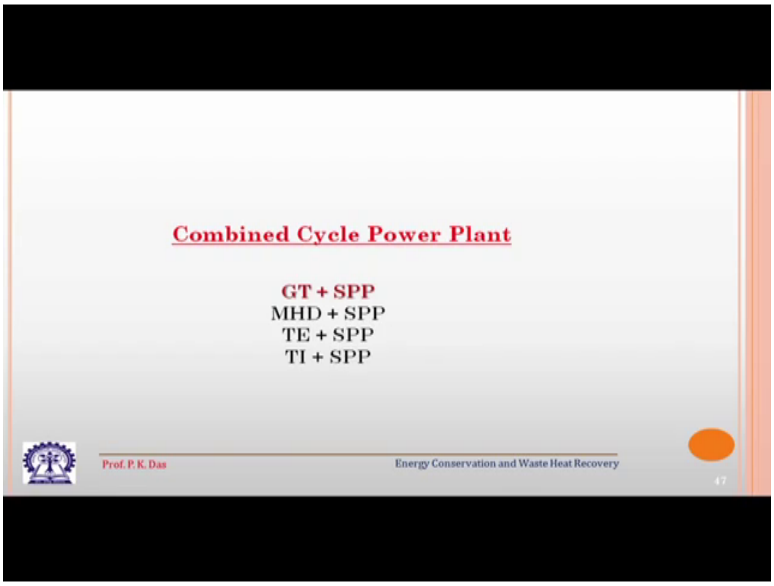
Energy Conservation and Waste Heat Recovery
Prof. Prasanta Kumar Das
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 23
Combined cycle

Hello, everyone welcome to the present class, where we will discuss a very important concept and this is important, because in thermodynamics, probably we have learned the basic cycles in our earlier courses of thermodynamics.

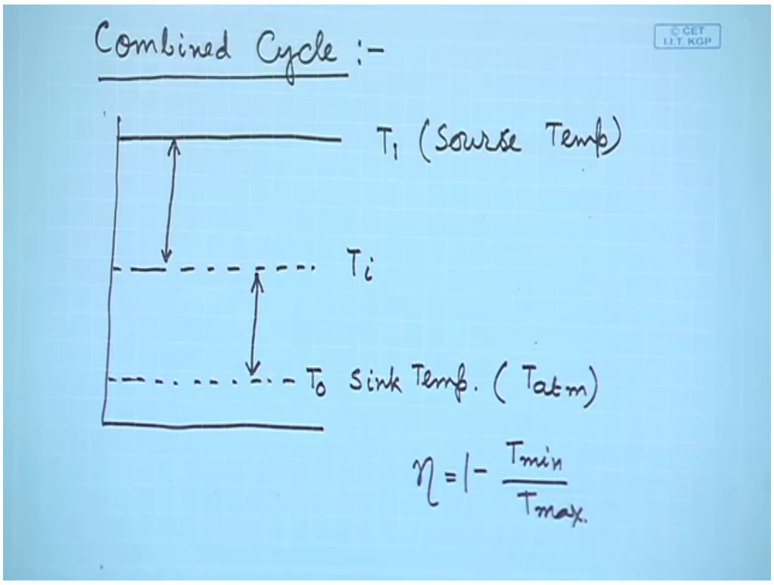
Now, we will see that how the basic cycles can be combined and how we can have a better conversion of energy, better utilization of energy, which we are taking from a source, which is available in the nature.

(Refer Slide Time: 01:08)



So, we will go to the concept of, we will now introduce the concept of combined cycle what is the combined cycle and why we should have combined cycle?

(Refer Slide Time: 01:15)



So, basically we are, we have discussed the cycle for steam power plant that is Rankine cycle. We have discussed the cycle for gas turbine power plant which is Brayton cycle and both these cycles we have discussed as if they are standalone cycle. Basically, they are standalone cycle, we can have power plant, based on either Rankine cycle, when the working fluid is a vapor, commonly which is steam or we can have a power plant, where the working substance is a gas and we can have the Brayton cycle.

But certain concepts, I have already discussed that for a cycle let us say, this is the thermodynamic plane a suitable thermodynamic plane, we like to have the maximum temperature of the cycle as high as possible and we also like to have the minimum temperature of the cycle as low as possible, but minimum temperature of the cycle, there is some sort of a limitation that atmosphere is the ultimate sink. So, the low temperature, the temperature of the sink that has to be close to atmospheric temperature.

So, let us say this is your sink temperature and this is T atmospheric and let us say depending on the fuel, we are having certain temperature. This is T 1 and let us say, this is T 0, this is your source temperature. So, this is your source temperature.

Now, what happened that, we have to have a cycle between T 1 and T 0. Now, it is not always possible to have a cycle between T 1 and T 0, because the working fluid that has got its own characteristics and it may not be always possible that we will have a cycle. We can have a cycle from T 1 to T 0. So, what happens either one has to have a cycle.

Let us say from T 1 to some intermediate temperature. Let us say, we call it T intermediate or one can have a cycle from some temperature T intermediate to T 0 that is the sink temperature. So, this becomes possible in many cases that with the working fluid, we cannot have a cycle from temperature T 1 to T 0. If we select some kind of a working through it, we will have a cycle between T 1 to T i and if we select some other kind of a fluid, we will have a cycle between Ti to T 0.

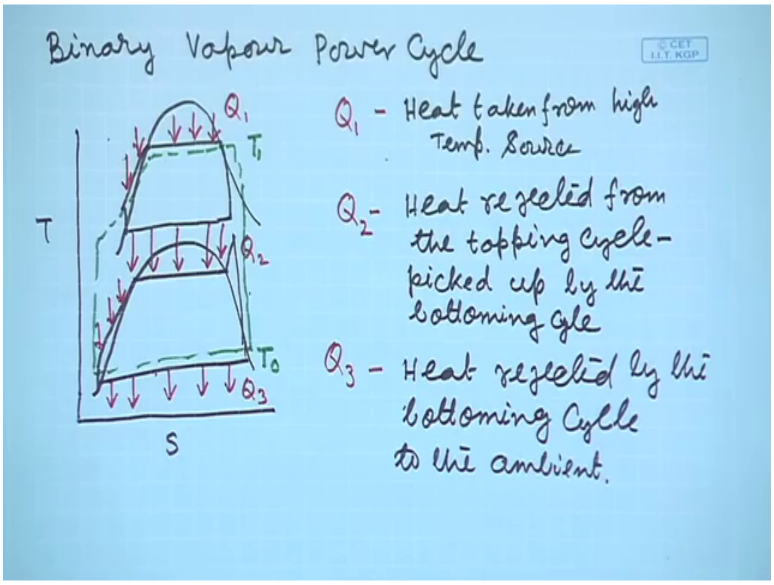
We know the Carnot efficiency, which is indicative off the efficiency, which a cycle can have, that is T minimum divided by T maximum so; obviously, when we are having some sort of intermediate temperature either we are operating between T 1 and T intermediate or between T intermediate and T 0. So, our Carnot efficiency will be low and the cycle efficiency; obviously, will be low.

So, what could be the remedy? The remedy is that, can we use combination of 2 cycles, then the cycle at the top which is called topping cycle. I have already introduced this term, will reject certain amount of thermal energy, that will be picked up by the cycle at the bottom, which is called the bottoming cycle and then the combination between these 2 cycle, thermal interaction between these 2 cycle is some sort of internal and we can assume them or we can take them as if they are a single cycle, but; obviously, there are 2 cycles. So, that is why this scheme, if energy is converted into work, by this kind of a scheme it is called a combined cycle. The power plants, which are operating on this particular scheme, they are called combined cycle power plant.

So, combined cycle power plant is very good for better conversion of energy, we can call, it is very good for energy conservation and again one way from one point of view. It is also a very good device for waste heat recovery, because suppose I wanted to have the cycle at the top that is your topping cycle, then there will be rejection of heat and we can utilize it better by using another bottoming cycle.

So, the concept of bottoming cycle, one can think of that it is nothing, but a principle of waste heat recovery and the best way of waste heat recovery, because by this, we are producing certain amount of work. So, there are different schemes, propositions, and postulations or suggestions for combined cycle power plant.

(Refer Slide Time: 08:36)



The one of the concept is that, one can go for binary vapor power cycle, sorry, what is the binary vapor power cycle? We have seen vapor power cycle, which is, which operates on a Rankine cycle, when vapor is the working substance of the cycle.

Now, instead of one vapor cycle, if we have 2 vapor cycles, like this has been proposed that, this is our TS diagram at the top. We are having one cycle and at the bottom, we are having another cycle and the heat rejected by the topping cycle is taken up by the bottoming cycle, and then, let us call it Q 1, let us call it Q 2 and let us say, this is your Q 3. So, Q 1 is heat taken from high temperature source, Q 2, heat rejected from Q 2 from the topping cycle, which is picked up by the bottoming cycle and Q 3 heat rejected by the bottoming cycle to the ambient by the bottoming cycle to the ambient.

So, you see basically, we can think of a, let us use some color, we can think of some sort of a system like this system is basically, taking heat at a temperature. Let us say this is T 1 and this is T 0. So, T 1 is much higher temperature and T 0 is the environment temperature. So, basically we are having a cycle between T 1 and T 0. So, our cycle efficiency will be high.

So, this is the concept of your binary vapor power cycle. Already I have told that this is one combined cycle and 2 vapor power cycle the first one or the, topping one people thought, probably mercury could be the working substance and the cycle at the bottom that could be a cycle, where the working fluid is water or steam. So, mercury and water vapor cycle could be a binary vapor, vapor power cycle, even people had thought that there could be 3 cycles.

Basically, then the top most cycle will operate at the highest temperature and that cycle could be a liquid metal like; sodium and after that there will be another liquid metal, which could be mercury and the lowest one that could be water or steam. So, this also conceptualized by people.

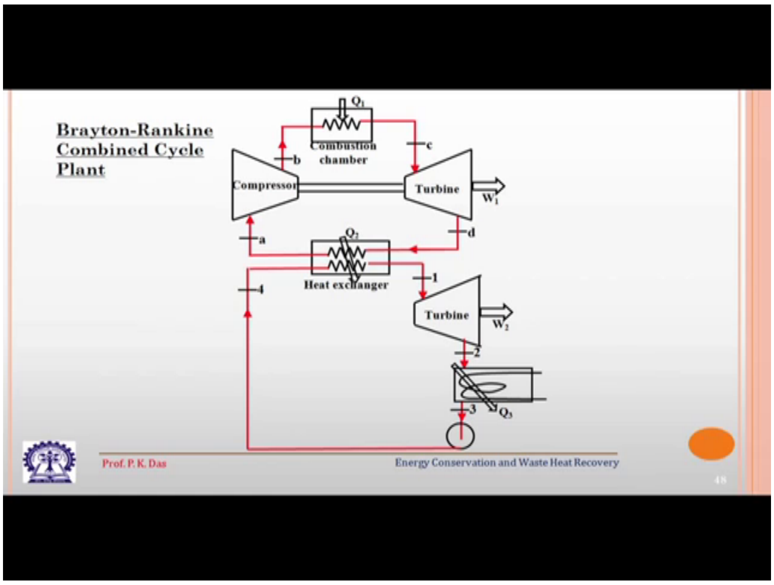
But somehow binary vapor power cycles due to before in kind of practical difficulties, it has not become commercially viable and this is only in the conceptual level, but there are certain possibilities of combined cycle power plant and there are certain commercial exploitation of combined cycle. Power plant very successful commercial exploitation, those I am going to discuss in the combined cycle power plant.

So, if we see here; I have written GT plus SPP; that means, gas turbine power plant and steam power plant. This is the most successful combined cycle power plant and all over the world in many places, this gas turbine plus steam turbine power plant, they are utilized and more and more use of this kind of combined cycle power plant. We will find in future, because of their high efficiency, high thermal efficiency. So, there they are very efficient converter from the thermal energy into work.

Then people have also postulated that MHD plus steam power plant that could be one viable option. MHD is Magneto Hydrodynamics already, I mean already there are certain demonstration units, but again there are technical diff difficulties. So, probably time, we will only say that, whether this kind of power plant, we will use in future or not there are power plants, where thermoelectric principle will be used for generating electricity and this is kind of direct conversion directly. We will have the electrical energy from the thermal energy, without going into the mechanical path and then bottoming cycle will be your steam power plant, then there could be thermionic and steam power plant.

So, you see MHD thermoelectric and thermionic, they could be topping cycles and in the later part of this particular course, the other instructor will elaborate on this we will not, I will not elaborate. Now on MHD or thermoelectric or thermionic, what I will like to do, we would like to spend some time on gas turbine and steam power plant combination, that is one of the successful, very successful combined cycle power plant.

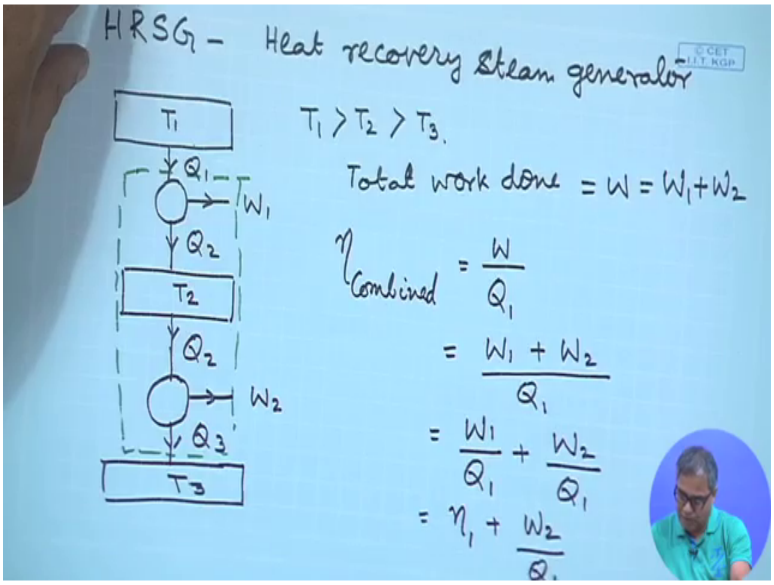
(Refer Slide Time: 17:50)



This slide you can see, a schematic diagram of gas turbine and steam turbine power plant; obviously, we have shown ideal processes. It is made up of ideal processes and the basic cycle. I have shown here, the ideal cycle that will be Brayton cycle and the ideal cycle for your steam power plant, that will be your Rankine cycle. So, it is a combined Brayton Rankine cycle. Topping cycle is the gas turbine cycle, already we have discussed the gas turbine cycle. Here, the gas turbine cycle will reject heat ideal cycle rejects heat in a heat exchanger and in the same heat exchanger that heat will be picked up by water, which will be converted into steam and go to the turbine.

So, this is, this heat exchanger intermediate heat exchanger. It is very important for the combination of Brayton and Rankine cycle in actual case of course, this cycle will not be a close cycle after this heat rejection to the working fluid of the bottoming cycle, which is water or steam, it will go to this tack and ultimately it will be left to the atmosphere.

(Refer Slide Time: 19:50)



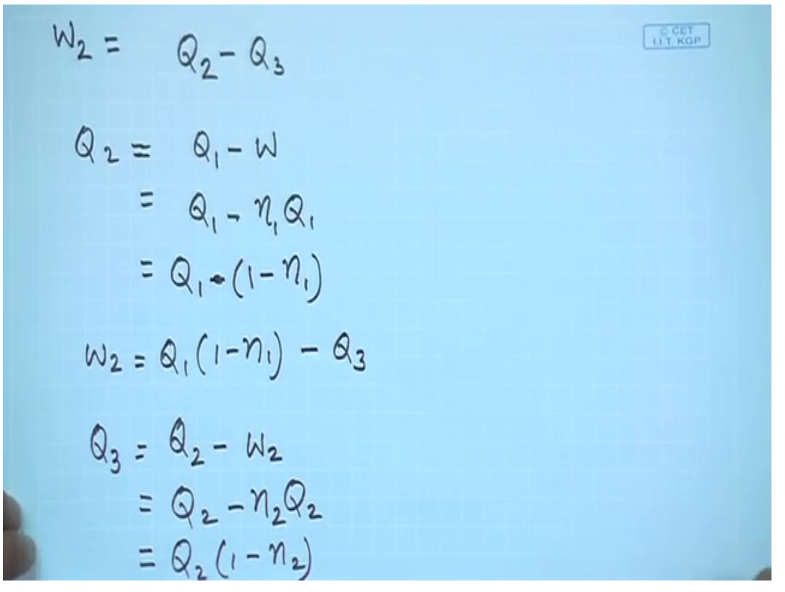
So, the heat exchanger over here this heat exchanger is called as HRSG or heat recovery steam generator, heat recovery steam generator. Now, combined cycle power plant of course, from the thermodynamic argument, I have told that it will have a higher efficiency, but let us see how it can have a higher efficiency. Let us do some sort of a small analysis, how it can have a higher efficiency, let us try to see.

So, let us say, this is the topmost reservoir at the highest temperature T 1, then we are having some sort of heat engine. This is taking Q 1 amount of heat and this is doing W 1 amount of work rejecting Q 2 amount of heat to some thermal reservoir, which is at temperature T 2, the from the same thermal reservoir Q 2 amount of heat is taken by another heat engine and it is doing W 2 amount of work and then ultimately, it is rejecting Q 3 amount of heat to a another reservoir, which is at T 3.

So, one can write T 1 that is greater than T 2 that is greater than T 3 and total work done that is equal to W that is nothing, but W 1 plus W 2 that is the total work done. So, efficiency of this cycle. Now, what we can do, the combined cycle can be taken like this, which is, which can be taught as a single cycle, which is taking Q 1 amount of heat and rejecting Q 3 amount of heat, while doing W 1 plus W 2 amount of work.

So, for this combined cycle, what will be the efficiency? So, the efficiency of the combined cycle will be ETA combined, that is equal to; again W by Q 1, that is the thermal energy. We are taking and that is equal to W 1 plus W 2 divided by Q 1. So, what one can write this is equal to W 1 by Q 1 plus W 2 by Q 1 W 1 by Q 1 is nothing, but the efficiency of the first cycle or topping cycle, that is equal to ETA 1 plus W 2 by Q 1 W 2.

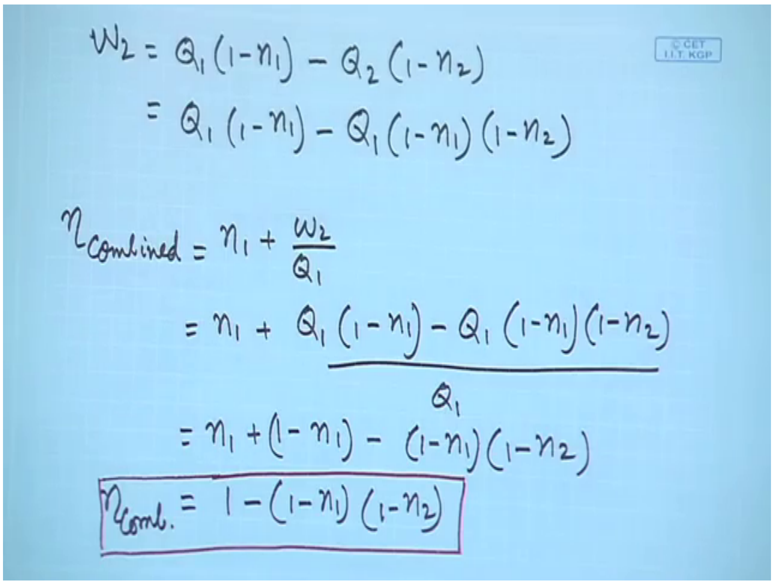
(Refer Slide Time: 24:14)



That is equal to W 2 is equal to Q 2 minus Q 3 Q 2 again, one can write Q 2 is equal to Q 1 minus W that is Q 1 minus ETA into Q 1. So, that is Q 1 minus Q 1 within bracket 1 minus ETA 1. So, Q 2 is equal to Q 1 minus W that is Q 1 minus ETA 1 Q 1 and that is Q 1 within bracket 1 minus multiplied by 1 minus ETA 1.

So, that is equal to your W 2 Q 1 minus, sorry, Q 1 into 1 minus ETA 1. So, W 2, that is equal to Q 1 1 minus ETA 1 minus Q 3 and what is Q 3 Q 3. We can write Q 2 minus W 2 Q 3 is equal to Q 2 minus W 2 that is Q 2 minus ETA 2 into Q 2 and this is equal to Q 2 1 minus ETA 2.

(Refer Slide Time: 26:59)



So, this is what we can write then ultimately we can write W 2 is equal to Q 1, 1 minus ETA 1 minus Q 2 1 minus ETA 2 and Q 2. We can write again replace by your Q 1 Q 1, 1 minus ETA 1.

So, then we have got the expression of W 2 in terms of in terms of Q 1, we have got. So, let us go back to our previous this one derivation ETA combined is equal to ETA 1 plus W 2 by Q 1. So, this is ETA 1 plus Q 1, 1 minus ETA, 1 minus Q 1, 1 minus ETA 1 into 1 minus ETA 2 divided by Q 1. So, it will be ETA 1 plus 1 minus ETA 1 minus 1 minus ETA 1 into 1 minus ETA 2 so; obviously, it will be 1 minus.

So, if there is no heat loss in between then the combined cycle efficiency will be given by this expression. This is an important expression, I can write ETA combined over here this is an important expression, it gives the higher limit of the efficiency of the combined cycle. When the efficiency of the individual cycles are known in actual practice, we will not be able to achieve this high efficiency, because whenever heat will be supplied from the topping cycle to the bottom cycle, bottoming cycle, there will be some amount of heat loss now. So, the efficiency of the combined cycle will be lower than this ideal case, the efficiency which I have derived just now. So, from here, we will take up and see the certain attributes of the combined cycle power plant in our coming lectures. Today, we like to close here.

Thank you.