Thermal Engineering Basic and Applied
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Lecture – 14
Reheat Cycle and Analysis (Contd.,)

I welcome you all to this session of thermal engineering and today we shall discuss about this cycle that is reheat cycle. In fact we have discussed about the cycle in the last class and in continuation of that discussion, today we shall go for the analysis and little more of this particular cycle. So, if you try to recall we have discussed about the Rankine cycle as well as several modifications of the Rankine cycle. So, let us write again those modifications.

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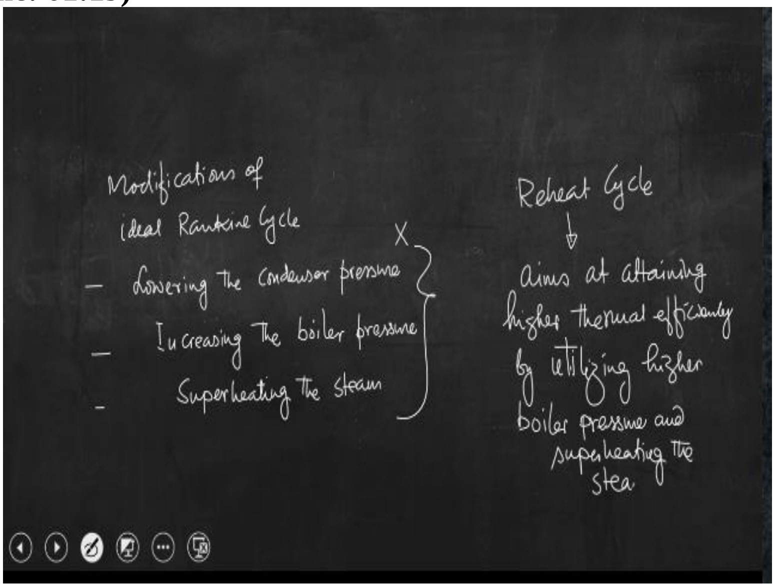

So modifications of ideal Rankin cycle

1) Lowering the condenser pressure number
2) Increasing the boiler pressure and
3) Superheating this steam beyond a particular point that is beyond point 3.

So, you know all these 3 modifications we have discussed essentially to have higher thermal efficiency. Nevertheless, we have also discussed about the demerits of every such modification in the context you know smooth and trouble free operation of the plant as well as the obligation of having higher thermal efficiency.

What are those? We have seen that by lowering the condenser pressure we can achieve higher thermal efficiency, but by doing this we are going to invite another problem that is the quality of steam at the exit of the turbine becomes very poor. So, it is not acceptable. Not only that, in addition to the quality of steam at the exit of the turbine, most importantly we cannot reduce the condenser pressure drastically, because mostly condensers are operated at a pressure which is below atmospheric pressure. So, if we reduce more then perhaps leakage of air from the surroundings into the condenser will be there and this air which is getting leaked into the condenser will create a resistance for efficient heat transfer between the flowing streams that is steam and water. So, this is not suitable.

If we look at the second one that is increasing boiler pressure, we have seen that if we somehow can design a boiler to operate at a higher pressure perhaps we can increase the efficiency. But again we need to compromise the quality of the steam at the exit.

Last one is superheating the steam. By adopting this particular modification, we can increase the efficiency as well as the quality of the steam at the exit of the turbine becomes high, I mean it is not very poor. So, it is quite important to go with this particular modification, but we have discussed that we cannot superheat steam beyond a particular limit, because that is restricted by the metallurgical consideration of the blade.

So, if we rule out the first modification as this is not the feasible way, even if we go for the second and third one, we have seen that these options are not the viable option for the enhancement of the thermal efficiency of the power plant. So, the idea is why not to look into the combination of these 2.

So, if we can increase the boiler pressure that means, if we allow boiler to operate at a higher pressure, together with that if we go for superheated steam, perhaps the problem associated with the reduction in the quality of steam at the turbine exit can be increased by superheating the steam and at the same time, if we operate the boiler at a higher pressure we can achieve higher thermal efficiency. So, idea is to combine these 2 options and to have a particular cycle.

So, to this end reheat cycle aims at attaining a high thermal efficiency by making use of the high boiler pressure as well as superheating the steam, but at the same time eliminating the expected probability of reduction of the steam quality at the exit and operating the plant at a temperature which will not lead to any problem like turbine blade cracking. So, this is what reheat cycle is.

Reheat cycle

So, this cycle aims at attaining higher thermal efficiency by utilizing higher boiler pressure and superheating the steam. So, basically we are going from the Carnot to the simple ideal Rankine cycle. By identifying several issues involved with the simple Rankine cycle, we have looked at modifications. And then having discussed about each and every modification we have critically discussed about the disadvantages feature.

Now, we have found that perhaps the first modification is not a viable option at all. Even second and third modifications are not also viable options, but we can use the combination of these 2 essentially to have high thermal efficiency but eliminating the problem associated with poor quality of steam at the exit, as well as we can operate the turbine at a high temperature without having any problem related to thermal crack generation in the blade. So, this is essentially the reheat cycle.

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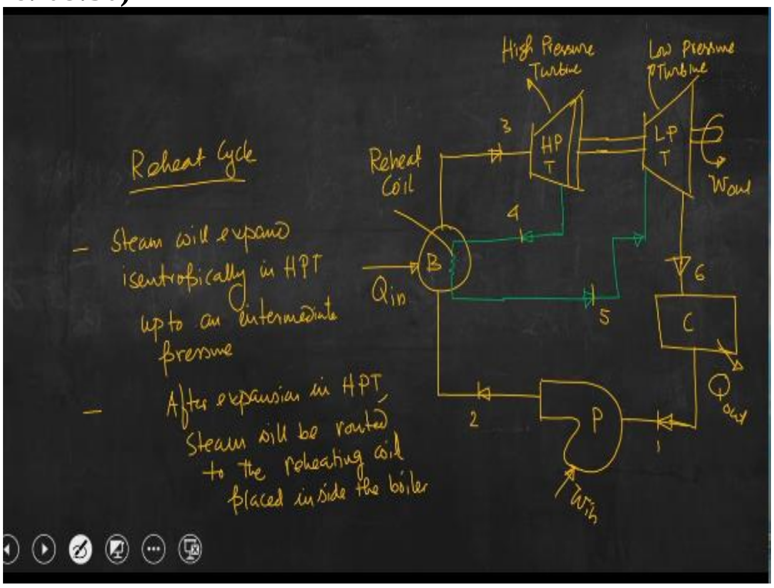

So now, we can discuss a little bit about this particular cycle that is reheat cycle. So, idea is we will be designing a plant in which boiler will operate at a high pressure and we also need to go for superheating the steam. To accomplish this, steam is allowed to expand in 2 stages. So, there are 2 different turbines, one is high pressure turbine and another one is the low pressure turbine. In high pressure turbine steam will be allowed to expand isentropically. At the exit of the high pressure turbine, steam will be taken for reheating through a separate coil in the boiler and that reheating will be done at an intermediate pressure and after reheating that reheat temperature would be approximately same temperature as it was done before entering into the high pressure turbine and this reheat steam will be again allowed to go into the low pressure turbine wherein again steam will expand isentropically to the condenser pressure.

So, let us draw the schematic diagram of such a cycle and then we shall discuss. So, there is the boiler, condenser, a low pressure turbine and a high pressure turbine. Then let us identify the cycle as 1-2-3-4-5-6.

So, this is different than the cycles we have discussed so far till now. So this schematic is different in one aspect that is here, the steam from the boiler will be taken into the high pressure turbine, steam will expand isentropically. At the exit from the high pressure stage turbine, that steam will be directed to a heating coil that is placed in the boiler and while steam is passing through this heating coil which is placed inside the boiler, it will be reheated again and that reheated steam will be taken to the low pressure turbine wherein again steam will expand isentropically and it will be allowed to expand up to the condenser pressure and the remaining part is as usual. So, basically you can see that condensate will be collected and again pumped back to the boiler.

So, Q_{out}, Q_{in}, W_{in} has been marked accordingly in the schematic diagram. So, again I am telling that the idea is steam will expand isentropically in the first stage that is high pressure turbine. And this expansion will continue at an intermediate pressure. So, you can understand steam is getting expanded. So, as steam is expanded in the high pressure turbine, this expansion process will continue at an intermediate pressure. So, steam will expand isentropic high pressure turbine up to an intermediate pressure which is not the condenser pressure.

Then after expansion in the HPT that is high pressure stage turbine, steam will be routed to the reheating coil placed inside the boiler. So this heating is continued approximately equal to the same temperature as it was having at state point 3.

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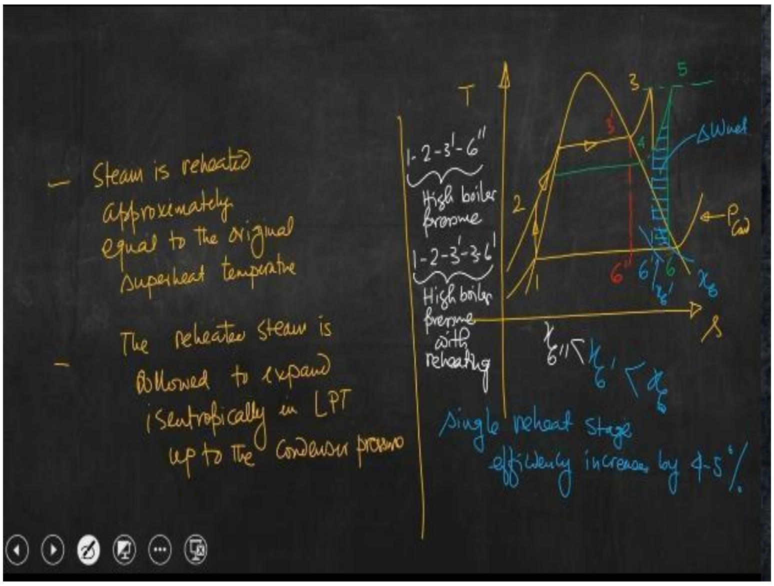

So, steam is reheated approximately equal to the original superheat temperature. Finally the reheated steam is allowed to expand isentropically in the low pressure stage turbine and this process continues up to the condenser pressure. So, this is all about the processes and you can understand the remaining processes are as usual. So, again steam will come to the condenser exchanging heat with the coolant which will be circulated into the condenser and the collected condensate will be pumped back to the boiler.

So, this is the usual process we have discussed. So, if we now draw the TS diagram which is very important. So, we can plot the condenser pressure $P_{condenser}$. You know that in the state point 1, the thermodynamic state of the working substance is saturated liquid. So, this is pumped to the boiler, so, objective is that the pressure will increase and the boiler is operating at a high pressure.

Because our objective was to combine these 2 modifications so that we can have high thermal efficiency without having the reduction in the quality of the steam at the exit of the turbine. So, we are allowing the boiler to operate at a high pressure as well as superheating the steam beyond point 3.

Then steam is going into the high pressure stage turbine and it does work. So, you know 2 turbines are connected to a common shaft. So, while expanding in the high pressure turbine, it does work on the rotating part of the machine and steam after doing work it is taken to this reheating the coil. So, this expansion in the high pressure turbine takes place up to an intermediate pressure.

So, this steam is reheated in this coil at approximately equal to the original superheat temperature. And then steam is allowed to expand. So, accordingly state 4, 5, 6 are marked in T-s diagram.

So, we are utilizing high boiler pressure superheating the steam. But, to accomplish this we are now using 2 differences turbine. It important to note that if we are allowing steam to expand in the high pressure stage turbine isentropically up to the condenser pressure, in that case, the corresponding quality of steam is x_6 & $x_{6'}$.

So you can understand quality of steam is becoming higher if we reheat steam and also we can have higher thermal efficiency. Because w_{net} is getting increased. So, this is the extra amount of work, we are getting because of this reheating. So, this is Δw_{net}. So if we allow steam to expand in the high pressure turbine up to the condenser pressure quality of the steam will be $x_{6'}$. So $x_{6'} < x_6$. So, basically we can increase the quality of the stream at the exit of the low process turbine and not only that, we also can increase the efficiency as Δw_{net} is getting increased which is clearly visible from this T-s diagram. So, this is the practice that is commonly followed in the modern steam power plant.

Now, we can see that we have drawn only one reheating stage. It is also possible to have multiple reheating stage. If we can have multiple such stages then perhaps efficiency can be increased. So, for a single reheat stage, efficiency increases by 4 - 5%. Now, try to analyse why it is so. You know that by reheating the steam, we are essentially increasing the average temperature at which heat is added in the cycle. So, if we try to go back to the previous classes, thermal efficiency will increase, if we increase the average temperature at which heat is added to the higher temperature part of the cycle.

So, by reheating the steam, it is because of such a complex arrangement, we are increasing the average temperature at which heat is added to the cycle and due to this we can have this increase in thermal efficiency. So, by having a single reheat, we can increase efficiency by 4-5%. But now, you may ask me a question that why cannot we go for multiple reheating stage.

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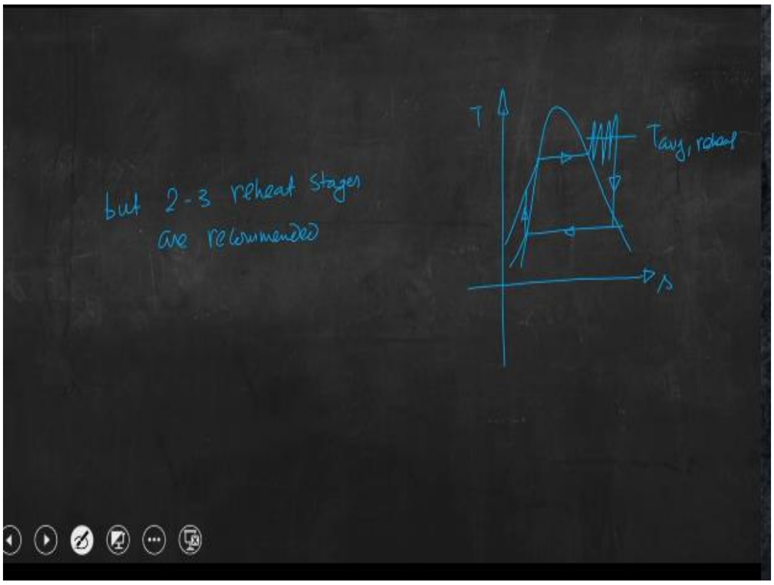

We can go for multiple reheat stage, but 2 to 3 reheat stages are recommended. Why? We again draw T-s diagram. So, if we have such multiple reheating stage then essentially there is $T_{avg,reheat}$. So, if we increase multiple reheat stages, average temperature at which heat is added to the cycle will increase and the efficiency will increase, but why then it is true that 2 to 3 reheat stages are recommended.

Because, by looking at this particular schematic, you can understand that for only one reheat stage, so many arrangements are needed. So, if we keep on increasing such reheat stages, then additional costs involved with the mechanical component also their maintenance will not be justified by the increment in efficiency.

So, let me tell you, we can go for multiple reheating stages then average temperature at which heat is added will be increased & efficiency will increase. But, 2 to 3 reheat stages are recommended why? Because the additional cost involved with the inclusion of one reheat stage will not be justified by the increase in efficiency that could be obtained. So, that is why it is seen that 2 to 3 reheat are recommended considering the cost involved with the additional arrangement as well as the efficiency that we will be getting out of this.

So, we have discussed that we are going to combine these 2 modifications that are increasing high boiler pressure and superheating the steam. So, if we now look at this particular T-s diagram, you can mark the high boiler pressure and state point 3' and 6''.

So, 1-2-3'- 6" cycle has high boiler pressure. And now 1-2-3'-3- 6' cycle is high boiler pressure with reheating. So, we are going to utilize high boiler pressure as well as reheating. Even if we are going for another reheat stage, we are going to increase the average temperature that means, we are increasing high boiler pressure to achieve the high thermal efficiency, but if we do not superheat steam then quality of the steam will be reduced. So $x_{6''} < x_{6'} < x_6$.

So, to increase the quality of the steam at the exit of the turbine, we need to go for superheating. So, idea is to combine these 2 modifications and that is what the reheat cycle is. So, you know that we have discussed about the operational aspects of this particular reheat cycle. We have also discussed about critical issues. So, we have also discussed about beyond 2 to 3 reheat stages which is not economically advisable to go for.

But one important advantage is that we are having same mass flow rate of steam and for that given mass flow rate of steam, we can increase the efficiency that means we are getting higher work output. So, net amount of work output is becoming higher for a given mass flow rate steam. So, it is signifying that specific steam consumption will be low and the plant will be smaller. So, basically if the plant is smaller the initial cost would be less. So, for a given mass flow rate steam, we are the efficiency by increasing this Δw_{net} so that signifying the low SS that means, for a given work output it requires less mass flow rate of steam.

Now, you know having discussed about this particular reheat cycle, I would say that the steam which is coming out from the high pressure turbine is having huge enthalpy. So, we need to make sure that while steam is again taken to the boiler enthalpy should not be lost. So, again it would be reheated in the boiler in this reheating coil and it will be taken back to the low pressure turbine. So, you know a mechanical cost is involved. Instead of going for this particular arrangement, if it is possible to have a certain I mean a particular or special blade material, which can withstand the same amount of temperature, then perhaps it is not advisable to go with this reheat cycle.

So, the idea is if the turbine blade material can withstand high temperature, then there is no need of reheating the cycle. So, this is what I wanted to discuss today. With this I stop here today and we shall continue our discussion in the next class with another cycle. Thank you.