Energy Conservation and Waste Heat Recovery
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Lecture - 20
Recapitulation of common power cycles (Contd.)

Hello everyone, we will continue with our discussion on steam power plant and I like to take up an example for steam power cycle with regenerative feed heating. For simplicity we will take the example of regenerative feed heating with an open feed water heater.

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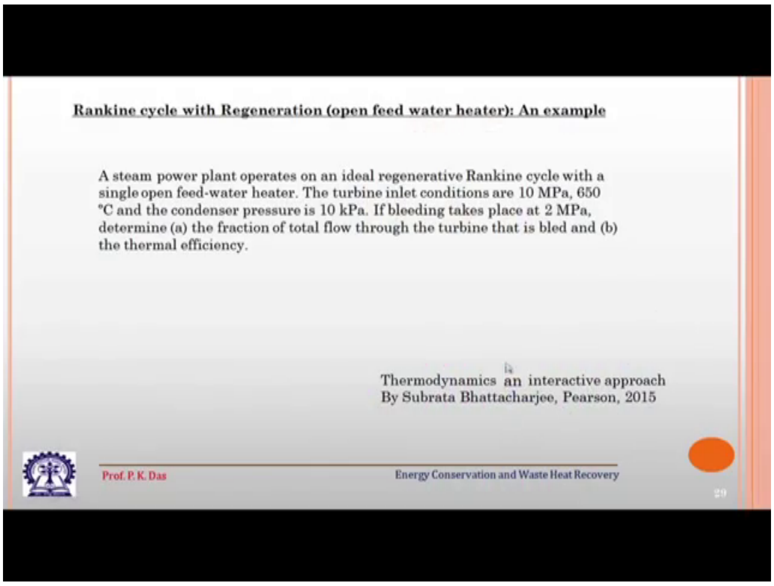

And the problem is given in this slide a steam power plant operates on an ideal regenerative Rankine cycle with a single open feed-water heater. The turbine inlet conditions are 10 mega Pascal 650 degree Celsius and the condenser pressure is 10 kilo Pascal. If bleeding takes place at 2 mega Pascal determine the fraction of total flow through the turbine that is blade and the thermal efficiency.

Both the problem let me acknowledge both the problems the previous problem and the present problem are taken from the book Thermodynamics and an interactive approach by Subrata Bhattacharya and the publisher is Pearson, 2015.

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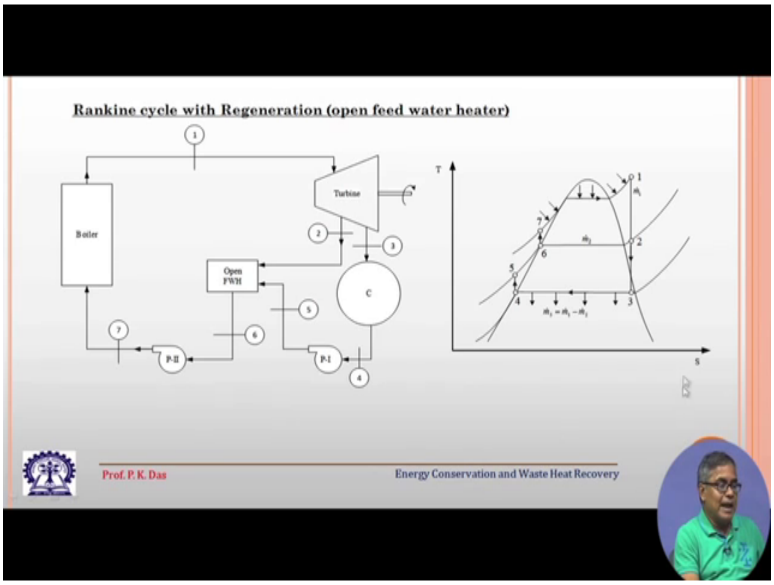

If we go to the cycle diagram the cycle diagram is given here and we have used the same state points whatever numbers we are showing here the same numbers are used in the problem itself.

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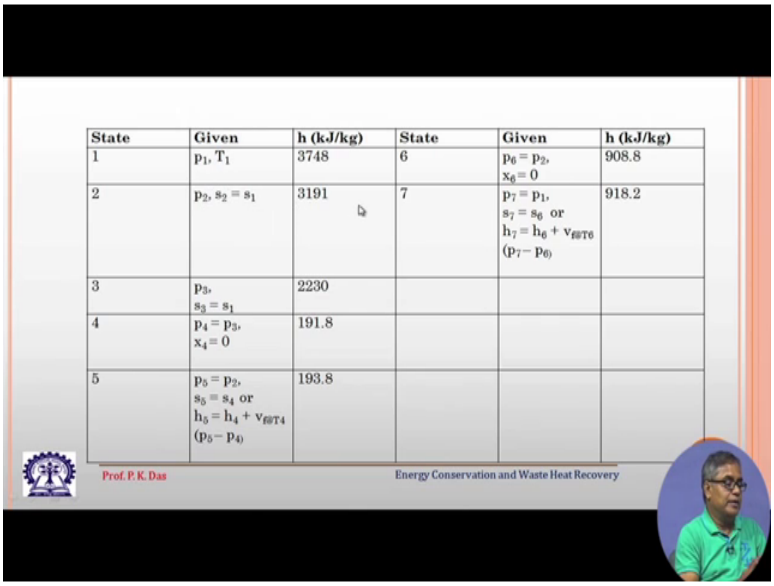

State	Given	h (kJ/kg)	State	Given	h (kJ/kg)
1	p_1, T_1	3748	6	$p_6 = p_2$, $x_6 = 0$	908.8
2	$p_2, s_2 = s_1$	3191	7	$p_7 = p_1$, $s_7 = s_6$ or $h_7 = h_6 + v_{f@T6}(p_7 - p_6)$	918.2
3	p_3, $s_3 = s_1$	2230			
4	$p_4 = p_3$, $x_4 = 0$	191.8			
5	$p_5 = p_2$, $s_5 = s_4$ or $h_5 = h_4 + v_{f@T4}(p_5 - p_4)$	193.8			

If we go to the state point we see at point 1 we have got pressure and temperature given. So, from there we can calculate the enthalpy then state 2 there is ideal Rankine cycle we have considered. So, the expansion up to state 2 up to which the entire amount of steam flows through the turbine.

So, this is an adiabatic reversible adiabatic process. So, s 2 will be equal to s 1. So, as this state at point 1 is known here we can calculate enthalpy which will be needed for further calculation and we can also calculate the entropy the same entropy value will be there at state point 2. So, from there pressure is also given. So, we will be knowing I mean we know the condition of steam completely. So, we will be able to calculate its enthalpy.

And then we can move to state point 3, in state point 3 that is the entry to the condenser in the entry to the condenser we know the pressure condition of the condenser. So, p 3 is known and again s 3 is equal to s 1 because we are following a reversible adiabatic expansion process. So, we know the enthalpy. So, enthalpy at point 1, point 2 and point 3 are known; that means, along the expansion line if you refer the cycle diagram which I have shown earlier. So, along the expansion line of the turbine we know all the enthalpy values at different point.

And then we move to point number 4 what is point number 4 if we now let us go back once to the cycle diagram. So, conditions were given here we could calculate the enthalpy this entropy and this entropy is same and the pressure is known. So, we can calculate the enthalpy over here also this condenser pressure is given. So, what we can do we can equate the entropy of point 1 and point 3 and pressure is known so this enthalpy also we can calculate and this state point is completely known. So, then from point 3 we can move to point 4 where it is saturated liquid and we can calculate the enthalpy at the saturated liquid condition, so that is also known. Then what we can do the way I have I have told that pump work can be calculated we can calculate the pump work and we can determine point 5, enthalpy at point 5 we can determine. So, let us go back to the, it will of solution.

So, at point 5 this is the condenser pressure p 2 p 5 is known and then s 5 let me see which is point 5 let me see once again. So, point 5 that you see it has been equated with point 2, this is one important thing that if this has to go to the open feed water heater then the pressure at which we are extracting the steam the condensate should be also raised to the same pressure otherwise it will not go here. So, this pressure is known this pressure is equal to p 2.

So, then in the palm in the pump p 1 we raise the pressure from point 4 to point 5 and then it goes to the mixing chamber. So, pressure 5 is equal to the pressure at point 2 then we will be able to calculate the pump work and enthalpy at point 5 that is what we have done p 5 is equal to p 2. This is an adiabatic reversible adiabatic process and the similar way as I have described for the previous problem we can calculate the calculate the change in enthalpy due to pump work and ultimately we get h 5 is equal to h 4 plus the enthalpy change due to pump work that is what and then we will be able to calculate the enthalpy at point 5.

Point 6 where is the point, where is this point let us see. So, point 6 is the point at the exit of the open feed water heater. So, now, we will do some sort of an energy balance for the feed water heater which I have also written earlier that steam with enthalpy at point 2 is entering these open feed water heater condensate with enthalpy at point 5 is entering the open feed water heater and from the feed water heater liquid water at saturated liquid condition and at a condition 6 that is going out.

So, now we can make an energy balance the energy balance already we have I have written. So, same kind of energy balance we can use and ultimately what we will get we will get the condition of point 6; x is equal to 0 that means, it will be at the saturated liquid condition and pressure will be the pressure of the extracted steam or bleed steam. Then we will get that enthalpy that is 908.8 kilo joule per kg.

Then again we have used another pump p 2. So, p 2 we have used and then for p 2 the inlet pressure will be p 6 or the pump to. So, inlet pressure will be p 6 and outlet pressure will be equal to the boiler pressure p 7 is nothing, but the boiler pressure. So, this will be the boiler pressure again we can assume the compression process in the pump is a reversible adiabatic process. So, by adding this pump work we can calculate the enthalpy at h 7.

So, now you see if we go back now you see that from point 7 there is this much of heating will be done in the boiler itself this is the economizer part of the boiler the economizer part of the boiler that has been reduced and then there will be evaporation and superheating. So, amount of heat that will be given in the boiler that is equal to h 1 minus h 7 that will give us the heat transferred to the working fluid in the boiler from the fuel all right. So, p 7 then we have got and the enthalpy we have got.

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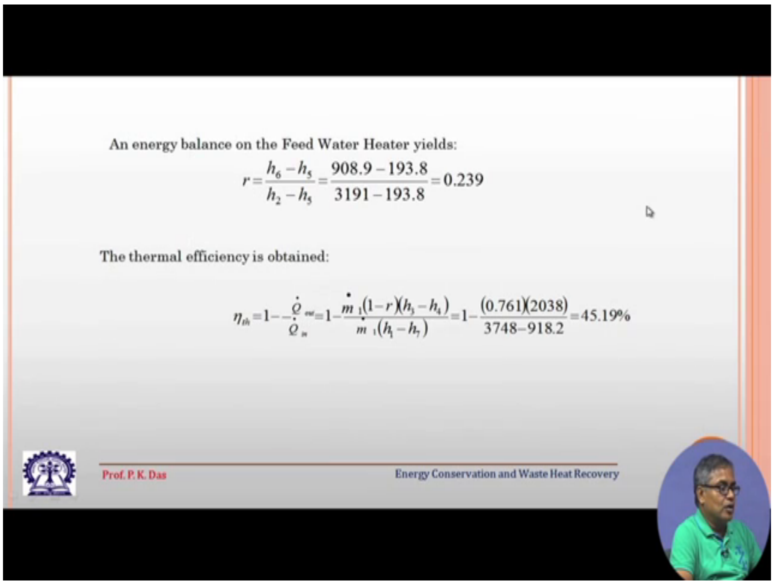

Next table we can go or next calculation we can go. Here from energy balance as I have ex explained earlier we can get that r which is the ratio of these 2 mass flow rates that is equal to 0.239; that means, this much amount of this is the ratio; that means, if the total mass flow rate we know multiplied by this quantity will give us how much steam we are extracting, all right.

And then we can find out the thermal efficiency. So, thermal efficiency can be calculated by different method.

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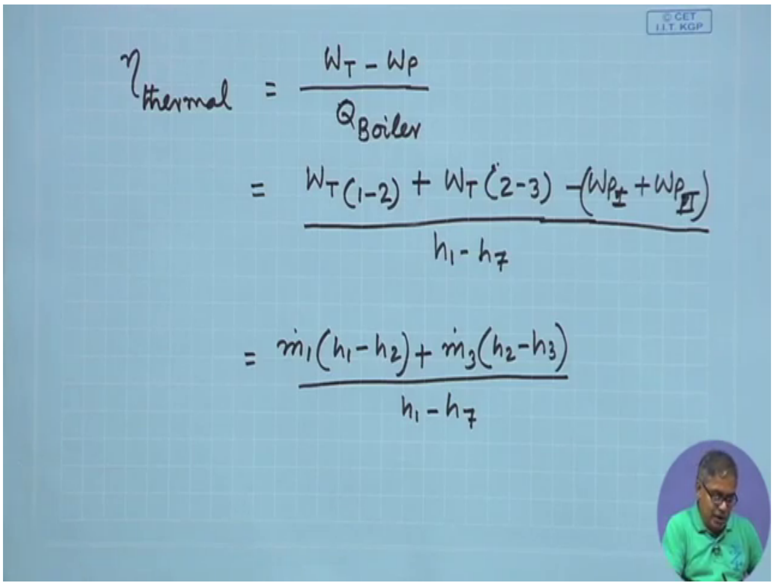

We can simply do eta thermal is equal to W turbine minus W palm divided by your Q boiler because that is the amount of thermal energy we are taking from the, that is the amount of thermal energy we are taking from the boiler. So, eta thermal is equal to W T minus W p pump by Q boiler and this W T has got 2 part, from 1 to 2 W T from 1 to 2 entire amount of steam has expanded and then plus W T from 2 to 3. If we see the cycle diagram this will be again clear that we have taken to work done this is m dot and one amount of mass is expanding from 1 to 2. So, there will be this enthalpy difference multiplied by your m dot 1. So, we can write. Let me write the next step first m dot 1 into h 1 minus h 2 plus we can write m dot 3 multiplied by h 2 minus h 3. So, this we can write. So, this is the turbine work.

Then there are two pump work. So, W p 1 plus W p 2 we have shown it by roman number, then W p 1 and W p 2. There are 2 pumps p 1 and p 2, so we can show that. And then boiler work you can show you can see that boiler work it is from 7 to 1, so we can write Q boiler is equal to h 1 minus h 7 h 1 minus h 7. You see all these quantities we have calculated. So, we can calculate the thermal efficiency.

But there is another unit also what we can do that thermal efficiency is equal to 1 minus Q dot out by Q dot in and Q dot out this is your Q dot out Q dot out what is the heat transfer in the condenser and this is the heat transfer in the boiler. So, this is your Q dot in.

So, this is also one way of calculating the efficiency and we will have 45.19 percent of efficiency. So, efficiency will increase there is a definite increase in efficiency if we go for feed water heating. It would be a good exercise if we do exercise it would be a good exercise that do not consider any feed water heating. So, you assume that entire steam the entire mass of steam is expanding through the turbine and this pump is raising the pressure from p 4 or p 3 up to p 1 or p 7 and then you do the cycle calculation and see what efficiency you get.

So obviously, the efficiency in the first case when there is regenerative feed heating we will get higher efficiency, but as I have told the work output will be lower. So, with this I have explained the working of ranking cycle and the modification of ranking cycle I have explained and the efficiency also I have efficiency, efficiency of the ranking cycle how the efficiency changes with feed water heating that I have explained.

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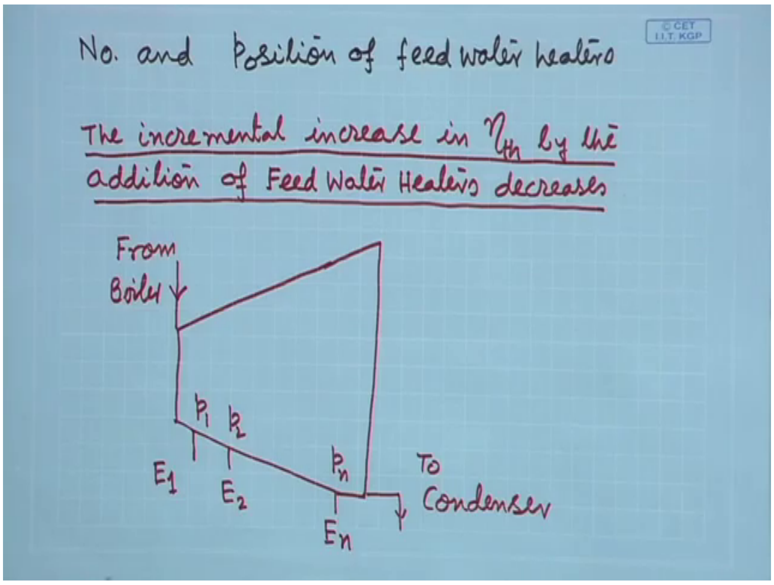

Now, I like to discuss a few additional points in connection with this that is number and position of feed water heaters. So, this is one thing I like to discuss. As I have told in a utility in an utility power plant; that means, in a power plant which is generating electricity large power plant there will be number of feed water heater.

So, now obviously, the question is where we have to place the feed water heater. How we know that at that particular fire means at what pressure we should extract steam. First thing is that feed water heater increases addition of feed water heater increases the efficiency, but if we see that what increase in what incremental increase in efficiency we get by addition of the first feed water heater. The incremental increase in efficiency by the addition of the next feed water heater is less. So, I can write this is important. The incremental increase in eta thermal by the addition of feed water heater decreases. So, this is a very important concept. The incremental increase in eta thermal by the addition of feed water heater increases or decreases sorry.

So, if it is so, when we are adding feed water heater we are having additional pipeline we are having additional pumps maybe and also we are having additional equipment like feed water feed water heater. So, with all these things the complexity of the pump plant that increases there will be whenever there is addition of pipeline addition of some sort of an equipment pump losses are also increasing. So, what we are getting we are getting an diminishing increase in efficiency and rather increase in the losses and some amount of irreversibility. So, we have to stop somewhere, so we cannot go on increasing the feed water heater infinitely.

So, that is one message I like to give you that there is a limitation depending on the plant size and depending on the operating condition of the plant of the cycle we have to select the number of feed water heater, but 6 7 8 number of feed water heaters are not uncommon in case of a large important. So, those many feed water heaters are used of course. It will depend as I have told it will depend on the size of the plant and it will also depend on the operating condition that means the pressure at which steam is supplied to the first stage of the turbine.

So, that is regarding the number. So, let us say somehow we have decided the number then how do I determine the placement of the feed water heater or rather how do I determine the extraction point from the turbine. Extraction point means this is a turbine high pressure steam is coming over here from boiler, here ultimately it is going to condenser and let us say we have got extraction point 1 I am denoting as E 1, I have got E 2, I have got E n, n number of extraction point. I am having corresponding to the pressure p 1, p 2 and p n in between I have got other extraction points.

So, how should I decide regarding p 1 p 2 p n etcetera for a good plant design? So, without going into derivation this can be derived, but without going into derivation. Let me explain how it is done or how ideally it could be done.

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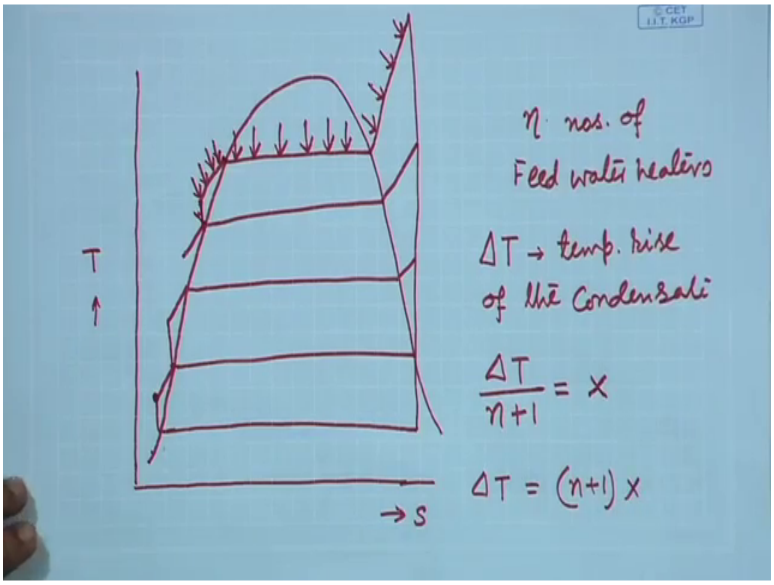

Let us say this is my steam power cycle and this side is T and this side is S schematically this is showing the cycle and there are different, let us say I am showing it only for open feed water heater just for the sake of understanding it.

So, you see the steam is to be heated from this condition sorry, the condensate has to be heated from this condition to this condition and out of this, this much of heating of condensate is coming from the boiler this is the heat transfer from the boiler and the rest of it is coming from feed water heater and let us say I have got n feed water heater, n numbers of feed water heater.

So, what I have to do let us say the condensate is coming at some temperature T and then I have to raise it to the temperature at which steam generation is there at the boiler pressure. So, corresponding to the boiler pressure I know the saturation temperature also. So, let us say I have to raise delta T amount of delta T the temperature rise of the condensate. So, by an approximate analysis by an approximate analysis it can be shown that delta T by n plus 1 if. So, let us say this is the quantity called X. So, this X amount of temperature rise will be there or should be there by each of the feed water heater by each of the feed water heater. If I raise the temperature of the condensate by an amount X where X is given by delta T divided by n plus 1. So, then what is happening? Delta T is equal to n plus 1 into X.

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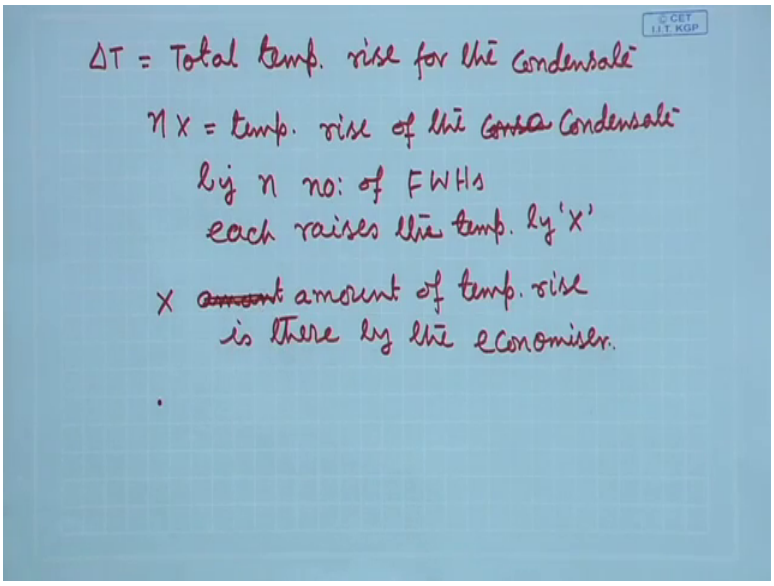

And if delta T, delta T total temperature rise for the condensate n into X is the temperature rise of the condensate by n number of feed water heaters each raises the temperature by X and then X amount of temperature rise is there by the economizer.

So, basically what we have done? We have by introducing feed water heater we have reduced the heat requirement from the economizer. Now we have decided that we will use in number of feed water heater. Each of the feed water heater will raise X amount of, each of the feed water heater will give X degree of temperature rise and then economizer will also give X degree of temperature rise.

So, assuming this as a thumb rule one can determine the pressures at which steam can be extracted. So, the end points from where the steam will be extracted by using this thumb rule one can determine that pressure. So, this will give generally this gives a good design and good energy utilization and that is what is also followed of course, keeping in consideration other plant type plant constraints. So, this is generally followed in steam power plant or steam power cycle design.

With this we come to an end of our discussion regarding the regarding the regenerative feed heating cycle. So, this is very important because all the practical cycle will have regenerative feed heating and regenerative feed heating is also a good example how we can utilize the energy in a better manner. So, with this we try to in this discussion and the next discussion we will take up a few more points regarding steam power plant and then we will move to other power cycle.

Thank you.