Energy Conservation and Waste Heat Recovery
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Lecture – 17
Recapitulation of common power cycles (Contd.)

Hello everyone. So, we were discussing regarding the basic steam power cycle the ideal cycle for steam power plant is the Rankine cycle and already I have shown the physical arrangement of Rankine cycle with 4 basic component boiler turbine condenser and feed pump.

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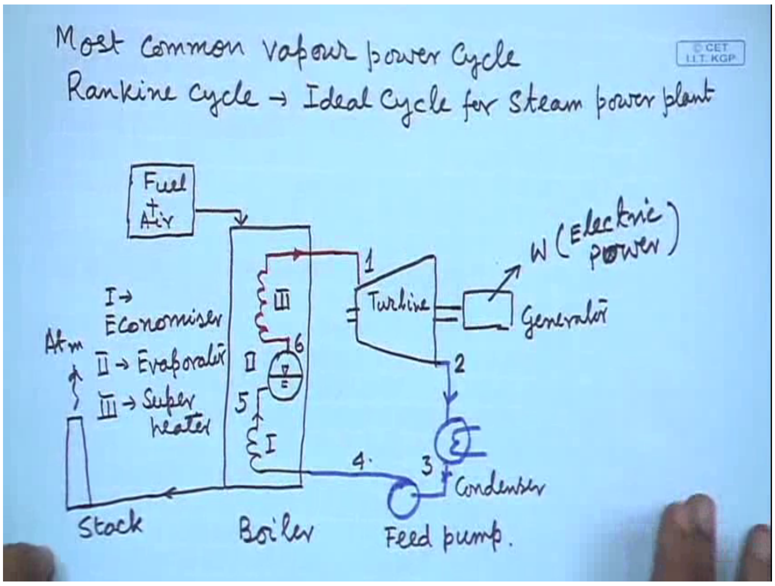

Then I have shown the Rankine cycle on a Ts plane Thermodynamic Plane.

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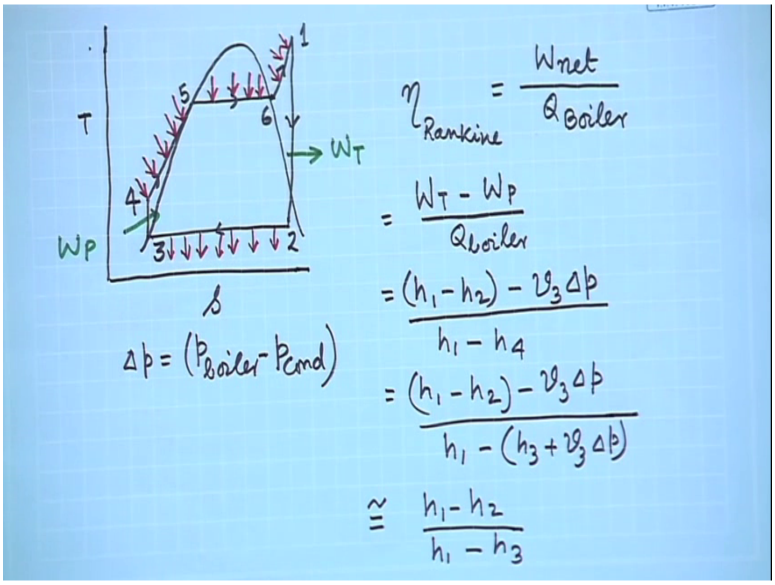

So, what we can do what is done very routinely that we can determine the efficiency of the Rankine cycle, eta Rankine assuming that all the processes are ideal process, then from the basic definition this is W net divided by Q Boiler . So, this can be written as W Turbine minus W Pump divided by Q boiler.

So, this again can be written as turbine work that can be assuming turbine to be a device which is operating under steady state steady flow condition and also assuming that the changes in kinetic and potential energies are minimum, there is no loss from the turbine one can write that turbine work is given by the enthalpy difference; that means, h 1 minus h 2 this is the specific enthalpy of steam expanding through the turbine. So, this is your turbine work minus W pump; the pump work is little bit tricky to determine because you see the pump the starting point where the or entry point to the pump, that is h that is 3 where the liquid is in the saturated liquid condition the condensate is that saturated liquid condition.

But when the water is pressurized it is in the sub cooled liquid region; sub cooled liquid region properties are not easily available. Conventionally we determine the property using a steam table. So, h 4 is not easily available in steam table. So, what we do we think of that it is work done by a device steady flow device again and this work done neglecting all kind of process etcetera it is some sort of a incompressible fluid which is pressurized. So, work done can be written approximately as v 3 into delta p. So, delta p let me write somewhere over here delta p is p Boiler minus p condenser.

So, basically the pump is raising the pressure from the condenser raising the condent pressure of the fluid from the condenser pressure to the boiler pressure. So, delta p is this 1. And then what is the heat transfer in the boiler, heat transfer in the boiler should be given by h 1 minus h 4, again h 4 is difficult to determine. So, one can write h 1 minus h 2 minus v 3 delta p, h 4 that can be written as h 3 h 3 can be easily calculated or looked from a steam table property table, this plus the pump work that has gone. So, one can write h 1 minus h 3 plus v 3 delta p.

Now, for most of the most of the or many of the steam power cycle the pump work is very small compared to other energy terms of course, this need not be true for steam power cycle where the boiler pressure is very high. Now assuming that pump work is negligibly small compared to other terms. So, one can write it is equal to h 1 minus h 2 divided by h 1 minus h 3.

So, all the values can be readily obtained from some sort of a property table or nowadays one can use some sort of engineering equation solver and then knowing the boiler pressure and condenser pressure and knowing the degree of superheat at the entry of the turbine one can determine the efficiency of the cycle of the Rankine cycle.

So, then once we define once we determine the efficiency of the Rankine cycle so we are in a position to find out how much thermal energy we are converting into work and then also again if we take a critical loop then we can think of whether or what are the possibilities of increasing this conversion. With this let us proceed with this basic idea now what I like to discuss at this moment that the basic cycle which we have shown which I have shown and whose performance parameter; that means, the efficiency we have determined well that is an ideal cycle.

So, there are many places where the cycle the actual cycle will deviate from the ideal cycle there are many places where there are irreversibilities let us have this quick discussion on those points and then let us see how we can modify the cycle so that we can have a better conversion of energy.

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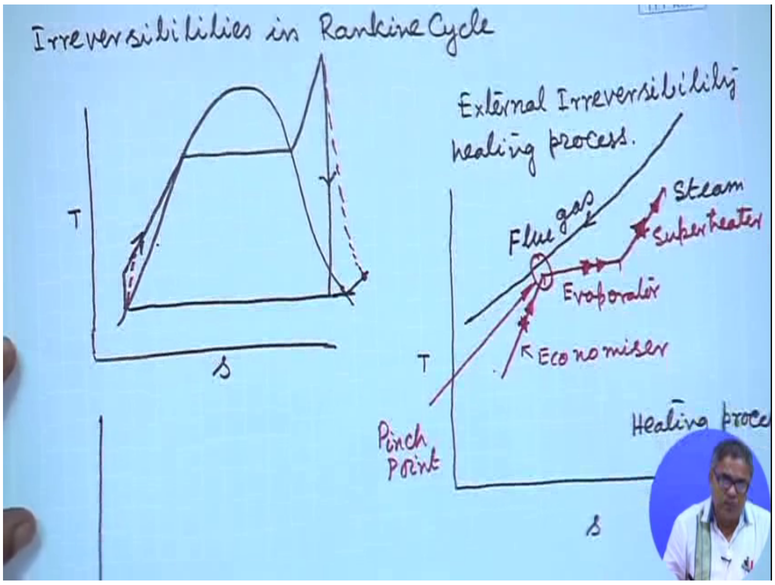

First let us look into the Irreversibilities of the cycle Irreversibilities in Rankine cycle. The Irreversibilities we can divide in to the figure which I have shown is a reversible cycle or ideal cycle there will be different kind of Irreversibilities and the Reverseabilities we can divide into 2 categories there will be internal irreversibility there will be external irreversibility.

Internal irreversibility of course, that will come due to friction due to kind of expansion in some places due to pipeline losses etcetera. So, those things will come and that will give some sort of a lower performance that will create a deterioration of performance of the cycle, but 2 things 2 devices which will give which are of particular concern is that if you see we have taken the expansion process and the compression process of the fluid, that is expansion process is in the turbine and compression process is in the palm pressurized process of pressurized these are we have taken reversible adiabatic or isentropic process.

Now it does not happen. So, in case of turbine there will be some sort of loss and due to the loss. So, exit of turbine will move somewhere over here in the pump also there will be certain amount of loss and the exit of pump the exit point of pump will move somewhere over here. Now these 2 losses are generally considered generally considered by introducing some isentropic efficiency of these devices for both for the pump and turbine we introduced some set of isentropic efficiency, there would be some sort of a pressure loss in the piping. So, the boiler pressure whatever boiler pressure we get at the exit of the pump the same pressure will not remain there will be some heat losses in the piping etcetera.

So, those kind of losses are there, but let us look into the external Irreversibilities which are very important and which are also important from the waste heat recovery point of view. So, for that we have to look into the heating and cooling process of the cycle. So, heating and cooling process of the cycle if we look into let us have the heating process External Irreversibility so heating process. So, how would be working flue it is heated. So, in a boiler there will be combustion and fuel will be burned and the hot flue gas, that will exchange heat to the working fluid so that the temperature of the working fluid will increase.

So, you see if this is your thermodynamic plane T and s this is the path of the hot flue gas or this is how the hot flue gas gets cooled and then this is how you are working fluid changes it is temperature. So, this part is Economizer, this is your Evaporator and this is your Superheated. Now here you see we have shown more or less a counter current flow type of sorry this arrows will be in the opposite direction sorry about that these arrows will be in the opposite direction counter current type of arraignment let me put another route to avoid any come ambiguity.

So, here you see one thing you have to remember when we have discussed the thermodynamic principles then we have told that heat transfer across a finite temperature difference causes irreversibility. So, here what we can see that there should be there is a difference between the temperatures at any location, there is a difference between the temperature of the flue gas and the temperature of the working fluid. In fact, that is essential that is essential because unless that temperature difference is there no heat transfer will take place.

So, temperature difference is needed for heat transfer, but at the same time it also creates some sort of irreversibility. So, always there is a tendency or this is look out of the engineers to have a good heat exchanger or good device which will allow heat transfer between these 2 streams while keeping the temperature difference between them the minimum.

Now what we like to do we like to bring these 2 curves closer, one curve is for flue gas this is for Flue gas or hot product of combustion and this is for Steam. So, we want to bring them closer.

Now if we being a try to bring them closer. So, this point will be the closest and this point is known as this point is known as Pinch point. So, this becomes this becomes the determining factor that how close we can bring these 2 cars, the lowest the pinch point the lower the pinch point rather the more difficult will be to transfer heat and more costly will be the equipment in which this heat transfer is taking place. So, there is a limitation from the pinch point and that determines what will be the external irreversibility, in this case this pinch point is a very unique point and particularly it is very important when there is a process like this where partially it is single phase heating, then it is phase change and then again single phase heating, and we will see it is further implication when we will proceed.

If we see the cooling process so this is for the heating process. If we see the cooling process let us draw it in this page itself. So, this is for the heating process. So, for the heating process we have got this diagram this is now if we see the cooling process then again we can think of let us take another page.

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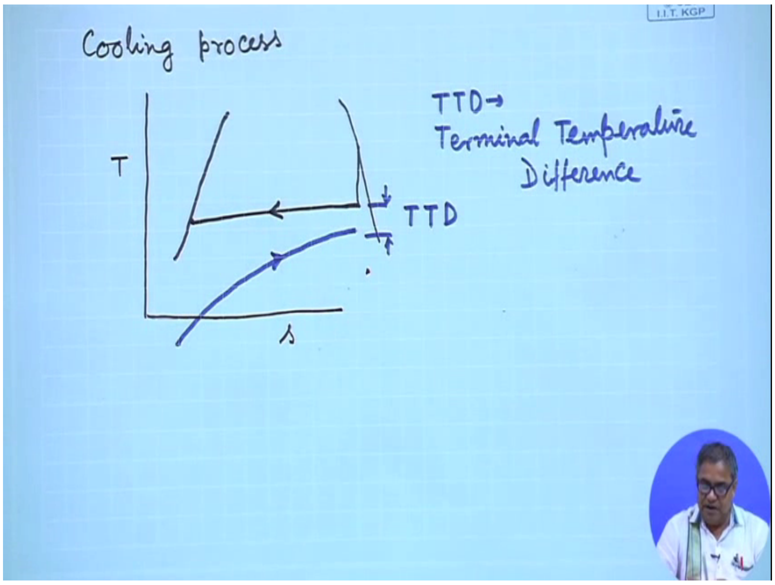

So, Cooling process; Cooling process this team is this is the 2 phase dome this is how the steam is getting condensed or getting cold and then in a condenser how this team is cooled it is cooled due to it is transfer of heat to the circulating water. So, the circulating water will have supply of heat from the condensing steam and the circulating water will have a change in temperature depicted by this blue line.

So, this side is again T and this side is s. So, here also show the same principle applies that if we can bring these 2 curves together close together, then we will have lesser amount of irreversibility and here you see this point becomes the determining factor and this is called for a heat exchanger this is called TTD; TTD is Terminal Temperature Difference. So, for a heat exchanger there is a terminal temperature difference, we cannot go beyond this terminal temperature difference if we go for a lower terminal temperature difference generally either the heat exchanger size or the design of the heat exchanger has to be changed or there is a cost implication.

So, you see that terminal temperature difference cannot be made equal to 0 and that is why there will be certain amount of external irreversibility. So, both we have discussed regarding some internal irreversibility and external irreversibility and basically these are losses due to losses we will have this kind of irreversibilities; that means, what I mean to say the lowest temperature which would have been ideally possible will not be achievable in this case due to the restriction of pinch point and in this case it would not be achieved in case of condenser it will not be achieved due to the terminal temperature difference. So, you see due to the inherent limitation of the process achieving maximum cycle temperature is restricted and achieving minimum cycle temperature that is also restricted.

So, from ideal cycle these are the 2 points which makes it less efficient the practical cycle will be less efficient for these 2 points for these 2 issues which I have discussed, more than that I have discussed 2 other things that there will be losses during the expansion process in the turbine and during the compression process in the from generally the pump energy consumption is less, pump losses are also less, that may not be a very serious concern, but the turbine losses could be significant.

So, what we can see from this discussion from this discussion it is clear that whatever ideal cycle efficiency we have derived in actual practice we are not going to get that. So, if we are not going to get that we have to do something we have to modify the cycle in such a way. So, that we gain somewhere to compensate this kind of process.

So, there are certain variation of design certain modification or improvement of design for the Rankine cycle and very quickly I like to go through those kind of variation design variation.

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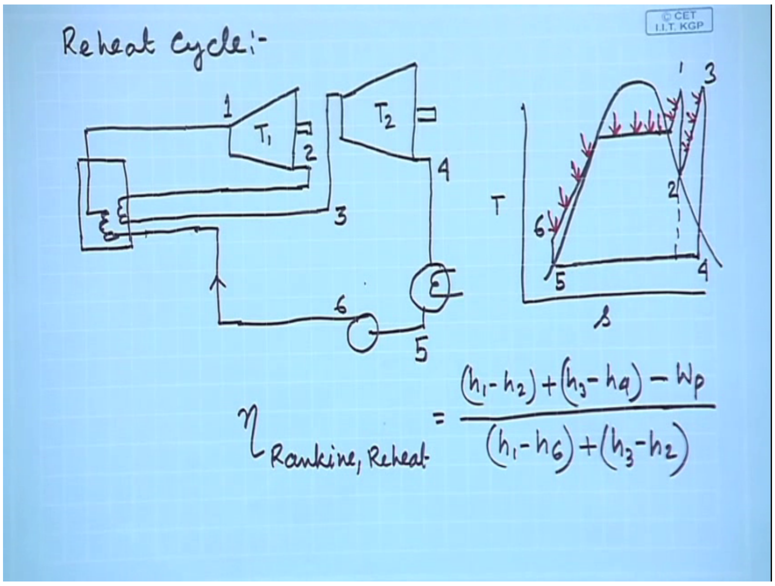

The first design variation which one can think of that is called Reheat cycle. So, Reheat cycle it is something like this we have got the boiler from the boiler, we are having the steam in the boiler that goes to the turbine expands and; obviously, the energy of the steam that is used for producing work and this team this low energy steam, now what I can do I can bring it back to the boiler heat it once again send it to a low pressure turbine to do some more work and then this team is taken to the condenser then there is a free pump and sent to boiler.

So, this is; what is the arrangement for a reheat cycle again if we denote these points this is one after the high pressure expansion in the first turbine it is 2; it goes to the boiler. So, when it comes it is condition is 3, it goes to the low pressure turbine and then it comes out after expansion this is 4, after this condenser it is 5 and then it goes to the feed pump it is 6 and then it goes to the boiler again and superheated steam is supplied to the high pressure boiler.

So, now, the cycle diagram which we will get is like this again in Ts plane we will have this kind of a cycle diagram. So, let us put the 0.1 to 2 expansions, then 2 to 3 that is heating, 3 to 4 further expansion in low pressure turbine, then 4 to 5 is condensation, then 5 to 6 that is that is pressure rise in the pump and then 6 to one again heating in the boiler.

So, you see heat addition is there at 2 places this is the usual heat addition process which we have seen in the first case also and in the second place there is additional heat addition when these steam is reheated and very quickly one can calculate the work done. Let us say this is turbine one this is turbine 2 and one can have that efficiency of Rankine with Reheat; that is one can take both the work the first work will be h 1 minus h 2, work by the second turbine that will be h 3 minus h 4, this from this the pump work W pump has to be deducted because in this kind of cycle generally the pressure level is high, boiler pressure is high, and pump work in most of the cases it is better not to neglect and then there is heat given by the boiler. So, that is h 1 minus h 6 plus again heat given by the boiler due to the heat for reheating. So, this is h 3 minus h 2.

So, what we get that using the same amount of working fluid we get some more amount of work out of the same plant. This is a good principle of energy conversion, but as far as efficiency of the cycle is concerned one cannot definitely say that it will increase the efficiency of the cycle definitely it increases the work output of the cycle, but regarding efficiency one cannot definitely say anything there could be some increase some slight increase in efficiency, but this is a good principle in most of the utility power plant this reheat cycle is used; reheat cycle has got another advantage which I like to point out the exit steam that is very dry without reheat we could have got the exit steam over here which is wet steam and not good for turbine. So, here it is quite dry and good for the turbine so this is another benefit added benefit for reheat cycle.

Generally these 2 temperatures are kept on kept at the same level this 1 and 3 are more or less at the same level because of material constraint we keep these 2 temperatures almost at the same level. So, this is your heat cycle it has got advantage in giving more power for almost the same kind of plant size of course, in certain places the plant size will increase, but that is minimal there are other modification which we will go into the coming classes coming lecture we will discuss about it, many of you have are familiar with this kind of variation of Rankine cycle basic Rankine cycle etcetera, but we assumed that the participants have come from varied background that is why we are quickly trying to have a recap. So, with this I like to end today’s lecture.

Thank you and next lecture we will continue with further modification of Rankine cycle.