then we are having attemperator. Then another junction, say this is junction 3, then radiant superheater. And finally, we will be having the sensor and steam will go out.

So now question is what we can see from these two particular configurations? In the both the cases, superheaters are placed in series, there is no doubt about it. In case I, you know that junction 3 is at high temperature. In case II, steam is first going through the convective superheater, then its temperature is controlled and then finally going to the radiant superheater and there is a sensor and finally it is going out. So now advantage of Case II is that at junction 3 for case I temperature is very high, but at junction 3 for case II, temperature is not that much high. So this is the advantage of case II. Depending on the requirement, the arrangement can be either case I or case II. In both the cases the superheaters are placed in series and we also can see the De superheater in the circuit and the function of the De superheater is to reduce the temperature.

If we try to summarize today's class, we have recalled the classification of superheaters, then we have discussed about the characteristic of both the convective and radiant superheaters. Finally, we have seen that temperature at the exit of the superheaters is very high and that temperature is not suitable for the turbine blade material. Accounting for that aspect we have also discussed about another device in which steam temperature is controlled. And that steam temperature is controlled by the device which is known as De superheater or attemperator and in this device steam temperature can be controlled either by using direct method or by the indirect method. We have discussed all these processes as well. And finally, through the circuit diagram, we have seen the placing of the superheaters along with the De superheater in the boiler. So with this I stop here today and we shall continue our discussion in the next class. Thank you.