Engineering Thermodynamics
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Week-10
Lecture-44
Vapor Power Cycle

Hello and welcome to the part 2 of Vapor Power Cycle In the last lecture we discussed about ranking of Vapor Power Cycle in which steam was used and in this, in condensed and liquid phase and vapor phase, both types of phases were used in the cyclic process Then we discussed how to increase its efficiency. We discussed two things in the discussion. Normally, the temperature at which you are putting the heat should be high. And the temperature at which you take out the heat should be low. So, it is common to improve any efficiency. But we also saw that if the pressure of the boiler increases, then your efficiency increases. Moisture will also be added to the turbine. The question is how can we increase the efficiency of the ranking cycle at higher boiling pressure? How the steam is being produced should not be additional at the final stage of the turbine. Because handling it will eventually become a problem with the turbine. So, one way is that you practically want that when it comes out of the turbine at a completely low pressure, then it should either become a saturated vapor or at least be a moisture content, this is what we want. One way is to increase the temperature at which you boil. If the temperature is high, then on the right side, if you see the TS diagram, then on the right side, you will see more exit when you leave the boiler. So, the pressure will be so high that when it expands from the turbine, it will be close to saturated vapor. But the problem is that when the temperature of the turbine is increasing, it becomes metallurgically unsafe. This means that the design that you have, the material that you are using, should be sufficiently strong, should be sufficiently suitable that you can handle that temperature and pressure. So that's why it's not so viable to use a very high temperature. The second way is that when you are expanding, keep the boiler temperature the same, but when you are expanding, that is, if you are using a turbine, then do not do it in one stage, but do it in two stages. So that when you expand to the second stage, it will be close to saturated vapor. So, you can see it like this in this diagram, the TS diagram. that your one is your There is a condenser output here. Of course, heat has come out from here. This is the pump work done and this part from 2 to 3 is the boiler Now if I wanted I could have done it like this If I had done it like this, I would have gone to turbine 3 to this point Suppose 6 dash So here the quality would have been less and the moisture content would have been more Now what we are saying is that this part is called high pressure turbine and when it will leave the stage, This is your exit, this is a high pressure turbine which is the first stage and it will use it as a reheater to reheat it back to the boiler and the pressure at which it has come out goes back to the low turbine at the same pressure so this is your second stage We are saying that this is the same temperature that is reached after the heat is reached. The temperature at which you have 3. But the pressure is different. This is your pressure. This is the P boiler pressure. And this pressure is different. This is the low pressure. And after that, this goes to the turbine. This is your low-pressure turbine. When this is heated, that means 4. From this point, it is called 4 to 5. is brought to this temperature. So, 4 is at low temperature. And 5 is at high temperature. The same temperature is 3. And finally, when it was expanded from the low-pressure turbine, it came to 6. So, the moisture content here will be very less. Another thing is that since it has been re-boiled, it means that we have added an additional Qin. So, the first Qin is here. Here also you have Qin. This is your Qreheat. Because it has been heated from the beginning. And the temperature is brought from 4 to 5. The pressure at which it is called. So, this pressure must be at low pressure.

$$q_{in} = q_{primary} + q_{reheat} = (h_3 - h_2) + (h_5 - h_4)$$

$$w_{turb,out} = w_{turb,1} + w_{turb,2} = (h_3 - h_4) + (h_5 - h_6)$$

So now if you look at it carefully, Reheat ranking cycle. It was ideal because the condition is internally reversible. We have said that it is reversible everywhere. But it has a reheat addition. And in the reheat, you have used the same boiler from where you have expanded the high-pressure turbine and reheated that stream and brought it to high temperature. And it expands further at low pressure. 6 supports. Other processes of other devices are the same as before. One goes to the pump from the condenser to the boiler and the other goes to the turbine. But we have done two stages. One is high pressure from the turbine and then it is reheated. Then it goes back to the low-pressure turbine. and then it expands and goes to condenser So what is the total Qin? The Q-in primary which is actually coming out of the boiler the main one which we used before is S3 minus S2 because this is your Qin S3 minus S2 and the second one is here 4-5 from 4 it comes to temperature 5 stream so this much change in enthalpy will be H5 minus H4 and total work Now there is also a work in this, you will also notice that there are two turbine works in this. So, one turbine is coming out from here, one is coming out from here, there are two types of work, which is turbine output. So, this is the total turbine output, W turbine 1, W turbine 2, and we will call this change enthalpy as well, H3 minus H4, which will be your W turbine 1, and this will be your W turbine 2, which is H5 minus H6. So this means that if we look at the efficiency of this, then eta efficiency w net equal to eta in and w net you can take out like that 1 minus q out minus q in, you can basically calculate like this but you can also take out w net like this w turbine out minus pump in you can take out like this now that you understand, now the question arises that If we feel that these two stages are not sufficient because this is also a problem here, can we try to improve it by increasing the number of stages? Because if we know that the average temperature increases further, then your efficiency will increase. This is at a higher temperature, this is at a lower temperature, eventually this part is at a higher temperature. If we repeat the stages, if we reheat it a lot, then we will get this average temperature. As it is said, if we reheat it again and again, then the average temperature will be higher. So naturally if you do it in two stages, then you will get this, then this. So, if you reduce the number of stages, then the average temperature can be reduced. But at one stage, normally you have a report of 4-5% efficiency improvement. means two stages, single reheat. Power plant efficiency increases by 4-5%. This is also very important. If your efficiency increases even a little bit, then imagine that this is your major unit in the industry. If your efficiency increases even a little bit, then you can save a lot of money. This is why this element is very important. If you do the number of stages, you will eventually get into the isothermal process. But this is not very practical because you will not get much reward for doing so many stages.

The expense you have to do and the return you will get will not be sufficient. So, on the one hand, there are two rates in the industry, but one rate is ideal. In general, there is a shortage, but people try to do it. You can do it. But there is also a practical limit to how much you can do. Let's see how all these concepts can be applied in a practical problem. First, let's check it once. Let's try to solve this question, so that you can understand how it is taken out. and the concept that we were talking about, that we have to reduce the moisture content you can understand that too from this question so here is a steam power plant which is given in this form which is ideal reheat ranking steam enters in high pressure turbine at 15 MPa and at 600 degree Celsius and it is condensed in condenser 10 kPa If the moisture content of the steam at the exit of the low pressure means here the moisture content is not more than 10.4% so it means that the maximum is 89.6% or 0.896% this is your quality now the question is that the pressure The steam will be reheated, which means that we have to remove the P heat and the thermal efficiency. Assume that the steam is reheated to the inlet temperature. It means that we assume that the temperature that we get after the reheat is the same as we assumed here. The same temperature that we get after the reheat is the temperature of the high-pressure turbine. So, this is your question. There are several things in this. First, you will assume that kinetic energy, potential energy, these are all negligible changes. You will also assume that this pump, this turbine, this is all isentropic. So, it is not written in this, but we will say that it is isentropic. Because it has an ideal word, it means that it is internally reversible. Now the question is how to solve this. For reheat, we have to determine state 5. So, we can determine state 5. because it is the same, it is an isentropic process. First, I will draw the TS diagram of this. So, your Vapor liquid is enveloped. Let's assume that This isobar is 15 MB, and it goes up to here close to Your 3 is here. This 4 will finally land here. Which is our... 10 kPa eventually this will come from here, so this is your 1 this is your 2, this is 3, this is 4, this is 5, this is 6 already has S of 6 which is your information 18F16 so let's go This information is given 896, so how to get it? First of all, let's see state 6. We have to get state 5, p. For that, we have to find out the other information, which state it is in. 5, which superheated state it is in. For that, we will use this information. S5 is equal to S6. So, let's first get S6 out, because what we have given is S6, we have given pressure. 10 kPa P6 is 10 kPa and we have X6 plus we have table up Saturated table up Constant pressure table A5 and from here you will get S6 SF plus Sfg is derived from P6 data P6 columns Row in fact So this information you will get from table Sf and Sfg you will get from table Which comes out as 7.3688 kJ per Kg Kelvin Now state 6 has arrived So naturally you will get Hb So Hf plus H6 Hfg This is given to you 2335.1 kJ per kg So you have complete information about state 6 Okay? Now after this point you can easily get out state 5 Because in state 5 you have the same temperature as initially high pressures now we will remove the curtain state 5 so same temperature T5 is equal to T3 is 600 degree Celsius and S5 is equal to S6 now you can extract this information because this information is given to you so if you see S6 at 600 degree then S6 is equal to 7.3 This information is 7.368 KJ per kg Kelvin. If you look at the table, the superheated one. So you will get this information in 4 MPa will come out And H5 corresponding H5 will come out to 3674.9 kJ So basically you will get P5 from here 4 MPa and corresponding P5 where it lies this condition this information is at 600 degree so you get this in 4M passcode and when you get from there then H5 is corresponding to 600 which is 4.9 KJ per kg so what does it mean that this steam is reheated will be done at 4 MPa pressure. so that your moisture content can be below 10.4% So the question was that steam should be re-heated, so this pressure came out.

Now we have to calculate thermal efficiency To calculate thermal efficiency You have to write eta TH 1 minus Q out by Q in Now Q out is coming out from here which is h6 minus h1, that is Qout and Qin is this one and this one so Qin is your h3 minus h2 plus h5 minus h4 and qout is h6-h1 So now you have to extract all these information. First of all, you have to extract information of 1, 2, state 1, state 2, state 3 and state 4. You have to extract information from 4 states to extract all these. Let's start with state 1. State 1 is 10 kPa and this is saturated liquid So you will easily get a saturated table So if I check it, you will get H1 H of fluid at 10 kPa and V1 will get V of F at 10 kPa. Now State 2 P2 is 15 MPa Because the pump is isentropic, S2 is S1 So from here There is an option that you So S2 is equal to S1 So from here you can either Use information S1 and S2 And from here also you can try to get it out Second option is to balance the simple energy and see that H2 is equal to H1 plus as much as you have pumped and worked. And this is your V1 constant at P2 minus P1. So P2 minus P1 will be your value. P2 is 15 MPa and P1 is 10 KPa H1 is already given here So from here you will get H2 Since V1 is given to you, you will get H2 easily So H2 is also found and H1 is also found So it means that the rest is H5 and 4 So now, H3 also So let's see H3, H3 is your P3 15 MPa and S3 is this information 15 MPa and 600 degree Celsius This is superheated condition. So, you have removed the table from there. So S3 and S6. So, you will get this information in table A6. 3583.1 kJ per kg. And this is your 6.6796 kJ per kg Kelvin. Now in this way, state 4. P4 is 4 MPa S4 is S3 Note that they are talking about P4 and S3 Since it is isentropic, entropy will be equal to S3 If you see S4 and S3 in superheated G is more than 4 MPa which means it will be superheated so you will remove the phase here now let's see state 4 as I said earlier state 4 is B4 State 4 is on P4 and its process is isentropic process. So S4 is equal to S3. In this case, if you look at the table, you will see that the corresponding S4 on F4 MPa is more than Sg. This means that it is superheated. you can see where it is at. You will get T4 at a temperature of 375.5 degrees Celsius. And the corresponding value of H4 will be 3155.0 KJ per kg. So now you have all the information. And from here you can extract the Qe in. Because your Qin is S3 minus H2 plus H5 minus H4 and then you can extract Qout is H6 minus H1 and from here you can extract eta is 1 minus Qout by Qin which is 40.45 which is 45% If you analyze this, if you have two reeds and one single reed, as we gave in the previous lecture, the moisture content there was 19.6% and from there you have increased the moisture content by 10.4% and the thermal efficiency has increased by 43%. So, this is the difference between reheating, that you have effectively reheated 2% but you have also done a good job in the operation that your moisture content has also decreased. So, in the next lecture we will increase this discussion and talk about regenerative vapor power cycle and then we will talk about some second law analysis. We will talk about cogeneration and how to combine gas and ranking power cycles. Till then I will take your leave and will meet you in the next lecture.