Steam and Gas Power Systems
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Module No # 01
Lecture No # 02
Rankine Cycle

Hello I welcome you all in this course on steam and gas power systems and today we will discuss about the Rankine cycle. Now topic to be covered in this lecture are first law of open system Carnot cycle, Rankine cycle performance parameters of Rankine cycle.

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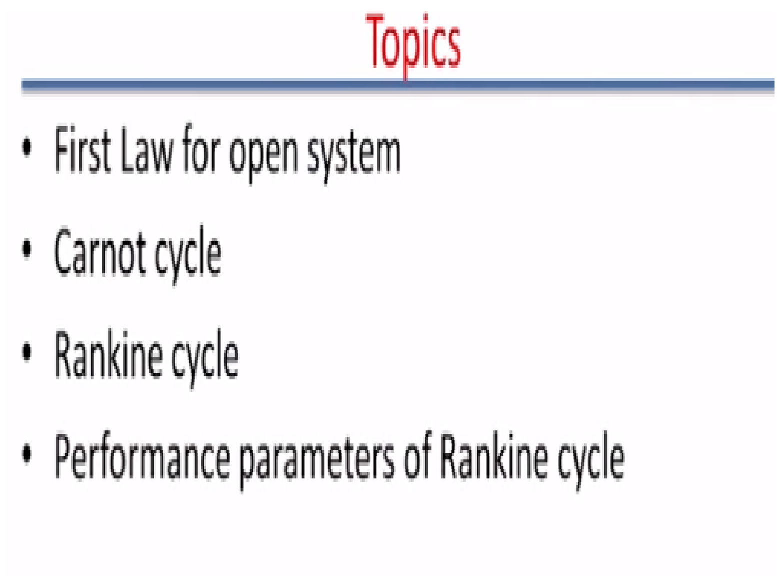

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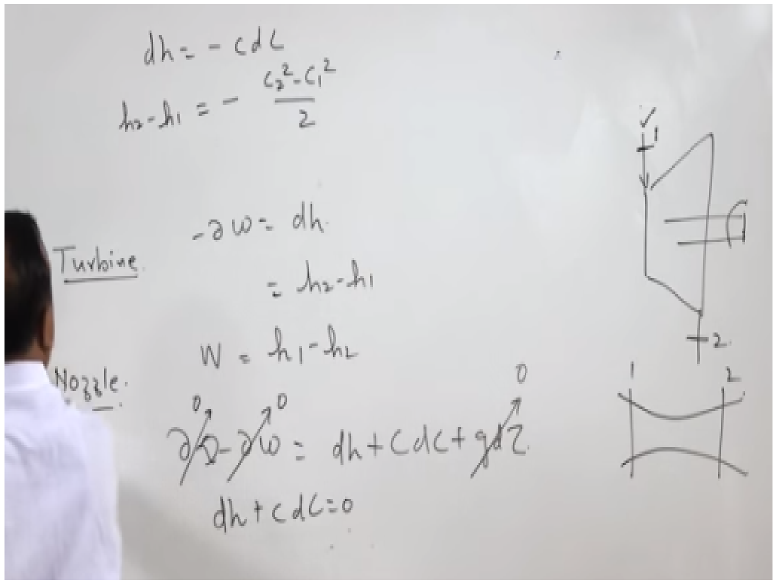

The first law of open system states that del Q - del W in an open system = DH + CDC + GDZ CDC is change in kinetic energy and this is change in potential energy and DH means change in enthalpy. We will take the case of turbine for first of all so turbine is a device where steam is passed at high pressure inlet is high pressure is T and outlet is low pressure is steam or gas and this turbine produces power shaft power.

Now in this case delta Q is 0 process is suppose to be the ideal case and isentropic process so there is no heat interaction with the surroundings. The change in potential energy is also considered 0 if there is a no change inlet and outlet velocity or there is an insufficient change in inlet and outlet velocity of the fluid this is also 0.

So - delta W = DH and DH is nothing but H2 - H1 or we can say the turbine output = H1 - H2 it means the work output we are getting from the turbine is the difference of an enthalpy at inlet and enthalpy at outlet of the turbine. Now the second thing is nozzle because the part before the turbine in order to increase the velocity of the steam the nozzle is used it is fixed before the turbine in some of the case in many of the cases it is part of the turbine itself.

So nozzle is a very important part of steam power generation system in case of nozzle again if we write del Q - del W = DH + CDC + GDZ. So nozzle is nothing but a passage of varying cross section in order to increase the velocity of steam again now state 1 to state 2 there is no heat transfer this process is also considered to be isentropic process so there is no heat transfer with the surroundings nozzle does not produce any output there is not shaft output of the nozzle. So this is also 0 change in potential energy in most of the cases is 0.

So DH = - CDC or H2 - H1 = - C2 square - C1 square by 2 or we can write H1 - H2 = C2 square - C1 square by 2 right. In most of the cases in nozzles it is assumed that the inlet velocity is tending to 0 it is negligible in comparison to the outlet velocity. So C2 can also be taken as under the root of two times H1 - H2.

So this is another second application now third application can be in case of pump now pump is also used in steam power plant just to pump the field water. And here also we can make use to first law for open system DH + CDC + GDZ so this is 0 right in pump it is again it is considered to be an irreversible adiabatic process isentropic process this is 0 and change in kinetic energy is also considered to be 0.

So DH is equal to - DH - DW because in the pump work is done on the system so work consumed by the pump is W and this = H2 - H1. And enthalpy of fluid outside the pump and enthalpy of the fluid which is entering the pump so and this is enthalpy of fluid which is entering the pump this is enthalpy of fluid at a this is state of this is the state 2 and this is state 1 and H2 - H1 will give the work consumed by the pump.

Now after this first law of open system will take up carnot cycle now in a carnot cycle there are four processes.

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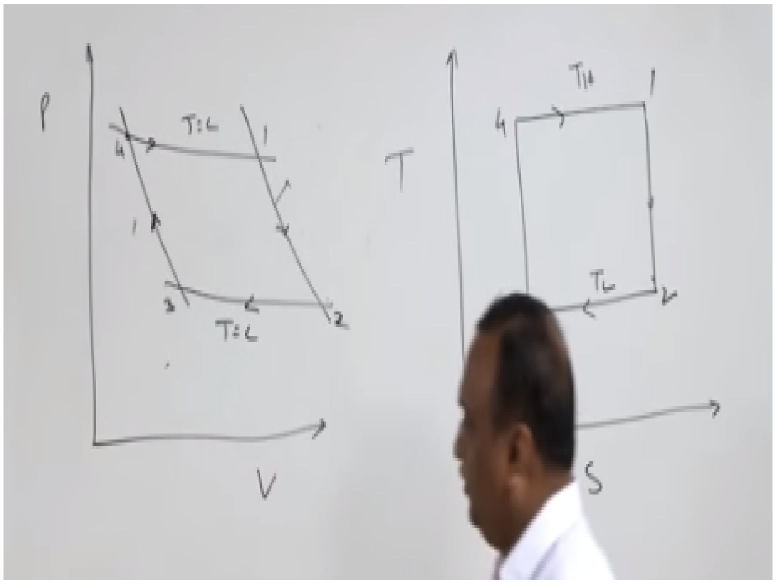

If we show Carnot cycle and PV diagram there four processes there are two adiabatic processes and two constant temperature processes. So these process starting from state 1 to state 2 adiabatic state sorry state 2 is here and state 2 to state three is temperature constant and then 3 to 1 sorry 3, 2, 4 this is 4, 3 to 4 is again adiabatic process now if it is cyclic processes where alternate processes alternative processes are constant temperature and constant entropy.

Now this process has to take place in minimum possible time if we have to maintain this process as isentropic process. So this process 1 to 2 has to be very fast now process 4 to 1 it is constant temperature process the constant temperature process has to be very slow because if this is process is no change in internal energy. Now if you transform this carnet cycle on temperature entropy diagram it is going to be a rectangle because temperature is remaining constant from process 4 to 1.

And 1 to 2 there is isentropic process it is going to be vertical line in on temperature entropy diagram 1 to 2 now 2 to 3 is again constant temperature process. So this is let us say TL and this is TH and we get state 3 and state 3 to state 4. Now if we use gas a liquid fluid here then there is a problem as I mentioned here because alternative processes have to be very fast and very slow.

So that is very difficult to realize in practice now we can go very close to the carnet cycle if we use the fluid and were in process 4 to 1 this change takes place because when the phase is take place during heat addition then temperature remains constant. So we ensure that process 4 to 1 and 2 to 3 phase is takes place then we can come very closer to the carnet cycle. So instead of using a ideal gas if steam is used in a carnet cycle.

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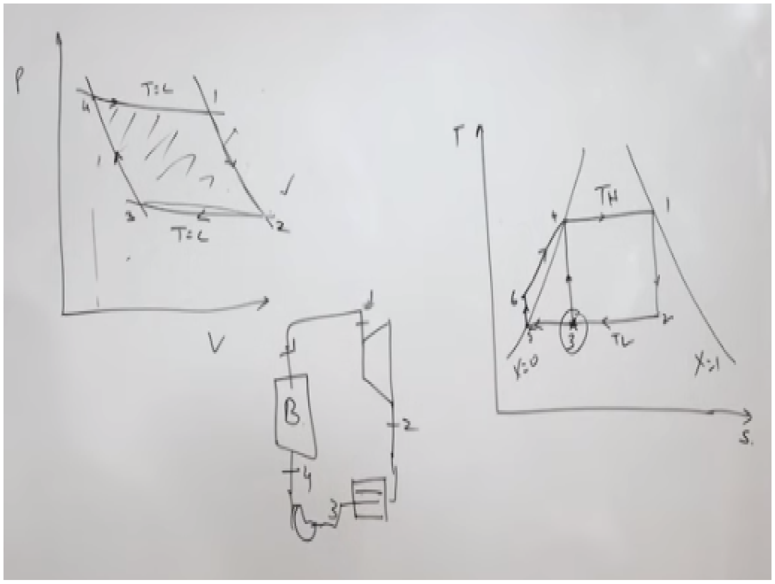

Now if steam and water is used in a working fluid in a carnet cycle then we can have this is saturation line X = 0 and this is X = 1 there the water vapor is dry and saturated and this is saturated liquid. So when the liquid starts boiling the temperature will remain constant so here we can realize process 4 to 1 four, process 1 to 2 isotropic expansion will remain constant and again for process 2 to 3.

We can condense the water vapor during condensation the heat will be rejected and temperature remains constant and at state 3 we can compress this mixture of because in this region it is going to be a mixture of water vapor and the liquid water. So the process 2 to 3 will remain in two phase region where temperature remains constant. So this is how we can come close to the carnet cycle but they are found again there are problems in this system also.

The first problem is way to take a because all these processes will be taking in different physical entities because process 4 to 1 will be taking place inside a boiler right so this is state 4 to state 1 for 1 it will go to a turbine four sorry this is 1 and this is 2 and from 2, 3 shall takes place inside the condenser 2 to 3 and 3 to 4 shall takes place inside a pump.

So all the processes all this processes they will take place inside different entities not a single entity. So now the question is when the process 2 to 3 is complete here in the condenser then vapor has to be removed exactly at this quality from the condenser otherwise will not be able to realize the state 4 second thing is we have compressors which can compress the gases.

We have pumps which can increase the pressure of the liquid but we do not have the any device which can compress the mixture of the liquid and vapor because the moment you start compressing this mixture the condensation will start in device will not work at all with high efficiency we can develop a device but the efficiency will be low. So this solution is not workable because we have problem from state 3 to state 4.

The second thing is if you look at the length of this cycle stroke of the cycle this much right and area is the work or energy produced in the cycle is this much area of PV diagram. So I am able to develop a carnet diagram it is going it may be very efficient engine because no engine can have efficiency then an engine working on carnet cycle between two temperatures TH and TL but in that case the engine will be highly efficient and bulky.

So in engine working on the carnet cycle nay be on this size if I take a gas engine working on a diesel cycle may be of this size right. So not only efficient size of the engine is also important now here let us go back to this issue is important because in process 3 to 4 a lot of energy will be consumed if we are able to make any device which can compress this mixture to this saturated liquid state.

So ranked it but need one modification and he made one modification instead of condensy mixture of state 3 mixture is condensed upto state four sorry state 5 this is state 4, state 5. Now entire vapor is converted into the liquid this is saturated liquid and then in turn vapor is converted into the saturated liquid now this liquid the pressure of this liquid can be increased with the help of a pump and we get state 6 this is temperature and this is entropy and after attainting this pressure this six the liquid is sent to the boiler for heat exchange and process 6 to 1 takes place inside a boiler.

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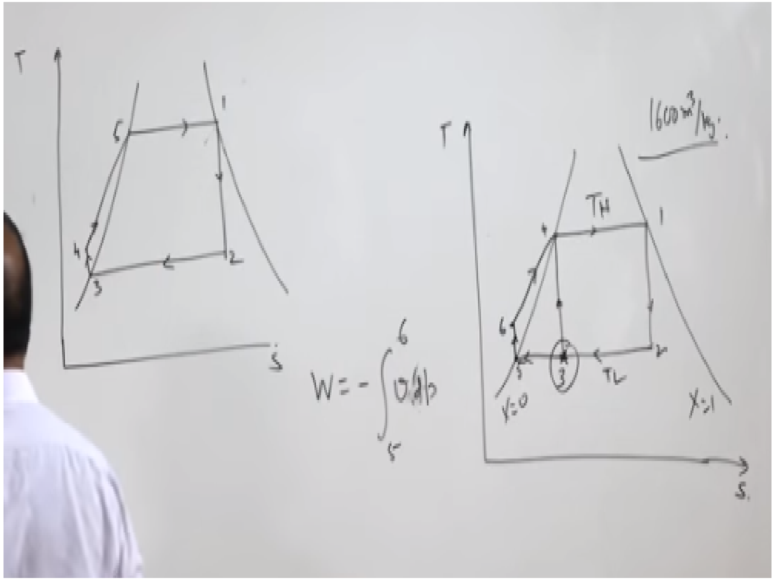

So now this carnet cycle is modified as rankine cycle if we show the cycle on PV diagram it is going to be like this sorry on temperature entropy diagram this is going to be like this state 1, state 2, state 3 and then state 4 and state 5 the moment the vapor is condensed up to state five the volume is reduced drastically for example at atmospheric pressure if we take saturated steam and if you compare the volume of saturated steam is saturated liquid.

The volume of saturated liquid is same is approximately 1600 times greater than the volume of saturated liquid. It means if we take 1 liter of saturated liquid at atmospheric pressure if we convert entire this 1 liter of water into the steam. We will be getting approximately 1600 meter cube of steam per KG of 1 liter or water and so the change in volume is very high.

So when all the steam is condensed in a condenser the volume of gas is produced of fluid is reduced drastically and it is very easy to compress because here the work consume will also be very less because it is going to be VDP from state 5 to state 6. Now this high pressure liquid will be sent to boiler and where heat exchange from state 6 to state 4 and state 4 to state 1 will take place from state 1 again fluid will enter the turbine and the work will be produced.

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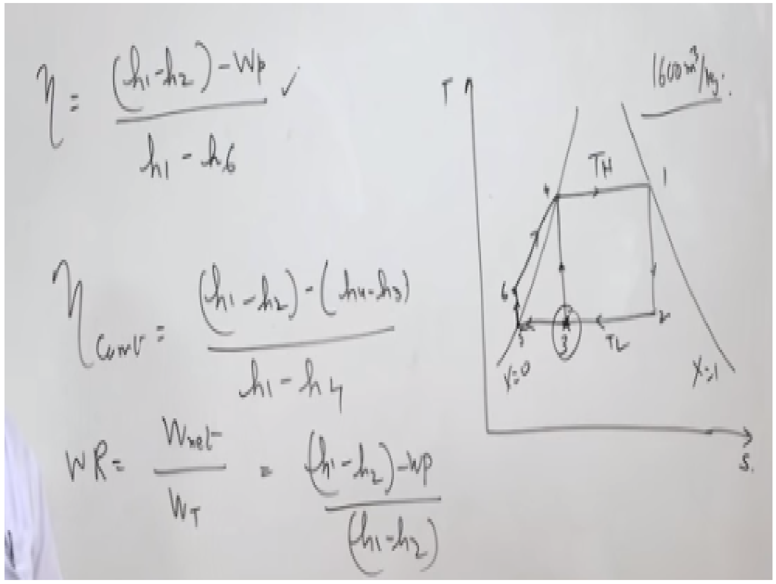

Now performance parameters are of Rankine cycle in order to find the performance parameter 1 is efficiency of the Rankine cycle efficiency of the thermal efficiency of the Rankine cycle. Thermal efficiency of the Rankine cycle is output of the turbine that is the work we are gaining and work done in the pump work consumed by the pumps.

So it is H1 - H2 - work consumed by the pump is often it is insignificant if you compare this value it becomes significant and sometime it is neglected also divided by heat given this is H1 – H6. This is amount of heat given to the system and this is work output of the system now if we take the thermal efficiency of carnet cycle it is going to be H1 - H2 – H4 – H3 because this is significant here it is significant we cannot neglect it divided by H1 – H4.

Now I will take one numerical and i will compare the performance of these two cycles the numerical states.

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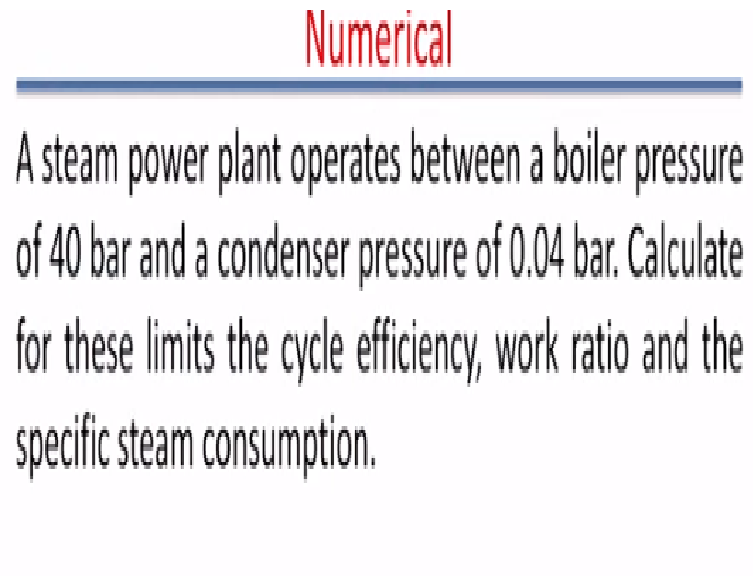

A steam power plant operates between a boiler pressure of 40 bar and the condenser pressure of 0.04 bar can be these limits calculate for these limits the cycle efficiency work ratio and specific steam consumption cycle efficiency thermal efficiency of the cycle. Now work ratio is the network divide by turbine work that is the work ratio. So here the work ratio can be H1 - H2 - WP divided by turbine work divided by H1 - H2.

Now if you compare the work ratio of a carnet cycle and a a Rankine cycle work ratio of Rankine cycle will turn out to be much higher than the work ratio of a carnet cycle. Now the second one is specific steam consumption specific steam consumption is steam consumption specific steam consumption is steam consumption per kilowatt hour this also we can drive from these values. So in order to start this we take first carnet cycle.

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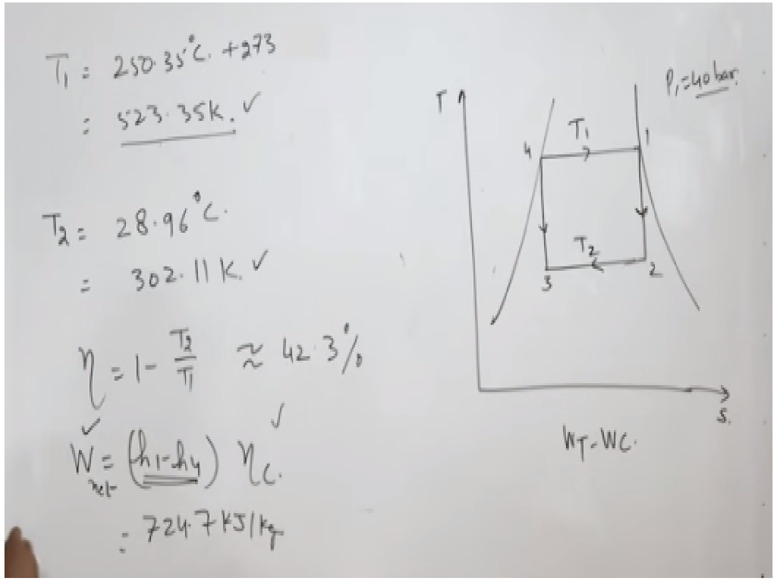

So in case of carnet cycle the pressures are for 40 bar and 0.4 bar now temperature this is TH and this is TL so TH or we can take T2 also in some of the books it is taken as T1 and T2. So T1 is saturation pressure at 40 bar because the pressure is 40 bar so at this pressure accordingly saturation pressure will be taken these temperature you can take from the steam tables you purchase steam table available in market and you purchase any of the steam table because steam table will be frequently required at this course and take this steam table has bullier diagram also.

Because we will be using sometimes we will be using Mollier diagram also so from stream table there is a table for saturation property is where for every pressure you will get the saturation temperature. So from that stream table I have taken at 40 bar pressure the saturation temperature is 25.35 degree centigrade now if I convert this into the kelvin then it is going to be 253.3535 kelvin because you had 273 you will be getting temperature in kelvin.

Now similarly you can calculate the temperature T2 at 0.04 bar it is 28.96 degree centigrade and if you convert this into the kelvin again you will be getting 302.11 kelvin. So we have two temperatures and I hope all of you can find the efficiency of the cycle because efficiency of the cycle carnet cycle is 1 - T2 by T1 this 1 - T2 - T1 will give you the efficiency of the order of 42.3%.

But if I ask you to find the output of the turbine now output of the turbine will be work. Now this work is network so this network involves the work develop in the turbine - work done in compression. So this is the network is H1 - H4 heat supplied multiplied by the efficiency and the network you will get H1 and H4 you will get from the steam table the at 40 bar pressure the enthalpy of saturated vapor and enthalpy of saturated liquid. So H1 and H4 will give you will get the network as 724.7 kilojoules per KG right.

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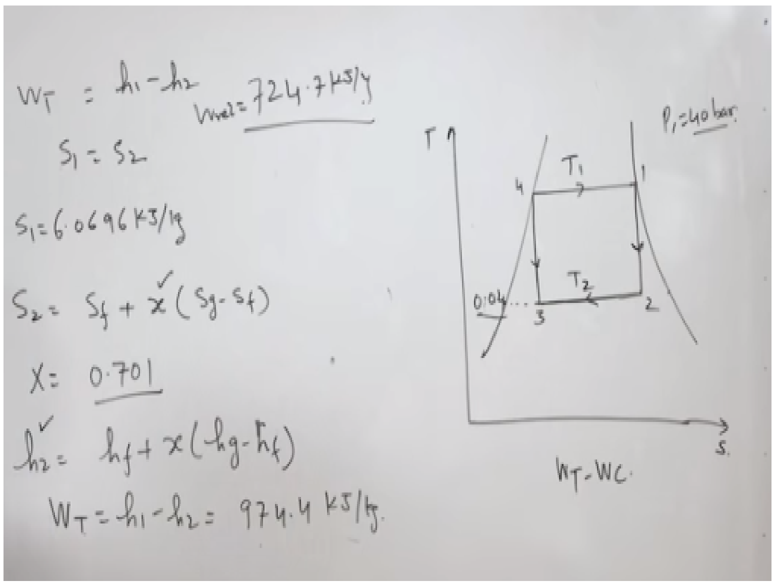

Now turbine work suppose I want to find the turbine for then turbine work is H1 - H2. So H1 we can get from the steam tables saturated such a such enthalpy of saturated vapor H1 this we can take from the steam table but what about H2. H2 is not even in the steam table so in order to find H2 we will take S1 = S2 it is a property of this process S1 = S2, S1 we can take from the steam table.

So S1 is 6.0696 kilo joules per KG kelvin and that S1 = S2 now S2 we know in this process because it is a constant pressure process and 0.04 bar pressure. So for 0.04 bar pressure we know the entropy of the liquid and entropy of the vapor. So we can always take S2 = SF + X SG - SF now from here we can calculate the value of X and in this case the value of X is 0.701.

Now once we have the value of X here X is the quality of vapor once we have the quality of the vapor at this rate to we can find H2 because H 2 is HF + X SG - sorry SG - HF at this pressure

0.04 bar pressure. So from here we will get the value of H2 now have value of H1 and H2 we can find the turbine work at H1 - H2 and in this case the turbine work is 974.4 kilojoules per KG right.

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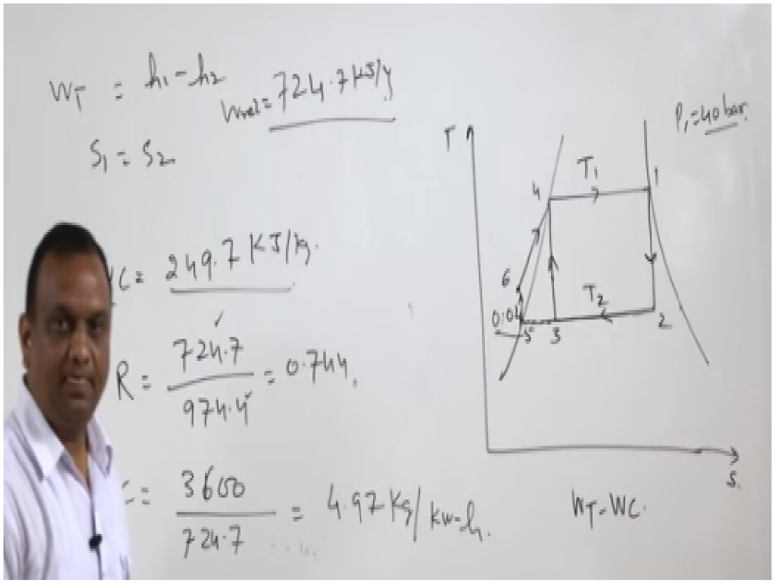

Network was network was 724.7 kilo joules per KV this was the network and this is turbine work. So difference of these two works will give the energy consumes with the process three to four is equal to that is work of the compression is to 49.7 kilo joules per KG. So this is the amount of energy is being consumed sorry in the process 3 to 4.

Now the work ratio is 724.7 divided by 974.4 this is the network this is the turbine work and this is going to be 0.0744 and specific steam consumption is equal to net output is how much 724.7 multiplied by 6600 that will give the specific steam consumption it is going to be 4.97 KG per kilowatt hour.

So we are getting all the values efficiency work ratio and specific steam consumption in case of carnet cycle. Now this is in right hand cycle this vapor is completely condensed pressurized and the you get 5 state 6 and then from state 6 heating takes place we can get enthalpy 8 state 5 but what about enthalpy 8 state 6 because heat added value is going to be.

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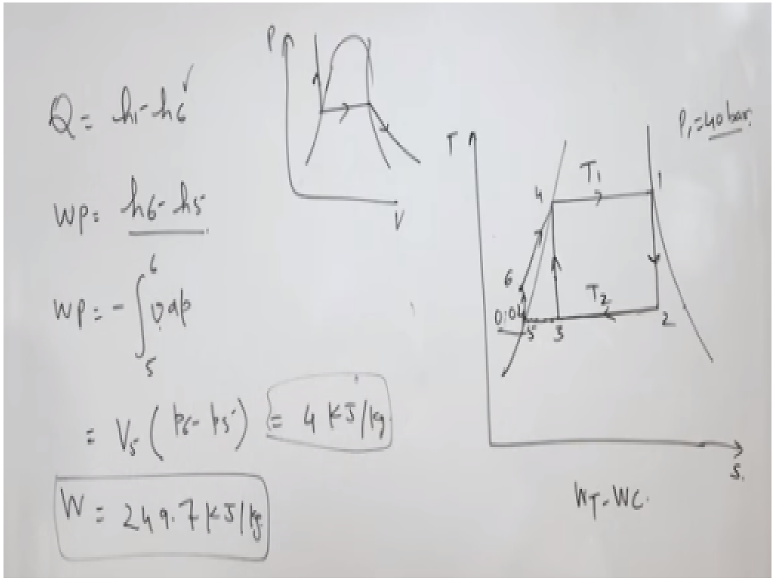

Here in case of rankine cycle heat added is going to be = H1 - H6 work in the pump is H6 - H5 but the issue is how to find H6 work is pump is H6 - H5 and work in pump is also - VDP from state 5 to state 6 in liquid if you pressurize liquid the change in specific volume is insignificant that is why on a PV diagram if we look at the PV diagram of liquids at a constant temperature this line is almost a vertical line at a constant temperature and then it goes like this and then again it goes like this.

So this can be taken as constant and DP is the pressure difference so we can always take specific volume at state 5 multiplies by T6 – P5. I have done this calculation and the specific work if the pump is approximately 4 kilojoules per KG it is almost insignificant if you compare the output of the turbine. In case of rankine cycle the work of the pump or pumping work was coming out to be 25.7 kilo joules per KG.

So you can compare the energy consumed in the carnet cycle and energy consumed in rankine cycle in pumping the fluid. Now again in order to find the efficiency of the cycle

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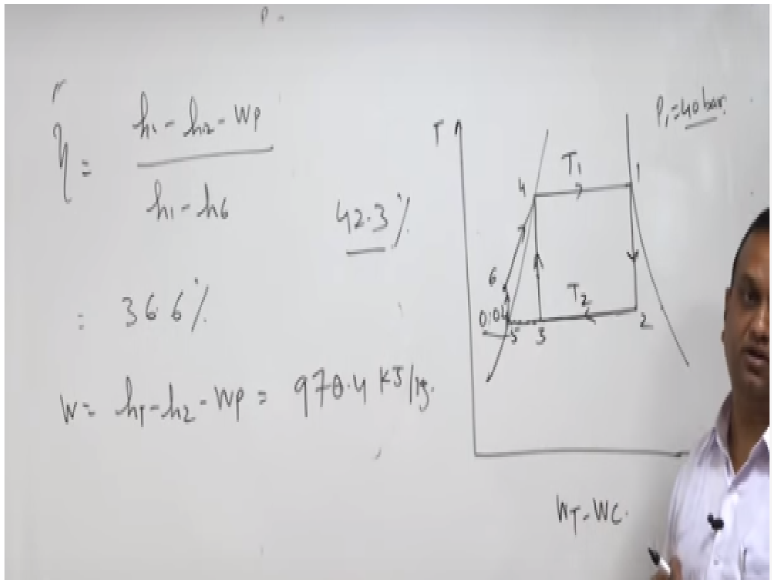

So thermal efficiency of the cycle is going to be H1 - H6 sorry H1 - H2 - pump work divided by H1 - H6 now we have all the values. H1, H2 with us H5 with us add the pump work you will get H6.

So using this equation the thermal efficiency of the carnet cycle comes out to be 66.6 % which is less than the carnet cycle in carnet cycle you are getting 42.3 % here we are getting only 36.6 % but at the same time you can see we ate getting more output more output work output is in this cycle is H1 - H2 it is same S was in the case of carnet cycle - work of the pump and were here work of the pump is very less only 4 kilo joules per KG.

So in this rankine cycle the efficiencies lower than this but are getting more output in this case and this is poor practical cycle if we compare with the thermal cycle now I will end my lecture here in the next lecture we will see how we can improve the efficiency of a rankine cycle.