Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Engineering Thermodynamics

Lecture – 27
Gas Turbine Cycle

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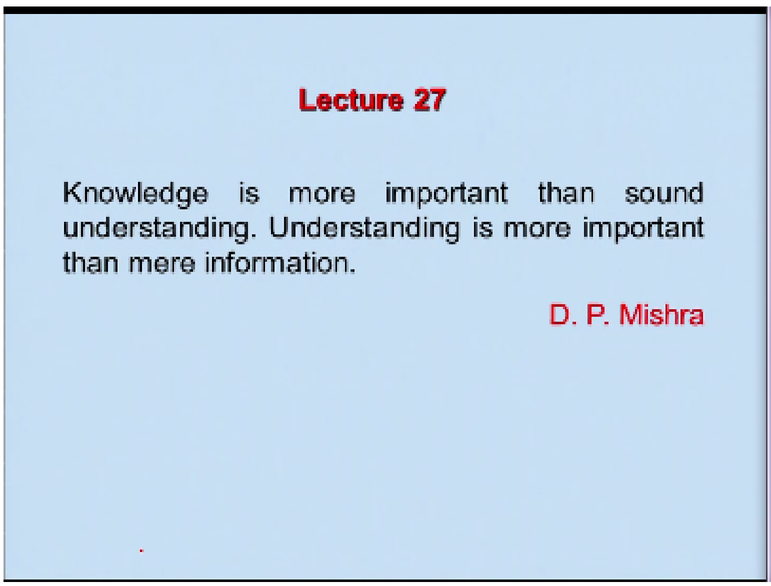

So let us start this lecture with a thought process that knowledge is more important than the sound understanding, understanding is more important than mere information. So if you look at we have discussed about the thermodynamics spanning over the three laws of thermodynamics first law of thermodynamics, second law of thermodynamics, and the third law of thermodynamics also we have discussed in the very beginning the 0^{th} law of thermodynamics laws we have discussed we have used it for analyzing what you call various processes.

And in the last lecture we discuss about the availability or we call it also exergy in some book you may find also exergy that will basically tell you that how much potential you are having or a system is having and I call that exergy basically in the talent of a person if you consider that way. And we have learnt that also how to what you call characterize a system in looking at their performances we have discussed about the first law of thermodynamic efficiency right that is the thermal efficiency and then we discuss also second law efficiency right.

And today what we will do basically we will be looking at how we can apply these first law of thermodynamics for practical problems right, of course we have looked at and then particularly we will be looking at the power generation and if you look at power plays a very important role in modern life, because we are quite dependent on the power electrical power, mechanical power and other things.

And whenever we do that we need to, you know what you call understand what are the power systems right, and all the power systems they work on it thermodynamic cycle because, you know otherwise we cannot get continuously the power right.

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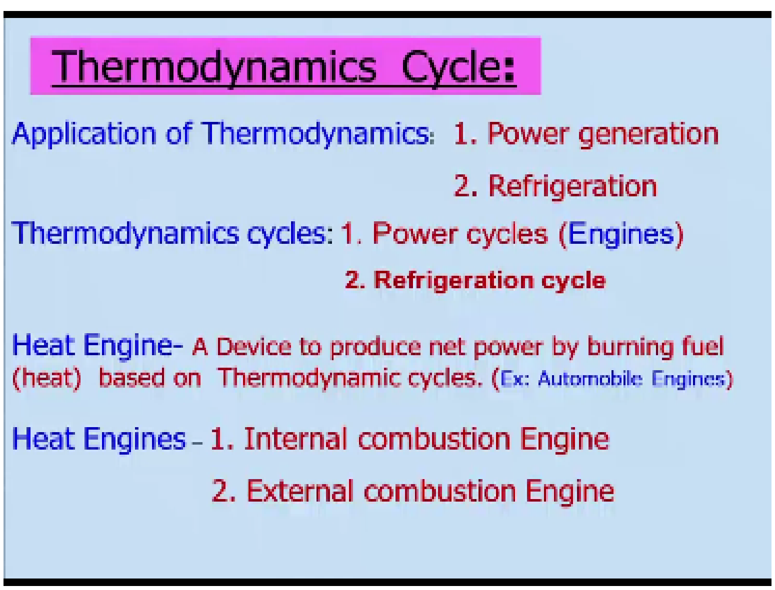

And we will be basically looking at power thermodynamic cycles and if you look at these things this thermodynamic cycle can be broadly divided in two categories one is the power generation, other is the refrigeration right. And these two systems if look at basically based on the thermodynamic cycles. And the thermodynamic cycles if you look at the one is the power cycle, and other is refrigeration cycle and power cycle means basically which will be basis by which the engines are being operated.

And this engines is we have already seen it can be you know like heat engines basically and we know that heat engines observes certain amount of heat from the thermal reservoir or a high temperature source and then it will be doing certain amount of work and then it will be rejecting certain amount of heat into the sink. But the refrigeration cycle or the refrigeration system which operates on a thermodynamic cycle what we call refrigeration cycle and it will be basically doing the other way around it will be observing certain amount of heat from the sink which is at a lower temperature.

And with the help of some work it will be giving what you call heat to the high temperature region right this source. So if you look at these engines basically can be what you call examples, you can think of automobile engines, and then gas turbine engines, rocket engines, and any other things you can think of. As I told that basically these are the heat engine device to produce net power by burning of the fuel's right, it may be fossil fuel, it may be nuclear, you know like kind of fuels.

And basically you will be generating heat and that act as a thing and this will be best operated on the thermodynamic cycles. And this heat and we are basically considering the combustion that is the burning of fuel and this combustion can be kind of divided in two categories, one is the internal combustion engine, other is external combustion engine. If you look at your automobile engine right is it an external combustion engine, or internal combustion engine most of you might be riding your, what you call automobiles right you will be riding your bike which is powered by the heat engine right yes or no.

So what is that is it internal combustion engine or external combustion the meaning is that, what is the meaning of internal combustion engine that is basically the combustion or the burning of the fuel will be integral part of the engine right that is internal part of it. And in external combustion engine you can burn some well and which is you know what you call not integral part of the engine.

And so that we can call it as an external combustion engine right, so you might have seen that nowadays there is a split AC air conditioner am I right. So if you look at condenser is outside okay and earlier days it was all together you can say it is a part of that now it is being separated out of course that is not the same sense what it is so can anybody tell me like automobile engine which we are using left and right and profusely rather is in an internal combustion engine or external combustion engine.

What are the examples of external combustion engine what are the examples of the internal commercial I think as you people are not saying anything let me tell you that this automobile engines that is the piston engines and your gas turbine engines which is being you used in your aircraft and also for power generation are basically internal combustion engine. Whereas if you look at the steam power plant where you will be using the boiler right and that is basically external combustion is there are several other external combustion engine I think I might not have discussed about dulling engine which is a very beautiful engine like that is basically ideally can give you the efficiency of the Carnot engine.

That is a lot of work was going on earlier days even still people are working on that that is basically external combustion, what might be looking at what are the advantages and design with an internal combustion engine, external combustion engine which will be better internal combustion engine or external combustion engine, of course that depends on the application and also kind of things.

So if you look at internal combustion engine will be you know the working fluid will be all the times not being controlled very well so the emissions and other thing will be high whereas the external combustion engine you can control it, you can remotely do that thing and then you know and there are several advantage disadvantage I will not get into it, because internal come let me just to tell you one or two internal combustion engine combustor is a part of the engine.

So that you can carry anywhere we like, but the external combustion is the combustor will be separate and then to carry that will be difficult. So, but however for power generation external combustion engine is good so that you can have, you can minimize the emissions and also maximize the energy utilizations. So that is another big topic which or a debatable topic rather to discuss about that.

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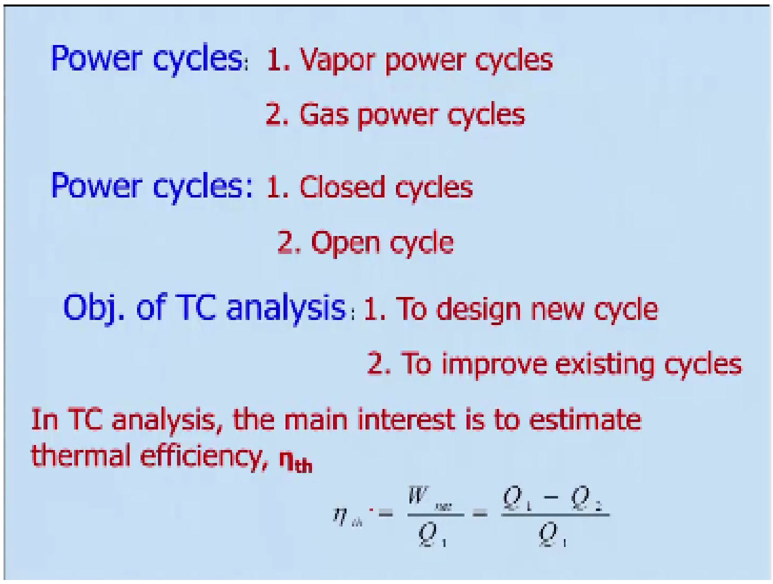

So if you look at the power cycle which generates basically the power it is not the cycle will be generating power it is the system which is operated on the thermodynamic cycle which will produce the power can be, you know therefore, we are labeling these cycles as a power cycle. And power cycle can be broadly divided two categories one is vapor power cycle, as the name indicates that vapor will be produced in the things it might be it is a liquid, and then it will be converted into vapor and again it will be converted into liquid form and then you will get.

And in another cycle or a heat engine in which there is no need to have a change process like gas will be working on like your automobile engine okay. And we take the fuel and then like of course the liquid fuel will be convert the gaseous form, but that is not the case and then you will be basically burning the fuel and then air mixed with air and then it will be working that will be discussing about the gas power cycle in detail.

And now of course we will be discussing about vapor power cycle today. And when you talk about this power cycle it can be broadly categorized into two again based on whether it is close cycle or open cycle. As the name indicates the open cycle means you will be taking some amount of what you call air from the atmosphere generally we take, because it is cheaper one and easily available and then you burned it and also put the exhaust to the what you call into the atmosphere again like most of the automobile engines are basically open cycle engines right.

But the closed cycle where the fluid like will be recirculated it would not be getting out of the engines it will be remaining as it is like you are refrigerant, if you look at of course that is not a engine, but it is a refrigerator if you look at we use the refrigerant right it will be go on recirculating right. So that is basically that cycle you can call as a closed cycle where the fluid would not be getting into out of the system it will be remaining recirculated right.

So and the example of the closed system is basically most of the vapor power cycles are pros cycles right, and open cycle you are basically you can think of gas power cycle but not necessarily always true okay that depends upon applications. So we need to discuss those things and our objective is basically to analyze the thermodynamic cycle in twofold one is to design a new cycle right.

Suppose I am not happy with the cycle and then I want to improve that one or another one is to improve the existing cycles, because as we had seen in the last few lectures rather we are interested to find out second law of efficiency to identify irreversibilities. So that we will pinpointed those thing and try to minimize their reversibility so that we can basically improve the efficiency of a system or an engine, or a refrigerator or any other things.

So that will be helpful and also we will have some understanding so that we will get. So in as I told that main interest in this thermodynamic cycle is to determine the thermal efficiency, because that will tell you how good the cycle is are also how good what you call the engine is or the refrigeration system is. And of course we will always also need to also look at the other performance parameters like a second law of efficiency we had seen in the last lecture right, how to determine that.

So that we will know to what extent we can achieve the performance, otherwise you may be thinking I want to achieve this, but it is not like possible. So you should know the , so the thermal efficiency if you look at is basically we know that the net work output divided by Q in Q_1, Q_1 is basically the amount of heat observed by the heat engine from the source that is the high temperature thermal reservoir.

And of course Q_2 is the amount of heat which is rejected into the sink right. So therefore this is the things which will be using in this for analyzing this thermodynamic cycle, and we will be doing that.

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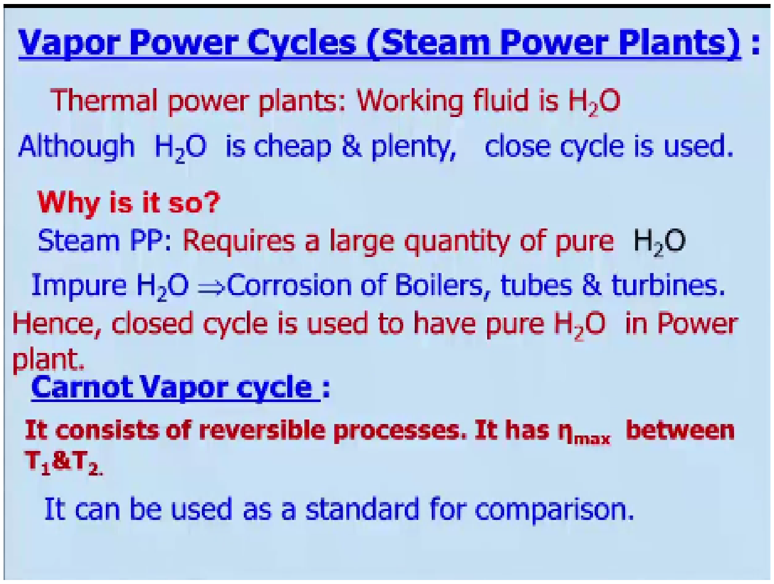

So now we will be discussing vapor power cycles and if you look at vapor power cycles the steam power plant is being operated based on that of course we missing think that what are the other fluids one can think of using you know like steam power plants are being used profusely particularly not only in our country in other places we depend on the coal for generating power and then steam power plant is being used you know like if look at something around 70% of the total may be little more 72 a 75.

We can say earlier days it was 90% of the pub power being generated by the vertical burning of coal so therefore there is a lot of scope for that but what I was asking is little different as it is there any other fluid which can be used as a vapor power cycles any idea of course now one has to look at the properties what are those thing suppose except water can we use some other fluid what are the other routes comes into picture any idea no idea, okay let me just tell you know like mercury can be used and sodium potassium and combination of sodium potassium and other things can be used.

Of course we will not be discussing about that will be basically concentrating on the vapor power cycle that is you know which is being used basically the steam as a working fluid and most of the as I told the thermal power plant we use the working fluid and that is water, water is a benign fluid you know see if you look at when I look at water I feel it is a very great thing that our earth is having water otherwise we could have no way but we are spoiling it in the you know in the process of development.

So if you look at the working fluid is the water and although the water is you know of course available plenty you know like it is available evidently is it so it is I mean if you look at that way if I look at other things and it is quite cheap of course it is getting costlier day by day which is artificial in nature but then we use it as a closed cycle of course if I use a mercury you know as a for generating power then I cannot afford to make it an open cycle why because it is toxic and then it is having lot of problems you know like and it will cause a lot of bees is also so but whereas but we use basically closed cycle for steam power plant why it is.

So I mean this is just a what you call very different kind of things you know right why it is so can any can anybody tell mean any idea because you know we are using clothes and water Emily we can just take some water and then you know take some produce steam and then after that we just dumped into somewhere you know like your automobile engines right we get some power and then leave as it is but we do not do that because of fact that you know that steam power only cause large quantity of pure water see if you look at the water and you might be knowing.

Particularly the water in IIT Kanpur is having lot of what to call solid contents other minerals right it is testing if you look at it boil it you will see the scaling is happening on your utensils did you do any time right in your room or something for this thing you will find so that scaling you know is will be producing a what you call corroding the blades turbine blades and it will be corroding the boilers and other things so therefore it is you know events you know very difficult to maintain those you know.

Vertical components and therefore we need to use the water which is will be not containing you know any solid particles and other things and you know like minerals which will dissolve in the water so therefore that is the reason why closed cycle is used you know in the thermal power plant otherwise if I will use the purify you know like kind of things then it will very costly affair if I just leave it that water which will be used for in this power plant will be quite pure in nature so therefore you have to you know cost will be very high.

So let us look at basically the continent vapor cycle because the Carnot is the reference cycle one can have that and if you recall it consists of reversible processes basically four processes you know like and two isothermal process and 2 isentropic passes right and it has a maximum efficiency when it is operated between you know high temperature that is T1 and low temperature T2 so we can what you call it can be used as a standard for comparison that is why always you know look at that is whether you could achieve that or not so let us say look at a typical.

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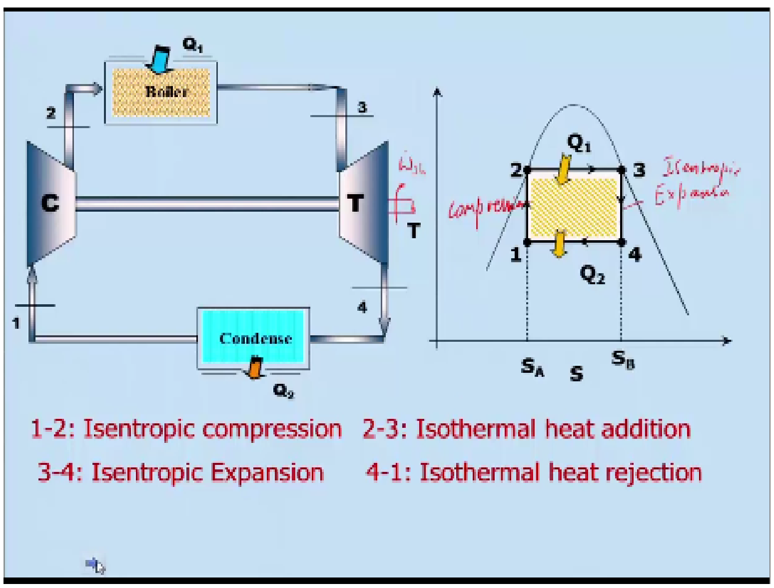

Protocol vapor power systems and which is will be having what you call a boiler like where you will be using you know boiling the water and producing the steam and giving certain amount of heat that is Q1 and which is basically burning the fuel and then that heat will be transferred to the boiler right it is external combustion you can if you look at fluid is going in the tubes and then it will be you know kind of things and then this steam you know will be expanded in a turbine right in this turbine and then of course it has to and produce some amount of war you know like if you look at this is the work which is shaft work which is produced.

And of course you can connect this turbine to a genset and produce electricity okay and then this condenser in that when this fluid will go through the condenser it will be rejecting the heat let us say Q2 amount of it and then again what will it do you will have to compress it says that it can go to the higher pressure you know right and then it will come to that so if you look at the processes that is basically as I told 2 to 3 certain amount of heat is being you know taken by the fluid from the boiler right.

And then it is expanded of course ideally that we are considering for the time being that is three to four and where entropy is remaining constant isentropically and then heat is rejected what you call 4 to 1 and then 1 to 4 is your compression process so if you look at so this is your expansion if you look at expansion process and this is isentropic as I told that entropy is remaining constant this process and this is your compression again isentropic and this is heat addition right 2 to 3 and heat rejection is 4 to 1 and temperature is remaining constant is isothermal heat rejection and heat addition also isothermal in the Carnot cycle.

Now if you look at what are the problems will face if we will use the Carnot cycle of course there would not be any problem for the heat addition because if the phase change processes take place then if you keep the pressure constant the temperature automatically will be constant there is no problem similarly heat rejection there would not be much problem of keeping the temperature in a practical sense keeping the temperature constant as the two phase flow is occurring right.

But however if you look at what will be quality here at the four of the steam if I consider this team at the for what will be quality is it quality will be one or it will be 0 or it will be in between it will be in between because of what you come two phase flow and for expanding the steam right in a two phase flow is very difficult and also it may corrode the blades right. Because of two phase flow is difficult to handle similarly there is a problem with the vertical compression also.

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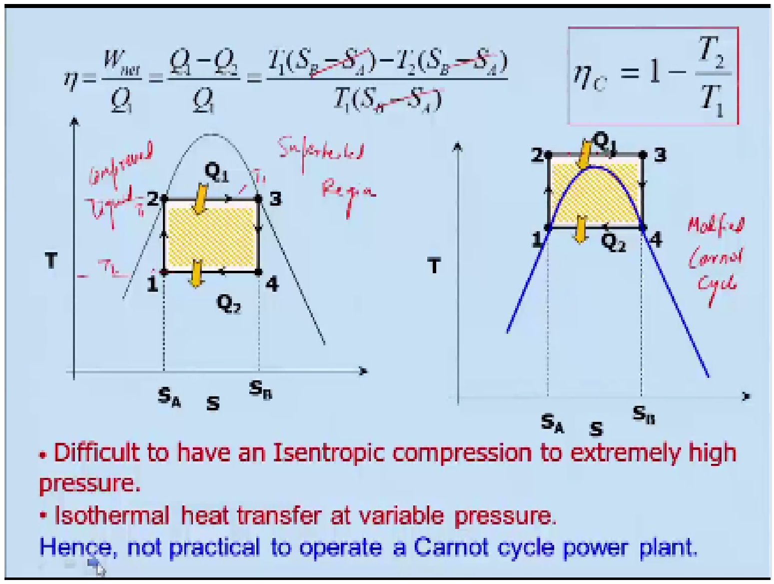

And so if you look at to overcome that problems right one can think of you know solving that problem show we can solve that problems, what we can do we can think of you know this compression if we can manage to have in this superheated region this is your superheated region right is not it and then this portion is your compressed liquid so if you do that then you are handling the single fake weed and then the problem may be sol right so if you look at I mean that we can think of that means you know like we can add the heat here 2 to 3 and then expand from this superheated region till the saturated vapor region 3 to 4.

One can think of and of course 4 to 1 there is no problem because one can do this thing heat rejections right and then of course it is a liquid here at the State one and then you can compress in a liquid that is releasing will fade to it so that problem can be solved, but if you look at here then it is very difficult where to control like so for example in the condenser when it is heated it being rejected between the station 4 and 1 to what extend it will be you know heat will be rejected such that you know.

It can go I am like you know I can be very happily reject to the saturated liquid condition but here it can be here it can be anywhere in between so then if you do that then you know that you cannot have a control over the even compression to till what extent practically if you look at but in the modified version of this Carnot vapor cycle you will also find in this region between 2 to 3 right there will be a problem because pressure will it the pressure will be remaining constant between state 2 to 3.

In the modified Carnot cycle this is your modified Carnot cycle will it be no because each point will be one pressure you know like if you look at it goes this is one point each one of them will be different pressure that means pressure is changing right you are trying to keep the temperature constant it is very difficult to manage in a system so therefore this would not also solve the problem okay we may think hypothetically look we can solve this problem but however we are getting a lot of problem between the heat addition earlier heat addition was a very simple process in the Carnot cycle that is 2 to 3 is that if I keep this pressure constant temperature automatically remaining constant isothermal.

Here I cannot keep these 2 to 3 you know constant pressure and then if I will vary this pressure than temperature also will change so it is very difficult to keep the isothermal heat addition between state 2 to 3 this is the problem so and of course that is the problem we will be addressing like how to do a practical vapor power cycles so if you look at the efficiency one can determine thermal efficiency w made by Q_1 and we know that there is double unit as we are Q_1 - Q_2 divided / Q_1.

And this Q_1 we have seen that is basically what you calculate you one is T_1 this is your temperature T_1 right this is your temperature T_1 and this is your temperature T_2 so T_1 is B – S_A right - and this Q2 is nothing butt to S_B - S_I and divided by T_1 S_B - SF 0 if you cancel this out you will get the Carnot efficiency is equal to 1-T_2/T_1 this we have seen I am like you know that basically it is dependent on the two temperature one is vertical sync temperature T_2 and the source temperature.

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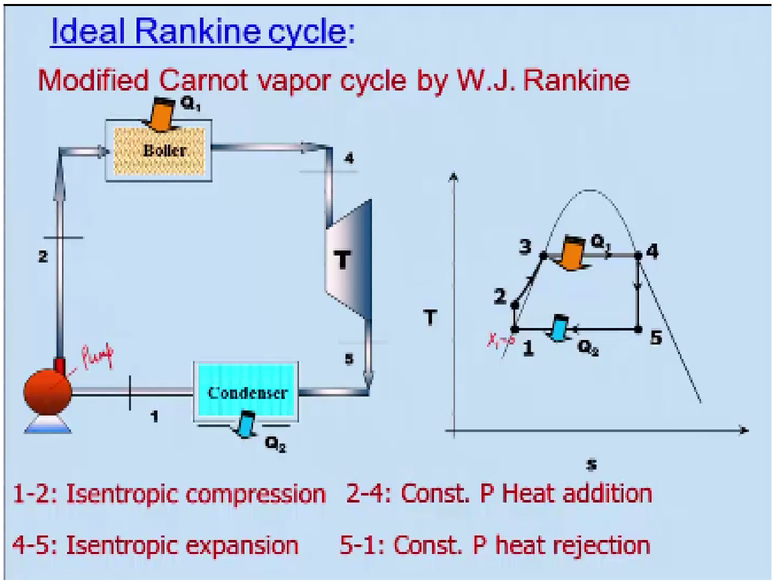

So what happened like whether we can solve this problem what we will do we will instead of this compressor what we are doing we are basically replacing with a pump this is the pump, you know what is the difference between compressor and pump, pump is generally will be handling the liquid you know like we use water pump and other things and the cycle is similar in nature right I am like there is a boiler component is a carbon.

There is a condenser only instead of compressor we are replacing with the pump that indicates that means in the condenser the liquid will come to the saturated from the vapor you know it will be coming to the saturated liquid point that means all the liquid there is no vapor as such. So and these cycle is basically modified by the W.J. Rankine and that is why you call this modified cycle as a basically Rankine cycle.

So if you look at the process what we are doing we are retaining the same heated is and 3 to 4 that is a constant you know what you call pressure and also the isothermal heat addition right, temperature will be remaining constant okay. And it is being expanded in the 4 to 5 that is isentropic expansion we are considering this is the ideal one okay, and actually it will be different.

And then heat rejected from 5 to 1 till it is what you call saturated liquid only liquid that means X in this case will be X_1 will be 0 quality of the steam will be 0 right, and therefore it is only liquid and then this one to two is nothing but your pump work and then of course heat addition it will be 2 to 3 right this will be sensible heating and then 3 to 4 will be constant pressure heat addition.

So this cycle is basically known as the Rankine cycle as I told and it was devised by him and this is basically we call it ideal Rankine cycle because the processes are isentropic in real situation it would not be both for the expansion between station 4 to 5 in a turbine and from station 1 to 2 in the pump the isentropic which is not possible in wheels therefore we are calling it as an ideal Rankine cycle.

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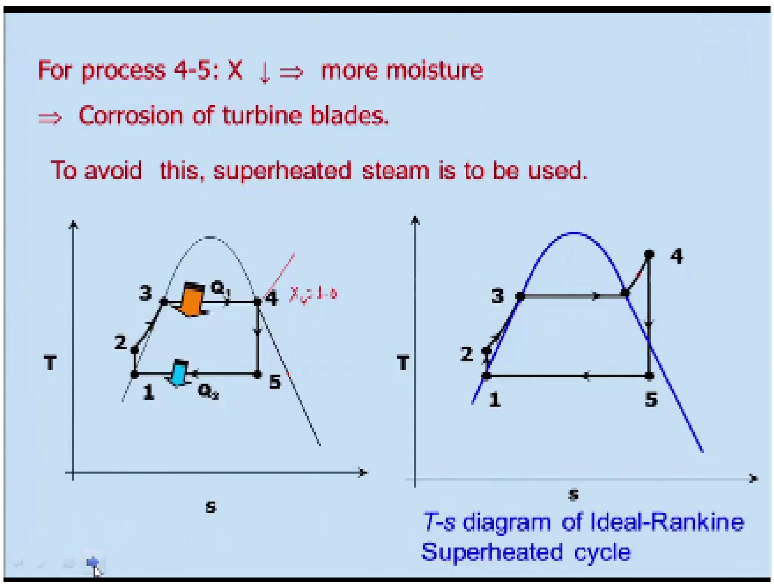

And let us look at the what are the problems will be facing here if you consider that 4 to 5 that here in this case what will be X, X_4 will be 1 but in this case X_4 means X is the quality of the steam and X_5 will be lower than that right that means it is if you look at here this is your saturated state this will be region where X will be 1 but here it is less than 1 that means if it is X is less than 1 right then it is moisture more moisture will be there.

If more moistures are there that means it will be corroding the turbine plates generally the you know quality of 0.9 or you know 10% moisture in the steam is allowed is a tolerable basically for a turbine but more than that you know like steam more than that what you call the liquid or the this thing that quality less than 0.9 is not advisable generally it is not been used. So to avoid this problem of having higher moisture content then we can use the superheated steam right.

Then how will go about that means instead of heating here what I will do I can go with this again heat it here further and then expand it so that is we will be doing so what we are doing instead of here saturated conditions and what we are doing we are super heating it to the higher temperature and then expanding so that if you find this may be lower you know moisture content right, so that you know we can overcome this problem by superheating the steam for them therefore what we get in modern what to color boilers is superheated boiler right, that means it can produce the superheated steam.

And this is of course known as superheated Rankine cycle you can say and this is also an ideal process okay, because the process in the turbine and the pump we have in our isentropic that we have considered.

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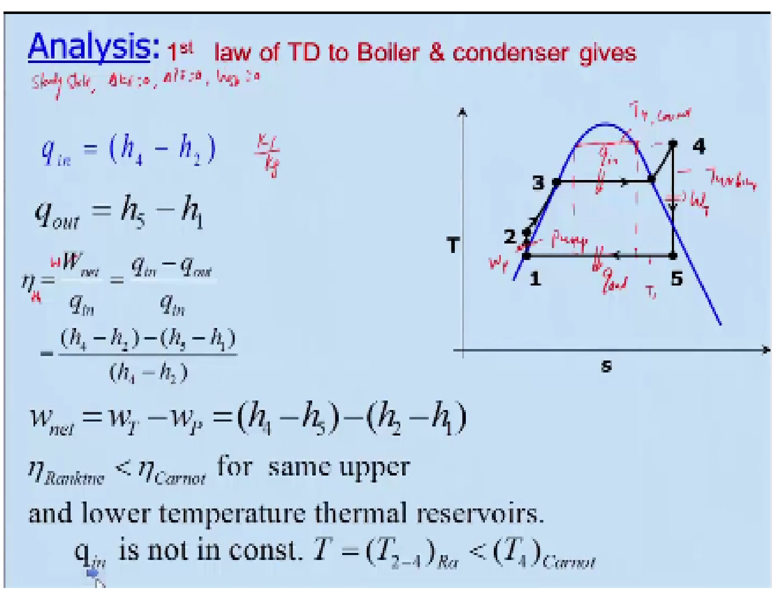

So we need to analyze this you know like which is things we will be doing we will be learning how to analyze each components and what we will be doing will be applying basically first law of thermodynamics to the boiler and condenser you know kind of things and if you look at which is your boiler, boiler in this part that is 2 to 4 is your boiler yes or no, this is the heat added so if you look at this is your q_{in} right.

So the q_{in} in will be basically h_4-h_2 is it right, so how we have arrived at this right we can consider as a boiler as a particle control volume system and then what are the assumption we are making here the steady state right we are making the assumption steady state and change in kinetic energy and potential energy is 0 right, steady state change in kinetic energy is 0 and change in potential energy is 0.

And then what else for this there is no shaft work is 0 right, so then we will land in getting q_{in} right is equal to h_4-h_2. So similarly q_{out} what it would be it will be h_5-h_1 right in the similar fashion we can derive from the first law of thermodynamics for a control volume is it clear to you yes or no, right. So what we can get we can get the thermal efficiency basically wη/q_{in} keep in mind that this could have been small one right that is the work done per unit mass.

See if you look at this unit what you are saying this will be kJ/kg okay, will it be kJ/kg right yes or no okay, right and the thermal efficient this will be q_{in}-q_i/q_{in} and what is q_{in}, q_{in} we have already seen h_4-h_2 and q_{out} is h_5-h_1/h_4-h_2 that is your q_{in} and the net work done will be basically the work done here is basically w_T and this work which is going out you are supplying it basically this is W_P pump this is your pump work and this is your turbine right.

So h_4-h_5 that is your the change in enthalpy - (h_2-h_1) the change in enthalpy in the pump right, that is the net work which the power plant will be producing. And if you look at the Rankine cycle efficiency is less than the Carnot cycle efficiency for the same source and the sink temperature right. Why it is so, because if you look at this temperature you know T_4 and T_2 there is a lot of changes in the temperature it is not remaining constant, right.

Whereas the T_4 will be remaining constant in case of your Carnot engine right are you getting, so therefore if I draw that you know it will be something here this reason what it would be if i look at the Carnot cycle Carnot cycle will be what let me just draw it maybe it will be helpful for you people to visualize so that will be my Carnot cycle you know this is my Carnot cycle so right it will be from here to there and then do that.

So therefore the temperature you know temperature here this $T_4$for Carnot and this will be T what you call you can consider as a T_1 right, temperature T_1this for the Carnot. So therefore the efficiency of the Rankine cycle will be lower than the Carnot cycle.

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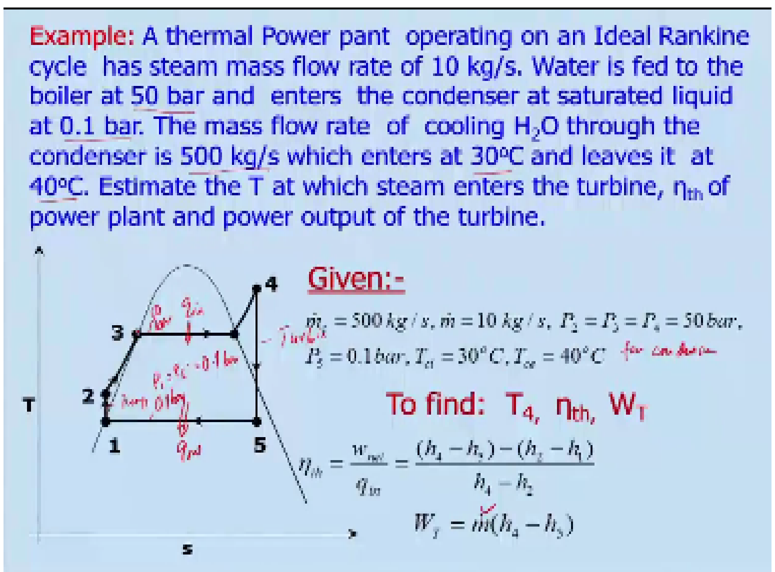

So we will take an example just to you know find out how we can work on that this example is about the thermal power plant which is operated on an ideal Rankine cycle and with the steam mass flow rate of 10kg/s right, and water is fed to the boiler at 50 bar it is a quite a bit pressure you know and enters the condenser at saturated liquid at point you know one bar right, one bar you know one atmosphere pressure.

So you are operating at basically you know like a 1/10th of that and the mass flow rate of cooling water through the condenser is 500kg/s which enters with 30˚ and leaves at 40˚C that means you know 10˚C difference is there and we will have to estimate the temperature at which team enters the turbine thermal efficiency power plant and of course the power output of the turbine. So if you look at like these are the cycle which will be being used for this analysis ideal case we are considering 1 to 2 is your what you call the pump work right, this is your pump and 4 to 5 pure turbine expansion and this is your q_{in} and this is your q_{out}.

So 2 to 4 is your boiler and 5 to 1 is your condenser, so what are the things are given if you look at the cooling you know for the condenser is given 500 cooling flow rate is 500kg /s and mass flow rate of the steam or the water in the closed cycle is basically10 kg/s and we know that P_2 is equal to the P_3 is equal to the P_4 because this is the constant pressure line and this is at 50 bar right and this is at 0.1bar pressure you can say that P_1=P_5=0.1 bar.

And of course the coolant inlet temperature is 30˚C and coolant exit temperature is 40˚C for condenser these two are for condenser. So we will have to find out T_4 right and we will have to find out also the thermal efficiency and how much work is being produced by the turbine right, that will offend you we want to find out efficiency also right, we will have to find out efficiency, efficiency is basically $w\eta/q_{in}$ and that is equal to h_4-h_5 this is your turbine work –(h_2-h_1) that is your pump work divided by the heat input to the boiler that is h_4-h_2 right, this is h_4 and this is your h_2.

And what is the turbine work turbine work is basically mass flow rate is given what is this $\dot{m}$, $\dot{m}$ is basically 10 kg/s it is given and into h_4-h_5 right we need to find out h_4 and h_5 how we will go about it right if I want to find out turbine work this is given this h_4 is not known and so also h5 so how I will go about it any idea, how I will evaluate this h_4 you know like we have already given this right, we have already given this 50 bar right and the pressure is given to you and this what you call we have given also this pressure that is 0.1 bar. I can get this point right this point I can get and again from the steam table right, so I will find out basically this one and then let us look at okay.

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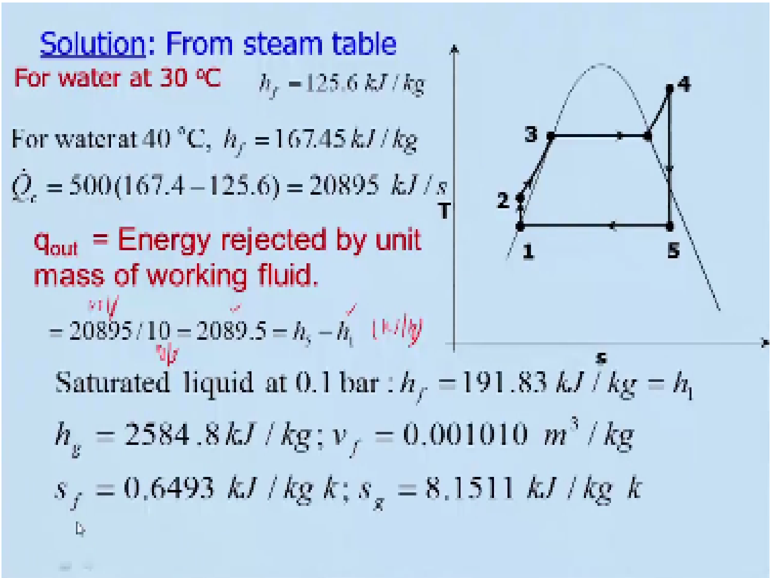

And we, is it we can find out these two points I can find out because basically we have given this temperature 30^0 Celsius and 40^0 Celsius and from the steam table at water $30^{0\ C}$elsius we can find out that h_f is 125 kilo joule per kg and for water at 40^0 Celsius, we can get h_f 160 7.45 kilo joule per kg from the steam table saturated steam table right, and we have given that Q .C that is the coolant you know use for the condenser is 500 kg per second right and into this one that is HF at 40^0 Celsius and h_f at 30^0 Celsius I will get this amount of heat you know that is kilo Joule per second kind of things I am getting right.

This is kilo joule per kg and this is kg per second so therefore I am getting this much of power or the heat will be extracted in the condenser. So the energy rejected by the mass of working fluid what it would be then q out what it would be this will be Q_c q .c divided by the mass flow rate of the steam which is 10 kg per second right so that is nothing but you 20,000895 divided by mass flow rate esteem that will give me 20 89.5 right per kilo this will be what unit this will be unit will be kilo joule per kg this unit will be kilo joule per kg okay yes or no because this is your kilo joule per second and this is kg per second 10 this unit will be kilo joule per second and this is kg per second.

So the second, second will cancel it out you will get kilo joule per kg here and that is equal to that is equal to h 5 - h1 so if you look at that we know this you know we can get this properties at h1 very easily from the saturated steam table and h5 we know from this. So and as I told just now the saturated liquid at 0.1 bar and from the steam table will give h_f is equal to 19 1.83 kilo joule per kg and that is nothing but your h1.

So and then if I know this one h1 and if I know this then I can get very easily the h5 right and we will do that and of course we need to know these properties like S_G V_F S_F S_G all those things we should get the data.

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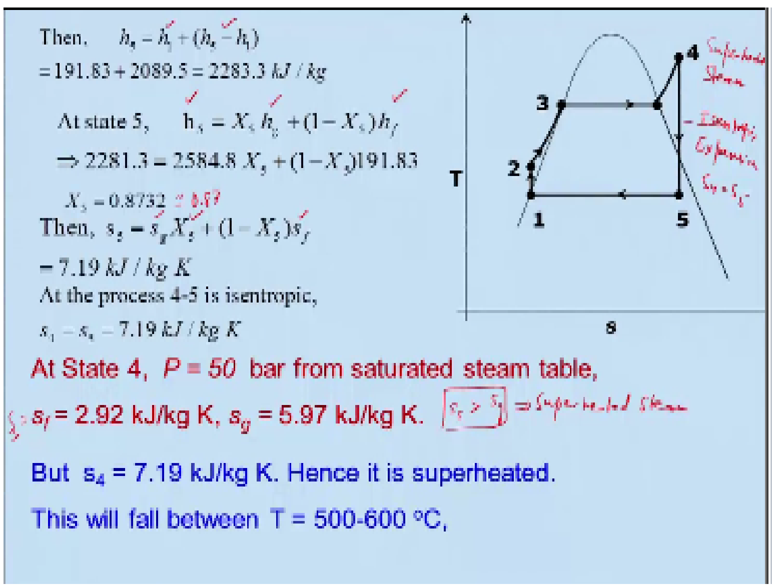

And so as I told earlier that we are basically we know this h_5 - H 1that is equal to this is known that is equal to 20 89.5 kilo joule per kg andh1 already we have we got from the steam table h1 right. So this is known, so we can find out h_5 right that is h $_5$ is equal to two thousand two hundred eighty three point three kilo joule per kg, so now I know what is h5 here at this point I know h_5 okay and whether we can you know it is possible to calculate that we will see so of h5 by knowing this h_5 I can calculate what will be x_5 x is your quality is not it why I need to find out quality here is it required is it required or not because I do not know this point okay right.

I need to find out this in general problem what it could have given that if given the pressure that is for this thing and which is already given and for the superheated steam you have not given the temperature right, so if it is given temperature then this is your super heated steam this point is your super heated steam right. So therefore you need to find out that and if you look at like h_5 is known and h_g is already from the steam table and H_F is known from the steam table and you can substitute these values and get X 5as 0.8732 right and you can approximate like as a is equal to basically 0.87 you can do approximately.

And then I will have to find out entropy right and I can find out S_5 entropy is 71.19 kilo joule per kg Kelvin because I know this SF and I know this SG I know x_5 and then we will substitute those values and get that and as I told that we are very much interested to find out this point because the entropy you know will be remaining same that is $S_5 = S_4$ because this is isentropic expansion so therefore $S_4 = S_5$ why so we will be using that condition.

So at state for we know this is 50 bar and from saturated steam table we can get S_F S_F is here corresponding to a vertical point 3 that is equal to S_3 you can say and SG is 5.97 kilo joule per kg right and if you look at this is S_4 and S_5 right S_4 is equal to 7.19 kilo joule per kg Kelvin okay are you getting, so therefore we now vary CEO that this is a superheated steam see in the problem it is not given it will be separated am I right yes or no in the problem is it given separated it is not given as a superheated steam right.

But however now we will find that is 5 $S_5 > S_G$ therefore it is superheated steam, so this will fall between the then you will have to find out temperature what allowed to find out temperature, temperature is 500 to 600^0 Celsius you will find out this entropy is coming that is what you call 7.19 kilo joule per kg and allowed to do interpolation and then get that values right.

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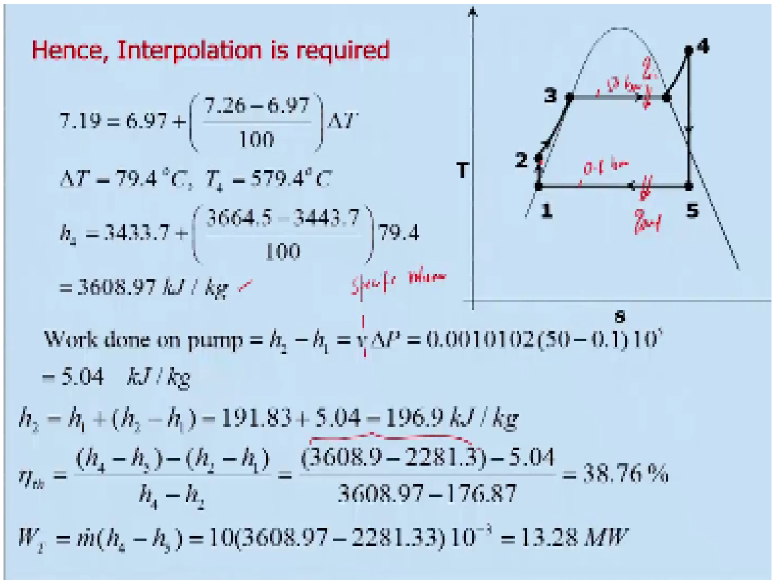

By interpolation if you look at I will get this that is your 500 to 600^0 Celsius for 500 you know this will be that the entropy and then you have to find out this entropy and this one and you will find out that δ T is basically 79.4^0 Celsius and then the t4 will be 579.4^0 Celsius by knowing this one then one can calculate what will be the h4 and the similar manner right because we you know that the enthalpy at two different temperature and that is 500 and 600^0 Celsius therefore you can get h4is 360 8.97 kilo joule per kg.

And of course the work done in the pump is S_2 - h_1 and which is nothing but V x δ P this is your specific volume, volume at what point at station 1 right this is basically you can say 1 x δ P and how much it will be this is what is will be δ P δ V will be this is 0 point 1 this is 0.1 bar and this is your 50 bar. So therefore that will give me what you call work done on the pump or work input into the pump.

So if you look at the specific volume is very, very low and this V 1corresponding to the saturated liquid conditions and which you can get thisvf1 from steam table corresponding to the point one bar, so you can note one thing that this is a very, very small values 5.04 kilo joule per kg right and of course you can find out what will be the h2because we need to find out S_2 and because we will have to find out thermal efficiency and that is your Q in right and I will have to find out Q out right and that is nothing but you will need to work you can think of doing that.

And that is H_4 - h_5 I mean change in this enthalpy between state of course in this case we can find out the network is change in enthalpy between the turbine that h_4 -h_5 and the pump or S_2 -h_1 so you will get this one thish4 we have already obtained right this is your H poor this is H 4 and then h5already we got from the balance in the condenser you know like and these if you look at this work this difference is quite a huge right it will be something you can think of around let us say 1400 you know kilo joule per kg and this is a very, very small 51 can neglect you know.

So this is a very tiny amount of work which is given to the pump that means you know the turbine is producing large amount of work and if you look at if you do a scaling over here you know generally this portion is being shown as a little bigger otherwise if I put a proper scale you know then it will be very, very tiny you cannot see even a diagram okay therefore we magnified it and then put it one to two.

So that network will be where by the turbine will be m.x h_4 -h_5 and that happens to be you know 13.2 8 mega what and of course this is known like a 10 kg per second so if you look at the back work ratio which we had defined that mean how much the power being consumed by the pump as compared to the power produced by the turbine that is VR = WP /WT and if you put that thing you know which is very, very small we will see whenever we look at some other power plant will see it is a very sizable amount that is the beauty of the steam power plant that work input to the pump is negligibly small.

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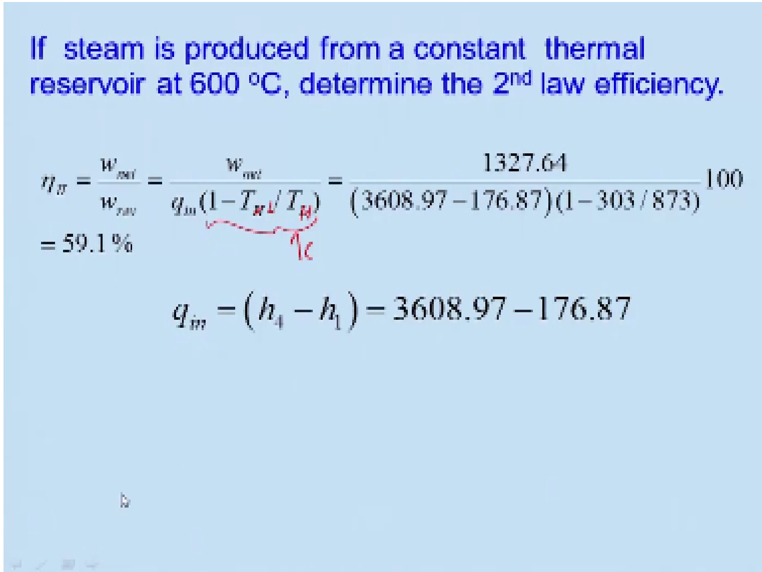

So if the steam is produced from a constant thermal reservoir at 600^0 Celsius right and if you look at we need to find out the second law efficiency and the second law efficiency is basically the net work done / the reversible work we have already seen this Q in x 1 – T_h /T_L actually it should be other around will be T_L / T_h, so that is basically Q in x 1 - T_L /T_h and this is your nothing but you Carnot efficiency you look at that way and then you when you substitute that you will get 59.1% is the second law efficient what was the first law revision see can you just look at your note and tell me it will be something around 38% right 38.76% is a fast way of efficiency.

And second law efficiency is basically 59.1% that means there is a lot of scope to improve you know the efficiency of this power plant of course we are considering ideal but still then there is a scope of from 38.7 62 the 59.1, so of course if you look at this Q in one can find out h4 - h1 and then you know that already we have done and then you can find out the efficiency, so we will stopover here and in the next lecture we will be discussing about other aspect of the Rankine cycle.

Acknowledgement
Ministry of Human Resource & Development

Prof. Satyaki Roy
Co-ordinator, NPTEL IIT Kanpur

NPTEL Team
Sanjay Pal

Ashish Singh
Badal Pradhan
Tapobrata Das
Ram Chandra
Dilip Tripathi
Manoj Shrivastava
Padam Shukla
Sanjay Mishra
Shubham Rawat
Shikha Gupta
K. K. Mishra
Aradhana Singh
Sweta
Ashutosh Gairola
Dilip Katiyar
Sharwan
Hari Ram
Bhadra Rao
Puneet Kumar Bajpai
Lalty Dutta
Ajay Kanaujia
Shivendra Kumar Tiwari

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