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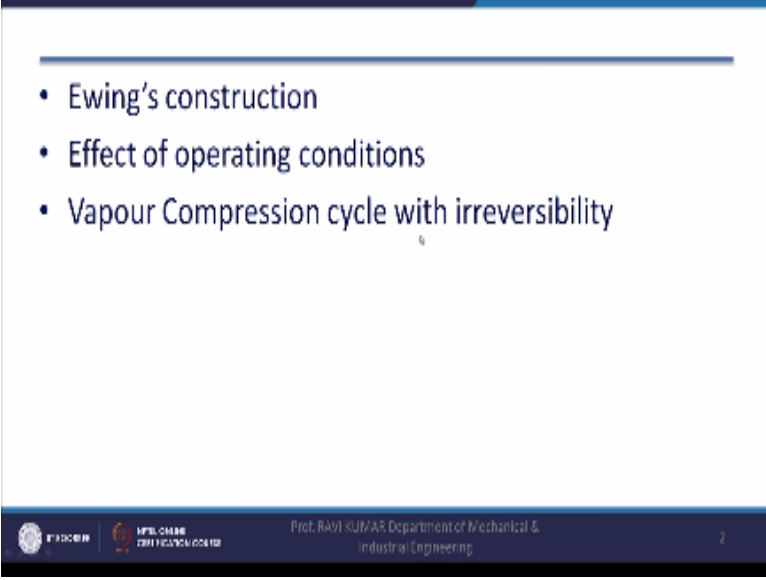
**Refrigeration and Air-conditioning**

**Lecture-11  
Actual Vapour Compression Cycle-2**

**with  
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Department of Mechanical and Industrial Engineering  
Indian Institute of Technology, Roorkee**

Hello, I welcome you all in this course of refrigeration and air-conditioning and today we will discuss the actual vapour compression cycle. We will be covering the Ewing's construction and that is very interesting.

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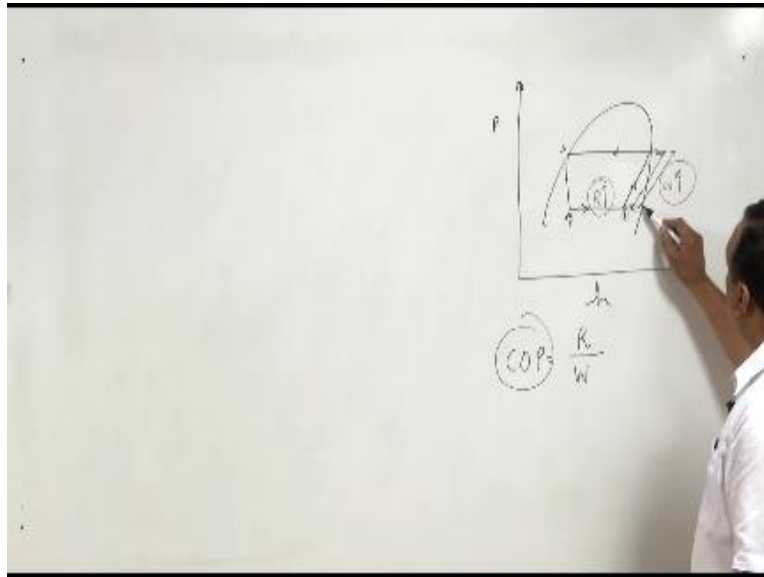
A slide from a presentation with a blue header and footer. The main content area is white with a blue horizontal line above the text. The text consists of three bullet points. The footer contains logos for IIT Roorkee and NPTEL, along with the name of the professor and his department.

- Ewing's construction
- Effect of operating conditions
- Vapour Compression cycle with irreversibility

Prof. RAVI KUMAR Department of Mechanical & Industrial Engineering

Effect of operating conditions, vapour compression cycle with irreversibilities.

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Now in a typical vapour compression cycle if we draw on a pressure and enthalpy diagram if there is wet compression it means the vapour is saturated after the compression and at the inlet of the compressor the vapour is not saturated it is a wet vapour. Now in this case if I keep on increasing the temperature of one, if I keep on increasing the temperature of one or this state 1 will be start shifting here then I will be getting vapour super heated after the compression.

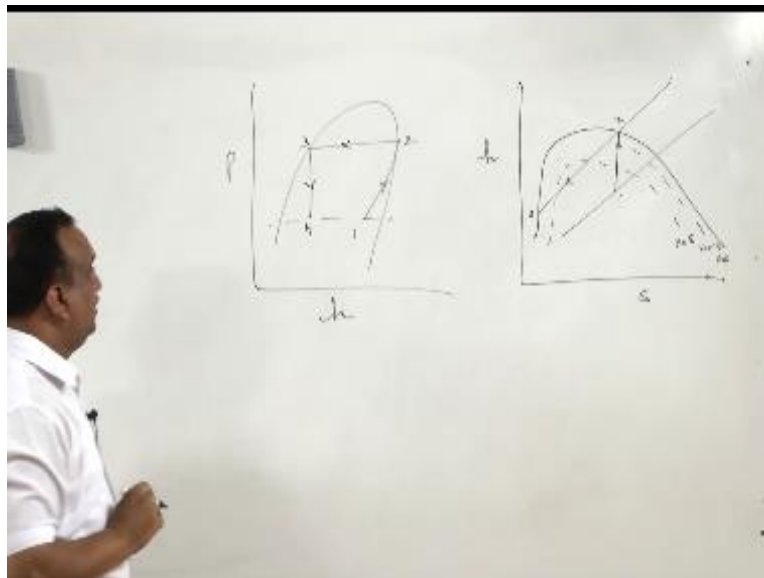
If we further shift it again I will get vapour super heated after the compression. Now here the issue is, if I keep on increasing this temperature T<sub>1</sub>, I will be getting more refrigerating effect, refrigerating effect will increase and at the same time from pressure work will also increase. Now the issue is what is the benefit, benefit means how it is going to affect the COP of the system, COP of the system is the ratio of refrigerating effect and the work assumed by the compressor.

So since we are shifting state 1 to the right side refrigerating effect is increasing and work is increasing, there should be one optimum value of the quality of vapour intersection of compressor which will visual give the maximum COP. The growth of moment we shift in this

direction were these constant entropy lines are diverging lines. So the moment we shift in this direction, the work consumed by the compressor increases.

Now Ewing's construction gives solution to this problem, now if we transform this pressure and pulpy diagram on molear diagram.

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This is molear diagram is enthalpy entropy diagram. And that can be drawn for any gas or any vapour. For example, refrigerant R131A if I draw molear diagram this is the saturation line, below this I think at different saturation lines for different qualities, for example  $X=0$ ,  $X=0.9$ ,  $X=0.8$  and so on. Constant pressure lines can be shown here as these lines parallel, they are not parallel, these lines, these are constant pressure lines.

So in the PV diagram PH diagram of any refrigerant these are constant pressure lines. So state 1 to state 2 can be shown here as state 1 to state 2, entropy is remaining constant that is why it is a vertical line. And state 1 to state 2 the change in entropy is 0 and it is going to be vertical line here. Now state 2 to state 3 is a constant pressure line definitely it is going to turn here state 2 to state 3.

And it is a liquid state this is also, here also it is shown in the liquid state. Now state 3 to state 4 is constant enthalpy line, enthalpy is constant. So constant enthalpy line in this case is going to be horizontal line. So this is refrigeration cycle on transformation of refrigeration cycle on enthalpy, entropy diagram.

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Now in this enthalpy, entropy diagram if I want to find COP of the system then the COP of the system will remain same that is refrigerating effect  $H1 - H4$ / work consumed by the compressor. Now we can do further manipulation in this equations and we can further write this equation as  $H1-H4/H2-H4-H1-H4$  both equations are same divide now by  $\Delta S$ ,  $\Delta S$  is change in entropy,  $\Delta S$  is change in entropy  $\Delta S$ .

So here we can write that  $H1-H4$  divided by  $\Delta S/H2-H4/\Delta S-H1-H4/\Delta S$ , now  $H1-H4/$  this is a constant pressure line and during this process the temperature also remains constant. If you look at the PH diagram this process the temperature remains constant. So during process 4 to 1 temperature remains constant, that is why change in enthalpy divided by the change in entropy shall give the temperature of temperature dividing this process that is  $T0$ .

Here also we can take  $H_2 - H_4 / \Delta S - T_0$  and this is equal to COP of the system. Now here in this case the COP is going to be maximum where this is minimum, that was  $T_0$  is fixed,  $T_0$  cannot be changed, but we have to ensure that this is minimum in that case, this expression means  $H_2 - H_4$  enthalpy of the vapour after compression minus enthalpy of the vapour after expansion or at the entry of the evaporator divided by  $\Delta S$ , because in this process  $\Delta$  is 0, in refrigerating process that is state 4 to state 1 the  $\Delta S$  is this much.

So  $H_2 - H_4 / \Delta S$  has to be minimum. Now  $H_2$  is here this is  $H_2$  and  $H_4$  is here,  $H_4$  this is  $\Delta S$  if you look at these values this is nothing but the slope of this line, if you connect 4 to it is slope of this line. If we can minimize the slope of this line, because this is also shown here as a straight line, but basically it is not a exactly is a straight line it is a slightly toad, so this line is something like this.

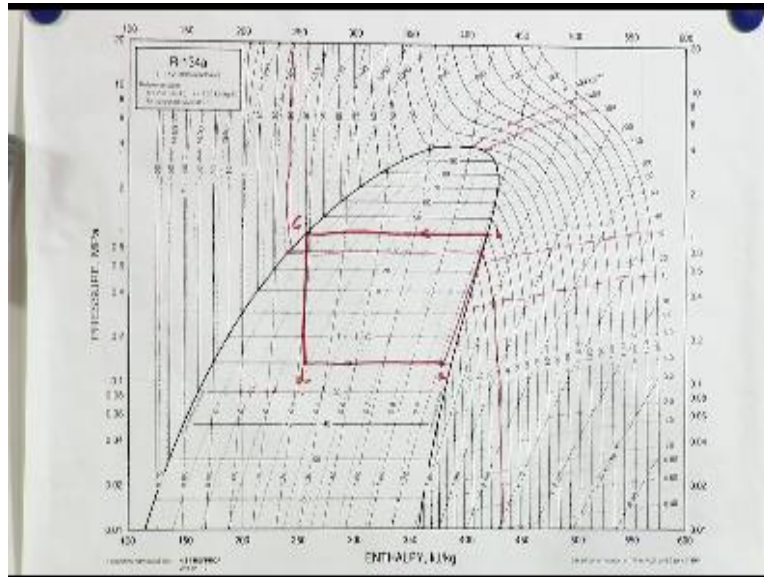
So this slope of this line has to be minimum, in which case it is going to be minimum when we draw a tangent from here, if we draw a tangent from here, then this point, this is 2M this point and then we draw a vertical from here this is 1m. Now process 1M to 2M, if we adobe the cycle or if we modify the cycle as 1M, 2M and then 3 and then 4 and then 1M. In this case this cycle will give the highest COP.

Reason be  $H_2 - H_4 / \Delta S$  is minimum in this case. Now if you further increase the quality, we can come up to here, then we will be getting 1S from 1S to 2S, but in this case, so this value of 1M is different for different refrigerants. In some of the refrigerants like ammonia or R22 it is in the wet region, in some of the refrigerant it is in super heated region like R134A but event construction is has limitation, it is varied up to saturation state.

So if we look at the R134A we will find as we are going from this point to this point the COP of the cycle is increasing, because for R134A the maximum COP is attained when the vapour is super heated. So that process is I am not covering the process here instead of that I would like to cover the effect of operating parameters or the performance of the cycle. Now we are very well

familiar with the vapour compression cycle. Now we will discuss effect of different operating parameters on vapour compression cycle.

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Now a vapour compression cycle on pressure enthalpy diagram is already shown here. In the previous lecture also we have amply discussed the pressure enthalpy diagram. But here I will like to again repeat it that in pressure enthalpy diagram on the vertical axis there is a pressure on mega pascal. This axis is on log scale on the horizontal axis there is enthalpy k.J.kg or a specific enthalpy.

There are horizontal lines which are constant pressure lines obviously they are vertical lines which are obviously constant enthalpy lines, there are certain inclined lines also, they are constant entropy line in this chart. This chart also has constant temperature line, for example -30, so -30 this is a almost vertical, this is not vertical, but almost vertical, then it becomes horizontal because during phase change the temperature remains constant.

This thick line curve, this curve is saturation curve, beyond this side, beyond this on this, this side of the curve there is super heated vapour, on this side of the curve there is a cool liquid, on this curve on the left on this side of the curve there is saturated liquid, on this side of the curve

there is saturated vapour, and the both the curves are joining here this is a critical point, beyond critical point there is no liquid phase.

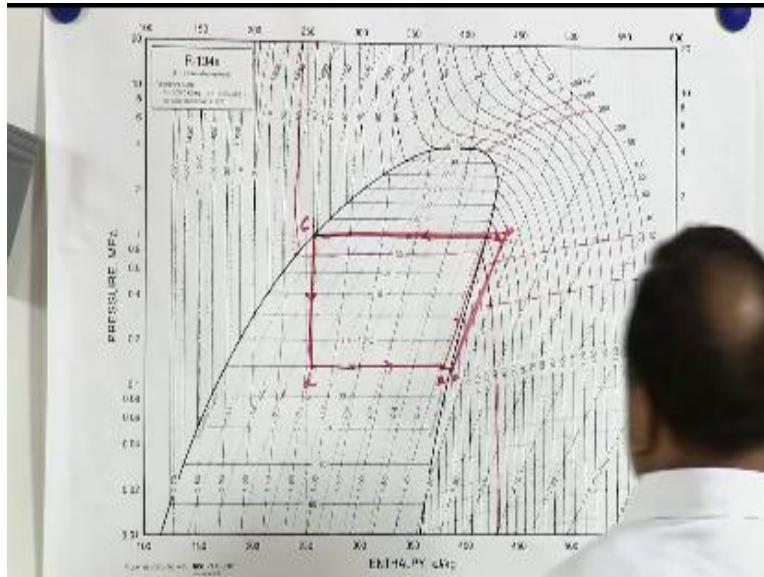
Now this is a typical cycle which is shown here having, I mean right section so after the compression the vapour is saturated, condenser temperature is  $40^{\circ}\text{C}$  the evaporator temperature is  $-20^{\circ}\text{C}$ .

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Now here in this case if I reduce the temperature instead of  $20^{\circ}\text{C}$  temperature, if I reduce the condenser temperature or condenser pressure to  $-30^{\circ}\text{C}$ , it means now before doing that.

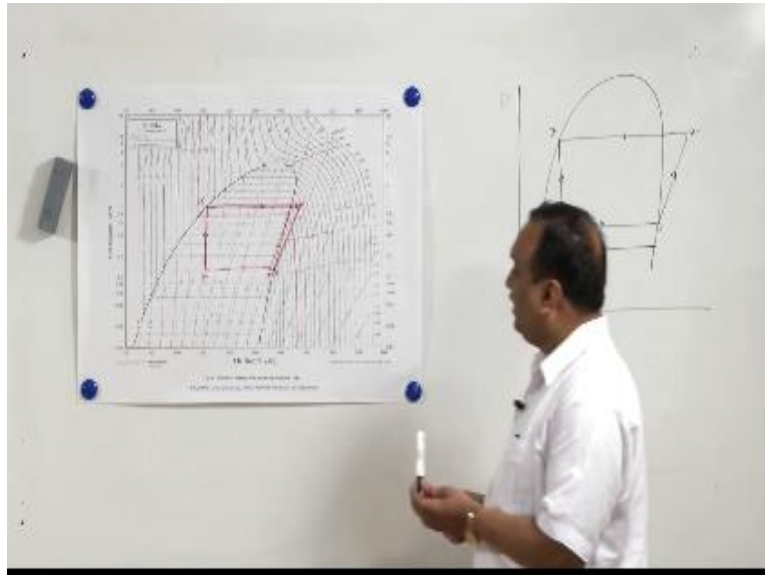
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I would like to take a cycle which has vapour saturated vapour at the section of this compressor, so we are going to get this. So B will be shifted here, A will be shifted here. So this is going to be the cycle which we are going to analyze. In this cycle the vapour is saturated at the section of the compressor, after the compression the vapour is super heated, condensed up to the saturated liquid and isenthalpic expansion takes place during process C to D.

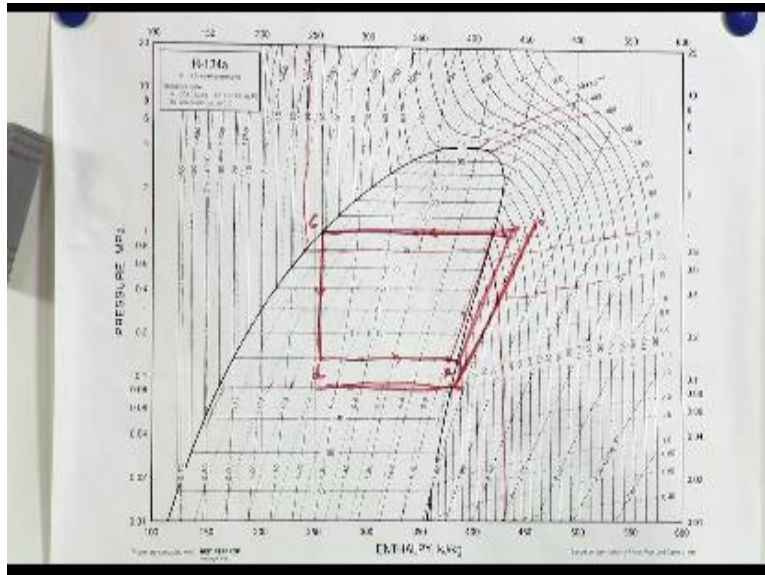


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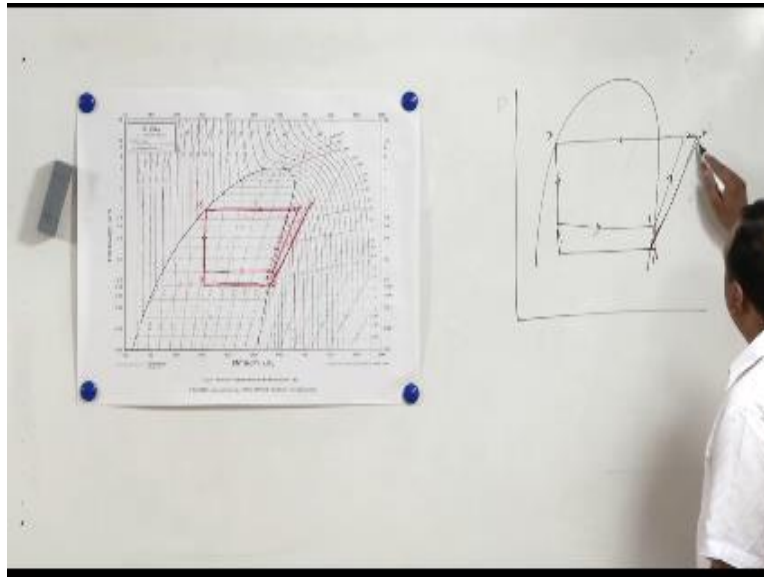
Now if I transform this cycle on PH diagram or in a separate diagram it is going to be like this. Now in this process suppose I reduce the evaporator pressure correspondingly the temperature will also get reduced. Now if I reduce the evaporator pressure in that case what is going to happen, in that case we are losing this much of refrigerating effect.

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The length of this line will reduce, so if I extend it up to 30°C then we will be losing this much of refrigerating effect. So when we reduce the condenser pressure sorry, evaporator pressure the refrigerating effect is reduced. That is first thing, now the second thing is what about the compressor work, since we have reduced the evaporator pressure that compression process will be shifted to this one. Now B will be shifted here, B will be shifted here if I show it here then it is going to be like this.

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This is 1 this is 1' now you can see from here itself the compressor work has also increased when we reduce the evaporator pressure. So when we reduce the evaporator pressure we are loser at both ends. First the refrigerating effect is reduced, refrigerating earlier it was 41 here now 41 has shifted to 41', so 1 has shifted to here 1' so refrigerating effect has reduced, at the same time the compressor work has increased. So we are loser at both the ends and COP of the cycle has to go down or it will definitely reduce in this case. Now the third is when we reduce the pressure the density of the liquid is also reduced.

If you look at the density here, it is approximately 6.5, at  $-20^{\circ}\text{C}$ , approximately, this is  $6 \text{ Kg/m}^3$ , this is  $8 \text{ Kg/m}^3$ , so it is approximately, 6.5 or 6.3, but when we reduce the pressure, the density will also reduce. It is drastically reduced; it will reduce to 4.5 to 4.3.

When density of the liquid which is entering the compressor is reduced, volume of the compressor is constant, volume of the compressor is constant, when the density of the liquid entering the compressor is reduced, the mass of the refrigerant which is entering the compressor is reduced, when the mass of the compressor entering the compressor is reduced, it means mass

of the refrigerant, which is being circulated, in the cycle, is also reduced, and that will also reduce, subsequently which will also reduce the refrigerating effect.

So when the evaporator pressure is reduced, in that case the refrigerating effect is reduced, compressor work is increased, mass of the refrigerant which is being circulated in the cycle is also reduced, due to change in density, and further if you look at the expression, of volumetric efficiency of the cycle, that is  $1 - \epsilon(P_2/P_1)^{1/n-1}$ . Now if you look at this expression, if we increase the pressure ratio, the volumetric efficiency is also be reduce.

So here in this case, if we reduce the pressure, evaporator pressure the volumetric efficiency will reduce, so we are looser at all the friends, we are looser at all the friends, refrigerating effect is decreasing, and pressure is this volumetric efficiency is decreasing, work ensured by the compressor is increasing.

So we are looser at all the friends, that is why in any case if the pressure of the evaporator is reduced, the performance of the system decorates, now the second case, when the pressure of the condition rises, when the pressure of the ten denser rises, now let us take again original, cycle, now instead of reducing the pressure of the, we evaporator, the pressure of the tendency increased.

When the pressure of the tendency increased, here, compressor will consume, more power, compressor will consume more power, this is the additional power which is going to be consumed by the compressor, at the same time refrigerating effect will be reduced, earlier you are getting 41, now we will be getting 4`1, so when we increased the condenser pressure, the refrigerating effect is reduced, and the compressor work is increased again to COP of the system will be reduced.

That can be shown here also, so instead of 40 suppose it is compressed to 50, 50<sup>0</sup>, so when we touch the 50<sup>0</sup>, then here you can see the refrigerating effect it will reduce, earlier we are getting refrigerating out of this , now we are getting refrigerating effect out of this process, and at the

same time sorry! Yes, here, we are getting refrigerating out of this process, earlier we are getting out of this, and at the same time compressor work is also increased.

Now the third case, if we super heat the gas, instead of taking saturated vapour if we super heat the gas, if we super heat the gas, and then during super heating in this process, the refrigerating effect will increase, because the gas which is coming out of the, evaporator is super heated and at the same time compression will also increase.

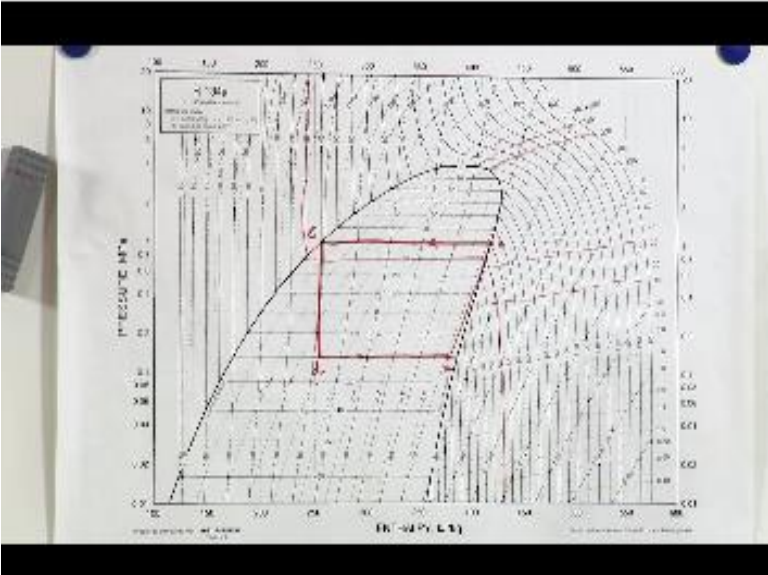
At the same time the compression work will also increase, in compression 2, this 2, 1` 2`, in compression 2, the process went to 2, so in 1` 2` process the work will be more, then process, 1 to 2, so but in super heat, the COP of this system may increase, or may not increased, it depends, I have told you earlier, also if you look at the evicts construction, for some of the refrigeration, like R20 ammonia, the maximum COP vapour is wet at the suction of the compressor, and for refrigerant R1 34A.

It has been found when the vapour is, slightly super heated, the COP is maximum, now the fourth operating parameter can be sub cooling of the liquid, if we do sub cooling of the liquid, by external means, if we are able to do sub cooling of the liquid through external means, definitely, refrigerating effect will increase, because, this cooling let us say 40<sup>0</sup>C, the vapour is sub cooled.

So now this sub cooling we are getting, free of cost it is done with the external means, however as i stated in my previous lecture, this sub cooling can be then attain by, super heating the vapour, from coming from the evaporator. In this case again for getting this sub cooling, we are super heating here, and more power will be consuming by the compressor, so if we are doing super heating with the help of vapour coming out of the evaporator.

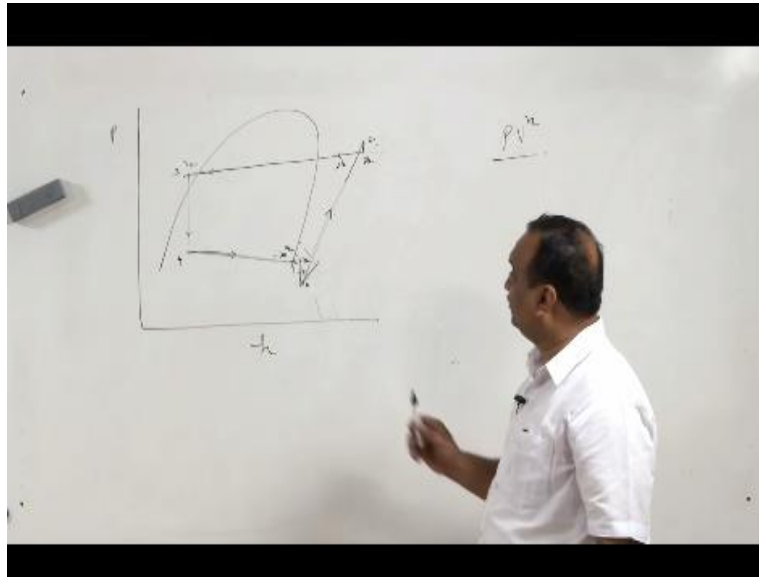
In that case we are getting more refrigerating effect, and at the same time, more power will be consumed by the compressor. Now after this, I will take up vapour compression cycle with irreversible, because the actual cycle, in actual cycle the process are not reversible, all the process are irreversible.

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At that is very important to understand, how the system behaves, actual practices, let us transform the,

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Vapour compression cycle on pressure and enthalpy diagram, and will start from the point, where, the vapour emergence from , the evaporator, now evaporator is connected to the compressor through a pipe line, and vapour which is coming from the evaporator, is approximately at, let us say , if evaporator temperature is  $-20^{\circ}\text{C}$ , so this vapour is at  $-20^{\circ}\text{C}$ , right.

This is state 1, but when the vapour enters the compressor, it picks heat from the surroundings, and it gets super heated, so vapour will get super heated, so we will get.  $1'$ , right. Now this is constant temperature lines so  $-20$  may be, it may attain  $-18^{\circ}\text{C}$ , okay, now this super heated vapour, enters the compressor.

And during this process, flow of vapour from the exit of the evaporator, to the entry of the compressor, there is a friction loss, so there is a friction loss, in the pipe line, so we get  $A''$ , further when the vapour is entering the compressor, there is a pressure drop, across the compressor volume, because when the vapour is entering the compressor, pressure in the pipe line is higher than the pressure inside the compressor.

So this pressure drop, takes place across the compressor valve, and we get let us take A1a, A1, A1, A A, sorry! 1A, 1B, so we get state 1B, I am repeating here, that vapour coming from the evaporator is saturated, in the pipe line connecting the evaporator to the compressor, the vapour get super heated, right.

We get state 1 A, then there is a pressure drop in the pipe line, we get 1B due to friction, and then here we get 1C, inside the compressor, because that is a pressure drop across the compressor valve also, now compression takes place and this compression is also not, isentropic, there is a poly tropic compressor.

In polytropic compression, there is a curve, there is it is  $Pv^n$  , and during this process heat transfer also takes place, earlier we have assume that is the isentropic compression there is no heat transfer, across the boundaries of the compressor, but in the process, 1 to 2, let us say 2, the heat transfer takes place, across the boundary of the compressor.

Now after this polytropic process, this the vapour come out of the compressor, the vapour comes out of the compressor, and this is condensed pressure, so the pressure inside the compressor or at the exit of the compressor, should be higher than the compressed, higher than the pressure, in the line, pipe line which is connecting the condenses, otherwise the vapour will not go into the pipeline.

So this pressure, so the pressure at the exit of the compressor can be denoted by 2, and pressure drop takes place, across the compressor valve. And this line is not a horizontal line it is a inclined because, the pressure drop takes place during this process, 2` to 3, now the vapour coming out of the compressor is at high temperature.

So when it enters the pipe line, when it enters the pipe line some amount of cooling takes place inside the pipeline itself, because the vapour is at the high temperature and after this we get, this is 2A, and we get 2B, from 2B to 3, the condensation takes place, and during this process also there is a pressure drop, right.



Normally we don't get saturated, vapour at the exit of the consist, normally it is sub cooled, so we will go to the sub cooling state, this is 3, now at 3, when vapour comes out of the condenser, right, it is in liquid state, it is in liquid state, and expansion takes place, inside an expansion valve, right.

So expansion takes place inside an expansion valve, and we get state 4, and the pressure of the state 4 is have the pressure of the state 1, it is also possible that some heat it may the liquid may fix some heat from the surroundings, and some heating takes place and we get, instead of 3 we get 3A here.

Expansion takes place in a an expansion device, and then 4 to 1 , process 4 to 1, again the pressure drops takes place in process 4 to 1, now here in the both the cases evaporator and the condenser the pressure drop is taking place, but in 4 to 1, pressure drop is more severe, or more of concern.

Because here the pressure drop is , due to friction the friction, friction in the fluke, and there is a pressure drop due to momentum also because, the vapour is getting vaporized, and the fluid is picking up the kinetic energy, and it is picking up the kinetic energy, at the expansion of the enthalpy of the flute, right.

So we have humility effect and there is a large pressure drop, in evaporator, however in the case of condenser, condensation is taking place, or the kinetic energy of the fluid is reducing, which is being converted to the pressure energy, pressure should rise here, but at the same time, pressure loss is taking place due to friction, okay.

So both this effects are compensating each other, and sometimes it happens that, there is a pressure rise in the condenser, normally it does not happen, but this can also happen, there is a pressure rise in the condenser, it means the conversation of the kinetic energy to the pressure energy is more than the loss in the friction, of loss of pressure during the friction.

However in the case of evaporator, the pressure loss they have cumulative effect, and there is a substation pressure drop, and it effects the performance of the system, also because the T4. These are two different temperatures, suppose this is -20, this be -15, so this also empower the performance of the system.

But this is the actual vapour compression cycle, and that is why the actual vapours compression cycle has COP much lower than the COP of an ideal vapour compression cycle, so we have discuss the real or the actual vapour compression cycle with the reversibility's, we have completed the vapour compression cycle with irreversibility. And now in the next class, we will go for a multi compression system with inter cooling.

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