Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Engineering Thermodynamics

Lecture – 29
Vapor Power Cycle 2

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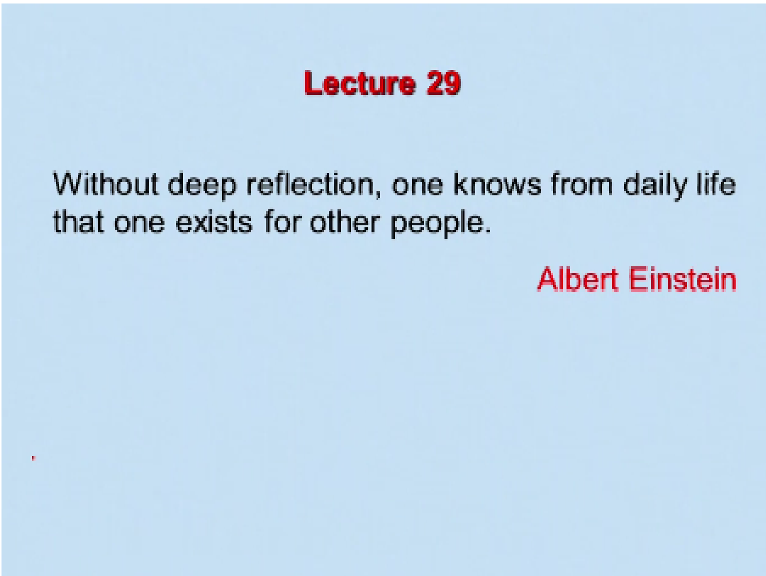

Let us start this lecture with a thought process from Albert Einstein who says that without deep reflection one knows from daily life that one exists for other people. It is a very important you know message that we should keep in mind while we are harnessing you know knowledge and this knowledge basically will be mean for the people let us recall that what we had learnt in the last few lectures. We basically started the discussion on vapor power cycle right and based on which steam power plant is being built and then we also looked at the ideal Rank in cycle.

Therefore we also explored how to enhance the thermal efficiency by using the reheat method right we also superheated the steam and then there was a limitation of the temperature of the boiler and the turbine material, so therefore in order to overcome that problem of limitation having the higher temperature at the inlet of the turbine and also the boiler, so we thought that we can do that reheat it right but is there any other way of enhancing the thermal efficiency if you recall that you know there is a components of the heat addition that is from the pump till it is what you call reaches the saturated temperature right 2 to 3 kind of things.

There you know the heat addition is very release now you who can operate on that you know enhance that one then we can enhance the average temperature.

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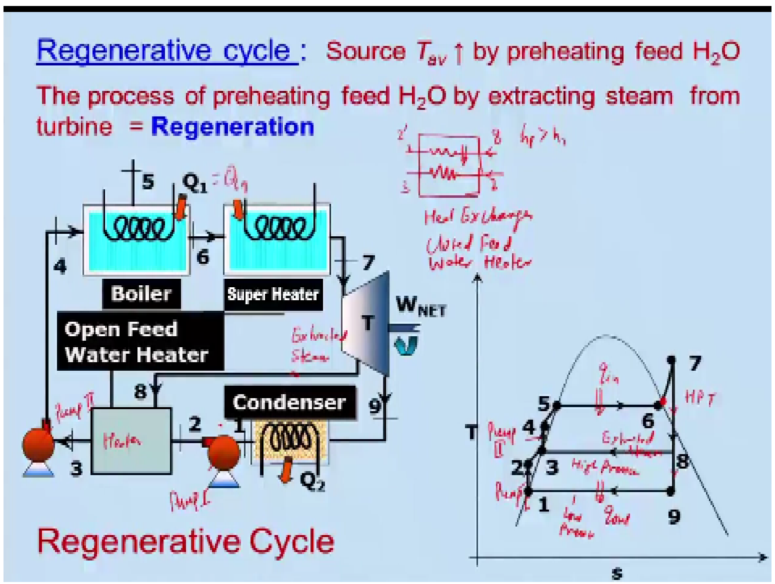

At which the heat is being you know being put into the cycle right from the boiler, so one way of doing that we can preheat the feed water what do you mean by this feed water basically the water from the condenser it will be getting back to the boiler am I right yes or no so we will have to preheat that what you call the heat we heat the water from the condenser what we call feed water and then we will have to put into the boiler, so that it will be you know ever having a higher average temperature right.

Then we can enhance the thermal efficiency now is it we will give externally or some of the heat which is you know can be utilized for heating the feed water, so what we will do if you will give externally then what will happen we cannot really enhance the thermal efficiency because work output will be similar in nature or same rather so therefore we cannot that means if you can use some of the heat which is you know getting rejected in the condenser then do that then we call it basically regeneration in this case what we do we basically extract the steam from the turbine after getting expanded in the high pressure you know portion of the turbine or high pressure turbine.

Then we will mix is that let us see how we can achieve this concept of regeneration and so if you look at this basically the cycle is now modified there is a boiler where heat being added and then of course this is usual to the any Rankine cycle but then the steam will be expanded in the turbine and some of the steam which will be extracted from here you know maybe some portion of the turbine where we can call it as a high-pressure turbine low-pressure turbine depending on the pressure because the pressure is very low you cannot really put into that because you need to have hyper.

So the steam is being you know extracted this is extracted steam from the turbine and then it will be having a what you call open feed water heater this is the heater you know and of course rest of the steam which will be expanded in the turbine further and then of course it will go pass through the condenser where it will be rejecting the heat and then you will have to also pump it to the high pressure and then it mixed together right and if it is mixed together that is why we call it as a open feed water heater right.

And then it has to be also again use this pump to augment it is pressure, so that it will reach the boiler because boiler will be at high pressure you know like so that and then it will and this completes your cycle because we are taking some amount of it and heating this what you call incoming fluid from the condenser right what we call feed water that is why you call it as a regenerative cycle.

So this you know component or to call this modified cycle is known as regenerative cycle and let us look at the processes little further you know like further in the sense some of the things might be repeated but however just to embed that thing in mind that I can say this is basically if you look at something 4 to 5 and 6 right this point is 6 basically write it here it is being heat added you can say this is Q in or I am like you can say also this is Q in right I am saying Q1 Q win okay.

Now it is being expanded in the high-pressure turbine right and then sorry it is expanded and then it is extract steam being extracted basically extracted team stream right and then it is further expanded the steam rest of the stream suppose you take you know few kg per second of the steam you know here let us say 10 kg are there you were taking 2 kg per second of the fluid from this team and 8 kg per second is being expanded further it is going to the condenser where it will be rejected outright.

And then it will come back to the this saturated liquid point and then it will be your pump right 1 to 2 is your pump right you can say pump 1 and this is basically pump 1 and this is your pump 2 right and this is again you know like it will be mixed with this free do water heaters and then again it will be pumped that is from 3 to 4 this is your pump 2 right and after that if you go back and this, so this is the cycle what we will call a regenerative cycle but if you look at the open feed water heater right is being used and so also the close feed water heater right what is the difference is there any differences between this.

If I say open feed water heater and clothes feed water heater in the open the extracted steam which will be high temperature right and it will be mixed with the old fluid which will be coming from the condenser right I mean mixing together and then it will be the temperature will be range that is the open freed water but there is another way of doing that that what is that that is basically I can have an heat exchanger for example I can have a fluid here let us say this is my heat exchanger this fluid is coming from let us say what you call 2 to 3 and there is another fluid is coming from here let us say right this is the cold fluid which is heated and this is coming from the 8 right.

I can say okay again this is what you call I can say maybe 3’ right okay, so this is the heat exchanger what I call this is as a close feed water heater are you getting because this heat because the this is the hot fluid right this will be if you look at h8 will be much higher than the s2 enthalpy you can say heat you can say whatever you call right and therefore there will be some heat will be coming to this fluid to hear right we have seen already heat exchanger.

So in this case the fluid is not coming direct contact with the you know hot fluid is not coming directly contact with the cold fluid but in this case it is all mixed together right for this what you need you need to have what you call another pump but the advantage with the open feed water heater is that you know the effectiveness with which heat exchange will be taking place will be one 100% very high right and also it will be a very easy and simple system you do not have to really have a very good material for the heat exchange and then you know complicated of scaling problems the you know whenever heat with a there will be scaling problems and other things and the pressure drop will be there of course right.

But in this case that disadvantage with the open feed water heater is that that you will have to use another pump but whereas because the pump has to be raised this liquid which will coming from the condenser will beat low pressure right this is the low pressure right okay, low pressure now this has to go to this is high pressure.

So therefore you need a pump right and then that also enhances the cost, so if you look at in real systems the generally combination of both open feed water heater and pros feed water being used right and but if you look at both are having certain advantages both are having certain disadvantages depending on to optimize that people use both you know in the in the actual steam power plant. So we will be taking this what you call open feed water systems and then trying to analyze that.

And so what let us recall that what is being done here is basically heat energy that could be lost in the condenser is being utilized in Heating the feed water that means you know we are take basically regenerating it we are rather you can say recovering it you know.

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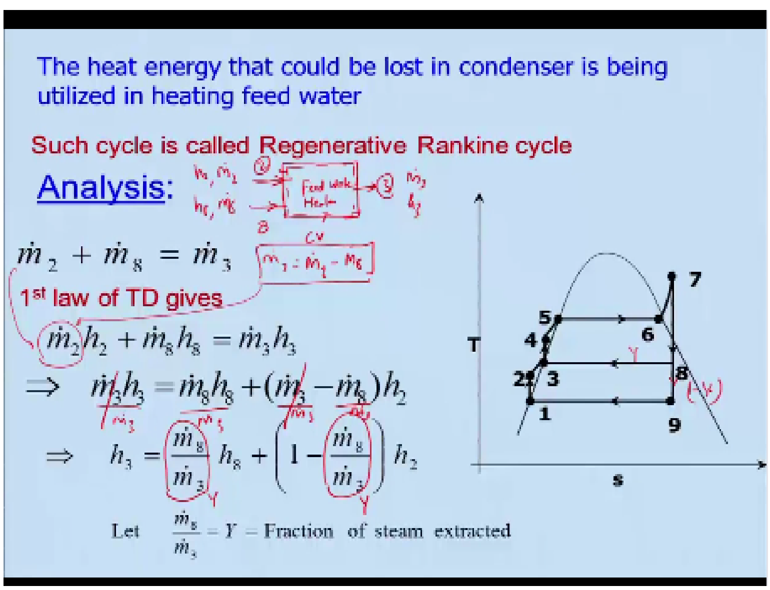

So what let us recall that what is being done here is basically heat energy that could be lost in the condenser is being utilized in hitting the feed water that means you know we are take basically regenerating it we are rather you can say recovering it you know the things so sometimes people call recuperative kind of things also the cycle is called regenerative sigh Rankine cycle and let us do the analysis, analysis will be similar in nature only the difference is that we will have to make a mass balance and the heat balance in a feed water heater that is the only difference rest of the things are same.

And will be assuming steady flow process change in kinetic energy and you know I cross any component and change in potential energy across any component will be zero you know like change in kinetic energy will be zero change in potential energy will be zero and then you know wherever work is there it will be work will be given otherwise in the expansion process will be assuming to be isentropic expanded.

So also in the compression process all assumptions whatever we have done for the other cycles like your read cycles and the simple superheated Rankine cycle will hold good so what we will do we will basically look at a feed water heater let us say this is my feed water heater we heat water heater right I can take this as a control volume and the fluid is basically let us say it is coming with the this is your stream two and this is your stream 8 and it is going out with the stream 3.

And what is that this is basically mass is coming m.2 here and m.8 here so also s2 and h8 right and similarly here mass 3 and s3 enthalpy right so what we will do we can do a basically mass balance that is mass flow rate coming from the what you call from the condenser right after the pump of course a plus the mass flow rate extracted from here from the turbine is equal to the total mass flow rate which will be feeding into the boiler right that makes sense.

So similarly we can apply the first law of thermodynamics for energy balance to the feed water heater that ism. 2 x S2 + m.8 h8 = m.3 h3 this is a simple what you call energy balance and what we will do we will have to look at it I mean instead of what you call these things right we can try to eliminate certain things so that we can find out basically you know like a relationship how much we are extracting for example like what I am saying that here that you just take this m2 here in place of m2 right.

From this expression I can put basically m2 = m .3 – m.8 and this expression I can put it here right I mean I can put it here and then I will get m.3 s3 = m.8 h8 + m.3 – m.8 I mean like reference that difference mass flow rate into s2 right so if I divide this thing by what you call m.3 here right what I will get I just divided by this m3 m.3 here this will cancel it out this will cancel it out.

So I will get s3 = m.8 /m.3 right and if you look at what is this thing that means the m3 is the total what you call amount of water or the fluid which is passing through that is the m. 3 we have seen this is a total and m.8 which is extracted right and this we can call it basically the fraction of steam extracted that is y and rest of the things will be 1 - y this will be also again y so if you look at how much you know a fraction I mean percentage wise you can say our fraction we can say this y being taken over here and the rest of the things is being extracted is y 1- y.

Of the total whatever m.3 you know is there like total mass flow rate so that will be helpful for us to you know analyze and then look at it.

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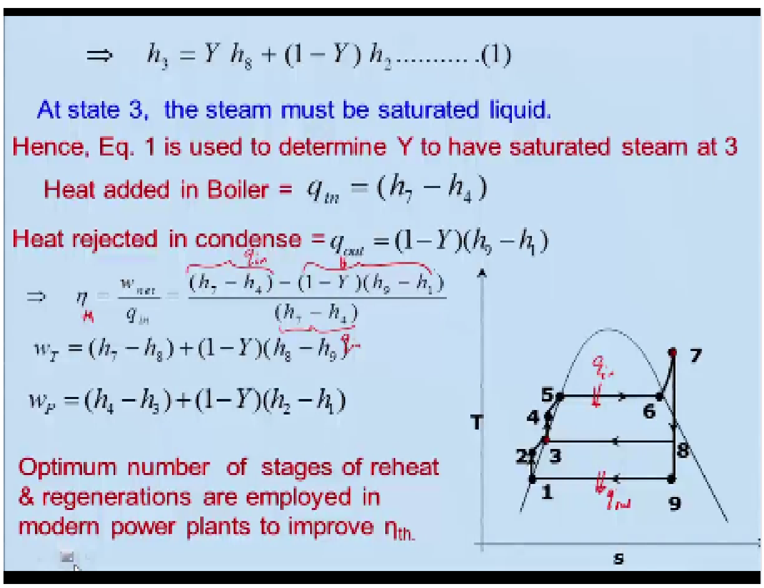

So then I can write down s3 = y h8 + (1-y)h2 right and that is basically if you look at that is the thing which will be It will be entering and then h8 is coming so that you will get a higher h3 otherwise it could have been you know suppose Y = 0 what will happen S3 will be same as that of the s2 and which is a very small you know like then it will be even y is equal to 0 there will be no extraction right y is equal to 0 means there is no extraction no regeneration right of the heat.

So at this three at the state 3 so if you look at their the steam must be saturated liquid and you know if you mix together in an open feed water heater then naturally it will go to the saturated state but if you go for a closed feed water heater you need to ensure it so therefore that is also quite complex suppose instead of here and if it is not coming here it will become here if you go for a closed feed water heater then you know it will be a problematic again you have to compress it and two phase flow you know is difficult to compress.

So therefore you know open feed water is advantageous than that of the clothes feed water heater right but however you know people do use both so hence equation use one basically used to determine the y that is the extraction steam extraction fraction to have a saturated steam at three and if you look at heat added in the boiler what it is basically a seven this point and h4 here and the rest of the heat is coming from the you are what you call the from the water feed water heater right.

So the heat rejected is how much that is h 9 - h 1 x 1 - y that is it rejected and if you look at if the y could have been zero then what could have been this could have been a larger that means we are gaining some heat being you know from the rejected heat and adding to the system adding to the your cycle type so the thermal efficiency basically will be equal to W net / qA and the if you look at the work done in this basically can be put in a little different way.

That means the heat in- heat out and if you look at what is this, this is basically Qin right this is Qin and what is Q out, q out is basically 1-y h 9 -h 1 this is basically q out and divvied by s 7 – h4 that is the of course the queue in this is q n so you can find out thermal efficiency very easily right and the work done is basically S7 - h 8 + (1 – y)h8 - h 9 if you look at the work done will be reduced definitely.

Because you are taking some what you call steam out of it and if the fraction is very small then it would not really affect much but however there will be reduction in the net at work extracted by the turbine and of course the pump also you need to have more extra work as compared to the simple cycle and h4 - s3 we are you know giving there's some amount of work otherwise you could have given from here to there right.

This is the extra work whatever giving and of course (1- y) s 2 - h1 right this is being little bit reduced this is also additional work so that you know network output also will be reduced to some extent so the optimum therefore it is very important to optimize it otherwise you know you will trying to do you know NS the thermal efficiency it may happen you may land in giving you know like decreasing it or may not be enhancing further you know like so one has to optimize the number of stages of reheat and regeneration general regeneration is not being used alone.

It is being clubbed with the reheat in other words the combination of the reheating and the regional system is being implemented in actual steam power plants right so and also optimization is very important and these are the basic equations which we will be using by you know for optimization of the steam power plant which is a very you know interesting and very important subject particularly.

This people who will be getting into the mechanical engineering and other thing they will learn how to optimize and what are the things again you have to do some exercises also like excess amines availability and do a lot of in optimization basically reducing the irreversibility in the system and also adopting the innovative ideas of how to basically the maximize the work output with the list heat input. So that is the thing what you need to look at it.

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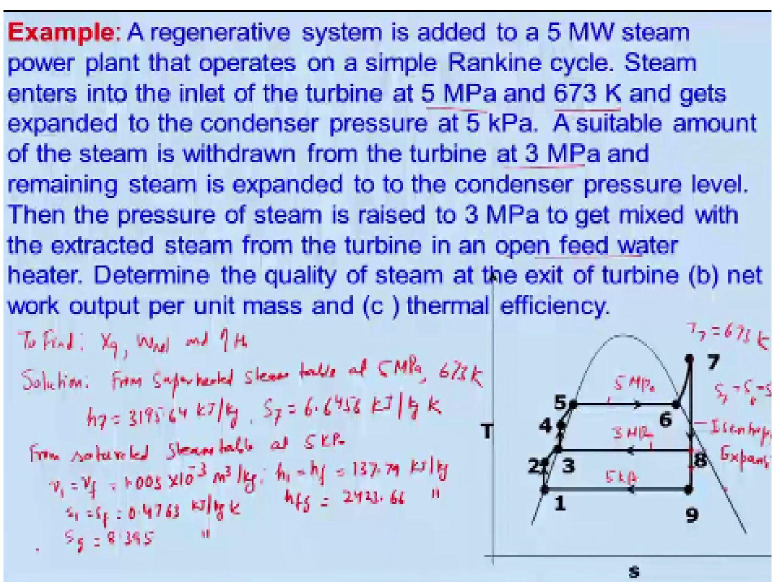

So what we will do we will now take an example and try to see some of the points what we discussed right and this example is related to a regenerative system and which is added to a5-megawatt steam power plant and it operates on a simple Rankine cycle right rather simple

Rankine ideal cycle I can say and steam enters into the inlet of turbine at five mega Pascal’s right this is five mega Pascal and 673 Kelvin.

So what is this point if you look at this point is basically s7 that is the pressure, pressure here is what you call five mega Pascal and the temperature is t7 is 673 Kelvin and gets expanded to condenser pressure that is your condenser this is your condenser so that is your basically5k PA keep in mind this is five mega Pascal’s right if you look at 0.1 mega Pascal is equal to one atmosphere right.

So it is 50 you know atmospheric pressure so and this is a KP a very low pressure generally low pressure being maintained at that this thing at the condenser a suitable amount of steam is withdrawn from the turbine at three mega Pascal. So this is the place you know which is steam is expected and this is 3 mega Pascal this pressure you know if you consider that this is because this is a basically constant pressure line.

You know you remember that this is a kind of thing so and remaining what you call steam is expanded in the condenser so this is expanded in the condenser pressure level that is 5kilo Pascal then the pressure of the steam is raised to 3 mega Pascal to get mixed with the extracted trip from the turbine in open feed water heater what we have just now discussed. Right and we will have to determine the quality of the steam at the exit of turbine basically here you know and network output per unit mass and then thermal efficiency.

That will have to what you can do now if you look at how to go about it so if you look at what we need to find will have to find basically x9 right and you will have to find out network output per unit mass and we will have to find out the thermal efficiency. So how to go about this how to go about basically what you will have to do we laughed we know this point right because from the superheated steam table right I can get this from superheated steam table at five mega Pascal and 673 Kelvin.

I will get the properties what I will get I can get h7 that is 319 5.64 kilo joule per kg and similarly I can get the entropy do I need entropy or not 6.6 458kilo joule per kg Kelvin right that means this point I know and of course you may say that why i need it because I will have to find out this point I will have to find out x 9 also right and I will have to find out how much work is being done in this you know expansion from 7 to 8 right.

That I will have to find it out and I will have to find out also how much you know steam is expect extracted from the turbine right and so for that I need to know this state right that means I will have to know this what is the quality of here quality at station eight and also the nine I need to know that and once I want to know the quality how I will get it because it is not given in the problem. So how will get it I will have to use the isentropic expansion condition.

That is what that iss7 is = s 9=s8 s7 = s 8 is equal to s 9that is the isentropic expansion right. So therefore I can use that and find out the quality and then look at it and then once I know the quality i can evaluate the properties here because I know the saturated condition from the steam table I can get corresponding to 3 mega Pascal this point and i can get also this point. So if I know quality I can find out what will be here similarly.

5 mega Pascal I can get this point here from this saturated steam table and also I will get saturated vapor you know conditions here and then if I know I can evaluate very easily h9 and then we can do the calculation right. So let us look at that from saturated steam table at 5 kilo Pascal I will get this data this data is basically v1 = VF that is this condition right = 1.0 0 5 x 10^{-3} meter cube per kg.

This is basically specific volume similarly H 1 = H F = 13 7.79 kilo joule per kg right and I can get h FG because h FG is required right that is the heat of vaporization h FG is 242 3.66 kilo joule kg and I need also entropy right in entropy will be s1 = sf is it required this one for 763 kilo Joule per kg Kelvin and s that is your sg 8.395 Joule per kg. That you can observe one thing that you know at what you call SAF liquid entropy is lower as compared to the gas entropy.

Right at the vapor entrance now okay and similarly we can get also the other data right from the what you call the corresponding to 3 mega Pascal right.

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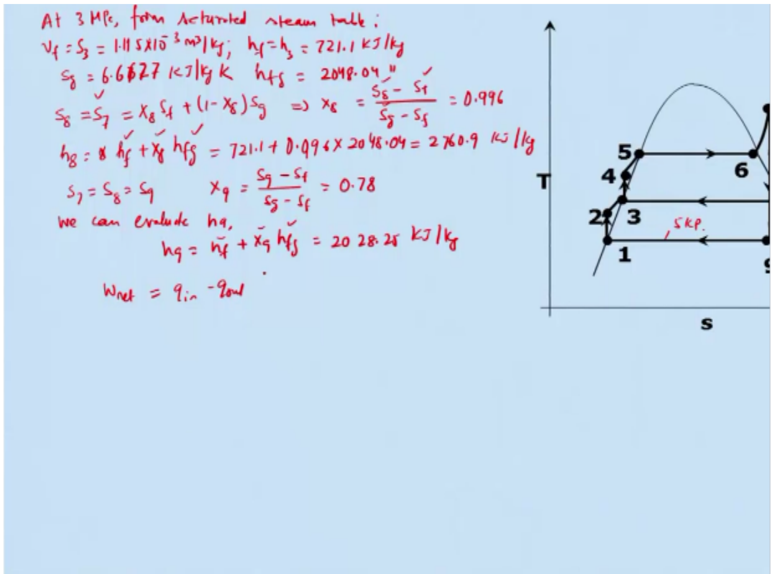

So let me just write down at 3 mega Pascal right at 3 mega rascals from the saturated steam table I can get these values that is basically vf = s3 = 1.15 115 x 10^3 3 meter cube per kg and hf =h 3 is 721.1 1 kilo joule per kg and I can get h fg is 204 8.04 kilo joule per kg and I get s g = 6.6 727 kilo joule per kg Kelvin. So if you look at we have got all the data point right is it something missing if it is missing you can get from the saturated steam table or the superheated steam table.

Right now we need to find out you know the what you call x8 so we know that what will be the you know s8 = s7 right and this is known this s7 is known or not s7 is known how from the superheated steam table corresponding to the 5 mega Pascal and 673 Kelvin. We have already got it so that = x 8 s f + 1 - X 8 vertical s G is a no right and from this I can get x 8=s 8 - s f / the SG – SF.

I know these values s8 I know SG I also know so if i substitute these values i will get 0.99 6 it is almost equal to the one you know you can assume but of course it is not exactly one ok you can approximately say it = 1 that means it is on the saturated vapor line it is a closer to that and by knowing this x8 I can find out what h8 very easily. What is that is basically x8 right or I can put in a little different form that is hf +x 8 h FG right.

So hf this point we know right saturated so this is known and this is X is known so therefore I can substitute these values let me put this number 7 1.1 + 0.9 96 x 204 8.04 ok I mean it = 2760.9 kilo joule per kg. So in the similar way I can find out x 9 right because we know that s 7 is = s 8 = s m so from that similar way I can find out x 9 is = s 9 - SF right s G - SF and this SG and SF corresponding toward corresponding to this pressure.

What is this pressure what is that pressure that is basically 5 kilo Pascal corresponding to that you will have to put and when you put that thing you will get 0.78. Okay are you getting so similarly you can find out h9 you know we can evaluate h9 as h 9 = hf + x 9 h FG and we know these values. So you will get basically 202 8.25 kilo joule per kg but you know by knowing this is it possible we can find out network done is it possible we cannot why because if you look at w net right will be what will be q in_ q out is equal it.

And H for right minus 1minus y h 9 minus h1 I can do this way or I can do like you know what is the net work done $_{s7}$ you know I can put this how much work done between state seven and seven eight and then will also what is the work done in the between state an eight and nine then I will have to find out compressor work and minus it you know I can do that way this is one way there is another way also you can do.

Right I can do this way basically w turbine minus W pump. that means in this case to pump are there so we will have to add you know this is equal to basically w p+ w2p right this will be there w similarly in turbine high pressure turbine and low pressure then you have to do all those things and do that it but this will be little simpler way so we know the a7 right do we know the h4 do we know h4 we really do we know heart not right.

So we need to find out what is that and then we do not know this why right we know this h9 already we have evaluated h9 we know this h1 is saturated condition so therefore we knows this is known this is known we need to evaluate why and we'll have to evaluate also the 4-h for right and then we can do that what is why then why if you look at is basically h3 minus h2 / height minus h2 am i right am I right so that s 3 is known to us or not so s 3 and s 2 is known to us so we need to find out.

This s too right how will find out $_{5}$I can find out physical to v1 into Delta P yes or no v1is known delta p is known so that delta is what delta p is this is a mega Pascal right and minus this five kilopascal will give me that and this is if you look at s2 is basically 13 7.79 and I am sorry this is plus h1 it will bright because h1 is known this is also known so this is kilo joule per kg right so h eight is known to us and $_{s3}$ also known to us right because that will be a saturated condition with that so if you get the s3 is equal to 7 20 10 point 1kilo joule per kg and this is known this is known and all these are known so you will find out this is basically 0 point22 .

So if I know this thing right and similarly you can find out h4. h4 you can find out- h 4 -s 3 right = to V into Delta P in this case 8mega Pascal to the what you call 50 mega Pascal right and then you can this is known to you like because this is corresponding to saturate the condition so you can get that as basically maybe 75 2 kilo joule per sorry 727 kilo joule per kg kind of things so once you know this thing right I can find out the network s7 right andh4 -1 minus y h 9 -h1 so all are known so you will get basically something 999.9 8 kilo joule per kg .

So once you get then you can get the thermal efficiency is equal to W net minus Q in minus Q in is equal to W net_ s 7 _H 4 so this is s 7h for both are known so you will get basically this will be not right this will be h 30k +s 3 that will give that so if we substitute these values because this is known this is known so you will find out that this will be something 0.40 for ones something 40.4 one percentage right so by this way you can solve this problems right and look at it and one can see that compared with that and then you will find out in this case .

It would take the same problem without regenerative the you know thermal efficiency will be coming something 38.4 percentage so that means this is without regeneration right so therefore there is an increase in the thermal efficiency but it need not to be always true that depends upon the how you of design and how it is being updated so what we will do will be basically looking at you know is there any other way of increasing you know the thermal efficiency.

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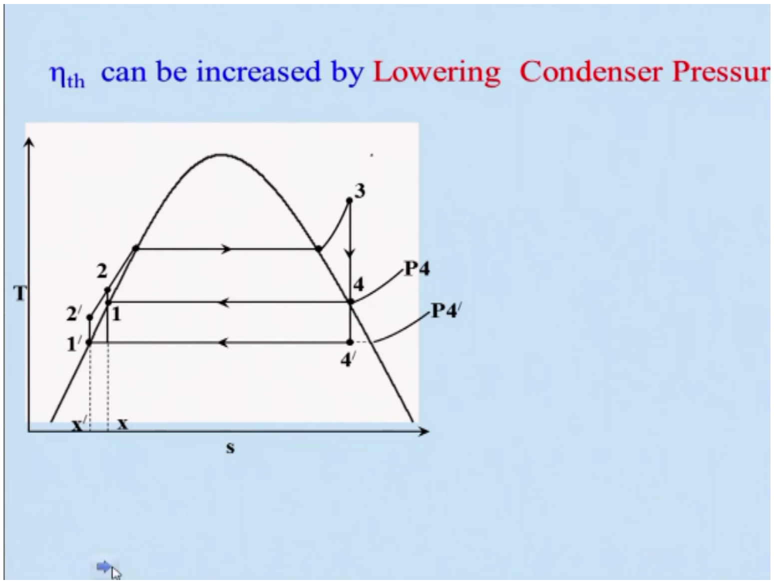

By lowering the condenser pressure right and if you look at that I can lower the condenser pressure but there is a some limitation as I told that less than the 7 kilo Pascal people is not really interested to do that because of some problem so if it is lower this is earlier it is operated one-two three four right but now the pressure is being lower that p 4 dash isles than the p4 so.

Therefore you know like there is a more work done here you know if you look at this is your area which is having what you call work done but however you know like there is penalty one has to pay because here one has to you know add somewhat on amounted feed kind of things so if you look at the net increase in work output is basically area one what you call for four dash and one this portion if you look at this portion is the net work net increase.

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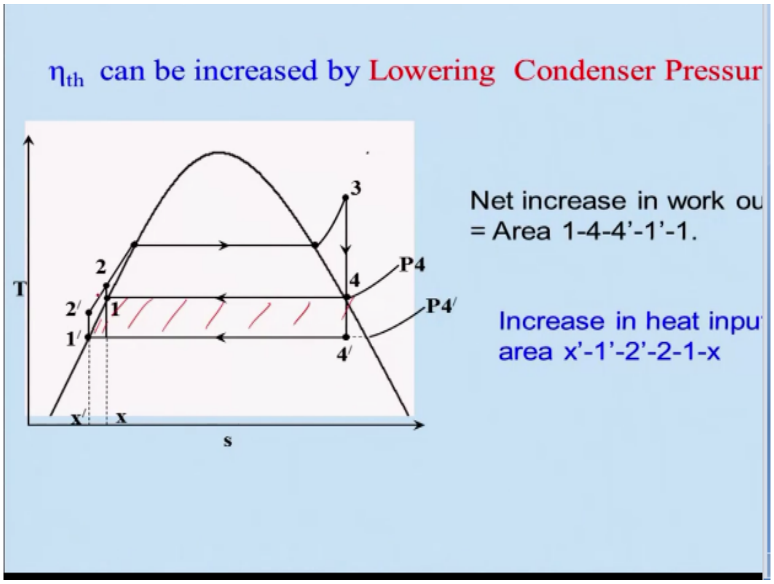

In work output right this portion but however this portion like that is what you call X dash one dash two dash and two of course 1x this portion this portion if you look at this portion is basically increase in heat input one has to give right of course this the more additional it and then one can also enhance the thermal efficiency and we will stop over here and we will look at in the next class basically about how to incorporate the losses into the system and analyze it for thanking you.

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