INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NPTEL
NPTEL ONLINE CERTIFICATION COURSE

Refrigeration and Air-conditioning

Lecture-08
Vapour Compression Cycle-2

with

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Hello I welcome you all in this course on refrigeration and air-conditioning. Today we will discuss on vapour compression cycles.

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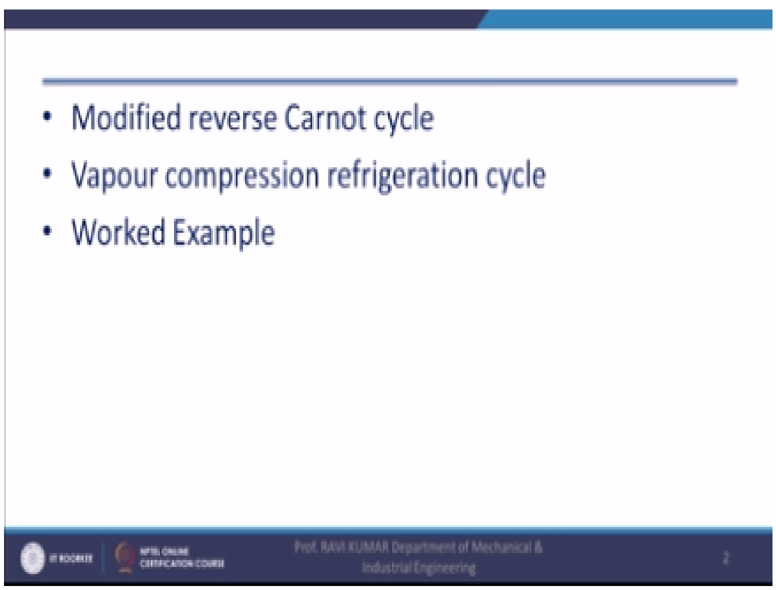

We will start with the modified reverse Carnot cycle, vapour compression refrigeration cycle and we will work out with example in this lecture.

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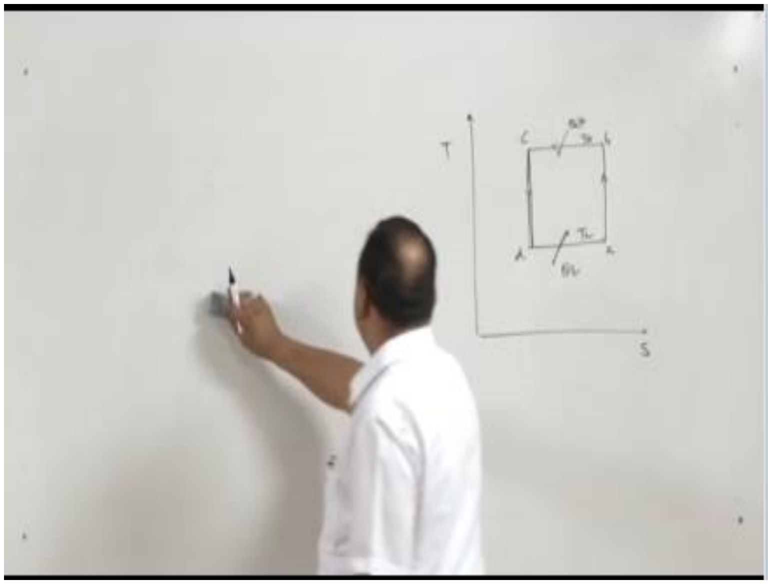

If we take reverse Carnot cycle and depict on temperature and pulpy diagram it is going to have two constant temperature processes and two constant entropy processes A, B, C, D A to B is compression, B to C is heat rejection, CD is isentropic expansion and DA is heat addition from the surroundings that is QL this is PL and this is PH. For air refrigeration cycle these processes are difficult to realize, because during these processes constant temperature has to be maintained constant, the temperature has to be maintained constant.

And these processes will automatically becomes very slow, but in case of vapour compression refrigeration system where vapours are used as a working fluid, the process D to A can be realized during boiling of vapour. And process B to C can be realized during condensation of vapour. Because at the boiling and condensation of vapour the temperatures remain constant, so we can use, if we use vapour in the Carnot cycle we can realize, easily realize the constant temperature heat tradition and constant heat rejection in the process.

Now the second problem with the Carnot cycle is we need an expander or expansion turbine. Ad expansion turbine in this case is going to be very small, because refrigeration systems are of the cap street 2 ton and 4 ton normally we use for domestic applications or even for the large refrigeration system this work attained during process C to D is going to be very small and it may not sufficiently supplement the work consumed during process A to B.

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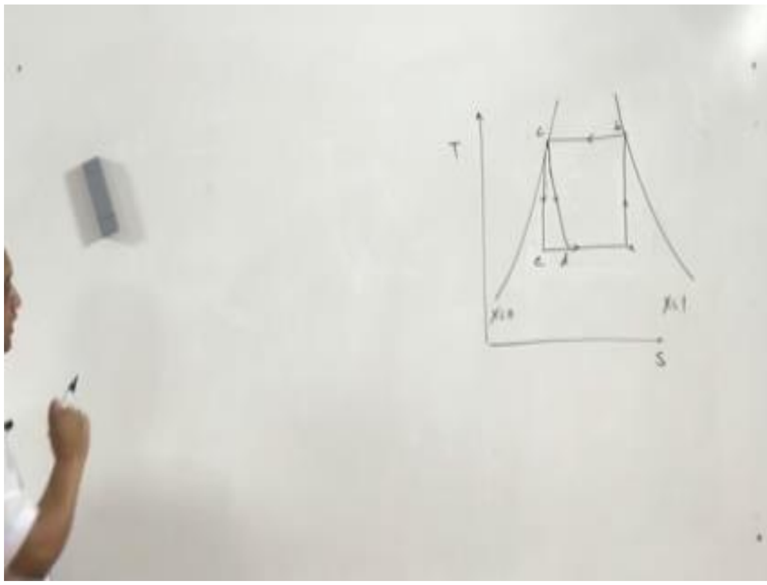

First of all at the state C if we redraw this Carnot cycle for the vapour then as we know there is a saturation line on temperature entropy diagram where the entire vapour is in liquid state and there is another saturation line where entire vapour in gaseous state. And the Carnot cycle will lie somewhere here. During process D to C the vapour, entire vapour will be converted into the liquid and heat will be rejected.

And during process D to A heat will be taken from the surrounding and the boiling of refrigerant will take place. Now process C to D refrigerants the isentropic expansion of the vapour not vapour as if as isentropic expansion of the liquid available at C. Now as I said earlier the provision of expander or the turbine is not advisable here because the work output is very small and this maybe the case that the work output will be is barely sufficient to work on the friction losses during this process.

And expanders are in turbines are costly items, so it may not justify the cost of the system as well. So instead of using an expander this process C to D is made isenthalpic. Now if we have high pressure liquid here it can be total to the low pressure with the help of a totaling device. So instead of having process C to D will have a process this B will be shifted to this point, D will be shifted to this point.

And the entire refrigeration process cycle will be A, B, C, D and this is constant enthalpy process. Now we will try to find refrigerating effect and work interaction during the cycle. Now I will further explain this diagram.

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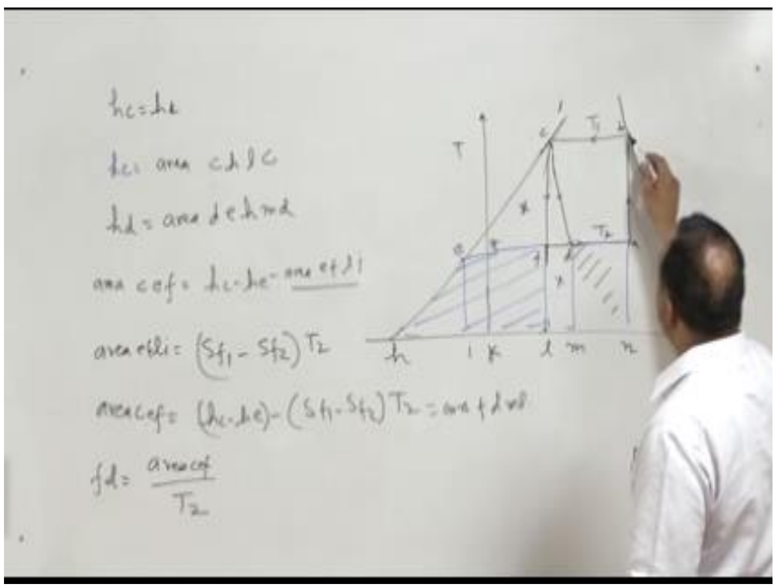

Now A, B, C, D, E this is F or we will say this is E, this is F then G and H, I, J, I K, L, M, N now why I have done this. I have done this so that suppose I want to have enthalpy at C, immediately I will take area of this figure, the area of this figure will show the enthalpy at C because enthalpy at this point H is 0, sorry the temperature at this point is 0 absolute 0. So this is the imaginary point, so this will give us the enthalpy at C.

Similarly if I want to have enthalpy at ED any of this diagram will give us enthalpy at E, so this is the, we will try to find the COP of this cycle with most basic technique by starting with the refrigerating effect. The refrigerating effect we will be getting during this process, it means the area of this area will give us refrigerating effect right.

We can find this area, this area we can easily find this area is SB-SC this is entropy at this point, entropy at this point minus entropy at this point multiplied by temperature. The temperature here is P2 suppose the temperature here is T1. So T2 multiplied by entropy at point B minus entropy, this is the right rectangle. So entropy at point B or point A or an entropy at point F, but sorry the point D.

But if we do not have the value of this entropy change during FD, we have entropy of F, we have entropy at A, but we do not have entropy at D and we do not know the length of this line. In order to find that we will start with the assumption that this is an isenthalpic process. Since this is an isenthalpic process enthalpy at C is equal to enthalpy at D, it means the area under this, so area I will write here, enthalpy of C is equal to area C, H, L, C.

Enthalpy at D is equal to area D, E, H, M, D so the enthalpy at C is equal to enthalpy at D it means this area is equal to this area right. If we quit these two areas it means that some overwriting is there, because this area and this area so this area is common to both, it means this area is equal to this area, I repeat.

Enthalpy at C is equal to enthalpy at D, enthalpy of C will be given can be attained by taking this area, enthalpy of D can be attained by taking this area out of these two areas this area is common, so we can always say that this area is equal to this area. Now if we are able to find the area of this diagram we can find the area of, definitely we can find the area of this diagram as well.

Now the area of this diagram, area C, E, F is equal to HC-HE this is area minus HE this area minus area E, F, L, I this area. So this will provide us, this equation will provide us area for C, E, F. Now area C, E, F as I said earlier is equal to HC-HE and area E, F, L, I that is sorry, E, F, L, I.

Now in order to find this area we can say that at state F the entropy is same as in the case, as in the state C and entropy at E is known to us.

And with the help of these values we can find the value of area E, F, L, I as (SF1-SF2)T2. So area of CF = HC-HE-(SF1-SF2)T2. Now as we know that this area is equal to this area, so area of FDML is this much, this is equal to area of FDML. So the length of FD or entropy change while going from F to D is going to be equal to area CEF/T2 and this will give us the value of FD. Value of AF is already with us.

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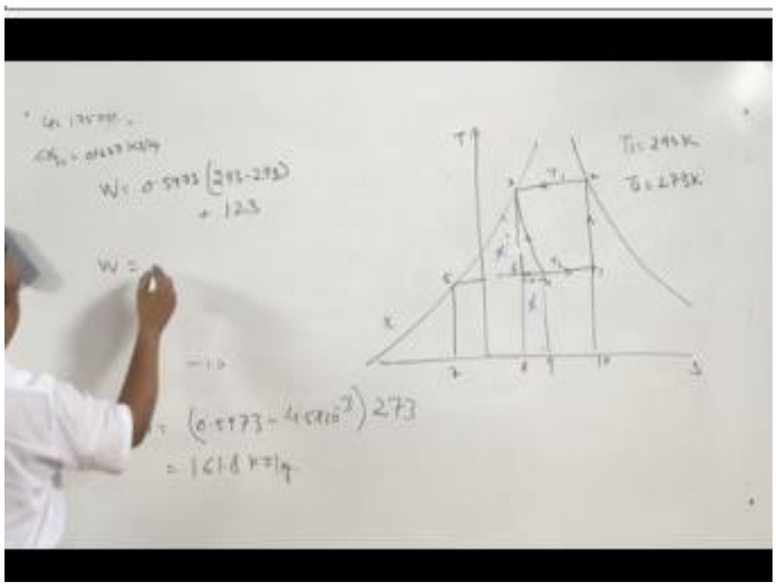

The value of AF is, so here AF we can find the value of AF this is going to be the change in entropy during this process or entropy of gas at 1 minus entropy of liquid or fluid at 1. Since we have the value of AF we have the value of FD also. Now the refrigeration effect takes place during process D_a, so the length of the $D_a$is going to be, af-fd, so through this process, we can find the value, of da, now for the refrigerating effect, if we multiply da/T2, this will give us reaffirmation effect during the process.

Regarding the work by the compressor, for the work by the compressor, the area of this diagram will give the work of the compressor, this diagram constitutes, this rectangle, and this area we have already calculated, right so this is the area, CEFC, area which we have already calculated, plus this area, and this area is going to be equal to Sg1-Sf1×(T1-T2), or the area of this rectangle.

In order to have clear inside of these phenomena, or this process, let us work out one example is given here, in R744, base refrigeration system, R744.

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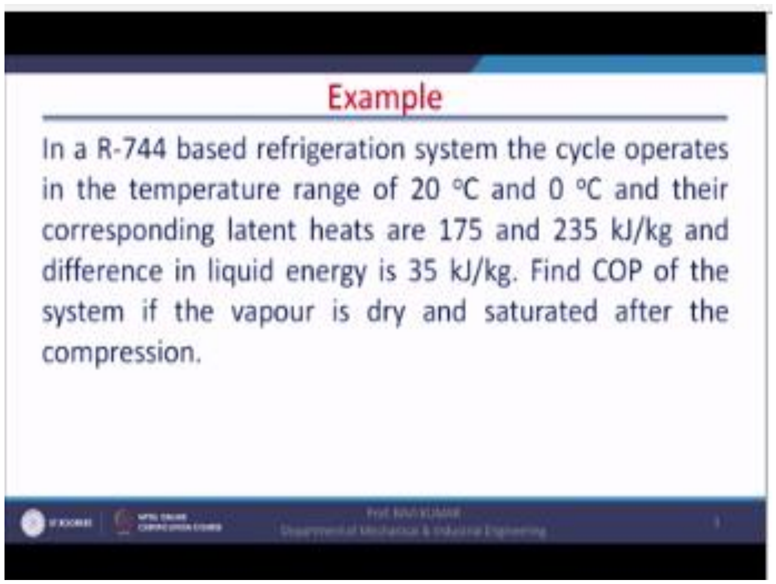

Stands for carbon dioxide, base refrigeration system, the cycle operates in the temperature range of 20^0C AND 0^0C, and they have corresponding latent heats are175 and 235 Kg, and difference is liquid energy that is liquid enthalpy 20^0C, liquid enthalpy at 0^0C, and the reference is 35 Kj/Kg find COP of the system if vapour is dry and saturated, after the compression.

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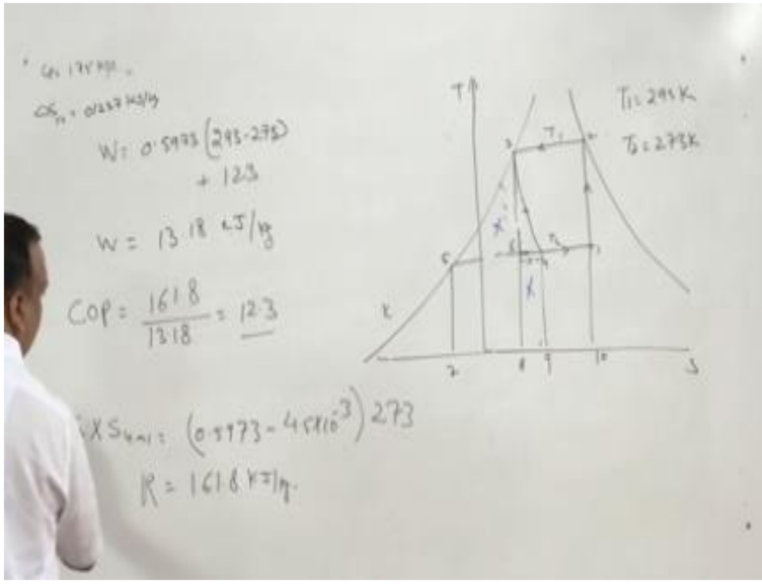

So again we will plot temperature entropy diagram and this is temperature T1, and T1, and temperature T2, constant enthalpy process instead of constant, entropy process we have constant enthalpy process, we have this is 1, 2, 3, 4, and then it will come 5,6,7,8,9,10. I will give the direction of the process going to do 2 to 3 and 3 to 4 and 4 to 1.

So here we have to find the refrigerating effect, and the work done by the compressor, and T1=293K, and T2=273K, because this is a 20 ^{0}C, this is a 0^{0}C, and if you don't have any information, about the entropies, we don't have any information about the entropy at 3, or entropy at 5.

We have the value 35 Kj/Kg, Q_{5-3}= Cp(T3-T5)=35kj/Kg, now T3-T5=20, so Cp(20)=3.5, so Cp=1.75 Kj/kg, now we will note this value here , Cp=1.75Kj/Kg K, once we have the value of Cp, we can find the change in entropy, during g this process, now change in entropy during this process is, ΔS_{5-3}= $Cp^{T3/T5}$, now we have Cp value with us it is 1.75, natural log 293/273, because T3=T1, and T5=T2.

And this gives the value of 0.1237 Kj/Kg K, we will note down this value also, ΔS_{53}=0.1237 kj/Kg K, now after this area of this area of 3563, area of 3563, is (H3-H5)-(S6-S5)×T2, now H3-H5, is already with us, it is 35 Kj/Kg , S6-S5, we have already S6 is nothing but the S3 and S5, we already know, it is , S6-S5= 0.1237×273, and this will give the value as 1.23 Kj/Kg.

Now i am repeating here we have calculated the change in entropy, between 3 and 5, so we are coming from 3 to 5, the change in entropy is 3 to 5, the change in entropy is 0.1237, and this change in entropy we are using here as S6-S5=S3×32, and S3-S5, so this expression will give the area of this.

Now this area, as we know it is an isothermal process so H3=H4, so this area is equal to this area, this area is equal to this area, we have already done that, and this area means it is a, so area 3563= area 6894=T2×distance, let us say 64 is X, multiplied by X, now X=1.23/273, and that is going to be equal to 4.5 $\times 10^{-3}$Kj/Kg K, now after retrieving the value of X.

Now we have the value of X, now this one S1- S6, now change in entropy during process, this condensation we have latent heats, latent heat at 20 ^{0}C so S2 to S3, when coming from 2 to 3 , it is going sorry! Latent heat, let us say, entropy during process, 3 to 2, that is increase in entropy, process 3 to 2, that is increase in entropy is going to be , 175/293, and 175/293, will give the value of 0.59743 Kj/Kg K.

Now we have , the change in entropy, between 1 and 6, and we have the value X, and if you subtract the value of X, we will be getting the entropy change, during process 4 to 1 and that is 0.5973-4.5$\times 10^{-3}$, and that will give us, and this change in entropy multiplied by T2, at the same time we will multiply it by T2 also, so it is multiply by 273, that will give us the value 161.8Kj/Kg, that is the amount of refrigerating effect we are getting here.

Now work assumed by the compressor, work assumed by the compressor is 0, area of this rectangle plus this value of this , area this area is already calculated, S53, we had already calculated as 0.1237 Kj/Kg, so the work will be 0.5973, that is change in entropy between these two multiplied by T1-T2, that is 293-273.

That will give the area of this diagram, so area of this diagram is S2-S3, S2-S3we have already calculated that is 0.5973 ×change in temp+ area, of this diagram, that is 1.23, we have already done, this gives the expression will give us the value of the work consumed by the compressor as 13.18Kj/Kg, now we have both the values, refrigerating effect, and work consumed by the compressor.

So COP of the system going to be 161.8/13.18=12.3, now today I have explained you how to find COP of vapour compression refrigeration system, with the basic principle, and on the same concept i have solved one numerical example.

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Acknowledgement
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