Steam Power Engineering
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Lecture -04
Carnot Cycle Examples

Welcome to the class. In last class we were started for the illustration or calculation for the steam power cycle where we started with the idea of Carnot cycle and Carnot cycle was comprised of four processes as what we know.

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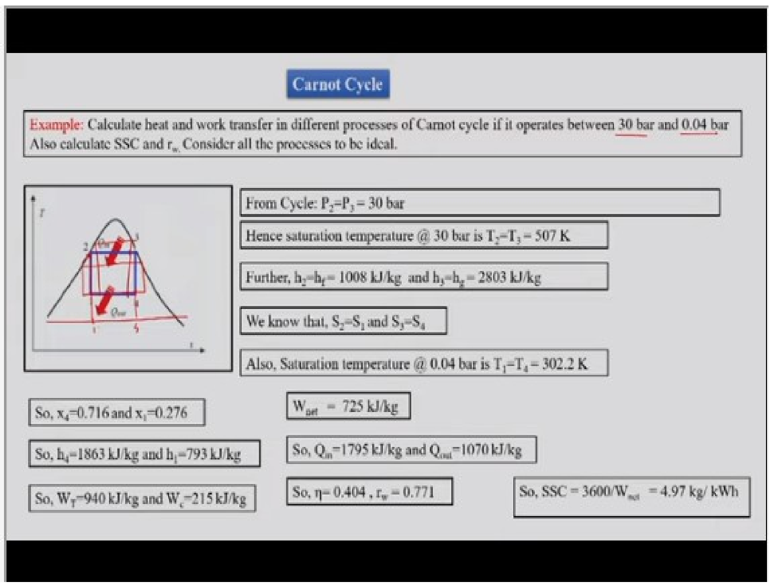

So, we were given an example that there are certain temperature and pressures or there are there is some operating pressure for the boiler, there is some operating pressure for the condenser and for that we had to operate a Carnot cycle between those two pressures and we have to find out certain performance parameters of the steam power plant. For all sake we were given that the pressure of the boiler is 0.30 bar and pressure of the condenser is 0.04 bar so these are the given things for us.

So, based upon that we did calculate all the corner properties like entropy, enthalpy using that we found out turbine work, compressor work we found out efficiency, network and then work ratio and specific steam consumption. We just have to remember that all the things were based upon

30 bar and 0.04 bar. So, if we would have been given a pressure which is more than 30 bar then we have to take the Carnot cycle like this. If we were given with the pressure lower than 30 bar then we have to operate Carnot cycle like this.

But if we would have been given a condenser pressure lower than 0.04 bar for the present case then we have to take as per the pressure given. If this is the pressure then our 1 and 4 points would come down so there are different formats for the Carnot cycle which would operate inside the dome. Carnot cycle as the constraint of its processes says it cannot come out of the dome so knowing these facts we will analyze the Carnot cycle.

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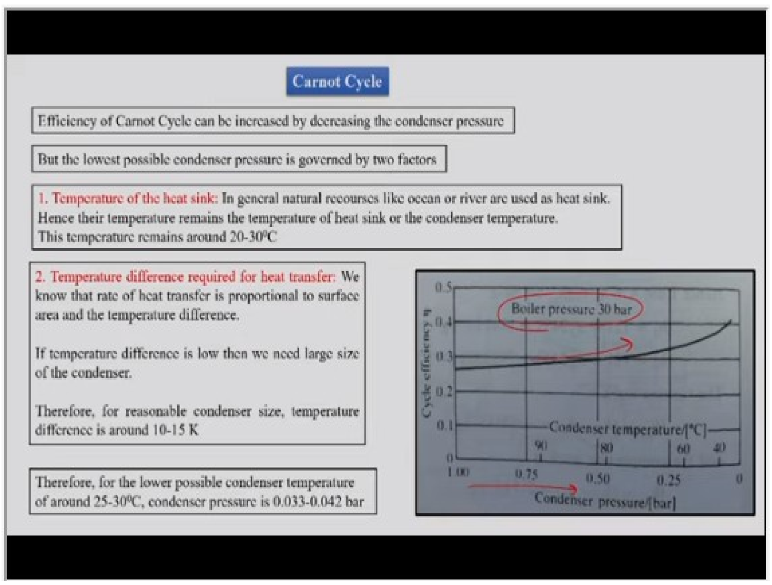

Here efficiency of Carnot cycle can be increased by decreasing the condenser pressure we know that efficiency of Carnot cycle is $1-\frac{T_{low}}{T_{high}}$. Here T_{low}temperature is the condenser temperature and at this moment as known to us is this condenser pressure is the pressure which is a saturation pressure. So, this process is phase change process so we have same temperature.

So, if we can decrease this temperature means we are decreasing the condenser temperature then we can increase the efficiency of Carnot cycle. But the lowest possible condenser pressure has a limit it is dependent upon two factors; first factor is temperature of heat sink so here we mean that who is the element, who is the sink which is take going to take the heat from the steam which is getting condensed.

So, if that temperature is in our control then we can control the condenser saturation temperature and hence we can control the pressure in the condenser. But there is a problem that natural resources are generally used to condensed the steam. So, there will be natural resources based like water from the river or water from the ocean would be fetched into the condenser and then we will have condensation of the steam and then that heat from the steam would go to the water and then water would get heated in this heat exchange process.

So, since we take water from the natural resources temperature of natural resource would be around $20^{\circ}-30^{\circ}C$. So, our pressure which is the condenser pressure has got a constraint that it has to be around $20^{\circ}-30^{\circ}C$ temperatures saturation pressure or the condenser pressure would be the pressure or the saturation pressure corresponding to $20^{\circ}-30^{\circ}C$.

Second is the temperature difference required for heat transfer we can go very close to the temperature of the surrounding or ambience or natural resource in the condenser. But in that case if we make temperature difference low and low we would need very large area of the condenser. So, as what we had seen earlier that there are irreversibility's associated here irreversibility's would practically lead to the point that we need larger area for heat transfer.

We had discussed that the direction of the flow of water in the condenser is not going to alter their irreversibility's. But if we try to have the temperature difference between the natural resources best water and a steam to be minimum then we will have very large area to supplied for the process of condensation. Therefore, in general process of condensation would be having temperature difference around $10^{\circ}-15^{\circ}C$ therefore lowest possible condenser temperature is $25^{\circ}-30^{\circ}C$ in that range.

Hence the condenser pressure becomes the corresponding saturation pressure which we can obtain from the steam table. So we can see here that if we reduce the condenser pressure so condenser pressure actually reduces in this direction we can see the efficiency increases as we decreased the condenser pressure for the given boiler pressure in the example. We have to remember that this plot is drawn for the example okay.

So, we had given that there is 30 bar pressure of the boiler and there was 0.04 bar of the condenser so that 0.04 bar is decreased to different pressures. Thus this is the one way in which we can improve the efficiency of Carnot cycle.

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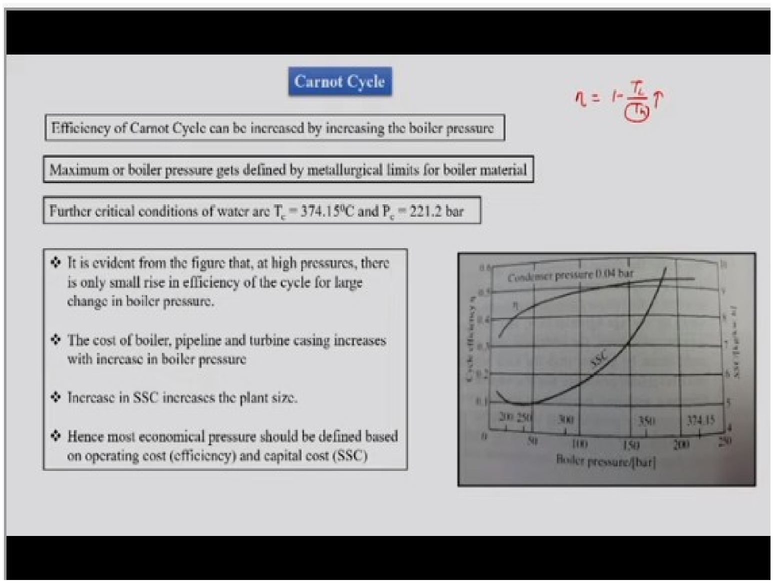

We can as well increase the efficiency of Carnot cycle by increasing the boiler pressure. We again can go back and see the formula for Carnot cycle efficiency it is basically 1 - efficiency is equal to $\eta = 1 - \frac{T_{low}}{T_{high}}$. And here we say that if we increase the boiler pressure; we increase the boiler pressure means boiler is the place where we are supplying the heat.

So we are increasing the, the temperature in which the heat is getting added so we are basically increasing the mean temperature of heat addition. And then that's why we will have increase in efficiency if we increase the boiler pressure and hence the saturation temperature and hence the mean temperature of heat addition. But there is a limit and that limit says that the materials which are going to be exposed to that high temperature should not melt and this is called as metallurgical limit and we should not go beyond that metallurgical limit.

But critical conditions for water are 374.15 degree Celsius and 221.2 bar and these are too high as compared to the metallurgical limit. As compared to the melting point of the metals which are used for making the boiler metal or making the boiler component or the turbine components. So, there is no much problem about the material limits in case of Carnot cycle but yes we cannot go higher than this condition.

Since we would come out of the dome and then the process of heat addition would not remain isothermal heat addition. Therefore the critical condition cannot be crossed in case of Carnot cycle. Then how does efficiency change? Efficiency increases with increase in the boiler pressure and hence the boiler temperature for the given condenser pressure of 0.04 bar of our example. So, it is evident from the figure that if boiler pressure increases we get higher and higher efficiency but at higher boiler pressure there is a rate of increase of efficiency is low.

But we have a problem that in case of increasing in efficiency we have to increase the strength of the components which are going to have stress under the boilers high pressure. So, the cost also increases but at higher pressure there is not much increase in the efficiency. So, we have to have compromise between the increment in efficiency and the cost of fabrication of the components. But there is a scene what we can see that there is large increase in specific steam consumption in case of Carnot cycle for the given example of 0.04 bar of condenser pressure.

And this increase in specific steam consumption is basically due to the fact that we are having decreasing W_{net} we can see it from the steam tables that as we grow the as will increase the boiler pressure. The enthalpy difference between the boiler inlet and boiler outlet decreases basically that decrement is due to the that decrement due to the decrease in latent heat of water with increase in the boiler pressure. And since latent heat decreases with increasing boiler pressure, we have actually lower W_{net} into the Carnot cycle.

And that lower W net actually increases the specific steam consumption but although work W_{net} is lower equally $Q_{¿}$is also lower so we have higher efficiency of the cycle. So, if we would like to have operation of the Carnot cycle then we have to have compromise between the specific steam consumption we have between the cost of the fabrication and also with the efficiency.

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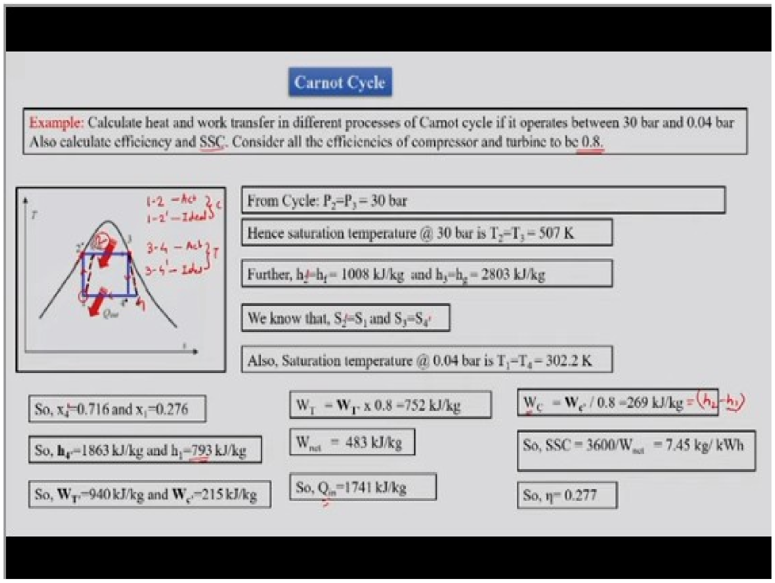

So, we will solve and now the same example but in different perspective which states that we are given with 30 bar and 0.04 bar as the boiler and condenser pressures. We again have to find out the efficiency and specific steam consumption but now we are told that turbine and compressors are not ideal. Turbine and compressor efficiencies 0.8 or 80%. So, given this fact we know now how to draw the Carnot cycle and Carnot cycle here is again ideally 1,2,3,4 where point 2 and point 3 are fixed ideally.

And then we can find out 1 and 4 but there is a problem that we are told that efficiencies of pump and compressor are 80%. So, we have to draw the real process in the pump and compressor so we name that 1 to 2 is the process in the compressor and 3 to 4 is the process in the turbine. Actual process is 1 to 2 but ideal process is 1 to 2' this is actual, this is ideal in case of compressor.

In case of turbine we have 3 to 4 is actual and 3 to 4' is ideal and this is in case of turbine. So we again know that $P_2=P_3$ and this is given as 30 bar; so knowing this we can know the properties at point 2' and point 3. So that having the temperature 507 so we know that $h_2=h_f$ and then that basically $h_{2'}=h_f$ and that is given to us as 1008 kilo joule per kg from the steam table.

So, we know that $S_{2'}=S_1$ and $S_3=S_{4'}$. So, these are the known things so that we can find out enthalpies at point 1 and 4. We know now the saturation temperature corresponding to 0.04 bar is $T_1=T_4=302K$. So we get $x_{4'}=0.716$and $x_1=0.276$ till this step the example is same as what we had solved for efficiency which is 100%.

Then we are suppose to find out enthalpy which is $h_{4'}$ we know now this enthalpy is same which is earlier enthalpy based upon this $x_{4'}$ it is $h_{4'}=1863 kJ/kg$,$h_1=793kJ/kg$. So, we can get ideal turbine work as 940 and 215 so we can now find out what is the actual turbine work. Actual turbine work is 80% of ideal so we get 752 as actual turbine work. Parallely, ideal turbine work compressor work divided by 0.08 is the actual compressor work.

So we got actual compressor work also. Knowing this we know now what is the W_{net}; W_{net}t is turbine work minus compressor work and this is 483. So, we know $Q_{¿}=h_3-h_2$ and h_2 enthalpy is to be calculated; so h_2 enthalpy is based upon that we have $h_3-h_2=1741=Q_{¿}$. Knowing this we can know what is the specific steam consumption and specific steam consumption is 7.45 kg per kilowatt hour.

So, this is how we can solve the example which would be given to us for the conditions where we do not have ideal components. Thus we have found out all the necessary parameters which are required to be found out. Only one thing to be noted over here that we were not knowing h_2 which is the enthalpy required for calculation of $Q_{¿}$. But we can find out from the actual work of the compressor; so actual work of compressor is 269 but we know $269 kJ/kg=h_2-h_1$.

Here we have found out h_1 so we know h_1 we know h_2-h_1,so you would have found out h_2. So buth_3 is also known so $h_3-h_2=Q_{¿}$; so this was one more thing to be noted over here. Otherwise, if we required, we can as well find out the entropy at point 2, dryness fraction at point 2. So, by this we have found out parameters like specific steam consumption and W_{net} knowing the $Q_{¿}$ and W_{net}we can find out efficiency and efficiency turns out to be 27.7% for the present example.