Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Engineering Thermodynamics

Lecture – 28
Vapor Power Cycle 1

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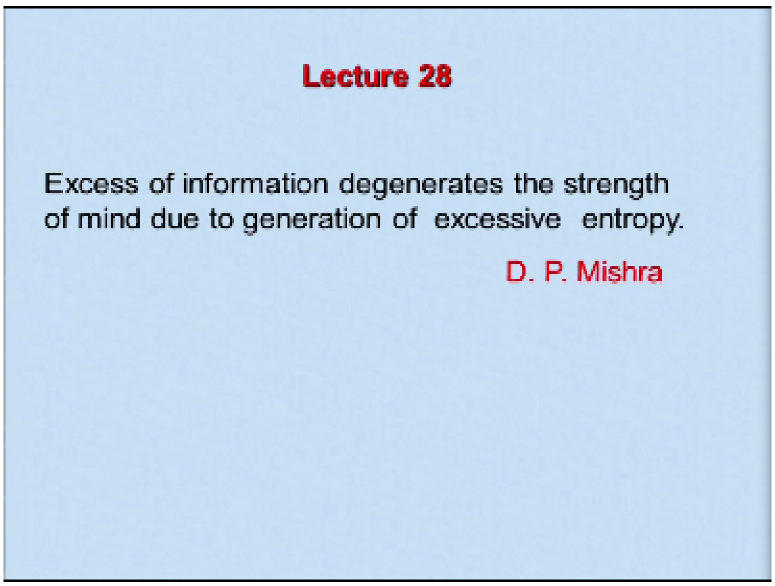

Let us start this lecture with a thought process that excess of information degenerate that strength of mind due to the generation of excessive entropy that we all experience in modern wall because we are bombarded with the information. And of course we are discussing about basically the thermodynamic where entropy comes into play and it is also true for our life and if you recall that we were discussing about the Rankine cycle and rather ideal Rankine cycle and we discuss in the superheated steam table.

And we will be taking an example and then see that how you can you know solve the problems by using the principle of the analysis procedure we have discussed in the last lecture.

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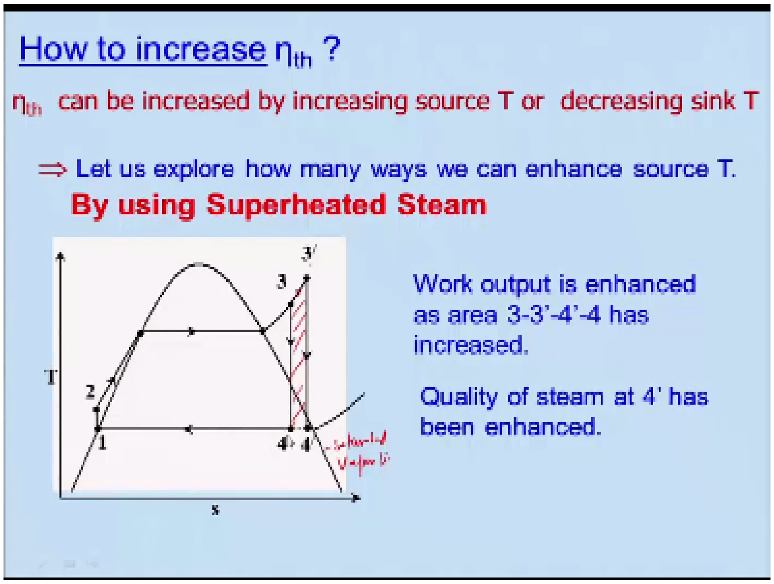

And so then question arises how to increase the thermal efficiency of the Rankine cycle what are the ways and means if you recall that when we are discussing about the Carnot cycle I had told that you can increase the thermal efficiency by increasing the source temperature right or by decreasing the sink temperature. So that is the way where we can increase the thermal efficiency for the Carnot cycle and a similar way also we can do for the Rankine cycle.

So and let us explore how many ways we can enhance the source temperature in this case Rankine cycle it is the boiler temperature like how we can increase what are the ways any idea, we have already done that like if you look at like we have super heated use the superheated steam that is the superheated Rankine cycle right instead of saturated steam right we have enhanced the temperature from saturated steam for a particular pressure to the superheated steam for the same pressure right that is one way.

We can also increase the what you call the pressure of the heat addition in the boiler we can increase right, and by that we can also increase the temperature as I told that we can use this superheated steam and if we will do that superheated steam like of course if we are operated from 3 to 4 and expanding we may have facing some problem right off the quality, of the steam being less than 0.9 then we are having problem, but if I will superheated further right from 3 to 3' what will happen.

And it of course the temperature of the what you call boiler will be higher and also the steam will be entering into the turbine at a higher temperature so question arises whether it can take that temperature or not depending on the material being used both in the boiler and the turbine. Of course the turbine is more critical, because it is a rotator element rotating system so therefore it will be having not only the centrifugal stress but also the thermal stress one has to take the turbine blade has to take.

But however if I do that let us say material available which can withstand high temperature then if I will expand from 3’ to the 4’ what happens that my there is a change in the quality if you can look at this is one quality you know quality this is 4’ is closer to the saturated line, saturated vapor line this is your saturated vapor line right. So therefore quality is improved that means you are basically winning in the both the side is a win-win situation right.

a result what happened the work output has been enhanced, if you look at this portion the work output is being enhanced apart from this work input right that is this portion right there is an additional here, there is increase therefore work output will be getting higher and thermal efficiency also will be higher and also the quality problem being solved are being improved like, and as I told the quality of steam at 4’ is greater than the quality at stream at state 4.

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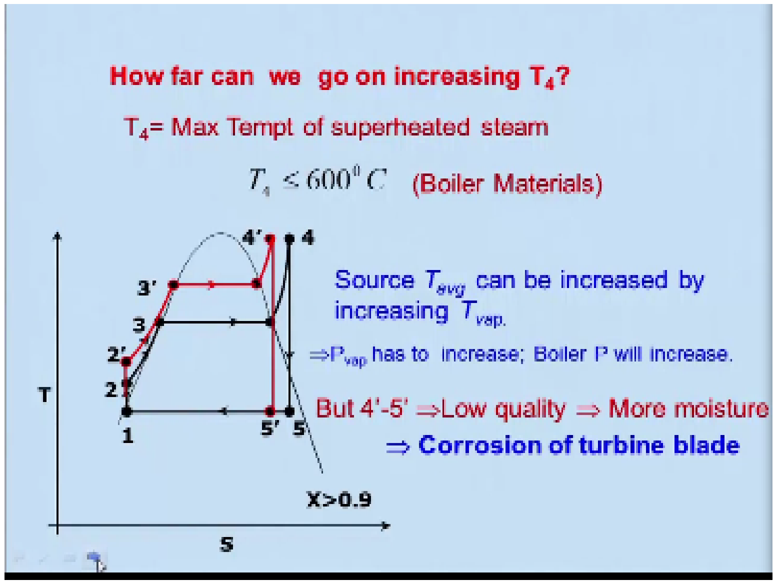

So therefore the quality has also improved. So question arises how far we can go on increasing the temperature 4, the maximum temperature, temperature 4 state 4 means the maximum temperature right, there is a limitation of that is metallurgical limitation that is the, like being done, because it is generally restricted to the 600°C that means it will be less than equal to 600°C as of now.

But tomorrow may be better material will be what you call available and then one can go for higher temperature like that way. So and as a result if the temperature is higher the source average temperature has been increased, because of you are going for higher temperature T_4 & P another way of going for is that you increase this boiler pressure like if you increase that pressure so what will happen this is coming over here of course keeping the temperature same because there is a limitation.

So that limitation is that I cannot go beyond 600°C so therefore if I keep what I let do there is another way that you can increase this boiler pressure right. And but then there is a problem if you do that and keep this temperature then again you land in the problem of the quality 5' quality 5' is basically away from the saturated vapor line. So therefore this will be lower than the 5 X will be lower than the 5.

So then you will have to learn how to handle how to overcome this problem. So as I told that 5' that lower quality of the steam that means more moisture will be there in the steam at the 5' as compared to the 5 state 5. So the corrosion of turbine of the blade will be occurring and that is the problem one has to look at it.

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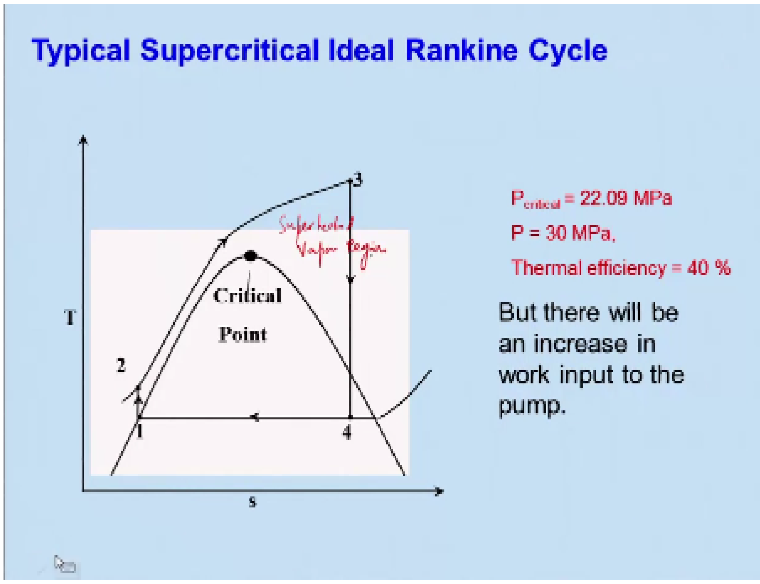

So there is another way of going by that that if you go on this pressure right if I go on increasing the boiling pressure I can reach a point critical point right, if I increase that critical point then like it will be a go directly the liquid will be converted directly into vapor this is your superheated vapor region right. So that what happened I can compress this and then go directly into the point 3?

And then expand it of course depending on I can go for little higher temperature you know for a particular pressure if you look at and that is the advantages of using that of course for that you should have a better material and other problems will be there and this kind of Rankine cycle is known as the supercritical Rankine cycle of course we are considering ideal therefore it is a supercritical ideal Rankine cycle.

And nowadays the people are using under this condition so if you look at as a result is thermal efficiency is quite higher as compared to the superheated Rankine cycles and if you look at the critical pressure is 202.09 mega Pascal but nowadays people are operating around 30 mega Pascal's in India we are having a few of the supercritical what we call power plant particularly recent one but the numbers are very less and we are basically importing this technology.

We do not have our own and I wish that some of you will walk and then you know do develop a better power plant and design basically supercritical and of course there will be an increase in work input in the pump so because it is going for the pressure right higher pressure so natural the work input to the pump is will be much higher as compared to the superheated steam power plant right so that of course I mean like because one has to pay this thing and so also the pump will be bulky and then cost will be higher lot of other problems comes into pictures so how can we increase the thermal efficiency.

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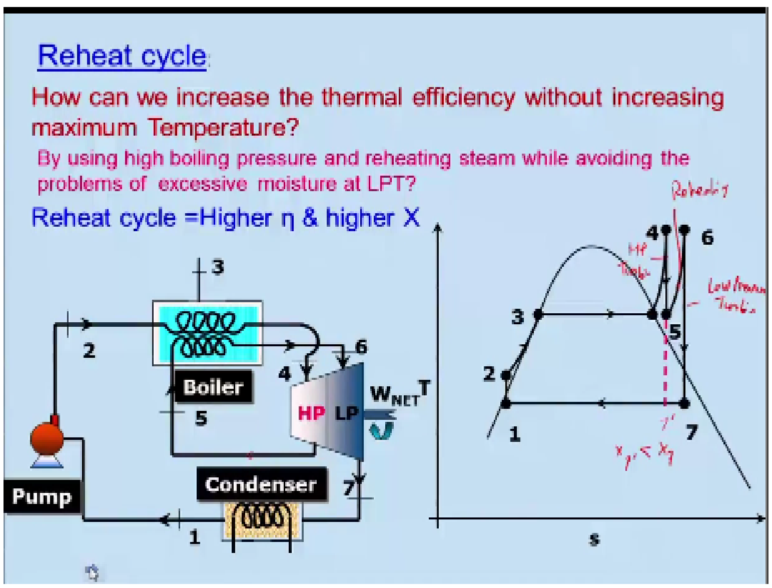

Without increasing the maximum temperature right because as I told there is a metallurgical limit, limit is for the time when it is 600^0 C you know we cannot go beyond that but then question arises how we can increase without really increasing the temperature maximum temperature right so what are the ways any idea so as I we discussed that we can use a high-boiling pressure right that is one way of doing it and another way is a reheating the steam while avoiding the problem of excessive moisture at LPD that means we will basically will be expanding the gas.

To certain extent maybe in the superheated region then reheat it and then go to again the maximum temperature and again expand it so that we can you know overcome the what you call the problem of the moisture in the other end of the expansion so if you look at a typical read cycle system is shown here in this case what happened is a boiler right and there is a turbine can be divided into two categories I mean like to portion one is high pressure turbine and this is low pressure turbine so in the first what will happen it will come in a heat being added in the boiler it will come to this high pressure turbine.

That is four and then it will be expanded once it is expanded it will go to boiler again and get heated up and come to the again expanded in a low pressure turbine and it will go to the condenser and then after, after that of course it will go to the pump and go back to the boiler right so that is known as reheating if you consider this thing so what is happening it is coming over here like you know the boiler then it will go to the what turbine and the expansion 4 to 5 is basically in the vertical high pressure turbine a and 6 to 7 is basically low pressure okay turbine and this portion what you call this portion is reheating 5 to 6 is nothing but you are reheating you are hitting again to the maximum temperature that was the T_4 is equal to P_6 you can think of ideal you know like that way.

So what you are doing you reheating as a result what is happening you are getting a expanding the gas in the low - pressure turbine to x and 7 which is closer to the closer to the saturated vapor line right and if it could have not done then what could have it could have happened in this way that is it could have expanded in this right if I say this is seven dash you know that means the quality of x seven dash could have been very less than X7 yes or no if you say that X7 is 0. 9 X7- will be definitely less than 0.9 okay.

It will be maybe 0.8 or 0.75 so that the moisture content at this point without reheating could have higher and then corrosion could have been more their problem so if you look at not only you are what you call avoiding the problem of the moisture or the quality of the steam but you are also adding heat here so that what happened the average temperature is again increasing you may get some higher thermal efficiency so we will basically it is a win - win situation we are getting higher thermal efficiency.

And higher quality of the steam right that means moisture content will be less so and let us look at how we can analyze this problem.

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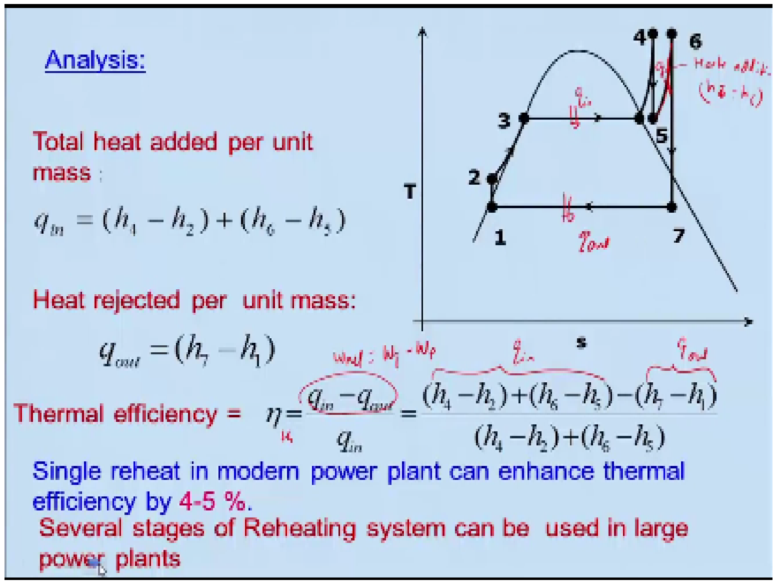

That is total heat added per unit mass will be equal to Q_{in} what is that this is from h_4 S_2 this one right Q_{in} and also the heat added here this is also Q_{in} h_6 - h_5 this is heat added this portion is heat added addition that is from h_5 is h_6 to h_5 right this edition is from here to here this portion that is your Q_{in} and heat rejected as usual that is Q out is nothing but your S_7 - h_1 so the thermal efficiency you can say that this is q_{in}-q_{out} right, that will give me the network output if you look at this person will be give me what net is equal to W turbine minus W pump yes or no okay, so that is nothing but your q_{in} we have seen h_4-h_2+h_6-h_5 of course this is your nothing but your q_{in} and h_7-h_1 is q_{out} and divided by the q_{in}.

So the single reheat system you know in modern power plant can enhance the thermal efficiency 4 to 5% which is a quite a bit if you know like increase your thermal efficient by 1%it will be because the power plant is a very order of mega watt right so therefore people strive to get even one person means you know they will be very happy and 4 to 5% is a you know quite a good consider. So several stages of read system can be used in large power plants it is not only the one but several but of course it will be having diminishing return later on like you will use.

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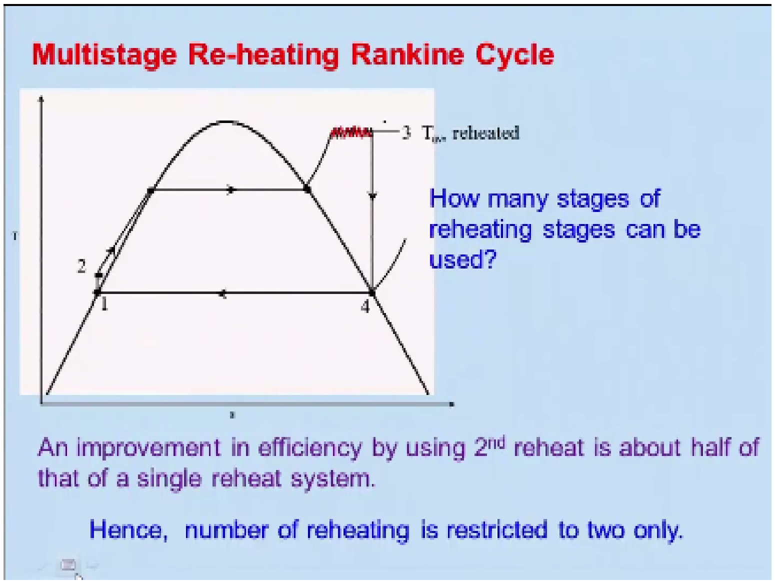

So multi stage kind of reheating cycle if you look at what will happen I can reheat here you know I will take this here and then the heat here again go on doing that so then what will happen this average temperature will be go on you know increasing so that it will be temperature will be you know kind of things so that of course you can get a steam at the end of the expansion which is almost one can think of getting a saturated vapor kind of one can get ideally at least and this efficiency you know will be much higher as compared to other.

Question arise how many stages of reheating stages you no one can go for it, so generally people were to call whatever the efficiency you get using the single one the first one first one heat if you go for the second one you will get the half of that let us say if it is 4% you know like in the first one you are getting then in the secondary heat system you will get around 2% not exactly but you know around that there is a ball part number.

So if you go for the third one again it will be reduced the efficient so that you will get diminishing return kind of things so therefore number of reheating you know system in practical power plant is restricted to only two because if you are adding it is a more extra you know like you will have to heat and then piping lot of you know a cost is involved in that.

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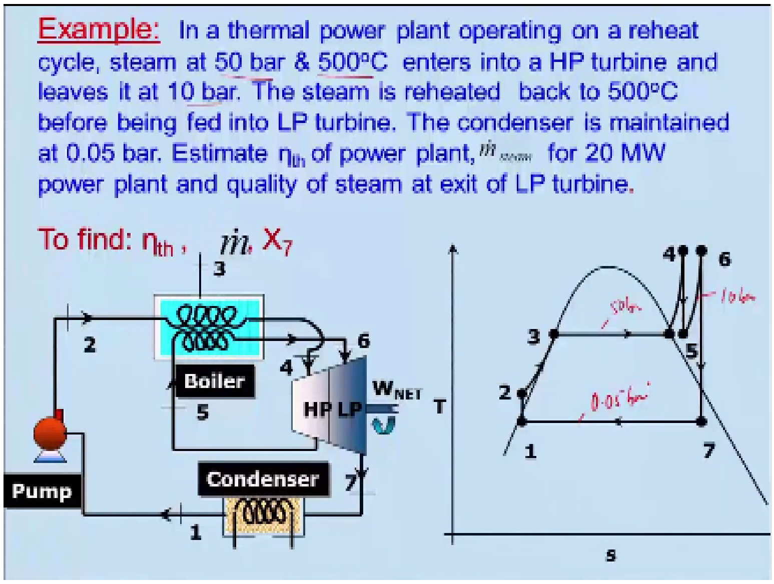

So let us consider an example like in a thermal power plant operating in the reheat cycle steam at 50 bar and 500˚C this pressure is given 500 I mean here itself one can say that it is superheated steam right, it is not saturated enters into a high-pressure turbine and leaves it at 10 bar right, and the steam is reheated back to the 500˚C that is a restriction for this power plant before being fed into low pressure turbine condenser is maintained at 0.05 bar, right.

Generally of course in this example 0.05 bar people use 0.7 bar for the condenser why they cannot go beyond 0.7 bar because there will be leakage problems you know like the low pressure there will be leakage problem in the condenser. So but in this example is 0.5 bar so estimate the thermal efficiency of the power plant and the amount of steam for the 20 megawatt power plant and quality of the steam at the exit of low pressure turbine.

So we need to find out the thermal efficiency and $\dot{m}$ that is ST and x_7 so if you look at we are basically to find out this x_7 here what it would be after the expansion and these temperature basically given as 500 ˚C and this is at 50 bar if you look at this is 50 bar and this pressure if you look at what is this pressure this is also constant pressure line what is this was pressure, this pressure corresponding to 10 bar and this is corresponding to 0.05 bar, right.

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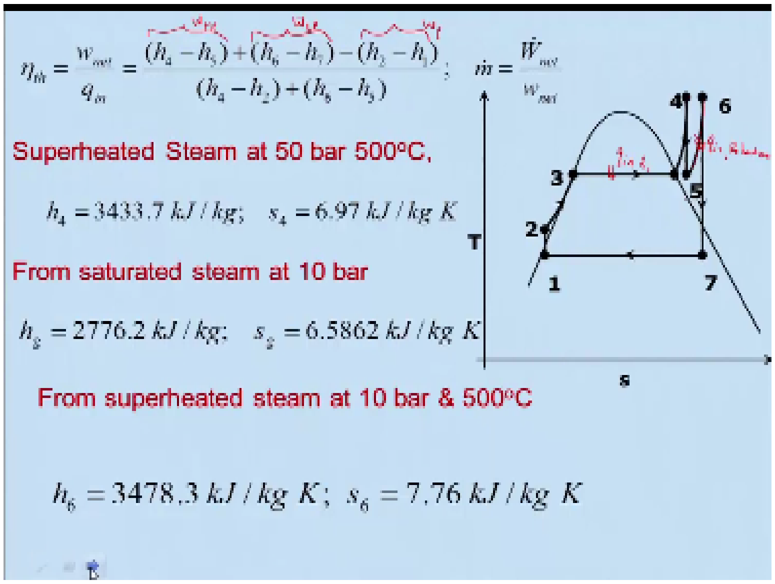

So we will see that how we can solve this problem like of course we need to find out thermal efficiency and which is basically h_4/h_5 that is your turbine work right okay, this is high pressure turbine h_4 to h_5 right this is your high pressure turbine yes or no, and h_6 h_7 is your low pressure turbine work done by the low pressure turbine and this is h_2-h_1 is your pump work and then q_{in} is given basically it is in two case one is h_4-h_2 this it in input right and h_6-h_5 here this portion heat being added right, q_{in} I can say this is q_{in} boiler and this is a re-heater know you can distinguish it okay, it is a boiler first and then again it is going to again going there.

So I need to have so if you look at I know this portion right the temperature and pressure so therefore I know this h_1 from the what you call superheated steam table. Do I know this enthalpy at the station 6? Yes, we know I mean from the corresponding to the pressure of 10 bar and 500˚C so superheated steam at 500 bar we can get h_4 and entropy we can get right we can also other properties which you have not mentioned here, right.

From the saturated steam table at 10 bar right we can get all these property S_G S_G all those things we can get and from superheated steam table mat 10 bar and 500^0 Celsius we can get this property's S_6 and SL H_6 the enthalpy at station 6 and entropy at station 6 we can get corresponding that you may be wondering why we need to data of the you know steam at the 10 bar right saturated steam table why because we do not know actually this point right h5 we do not know it may be superheated it may be here also it may be in the weight mixture region right. So therefore we need to know that.

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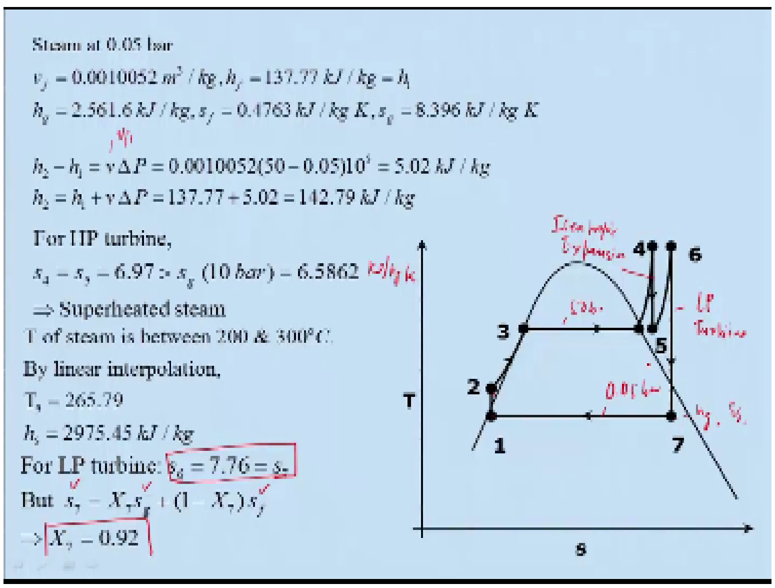

So of course from the saturated steam table corresponding to 0.05 bar you can get BF + Hf all those things wit and they keep in mind that this is nothing but your h1 here h1 and you can get SG this is corresponding to hg here correspond to 0.05 bar right and here basically and if you look at this is SG you can find out and this is that like and if we can get this you know how much enthalpy, enthalpy h2 - h1 nothing but V δ P and this is corresponding to this is basically corresponding to basically vf1 you can say right.

And the pressure you know the difference pressure one is 50 bar this is your 50 bar and this difference it calculate and then you can get this h2 because we need to find out how much eaten similarly in the 44 high pressure turbine we know that entropy at station four is equal to entropy at station five because of fact that this is an isentropic expansion right that is four to five. So and we found that that S $_4$ = S $_5$ = 6.9 7 kilo joule per kg Kelvin which is greater than S_G that is 6.85 this is basically kilo joule kg Kelvin right.

Therefore it is a superheated steam in some problem it need not okay if it is in between suppose these valuess4 is less than 6.5 862 in this case then it could have been having some quality or the kind of the wet mixture is not a vapor so it will be that but in this example it is turns out to be superheated steam. So if it is superheated steam therefore you will have to find out what will be the temperature right and then because you need to know the temperature superheated steam you a pressure is not good enough to find out by linear interpolation you will find out that what it would be the you know kind of entropy that we have done we would not repeat it and you will get the temperature once you get the temperature then you will find out what will be the enthalpy at station five.

So from the low pressure turbine right also the similar one that is s6 this is your low pressure turbine right the expansion process is isentropic, so therefore $S_6 = S_7$ right $S_6 = S_7$ and we know this what you call S_6 is known to us and so also the S_7 and S_G is known from the corresponding 2.05 bar and SF is known. So we will find out $S_7$is happens to be something 0.92 okay, so once you get this quality S_7 then you can easily find out what will be the enthalpy.

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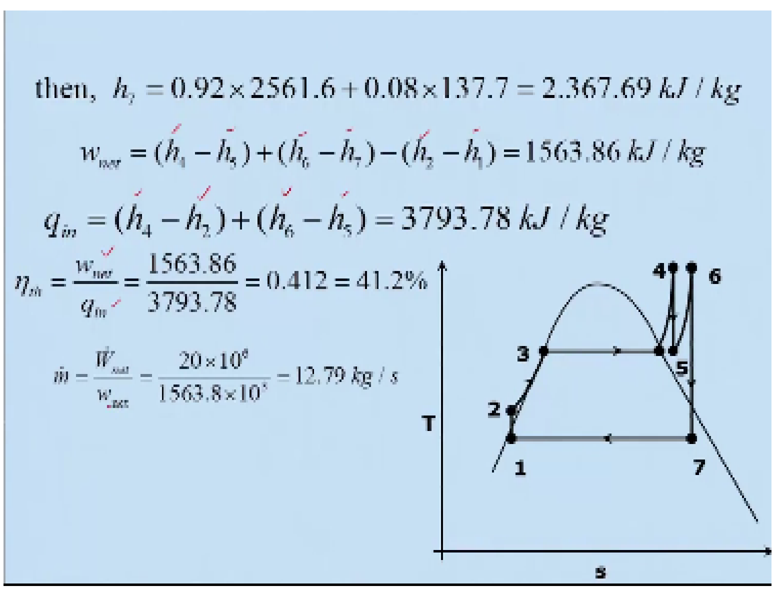

So then enthalpy would be basically you substitute these values and you will get right this is your what to call X_7 right and the net w net though we will find out h $_4$ - h $_5$ + S $_6$ - S_7 this is basically what you call high pressure turbine and then work and then low pressure turbine work-the pump work and you will get 156 3.86 because all these are known right 67 S_2 h $_1$ already we have evaluated.

So you will find similarly you can find out Q in and q in having two components one is the boiler h_4 - S_2 and s 6 minuss2 is the written portion because you reheating it stream, so that all are known h_5 is known h6 is known and S_2 already you have evaluated h4 you know, so you can calculate that 379 3.78 kilo joule per kg and from that you can find out the thermal efficiency because we have already evaluated the network output and heat net heat input and then it happens to be 40 1.2 percentage if you look at if you would not read it you will find that you know like it is lower than that.

And we know the power that is 20 megawatt right and we know the work specific the work in network output from this system for this power plant per unit mass then you can find out the amount of steam is the 12 point 7 9 kg per second. So we will stop over here and we have seen that how you can use the rate cycle and how you can solve the problem in the next class we will be talking about the regenerative you know systems where you can utilize the heat which is being rejected by the condenser thank you very much.

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