Thermal Engineering Basic and Applied
Dr. Pranab K Mondal
Department of Mechanical Engineering
Indian Institute of Technology – Guwahati

Lecture – 13
Reheat Cycle and Analysis

We start our discussion today on topic thermal engineering basic and applied and today we shall discuss about the reheat cycle and while discussing about reheat cycle again we shall try to see several issues which are involved with this particular cycle. But, you know that if we try to recall in the last class, we have discussed about the modifications of simple Rankine cycle. In this context, we have also discussed the effect due to the lowering the condenser pressure.

And in continuation of that particular aspect of enhancing the efficiency of the cycle, today we shall briefly discuss about other 2 possible ways by which we can increase the efficiency of the simple Rankine cycle. We shall discuss both the merits and demerits associated with the modifications that we are going to discuss today. And also we shall discuss that even after having these modifications with this simple Rankine cycle, still the cycle cannot be considered in the real power plant essentially because of some disadvantages features. And while we shall be talking about those disadvantages features reheat cycle seems to be an alternative and we shall discuss this part again.

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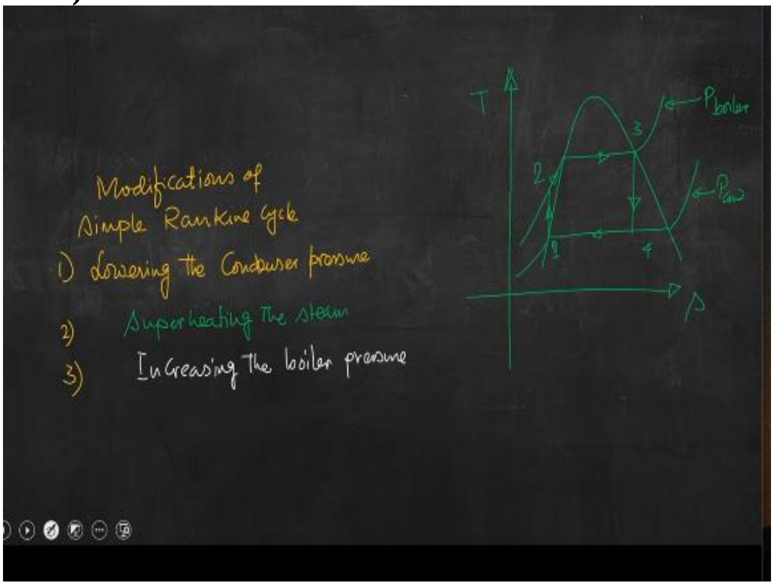

Modifications of simple Rankine cycle

We have already discussed in the last class that is

1) Lowering the condenser pressure.

About number 2 and number 3 modification we are going to discuss today.

2) Superheating the steam beyond the particular point that is point 3. So, if we try to draw the T-s diagram here for the simple Rankine cycle then we can plot $P_{condeser}$ & P_{boiler}. We can also plot the state points 1,2,3,4. So, superheating the steam beyond point 3 that would be an alternative to enhance the efficiency of the cycle that is quite visible if we really look for T-s diagram. We shall discuss today that point.

3) And finally, another important point is increasing the boiler pressure.

So, today we shall discuss these 2 aspects one by one. Let us first look at the second one that is superheating the steam.

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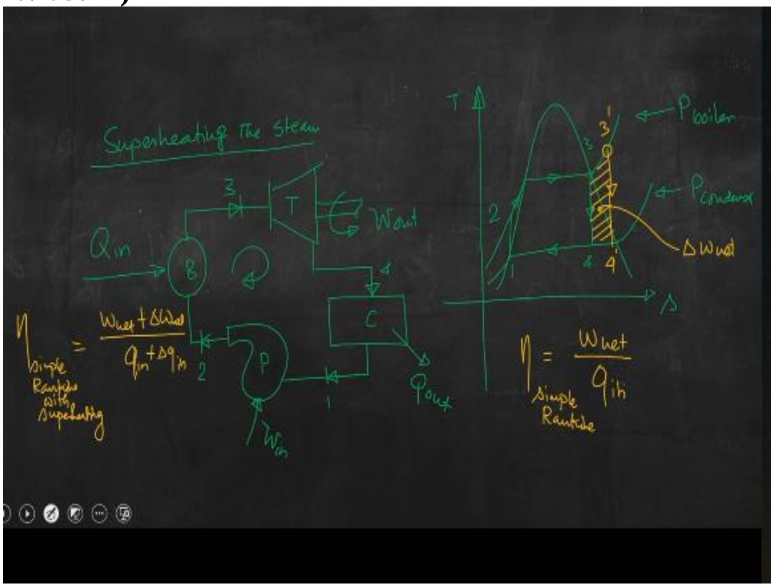

Superheating the steam

We shall discuss this particular aspect by drawing the processes in T-s plane. So, if we go for the T-s diagram, there is $P_{condenser}$ and P_{boiler}. You can mark the state points 1, 2, 3. Let us briefly draw the schematic of the power plant as shown in the slide. So it is not mandatory that always you have to consider inlet to the pump to be point 1. Denoting point is up to you.

We are trying to stick to the same notation exactly what we have followed in the previous classes. So, we can mark $W_{out}, Q_{out}, Q_{in}, W_{in}$ in the schematic diagram. Now, you will see that if we allow steam to expand in the turbine from point 3 and we can get point 4. So, this is basically what we have seen in the context of simple Rankine cycle. Today, we shall discuss that we will allow steam to be superheated beyond point 3.

So, if I try to identify that particular process here say we are allowing steam to be superheated beyond point 3 and this is point 3' prime and this point is 4 prime as shown in slide. So, you can see that if we allow steam to be superheated beyond point 3, this is the additional net work we are going to get, which is Δw_{net}. I am writing in the specific form. So, if you look at carefully that by superheating steam, we can get this additional delta Δw_{net} and probably it is because of this reason, efficiency can be increased.

$$\text{For Simple Rankine cycle; } \eta = \frac{w_{net}}{q_{in}}$$

$$\text{For Simple Rankine cycle with superheated steam; } \eta = \frac{w_{net} + \Delta w_{net}}{q_{in} + \Delta q_{in}}$$

So, this q_{in} is very important. To achieve this extra work output we need to supply more heat that we can easily say. That means if we allow steam to be superheated from point 3 to 3', we also need to supply additional amount of heat which is required for superheating this steam so, here we have written $q_{in} + \Delta q_{in}$. All these are specific quantities.

So both the quantities in numerator and denominator are increasing by these small quantities. So, if the relative increment of Δw_{net} is greater than the increment of Δq_{in}, then we can say that the efficiency of the simple Rankine cycle modified with superheating would be higher than the simple Rankine cycle.

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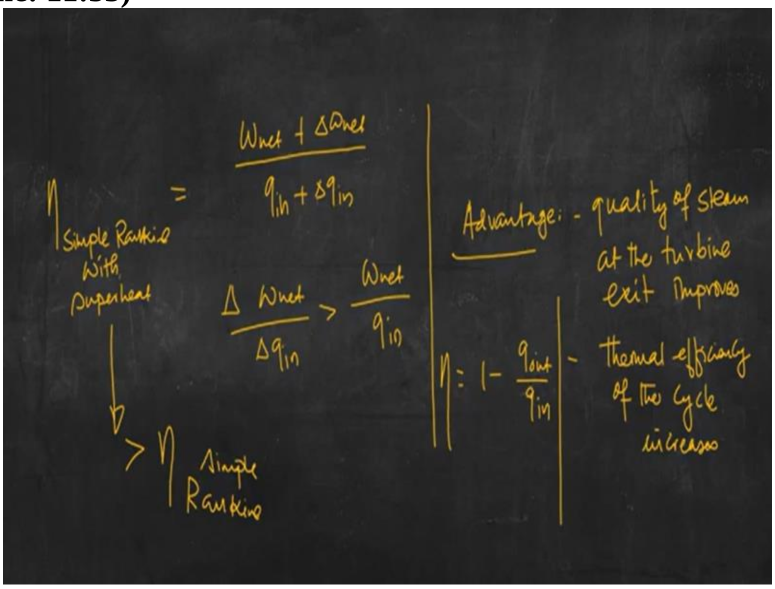

$$\eta_{simpleRankine\ with\ superheat} = \frac{w_{net} + \Delta w_{net}}{q_{in} + \Delta q_{in}}$$

$$\text{Now,} \qquad \frac{\Delta w_{net}}{\Delta q_{in}} > \frac{w_{net}}{q_{in}}$$

This is seen in practice. We are talking about $\Delta w_{net} = q_h - q_l$. So, you can see that, if we try to superheat steam beyond point 3, we need additional amount of heat to be supplied for this superheating process.

Additionally, if we allow steam to be superheated from 3 to 3', you can see from the schematic depiction that this additional amount of heat must be rejected in the condenser that is Δq_{out}. So, this additional amount of heat must be rejected if we allow steam to be superheated from 3 to 3'. Even after having this amount of heat rejection. Can we really have higher efficiency? Yes, because

$$\frac{\Delta w_{net}}{\Delta q_{in}} > \frac{w_{net}}{q_{in}}$$

$$\text{Hence,} \, \eta_{simpleRankine\ with\ superheat} > \eta_{simpleRankine}$$

So, q_l is increasing, but that increasing q_l is basically linear that decreases the rejection basically q_{out} the amount of heat which is rejected that is linear, while the amount of heat that we are supplying is not linear, so this is nonlinear. So, basically though there is some amount of heat that must be rejected, if we increase the temperature of steam beyond point 3 rather if we superheat steam beyond point 3, but you know that q_{out} is not relatively higher than the amount of heat that is added. Because q_h that is the amount of heat which is added to achieve this Δw_{net}, is nonlinear. I mean heat is added nonlinearly while heat is rejected linearly. So, in that case, we can achieve the higher thermal efficiency.

The very important advantage is that by superheating steam beyond point 3, we can increase the quality of the steam at the exit of the turbine. And number 2 advantage is thermal efficiency of the cycle increases.

$$\eta = 1 - \frac{q_{out}}{q_{in}}$$

As I told you q_{out} increases as compared to this simple Rankine cycle for this particular case and q_{in}also increases. But the increase in q_{in} is nonlinear while the increase in q_{out} is linear which is easily observable from this T-s diagram.

So, it is because of this reason, already I have written that

$$\frac{\Delta w_{net}}{\Delta q_{in}} > \frac{w_{net}}{q_{in}}$$

The resultant effect of this is the increase of the efficiency of this Rankine cycle with superheating.

The disadvantage is that if we try to increase the temperature of steam beyond 3 additional arrangement must be there. So, additional amount of heat must be supplied by increasing the temperature of steam beyond 3, which in turn is going to increase the average temperature at which heat is added to in the boiler. Efficiency will increase, but to achieve that in practice special arrangement needed which is costlier. Not only you know initial cost, but also the operational cost is higher. So, the superheating process requires a special arrangement to be done inside the plant, inside the boiler to be precise. Not only that, apart from the initial cost, we need to have proper maintenance during the operation of the plant. So, you know operational cost is involved. So, that is one of the disadvantages.

Second is we cannot increase the temperature of steam arbitrarily because that is restricted by the metallurgical consideration of the turbine blades. This is the basically again sensible heating, so, we can increase steam temperature from 3 to 3' and even 3'' quality will keep on increasing at the exit of the turbine. So, that is of course, a favourable aspect of this particular process, but we also need to keep in mind that the blade material should be able to withstand that temperature. There should not be thermal crack generated within the blade. So, this is again another disadvantage.

Increasing the boiler pressure

So, next modification is the increasing the boiler pressure. Again let me draw the T-s diagram, there is $P_{condeser}, P_{boiler}$. So in the last slide we have seen that we increased or superheated steam from 3 to 3'. So, I mean essentially what we are doing? We are increasing the temperature which in turn increases the average temperature at which heat is added.

So, for superheating, I told you that it requires special arrangement to be done inside the boiler, hence not only the initial cost, but also the operational cost is involved with this particular arrangement. So, I mean instead of looking at that particular aspect come to increase this additional heat. So, basically what we are doing? We are supplying this amount of additional heat. So, can you know supply this amount of heat even at a constant temperature in the boiler itself?

So, as I told you the steam which will be generated in the boiler that will be again taken through some special arrangement, so that steam can be superheated. So, instead of doing that, if we look at another way of getting this amount of additional heat, but at a constant temperature inside the boiler then that is nothing but increasing the boiler pressure.

So, just for the discussion, the idea is that we are increasing temperature up to 3'. So, without superheating we also can achieve the steam temperature up to that by increasing the boiler pressure. By how?

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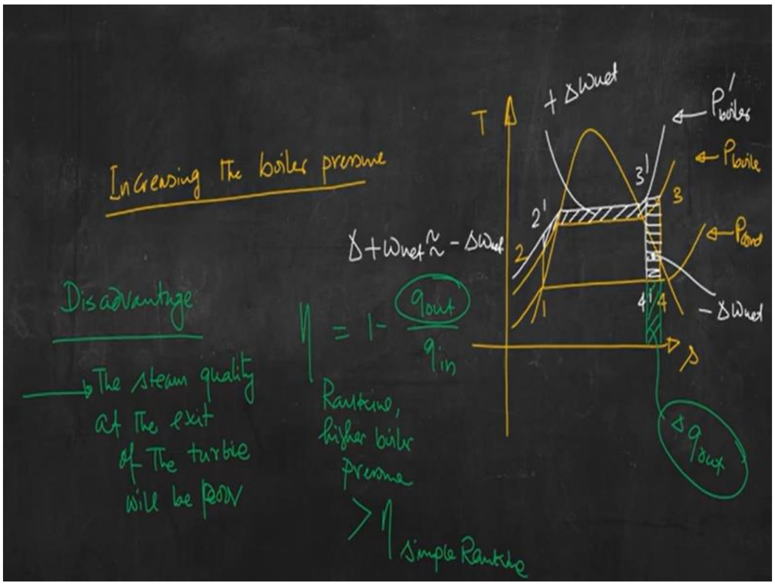

Say we are superheating steam up to this particular point, and the cycle is 1-2-3-4. Now, we can increase boiler pressure. So, this is the temperature, maybe we can have also, this is 2`. So, this is the concept.

You know that without superheating, we are trying to achieve this additional amount of heat, I mean we are trying to increase the average temperature of heating by increasing boiler pressure from P_{boiler} to P'_{boiler}. So, you know that the temperatures at 3 and 3' are same. So, what we are going to have? We are going to have additional amount of w_{net} that is the hatched portion which is $+\Delta w_{net}$.

So, if we increase boiler pressure that means if we allow boiler to operate at a higher pressure, we can achieve this additional amount of heat that we used to get by superheating steam in the earlier case. But if we look at this T-s diagram, we can also see that at the cost of this +Δw_{net}, we are also having this amount of work that we are not getting now, which is -Δw_{net}.

So, if we do not superheat steam rather if we allow to boiler to operate at a higher pressure probably we can get the same average temperature at which heat must be added to the cycle. So, if we do so, you can see that we will be getting this +Δw_{net} and this -Δw_{net} is the amount we are not getting, which you can see from the schematic depiction.

So, basically this 2 Δw_{net} are equal. So we can have this particular method that means, we are allowing boiler to operate at a higher pressure so that superheating arrangement is not required. Now, we can have the same temperature at which heat is added to the cycle. Though we are getting +Δw_{net} by operating boiler at a higher pressure, but at the same time we need to compromise this amount of -Δw_{net}.

So, this +Δw_{net} and -Δw_{net} are equal so they will cancel each other. So the overall effect is null so there is no additional effect. But, if you look at this T-s diagram carefully, you will find that by allowing boiler to be operated at a higher pressure we are going to reduce this Δq_{out}.

So, if we allow steam to be superheated up to this point, and now, if we allowed boiler to be operated at a higher pressure probably we can save this Δq_{out} amount of heat rejection in the condenser. So this is basically the quantity we can save. So, what we can do? We can reduce the amount of heat that must be rejected in the condenser if we allow boiler to be operated at a higher pressure.

So, we are not going to compromise the mean temperature at which heat is added and we are also not going to get additional w_{net} because +Δw_{net} and -Δw_{net} will cancel each other. But we can reduce q_{out}. So, you know

$$\eta = 1 - \frac{q_{out}}{q_{in}}$$

So if we can reduce q_{out} by having this special method then we can increase the efficiency of the cycle.

$$\eta_{rankine\ with\ higher\ boiler\ pressure} > \eta_{simple\ Rankine}$$

So, we can increase efficiency only by reducing the amount of heat that will be rejected in the condenser. So, by saving a certain amount of heat rejection, we can increase the efficiency of the Rankine cycle modified with this increasing boiler pressure. The gross effect of +Δw_{net} that we are going to get out of from this particular higher boiler pressure and this additional reduction in -Δw_{net} due to this superheating will cancel each other.

So, the gross effect is increasing efficiency, and the advantage is that we do not require special arrangement for superheating the steam. So, if we can eliminate it, there is no need of initial cost as well as the operational cost for this special arrangement. But disadvantage is that by increasing boiler pressure again we are going to deteriorate the quality of the steam at the exit of the turbine.

So, in the last class, we have discussed about lowering the condenser pressure. If we lowering condenser pressure, we have seen that maybe you are going to have a particular condenser which will operate at a pressure which is less than atmospheric pressure. Though we cannot reduce condenser pressure drastically, but even then we need to compromise the quality of the steam. Today we have discussed that in superheating the steam, the only disadvantage is that we need additional cost for the installation of a special system for superheating as well as the operational cost. And also you know that we should be careful about the selection of the turbine blade material such that a particular material would be able to withstand that high temperature. While coming to the third option that is increasing the boiler pressure, we can see that though we can increase the efficiency of the cycle, but again we need to compromise the quality of the steam at the exit of the turbine.

So, considering all those, you know that although we have discussed about the modifications of simple Rankine cycle, but none of these modifications that we have seen from the discussion is suitable for the power plant essentially to have higher efficiency without inviting any additional problems. Though modifications are there, employing either of these modifications we can increase the efficiency of the cycle, but at the same time, we are also going to introduce another problems.

Reheat cycle seems to be an alternative to be precise, for the increase in efficiency of the plant essentially by exploiting the high boiler pressure and superheating the steam, but at the cost of increasing the quality of the steam at the exit. So, let me tell you again that either by lowering the condenser pressure or increasing the boiler pressure, we need to compromise the quality of the steam. If we need to go for superheating this steam, then we need to again consider the additional costs involved with the initial as well as the operational issues. I mean, we can see that though we can increase efficiency, but we are going to have several other problems. Reheat cycle offers an alternative. The advantages of reheat cycle are that it offers higher thermal efficiency by exploiting high boiler pressure, superheating the steam and also eliminating the high moisture content of the steam at the exit of the turbine.

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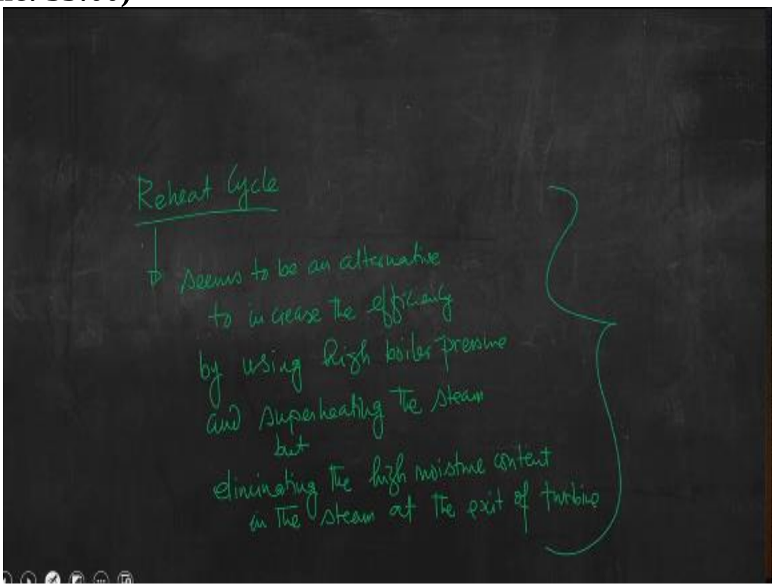

So, reheat cycle seems to be an alternative to increase the efficiency. I mean, we can increase cycle efficiency that means, we also can expect that the efficiency of the plant will increase. Because essentially all the processes will be compared by this particular cycle. So, all the processes of a power plant will be compared by this reheat cycle. So it seems to be an alternative to increase the efficiency by using high boiler pressure and superheating the steam, but, eliminating the high moisture content in the steam at the exit of the turbine. So, this is very important.

So, this cycle seems to an alternative. We are claiming that the cycle will offer high thermal efficiency. If you would like to have it, we need to have high boiler pressure that means the boiler should be operated at a higher pressure, we also need to go for superheating this steam.

But if we can have high boiler pressure and if we can have special arrangement that we can increase the superheating the steam, we can eliminate the probability of having high moisture content in the steam at the turbine exit. So, idea is we will be using high boiler pressure. If we use high boiler pressure, then we will be superheating the stream but the degree of superheat should be controlled.

So, if we allow boiler to be operated at a low pressure and then degree of superheat that will be needed to achieve high thermal efficiency will be very high. If you would like to have a higher degree of superheat then probably arrangements should be again much more complex and initial as well as operational costs will be higher. So, instead we are thinking to increase high boiler pressure, so that the degree of superheat should be within a controllable limit.

And also if we can superheat, probability is that the moisture content at the exit of the turbine also can be reduced. So, the idea is to use high boiler pressure, so that the degree of superheat can be reduced. Still you need to go for superheating, so that moisture content at the exit of the turbine can be reduced. So, if we can do it, probably we can increase the efficiency of the cycle and that is what the reheat cycle is. So, with this I stop here today and in the next class we shall discuss about the reheat cycle and we shall go for its analysis. Thank you.