Energy Conservation and Waste Heat Recovery
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Lecture – 19
Recapitulation of common power cycles (Contd.)

Welcome back if you recall we were discussing modification of Rankine cycle, which are very important for effective conversion of thermal energy into work we have discussed a Rankine cycle with reheat.

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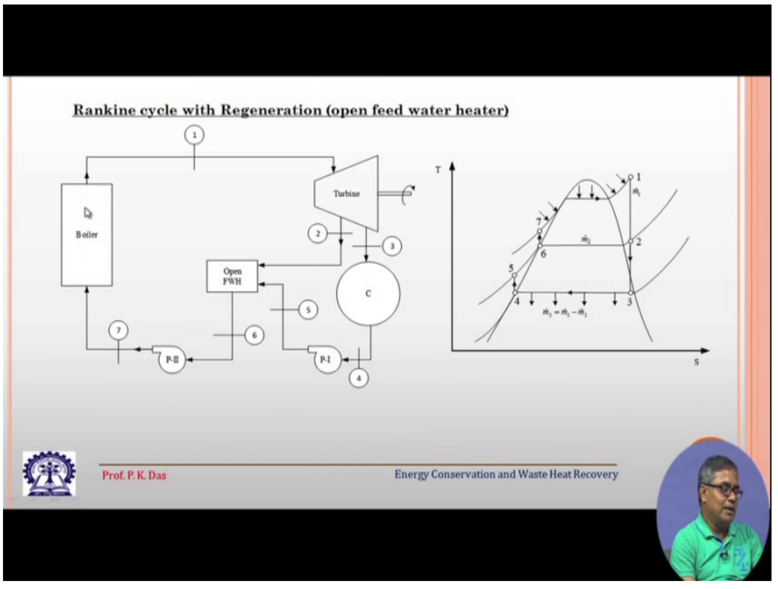

Now we like to discuss Rankine cycle with regeneration we like to spend some amount of time and this particular scheme I am calling it or it is called as open feed water heater. So, regeneration with feed water heater which is open type feed water heater.

Let us look into the arrangement of the basic cycle; the arrangement of the basic cycle we kept it very simple because first we like to develop the concept and here only one feed water heater and that is open type feed water heater that has been shown in the figure. So, let us start with the Boiler this is the boiler in which there will be some economizer part and then there will be a steam generator or evaporator part and then there will be super heater. After that superheated steam at high pressure will go to the turbine and it will expand up to condenser pressure, but not the entire amount of steam.

When the steam is expanding from the inlet pressure to the exit pressure of the turbine in between certain amount of steam we will take away from the turbine this is called bleed steam. So, steam is blade; blade out of the turbine and this bleed steam will be utilized for heating the condenser. Now the rest of this steam is allowed to expand up to the exit pressure of the turbine, then at the exit it will go to the condenser it will get fully condensed ideally we will think that saturated liquid is coming out of the condenser and in the after that it will go to a feed pump. So, the feed pump is not feeding it to the boiler directly, but it is feeding it to some sort of a open feed water heater.

So, you see the feed water will be heated in between before it reaches the boiler. So, feed water what is coming out of the condenser it will be taken in to some sort of a heater and in that heater the bleed steam which we have taken out of the turbine that will be also fade and there will be a direct contact between the feed water heater sorry between the feed water and the steam and our cycle will be designed in such a way. So, that ultimately we will get liquid condensed liquid in the saturated condition and that liquid will be taken to another pump this is pump 2.

This pump will ultimately raise the pressure to the boiler pressure; that means, this pump will be able to supply the feed water heated feed water to the boiler. So, this is what is our cycle diagram physical arrangement of a Rankine cycle with regeneration and when we have used one open feed water heater; open feed water heater is like this we can see this diagram schematically very simple schematic diagram I am showing the internals are much complex.

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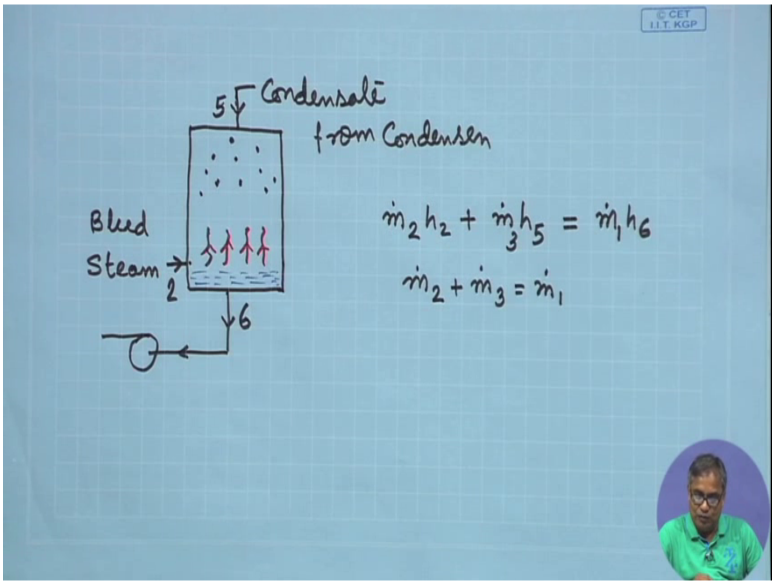

So, let us say we have got Steam over here, Bleed steam over here, Condensate from condenser. So, this will be falling in the form of spray very simple arrangement I am see showing and this steam will move steam will move in the upward direction.

It is designed in such a way this device that the steam and water droplet they get enough time to contact with each other and then the steam will condense and then ultimately at the bottom we will have condensate which we assume that it will be in the saturated liquid condition and it will be taken to a pump which will pump it back to the boiler. So, this is the arrangement and this kind of condensation is called a direct contact direct contact condensation. So, in an open feed water heater we will have direct contact condensation and by this direct contact condensation the steam will condense and the condensate which is coming from the condenser it is temperature will increase.

Now, we let us go to the thermodynamic plane and as usual I will try to explain it with the help of a Ts diagram let us say we start from the turbine. So, in the turbine from 1 to 2 if m dot 1 is the total amount of mass flow rate so m dot 1 a mass of a steam that expands from 1 to 2. At 0.2 a m dot 2 amount of a steam is blade extracted from the turbine and then from 2 to 3 m dot 3, which is m dot 1 minus m dot 2 that amount of steam expands, then at 3 we get this mass flow rate and this then this amount of steam then is condensed in the condenser and it reaches 0.4 which is the saturated liquid condition.

Then there is a pump p 1. So, that rises the pressure up to a 0.5. So, this pressure is raised over here. Now whatever steam we have got at 0.2 that steam and this condensate at 0.5 they mixes. So, what will happen; this steam it is it has to condense? So, it will condense and come to 0.6 saturated condition, this liquid that will get heated and it will also come to 0.6. So, basically then 2 streams are mixing and ultimately we are getting 1 stream of fluid which is a liquid that is at 0.6.

So, if we come back to our a previous diagram then what we can tell that this is your 0.5 this is your 0.2 and this is your 0.6 this is also there in this a diagram in this diagram also it is there. So, this is your 0.5 this is your 2 and this is your 0.6 and by one energy balance which we will see later on or now itself we can do it this energy balance we can do let us say m dot here if we do the energy balance. So, a let us say the enthalpy at 0.2 is a h 2.

So, the mass which is coming to in steam stream 2 so that will be m dot 2 into h 2, that is entering and the mass of the condensate which will come. So, that will be m dot 3 m dot 3 and this will be it will have an enthalpy of h it will have an enthalpy of h 5 m dot 3 and h 5 and then it will give us m dot 1 and h 6 and then we have got another equation what is that m dot 2 plus m dot 3 that is equal to a m dot 1. So, these 2 equations are there and state points are known. So, we will be able to calculate what is m dot 2 and m dot 3 that we will be able to calculate.

So, this is one scheme and let me tell you the advantage of this scheme now there are a few questions to be asked that you see the steam has to be heated sorry the condensate has to be heated from point one 2 up to up to this point; that means, where we are getting saturated where we are getting saturated liquid up to this point saturated liquid at boiler pressure, this has to be this at this condition the liquid from 0.5 to this point steam sorry condensate has to be heated.

And this is generally in our earlier example whatever we have seen that this is generally done in the economizer. So, economizer the flue gas is used to heat a condensate from the pump outlet condition to the inlet condition to the a evaporator or boiler drum. Now what happens initially the; a water or condensate at is at a much lower temperature. So, you see if you recall the; a diagram which I have drawn if you recall the diagram which I have drawn.

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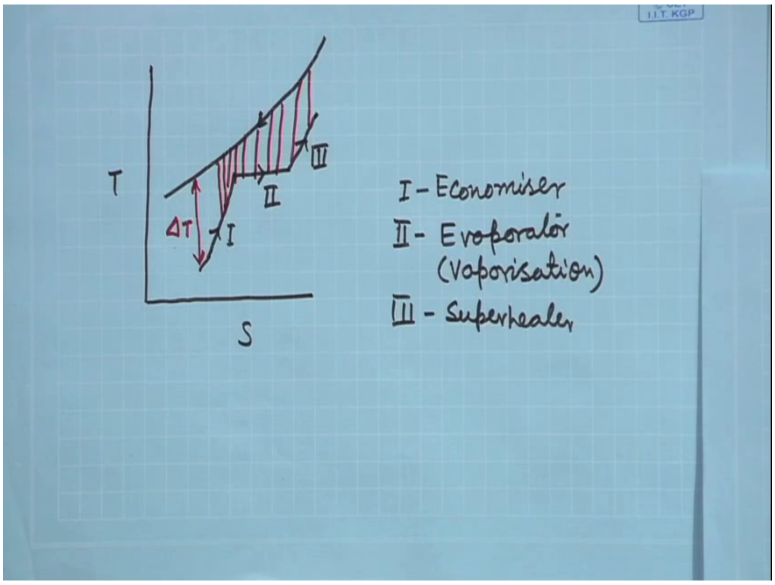

Let us say again it is a TS plane and this is the way flue gas is being cooled and this is the way steam generation is taking place.

So, here you see this is first part, this is second part, and this is third part. So, first part is Economizer. So, this is we can call it Evaporator this is Vaporization takes place and third part is your Super heater. So, you see the temperature difference if we see then you will find that at this point the temperature difference is very large if this is our delta T. So, this delta T is very large to start with because 1 stream is having liquid water at the outlet of the pump of the condenser. So, temperature is very low, but the flue gas corresponding temperature of the flue gases the product of combustion that is not that low.

So, here what we find that lot of irreversibilities are there because of this high value of delta T. Now if this heating can be done some other by some other means some other means I like to say that if it can be done internally by cycle modification not burdening the fuel specifically for this kind of heating then we have got one advantage one thermodynamic advantage. The thermodynamic advantage is that that let us say this heating is done internally by cycle modification, then external heating is from somewhere here and external heating you see I am doing at high temperature heat addition at high temperature is beneficial that is why I have discussed this point also earlier carnot cycle is having a higher efficiency compared to other cycles operating between the other reversible cycles operating between the same temperature limits.

So, this is the cycle modification we want to do and that is what we have we are attempting through a regenerative steam power cycle. The next question is that we are using steam for this heating initial heating of the condensate is it beneficial. Now well what we do is like this initially the entire steam expands to the turbine here this steam is at high pressure it has got high potential to do work, at lower pressure when the work producing potential of the we can call also Exergy; Exergy of this steam has reduced then that low Exergy steam part of that low Exergy steam we are using for heating the water.

So, thermodynamically this is a very good very good arrangement to get most out of the energy which we have taken from a high temperature source or combustion. So, the benefit which I will get derive out of this kind of a cycle that there is a definitive increase in efficiency of the cycle. The efficiency of the cycle will be higher if we go for feed heating and; obviously, the work output per unit mass flow rate of the working fluid or steam per kg of steam the kilowatt or megawatt produced megawatt produced that will be less because part of this steam we are not using for producing work we are using for heating purpose.

So; obviously, that will reduce we will see how to take care of that, but the efficiency of the cycle will be very I mean we will have some increase in the definite increase or good increase in the efficiency of the cycle. So, that is the key point of our regenerative feed heating or regeneration and that is what is adopted in all the practical steam power for a cycles all your utility power plant we will have reheating incorporated in the cycle.

Now here we have called open feed water heater we have shown open feed water heater this is not the only one feed water heater which are used this is not the single most field feed water heater which is used in practice there is something called a closed feed water heater.

So, let us see what is a closed feed water heater, if we go to the next slide so here it shows the closed feed water heater, this scheme remains almost same the steam expands from 1 to 2 that is from 1 to 2 the entire amount of steam expands and then certain amount of steam is blade or extracted. So, this is extracted and taken to some sort of a feed water heater which we are calling as a closed feed water heater, why it is closed it will be clear now the rest of the steam expands from 2 to 3 and after 3 I mean at 0.3 it enters the condenser it condenses up to 0.4. So, once it condenses then it passes through the feed water heater through some sort of a pipeline through tubes because this is nothing, but a heat exchanger regarding which we will learn in later classes.

And the steam which has been extracted that will be used to heat this condensate or water, but not by direct mixing it will flow outside the tube so that indirectly through metal equal of the tube it will transfer heat to the condenser. By that process what will happen this stream will get heated up and come out of the out of the feed water closed feed water heater and the steam which is entering here from the turbine that will get condensed. Now there are 2 options one option is that that this condensate we take we take another pump and then we have got some sort of a mixing chamber where we mix this hot water which is coming from the condenser. So, you see this is the water which is coming from the condenser and the condensate which we have got from the closed feed water heater.

So, with the help of a pump we mix it both are liquid we mix it and then we send it back to the boiler. So, this is one scheme. So, everything is moving in the forward direction, everything is moving in a direction to the boiler. Another scheme could be the condensate which we get that is at high pressure, compared to the condenser that is at high pressure because after condenser there we have employed a pump and we have raised it pressure. So, this condensate will be at high pressure in the liquid condition and there could be some sort of a trap or valve arrangement with that it can be returned back to the condenser.

So, it is moving in the backward direction the condensate is moving in the backward direction either the condensate then move in the forward direction and go to a mixing chamber or the condensate can move in the backward direction and go to the condenser. Both the arrangement has got their pros and cons when we are sending it back to the condenser you see we have to use only one kind of a 1 pump because this line is not there with only one pump we can do whatever we wanted to do and the mixing chamber also we can eliminate.

So, simply it will go to the boiler and with the help of a single pump we can do this, but then the difficulty or rather the drawback of this a process is that this condensate which is at some sort of a high temperature. So, that high temperature condensate again I am taking to the condenser and it has to be cooled back and then some amount of energy wastage or a inefficient use of energy is there. So, that way from the thermodynamic point of view this is not very good, but may be practical a operation point of view this can be an option that we send back the condense condensate to the condenser again.

Now, when we are sending back the condense condensate to the condenser again. So, there could be some sort of a placing which I will describe now. So, let us first take the a first option. So, steam is expanding here this team is being extracted and then the rest of the steam is being condensed in the condenser a pressure is raised by the pump and here you see the steam which we have got at a 0.2 that will get that will get condensed, that will come to 0.8 which is 0.8 here from 0.8 to 9 there will be some sort of a pressure rise. So, this is what we can see and this steam when it is condensing it is also heating the water which is coming out of pump 5. So, this heating process which is from 5 to 6 that is shown here and then there is ultimately some it is some at a some at a high pressure and it will go to the boiler.

If we have to take back then after 0.8 it has to be sent to the condenser, at 0.8 it is in liquid condition in the condenser when it is going it is going at a low pressure, high temperature water is going to a low pressure condition and for that there will be passive or generation of steam. So, part of it will get into steam part of the stream will get converted into steam and that will go to the condenser and then extra load the condenser has to take care of the extra load of cooling.

So, as I have told from the energy conversion point of view this is not a a good option, but even then a from practical point of view in many cases this is applied. So, this is how the closed feed water heater operates. Now the question will be there that I have shown 2 feed water heater, what is used in a practical steam power plant in a practical steam power plant. In fact, we have got mixture of both we have got in a large steam power plant there will be number of feed water heater.

For example, for a understanding we have taken cycles with only one feed water heater, but in practice there will be number of feed water heaters some of them will be open feed water heater and some of them will be closed feed water heater.

And we will have a combination of both and this design of course, how many of them will be open feed water heater and how many of them will be closed feed water heater. What will be the position of the feed water heater with respect to the extraction point this is called the extraction point with respect to the extraction point of the turbine, that is that comes into detailed design of the cycle and detailed design of the plant that is not within the purview of the present course we are not going to discuss that, but there will be a combination of open feed water heater and closed feed water heater.

I like to add another point here the point is we buy feed water heating, by extraction of steam if we go for feed water heating we have got definite in increase in efficiency, but what we pay for is that for the same circulation rate of the working fluid we get some less amount of power and if we see reheat cycle reheat cycle I told that there could be marginal increase in efficiency, but definitely we get more work out of the same amount of fluid circulation through this cycle.

So, you see these 2 options of a modification of a Rankine cycle they are supplementary to each other. So, if we combined them together then what we get we get more work and at the same time more efficiency so; obviously, this is exploited in practical power plant in utility power plant large steam power plant we have got both reheat and regeneration and again we have regeneration with both open feed water heater and closed feed water heater. So, with this message I like to end this particular lecture what I will do in the next lecture I will take up a problem and try to see how the calculation simple calculation can be done for a regenerative cycle for a cycle with regenerative feed heating.

Thank you