Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Engineering Thermodynamics

Lecture – 30
Vapor Power Cycle 3

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Let us start this lecture thought process from Thomas Alva edition.

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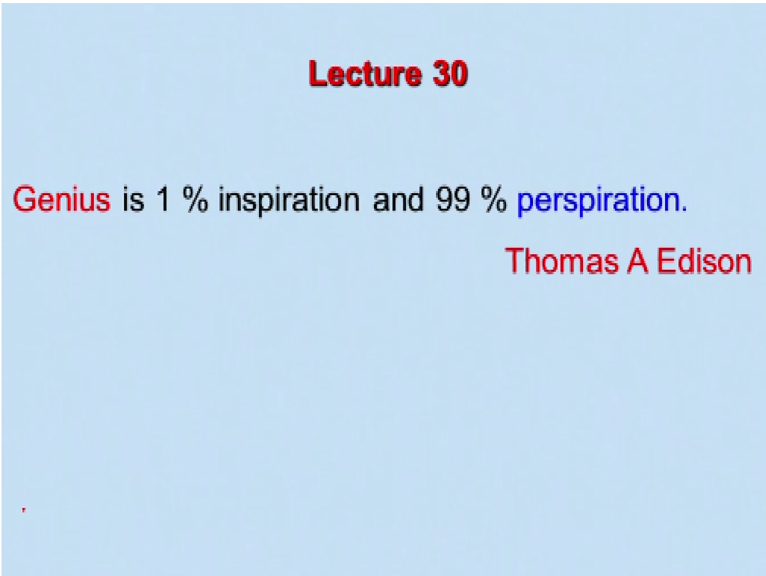

Genius is 1% inspiration and 99% perspiration which basically indicate that you know you may have your talent what I call exergy or availability unless you work hard you cannot really utilize that talent for the benefits of yourself and also for the society, so let us relook at what we learned in the last few lectures basically we looked at reheat cycle, Rankine cycle, regenerative Rankine cycle of course before that we discuss about the superheated Rankine cycle if you look at what we are doing we are basically trying to find out ways and means of enhancing the thermal efficiency.

Question arises is there any other way of enhancing thermal efficiency if you look at the basis of enhancing the thermal efficiency is basically to increase the temperature at which heat being added to the plant other to the cycle and also heat being rejected in the condenser in this case. So if we can lower you know the condenser pressure.

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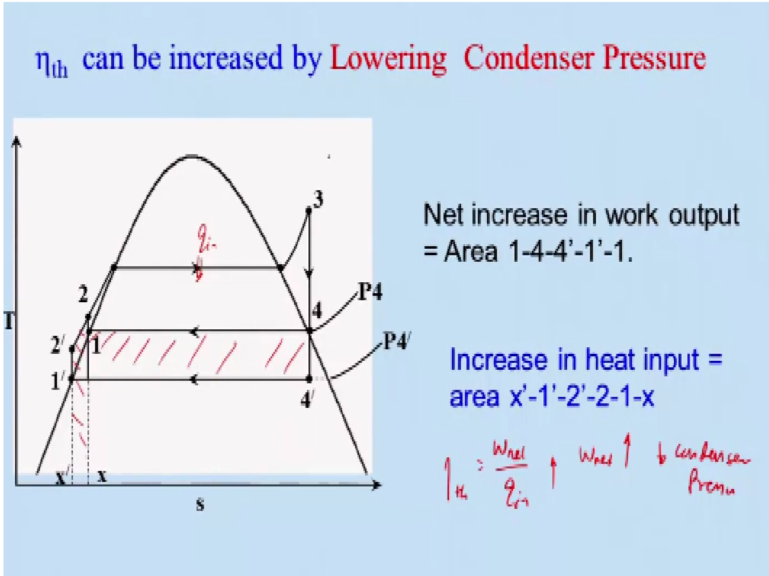

Eventually we can decrease the temperature at which it will be rejected, so that we can enhance the thermal efficiency but if we will do that then let us look at what are the things we are gaining and what will be losing in the process, so if you look at earlier the cycle is 1, 2 and then you know a 3 this is basically 2 to 3 is your heat addition that is your Q in and 3 to 4 is your expansion and then 4 to 1 this is your actual cycle if it is operated with that but what happened we have now changed the condenser pressure right from p for to the p4' right that means you know there is an extra work what we are getting right.

So what is that extra work extra is basically 1, 4' and 1 dash 1, so this portion of extra work we can get by lowering the condenser pressure right but however we will have to now you know add some more heat into that like in the area basically X1', 1' 2 and 2 1 X so this portion basically will be giving some heat input right, so therefore of course we may gain more with this lowering the condenser pressure but there will be associated problem as I told lower the pressure.

Then there will be leakage problem you know that has to be properly sealed otherwise what will happen the atmospheric air you know in the condenser will be getting into if there is a small leakage somewhere and then you know like it will be a very difficult for the heat transfer to occur because this will be what you call not only the 2 phase flow and also the addition then it will be causing some problems right and therefore people restrict this the condenser pressure to the 7 kilo Pascal kind of thing.

Of course in some of the example we may be putting 5 kilo Pascal or something but however with the you know better technology one can lower as well right, so that is of course the future this thing, so I mean this is the another way what I told you just now that lower the condensing pressure and you can get a thermal efficiency because there is a work what you call higher work output and therefore that will be if you look at the you know for the same input, so the thermal efficiency will be higher.

Because why if you look at the thermal efficiency is equal to W net / q_{in} but the same q_{in} you are basically increasing you know network output because the network output is increases with lowering the condenser pressure right, so therefore the thermal efficiency will be what we call higher in this case.

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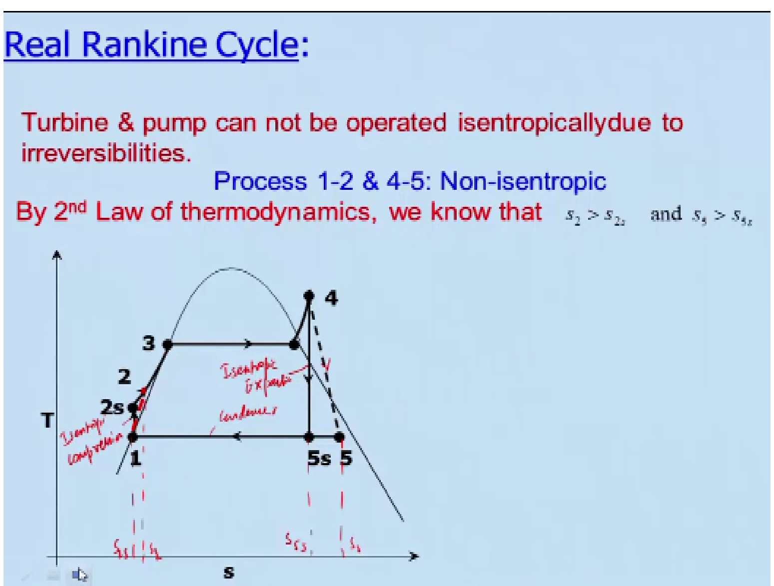

So if you look at till now what we have done is basically taken the simple and ideal rankle cycles I mean not only the ideal cycles in that case what we have done we have basically considered the pump and the turbine to be operated isentropic that means there would not be any losses in that is it really possible to have that certainly no I am like you cannot have operate a turbine or a pump right or any other component as a matter of fact that without any losses.

So losses will be there means there will be irreversibility right and irreversibility will be there that means if irreversibility will be there then the process cannot be considered as isentropic right and beside this will be considering also that there will be losses in the vertical boiler pressure because we know that the whenever the flow is taking place in a pipe there will be some losses because of friction of the pipe and then we are adding also heat there will be also losses right and kind of things.

So therefore there will be losses both in the boiler and also in the in the condenser, so if you look at boiler is from 2 to you know 4 this region 2, 3 and 4 this region there will be also losses and we can look at what are the losses and other thing but in this analysis what we are going to discuss now will be not considering any loss of pressure in case of boiler that means it will be remaining as it is but in actual system there will be pressure losses right.

There will be also frictional losses right because of you know this thing friction there will be pressure losses, so therefore that we are not considering here but and so also in the condenser this is your condenser right what you call this is your condenser and there will be lost you know drop in the pressure, so that also we are saying that look it will be remaining what you call constant for our analysis.

It is a simplifying but however in our analysis what we'll be doing that 4 to 5’ is your ideal you know expansion that what we have already considered isentropic expansion 4 to 5’ is your isentropic right expansion right but we are saying that is not possible and because of losses will be there therefore the you know areal situation that the expansion will be non isentropic that is from 4 to 5 I have shown as a dashed line similarly if you look at in the compression this 1 to 2s is your isentropic compression.

And 1 to 2 that is here you know which has shown as a dashed line in the rate that is your actual compression right if you look at from this diagram itself that for the you know pumping work of our increase in the pressure you need to give more amount of work in actual situation as compared to the isentropic compression yes or no because you know like if you look at of course you take temperature but if you go to the enthalpy that you will find the enthalpy change between the state 2 and 1 is higher as compared to the enthalpy change between the state 2s and 1 right.

So therefore more work input should be given in actual situation as compared to the isentropic case what we had considered for ideal Rankine cycle in the similar way if you look at the amount of work which is done by the turbine during expansion of the steam between state 4 to 5' is less as compared to the work done for an isentropic Kelly operated turbine right, so therefore you know what you are doing you are getting less amount of work you know in the turbine and you are giving more amount of work to a pump for a real system right.

So of course if you look at that this from the second law of thermodynamics entropy is greater than s_2 s right because of you know there will be irreversibility, so therefore if you look at this is your s_2 and s_2 and this is your s_2s right and if you look at this 5 what will happen this will be you s_5 and this is your s5s right, so therefore also the s_5 is entropy s_5 is greater than the s_5s means isentropic process for isentropic process entropy will be lower and for actual process entropy will be higher therefore irreversibility will be there and there will be input.

Now so this is we call it basically a real Rankine cycle of course I would like to put that it is not real rankin say rather semi-real Rankine cycle because we are not considering the losses in the boiler and also the condenser okay but for our purposes will can call it as a real Rankine cycle.

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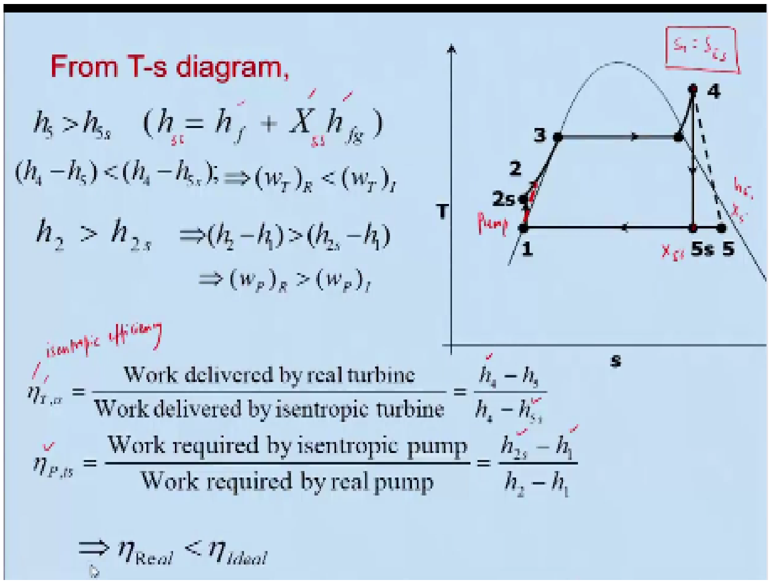

And let us look at how we can analyze this thing right because if you look at earlier days earlier what we are doing for ideal cycle I will be knowing this point if I mean it should be given to you either from the you know superheated steam table pressure temperature or I can go from here you know from the condenser pressure and then do that right we have done in the example first example when I took I did other way around where the superheated you know condition was not given temperature was not given right.

But the pressure was given so let us say that it is given that is this pressure is known like three to four pressure Is known and temperature is known from the superheated steam table you can get and by getting this you know you can because this is isentropic process therefore you will get 5s point here and if I know this condenser pressure and saturated condition if I know the quality of the steam here at 5s then naturally I can get.

And how can I get that I know that s4 = s5 s that is correspond to isotropic by the from this condition I can get what will be the x-5 s right and then once I know I will get enthalpy and then I can get enthalpy here and then all other points is very easy to do that right but however how I will get this you know a five because I need to know this entropy here x5 right and also I should know that what is the quality that is x5 I should know also h5 right.

I cannot afford to say that is five that entropy at state 5 is equal to entropy at four it is not possible it is not nice interview process to how to go about that how we will do that right for that you know it is quite difficult but what we will be doing will be putting other way around we will be defining certain terms right by considering that if you look at h 5 > h 5 s right and therefore of course as I told if I know this what you call xh5 I can find out what is H5S right I can find out very easily fine.

This I can get out 5s if I know this 5s right I can get and how I will get this x5s by using this condition s4 = s5s so I can find out x5 and this is known and this is known this is known I can find out but even if I will do that but I cannot find out h5 right and also we know that h4 – h5 right that is the actual work what you call done you can say is less than the h4 - h5 s right that means the work done by the turbine under real condition or the is less than the work done by the turbine.

Under ideal condition right it will be obvious am like kind of thing so if it is so then if I can find out a relation between that how it is then you know I can find it out for that what we will do we will have to define a term known as isentropic efficiency which is you know defined as work delivered by the real turbine that is H4 - HY divided by the work deliver by an isentropic turbine that is H4 - H 5s here.

And these efficiencies is basically known as isentropic efficiency because we are comparing with respect to isentropic conditions right which is an ideal case so if I know this you know I know this h4 I know this h5 I know this then I can very happily find out h5 yes or no so but that means I should know this efficiency beforehand for this analysis which you can I am like you know get from the other experiences and similarly for the pump this is your pump basically right this is your pump is 1 to 2 s and 1 to 2 right and s 2 > s2s.

And we know therefore the s2 -h1 > s2s – h1 what is saying it is saying basically the work into the pump will be higher than that of the or the work input to the real pump or the pump under real situation will be higher than work input to the pump under ideal condition so therefore we can also define in similar way isentropic efficiency for a pump is work required by the isentropic pump that is basically s2s – h1 right this will be smaller one.

And the work required by the real pump that is s2 - h1 a similar way you know h1 is known to you and s2 is not known s2s is known to you and then if it is known to this isentropic efficiency you can calculate s2 very easy right so this way we will analyze the real cycle analysis you know Rankine cycles and keep in mind that as the what you call work output from a turbine for a real case is less than the work out put in a turbine under ideal condition.

And the also the real pump or the pump under real condition takes more work input as compared to ideal therefore the work network then will be what will be reduced for the same it put in put there for the real cycle is always less than the ideal cycle therefore the thermal efficiency of the real cycle will be always less than the thermal efficiency of ideal cycle.

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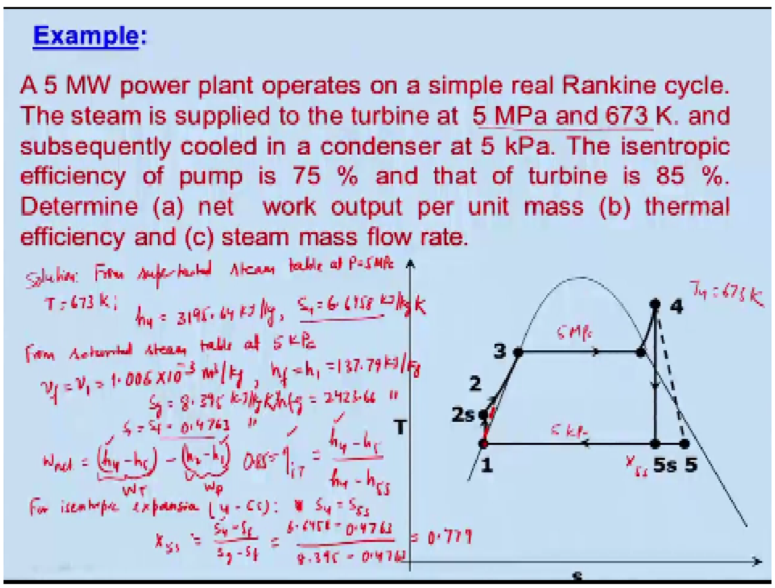

So let us take an example to you know concretize our ideas what we have learnt just now that is you know a five megawatt power plant operates on a simple real Rankine cycle here simple means I have not considered the reheated reheating cycle or the degenerate it is a simple one right and the steam is supplied to the turbine at five mega Pascal and 673 Kelvin it is similar to that what we had done earlier right.

And subsequently cooled in a condenser to 5kilo Pascal this is your 5 kilo Pascal and this is 5 mega Pascal and temperature is T4 is 673 Kelvin and isentropic efficiency of the pump is seventy-five percent and that of the turbine that is isentropic efficiency of an eighty-five percent and we will have to determine the network output per unit mass thermal efficiency and Steam mass flow rate right.

So how to go about it right so if you look at it is a similar manner what we will do we will basically know this pipe Omega Pascal's and we can very happily find out this h4 yes or no from the superheated steam table right so if you look at solution from superheated steam table at p is equal to five mega Pascal and temperature 673 Kevin I can get h 4 = 3195.64 kilo joule per kg and I need also entropy so s4 = 6. 6458 kilo joule per kg and Kelvin right and also we can get the data for this point that is for what you call from the saturated steam table from saturated steam table at five kilo Pascal pressure right I will get as V F which is nothing but your v1 in this diagram 1.005 x 10^{t-3} m^3/kg if you look at is a very small number.

And HF which is equal to h1 because this is the saturated liquid point is equal to13 7.79 kilo joule per kg, HFG = 2423.66 kilo Joule per kg and we need to also know this hg is 8.395 kilo Joule per kg Kelvin right and of course you know we can write down S_f which is nothing but s1 this is 0.4763 kilo joule per kg Kelvin. Now see basically if you look at we need to find out this point right if I want to find out network output per unit mass what I will have to do we will have to basically find out network output that is nothing but you are in actual system h4 - HY is a no further real turbine - h2- h1.

This is for the pump this is for the turbine this is for the pump right and if you look at h1 is known to you right h4 is known to you h5 is not known and h2 is not known. So how to find out what will it do we will have to basically you know find out the h5 I can find out very easily what is that is entropic turbine. What we know that h4- h5 / h 4 - h5s is a no we have defined this and this is known.

What is these values this values is 0.85given so h5 that means h4 is given now we need to find out h5s so how we will find out h5s I should know what is X5s then only I can calculate right so h 5 s if you look at can be calculated very easily if you know this quality at station 5s. So how you will calculate the quality will have to do you know isentropic process for isentropic expansion that is for 25s we know that is X we know the s4 s5s.

Right and from that I can find out and then i will get X 5swill = s 4 - s f / Sg- S_f and this S_f and S_G at what pressure that is corresponding to 5 kilo Pascal this point. Right and s4 we know this is known right this is your s4 so if you and S_f is known which S_F this is this basically this Sf right and Sg is known that is 8. Let me put that number that is 8.935 so if you look at this is let me put some number then you will get some idea. Otherwise I feel you people are not getting 6 45 8 minus 0.4763 / the SG that is 8.395 - 0.4763 and which = 0.779 once I get x5s it will be very easy to find out h5s.

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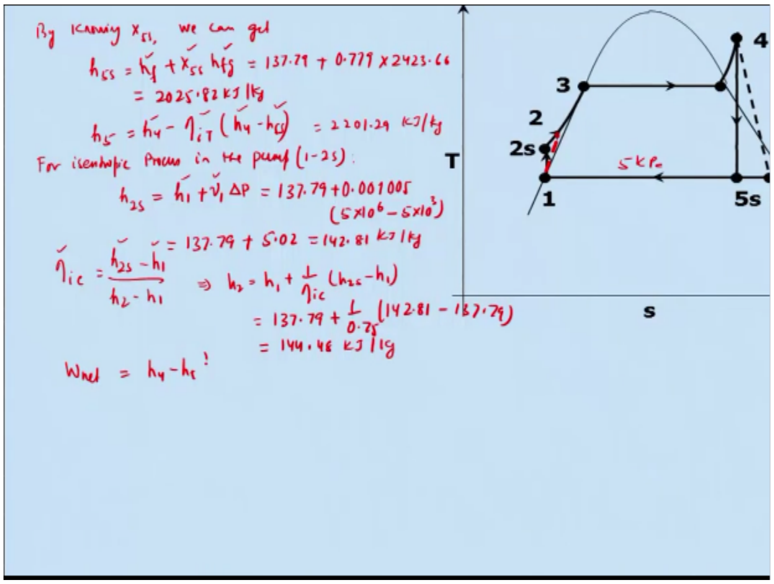

So then I can calculate by in you know by knowing x5s we can get h5s as hf + x5sh F_G right. So if you look at h_{fg} you know is given this is given this is already we have evaluated hf we have evaluated so if we just substitute these values you will get 13 7.79 that is HF plus this is your X 5 s that is quality into h FG is242 3.66 and we will get 20 25 82 kilo joule per kg. Once we get that you know we can get very easily hy = h4- turbine isentropic efficiency x h4 - h55.

What it will be 5s is a no 5s so therefore we know these values all those are known to you so if we substitute these values you will get to 201.29 kilo joule per kg? Right so what you can observe right h5 is higher as compared to h5s right because this is 220 1.29 kilo joules per kg. Whereas you know h5s is 202 5.82 kilo joules per kg right that means it is not really expanded you know much Emily as compared to the isentropic process.

So now what we will have to find out we can find out very easily what is the work done by the turbine right I can find out by the turbine in the real situation right very easily. But we need to find out net work done right okay right so that we will have to find out now by looking at the pump. So in the pump what we are doing we are assuming that you know in incompressible fluid therefore I can get very easily for this process you know or isentropic process.

In the pump that is 122s and that is h2s = h1 + v1 or Δ P so if you look at that we know this already this is corresponding to VF ear right this is known and h1 we already know at the this is your 5 kilo Pascal right this is your pipe kilopascal corresponding to that. So if we substitute these values you will get 13 7.79 plus this is a very small values you know 001005 of course into 5 x 10^3 that is 50 mega Pascal and 5 kilo Pascal you need to be little careful about unit and you will find out this is basically very small number right 137.79 + 5.02 = 142.81 kilo joule per kg. Right if you look at this change in the by the pump is very be 1 Δ P is basically work input is very small.

Now we need to calculate basically h2 because the fur the pump work is nothing but your s2 - h1 but we do not know we have just found out s2s so we will have to use again invoke that efficiency of the isentropic efficiency of the compressor that is ic = s2 - H 1 / s2 - h1. Right so in this case if you look at h1 is known this is known this is known this is known so you can calculate very easily that = h2 is h1 + 1 over ETA C x s2 s - h1.

Right if you substitute these values you will get1377 9 + 1 x 0.75 into one 42.8 1 -13 7.79 and you will get s2 =1404.48 what you call kilo joule per kg actually some people you know do not do this calculation right because they say it is very small I will neglect it I would suggest that do not do that in your exam you know we may do in our calculation for sometimes but do not do that if it is given please do that some people say that look I have done this way it is neglect it is very small tiny values I need not to calc know in your class in the exam you cannot afford to do that assumption pump work okay.

I am saying so you will have to calculate and also when you calculate you have a feel what you are getting so the W net if you look at is nothing but your h4 h5 _2 _h1.So we know this h1 we know already h5 we have calculated this is your h 5 this is your h 5 and s2 we have just now calculated this is you too right so h1 already we have evaluated from the saturated steam tables we can get that very easily this one that is 31 95.6 4-2 20 1.29 that is your turbine work minus 14 4.48 minus 13 7.79you will get nine eight seven point six kilo joule per kg and if you look at the compressor work is very small I mean you can see this is your I call pump or not the compressor pump work okay.

And turbine work is very large so the thermal efficiency you can evaluate very easily that is w net / the queue in is equal to W net H what you call for that is your H for right _h2 this is your work input or not I sorry heat input or not this is your heat input h 4and s 2 so this is I mean known to you this is 98 7.66 into h 4 is your 3195.64_ what you call h 2 s 2 already we know that is your 1 40 point 48 so you will get 0.3237 is equal to 32 point 37 percentage.

But if you do this ideal you know cycle this is the real cycle okay a real cycle but if you look at ideal cycle right what it would be it will be something38.4 percentage if you look at there is something around six percentage you can say you know decrease in the what you call real situations in the real engines real power plant but keep in mind that it will be much lower because we have not considered the losses in the boiler and also the condenser okay we have only considered the losses in the compression sorry pump and the turbine okay.

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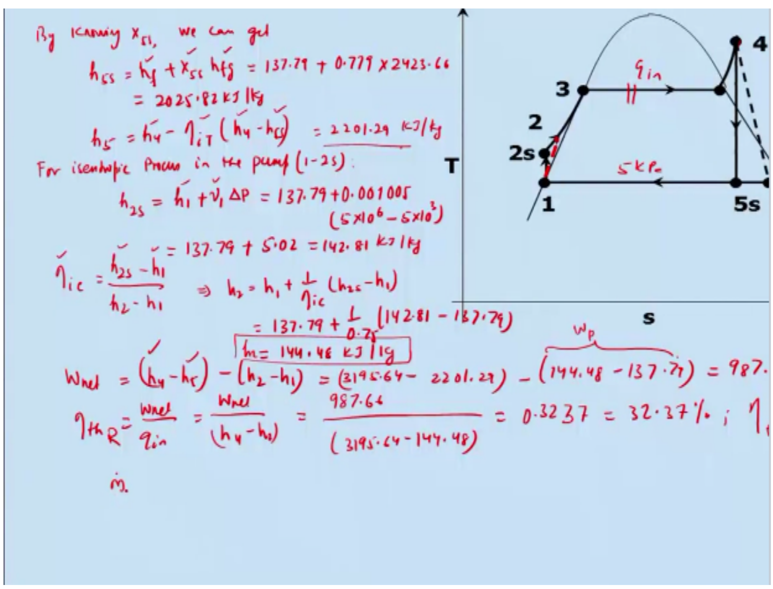

So but we need to calculate another point that is the amount of steam you know produce to produce five megawatt power plant so that is a very easier thing to do because we know this you know power so that is power divided by the net work input right double unit right that will give me power is basically five megawatt then basically you know 5 into 10 power23 kilowatt / the work network is 987.6 kilojoules per kg so I will get something5.06 kg per second now this is a real situation you know for real engine real power plant but in the ideal case what it would be will it be higher or will be lower it will be lower for the same work you know same power level because this work input or network done basically.

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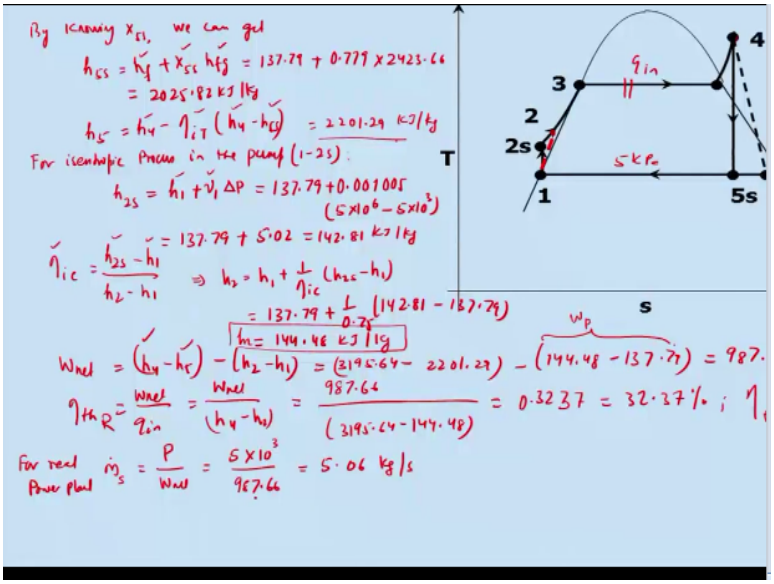

It will be higher so therefore the amount of steam whatever in will be consumed this or the being utilized is lower so if you look at that you know the steam will be basically increase for the real cycle the change in the steam flow rate will be something 18.6 percent difference will be there right if you do for the ideal and real and compared and then do that so what we have seen he is that you know we can analyze the real cycle by considering the losses through a little indirect way by considering the isentropic efficiency for the turbine and the pump and in some cases we may consider also the losses in the boiler and condenser .

Then you know efficiency will be much lower than the ideal one so we have learnt basically about the what you call Rankin vapor cycle Rankin cycle right and both reheat regenerative and also the superheated Rankin cycles keep in mind that we have considered those things are for the ideal but that can be also analyzed using this real cycle analysis what I have discussed just now for a simple system right that might be several ways of also enhancing the thermal efficiency.

Of the steam power plant right is there anything coming to your mind which we can utilize for example like some of the heat being rejected in the condenser now if in a in an industry I need some you know steam or something and the lower you know this thing I can heat use the heat so I can combine the power plant with the heat input then I can utilize that you know then we can have a total efficiency will be very high that is a several ways and means of doing and we call it as cogeneration .

You know like we will be generating both the power and the heat so that you know Oh generative power plant one can think of and that is being used in Western countries I think in our country will be using that in sour some of the industries in modern time you know recent time people have adopted the cogeneration there will be several other ways of doing like you know what we call combined cycles right where you can take this heat and use it or you take the heat from another cycle and then use for generating the steam and then run the power plan .

That is known as combined cycle you know have two cycles you can combine and get that so there are several you know complex systems have people have developed to improve the efficiencies I would not be discussing all that thing because that is not a part of your horse but however I will encourage you people to look at the interesting and very complex cycles what people have adopted in recent time to enhance not only the thermal efficiency but also the reduce emission so that is also another aspect one can be done and will this I will stop over in the next class we will be talking about gas power cycles and then we will be discussing about thank you.

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