Engineering Thermodynamics
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Module 7
Lecture No 50
Refrigeration Cycles

Okay Welcome back we are going to start a new topic. it is on refrigeration cycle okay.

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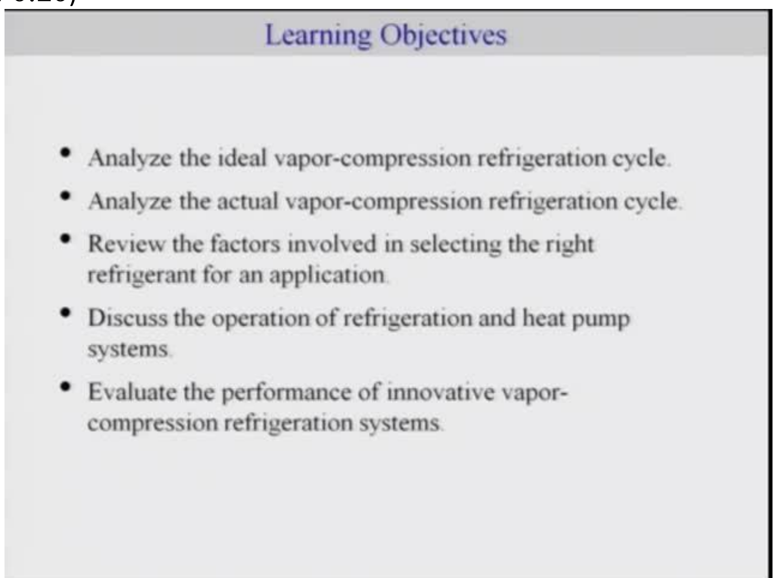

So in this particular topic, we are going to analyze refrigeration cycle based on vapour compression and other factors related to that.

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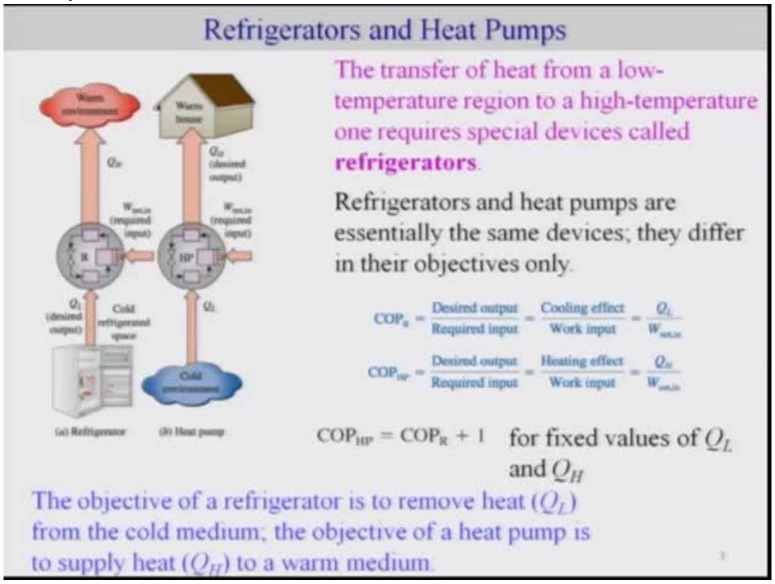

So let me start with the definition again with the refrigerator and heat pumps. So the refrigerator basically comes from the fact that it is utility is to transfer the heat from a low temperature region to high temperature region and it cannot be done due to the second law constraints and hence you need a specific device that is your refrigerator. The refrigerator and heat pumps are essentially the same devices and they differ in the objectives only.

The refrigerator is mainly to have a cooling effect and thus desired output is the cooling effect whereas the heat pump desired output heating effect okay. So objective of refrigerator is to remove the heat from the cold medium and the objective of the heat pump is to supply heat to warm medium okay and we have already discussed in our previous lectures the definition of coefficient of performance for refrigerator and heat pump okay.

So how do you operate refrigerator in a heat pump okay in as we discussed for the case of the vapor power cycle we can start with basic idea of a Carnot cycle and in this case, it will be a reverse Carnot cycle. So we can look at the the basic philosophy of making use of a refrigeration cycle based on reverse Carnot cycle.

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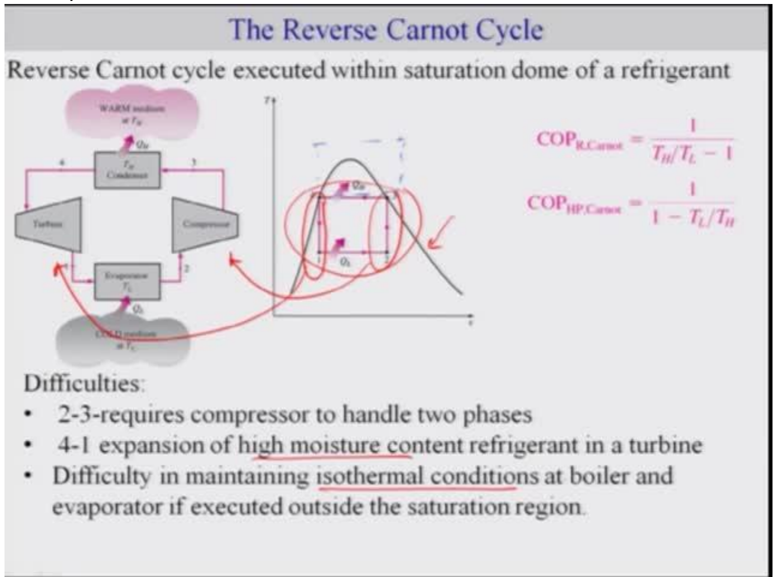

Now we know that for the Carnot cycle yield the maximum thermal efficiency for a give temperature limit and thus our idea here to make use of Carnot cycle as a standard. Okay and we can use this refrigerant okay saturation dome and this is our Carnot cycle okay. So this is your Carnot cycle. So of course the cycle has an evaporator, compressor followed by condenser and the turbine. So this is reverse process or reverse cycles compared to that for power cycle.

Now there are certain problems and the problems are almost similar as we have noticed in our discussion of vapor powers cycle that for the case of 2-3 which is nothing but your compression okay and if you operate your Carnot cycle within the saturated dome of refrigerant then you have to worry about the handling the 2 phase system within the compressor okay and that is one aspect of the problem.

The other aspect is that that when you consider a turbine, a turbine has difficulty in expanding mixtures and that will be the case for 4-1 so 4-1 expansion of high moisture conten is the concern, it is difficult to do that okay so we might like to change this Carnot cycle such that some part operate outside the saturation dome but the difficulties are same as we have observed for vapor power cycle.

So for example that if you want to maintain the isothermal condition at the boiler and evaporator, it will become difficult when you operate for example in this kind of situation where some part is outside okay such as condenser okay.

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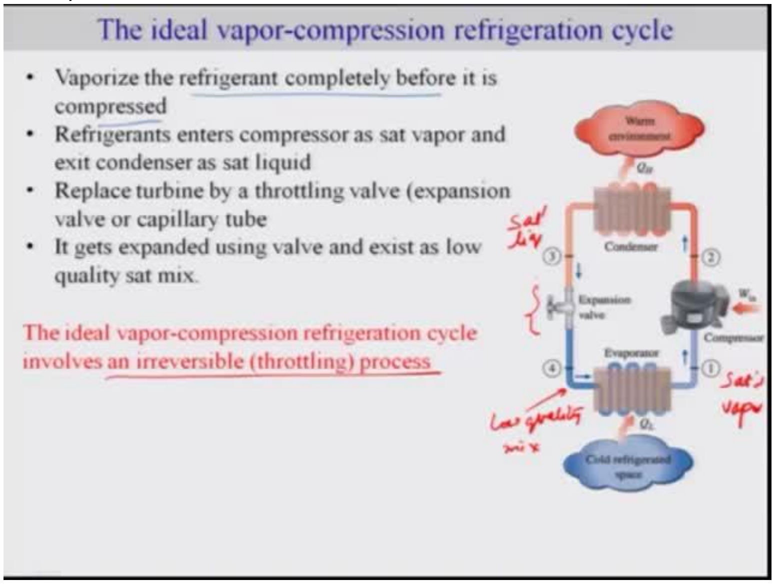

So what is the alternative to get rid of all these issues and the one, couple of things which we can do is to completely vaporize the refrigerant okay before it gets to compressor okay which essentially means that what we can do that this here would be a saturated vapor okay. And now this is compressed okay, goes to superheated vapor and this would be completely condensed liquid. And we can replace turbine by expansion valve and this here would be your low quality mixture okay.

So what we did was that we avoided the issue with the compressor by considering saturated vapor okay compressing to hot superheated vapor and then we also avoided the issue of turbine where we replaced the turbine which is more costly by an expansion valve okay and this expansion and the purpose of making use of expansion can be utilized by an expansion valve as well okay.

So this would be your ideal vapor compression refrigerator cycle okay. It should be noted that this will involve certain friction ok and hence this cycle which involves the expansion valve is a irreversible process or irreversible cycle okay.

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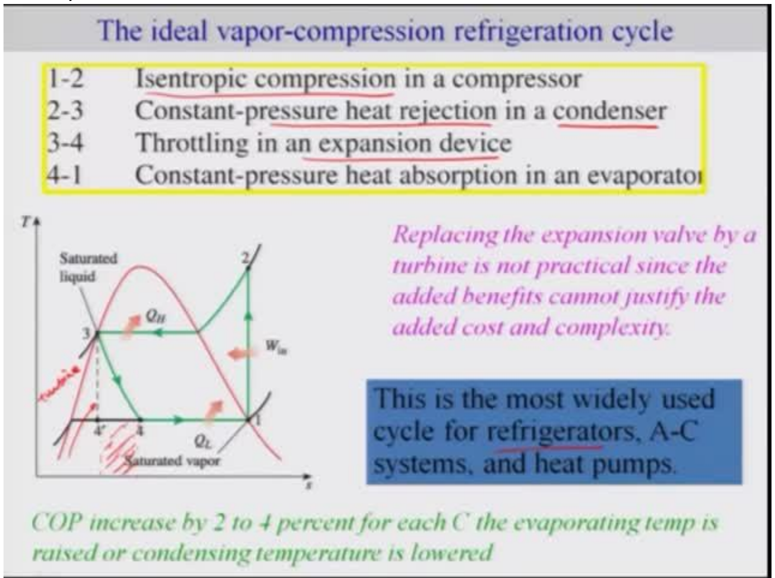

So let me summarize what we discussed so we are going to vaporize completely before the refrigerant enters the compressor and then we will undergo the isentropic using the compressor. So if you put down the processes on a T-S diagram, this is how it is going to look like. So you have 1 to 2 is isentropic compression okay, followed by a constant pressure heat rejection in a condenser. So this is 2 to 3 and this is at saturated liquid okay and then it undergoes a throttling process 2 to 4 okay in the expansion device followed by constant pressure heat absorption in an evaporator.

So 4 to 1 is constant, that is how this whole cycle is. Now you may think that you know making use of turbine so if you use the turbine, of course it is going to be isentropic. And an ideal turbine will undergo isentropic expansion, that will be your 4 to 3. So this will be for your turbine if you use turbin. So that way we can increase the heat kind of the heat extraction from the evaporator that means QL will be more if you have used the turbine but the added benefit cannot justify the cost and the complexity of making use of turbine and thus expansion valves are typically used for more practical reasons okay.

So this particular ideal vapor compression refrigeration cycle is a commonly used for refrigerator, air conditioned system and heat pumps. Now it should be noted that the coefficient of performance increases by 2 to 4% for every each small change or degree Celsius, the evaporating temperature is raised or condensing temperature is lowered. So that is based on the analysis.

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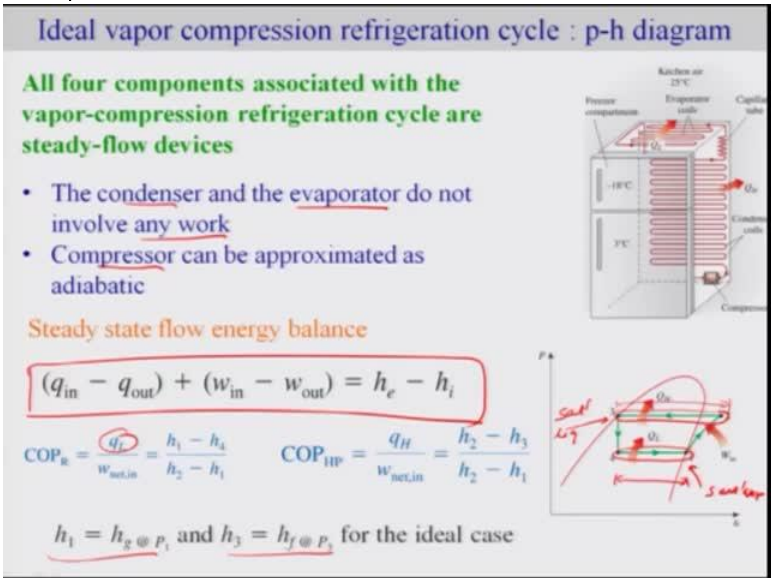

So we can start with the analysis a bit. So there are 4 components in this vapor compression refrigeration cycle okay and we are going to consider that to be a steady flow devices and one can write complete energy balance of that. As we know the condenser and evaporator will not involve any work and we are going to consider compressor is adiabatic, considering that, a steady state energy balance would be simply this okay.

So Qin minus Qout plus Win minus Wout and that will be your simply H exit minus HI or change in enthalpy. So you can apply this steady flow energy balance for each of the devices. Now what about the coefficient of the performance for the refrigerator? That will be your QL divided by Wnet in. One can also describe this ideal vapor compression refrigerant cycle not only this the TS diagram but as well as also on PS diagram.

The reason being that if you are using throttling process then of course H is constant so considering that when you make use of a PH diagram, your 3 lines are going to be straight line and their energy transfer is is directly related to the length of this process. Now this will represent the amount okay of the heat transmitted or rejected. So that length becomes quite you can directly relate to that and of course we have 3 lines which are straight lines.

Now making use of this information, one can find out your COPR, the QL is nothing but your H1 minus H4 which will be your this in H1 minus H4 and Wnet is of course your change in an enthalpy across the compressor which is S2 minus H1 okay and similarly COP, H would be your QH will be S2 minus S3. Okay so that would be your this divided by Wnet okay.

Now for the case of ideal conditions, of course, you are assuming that before entering the compressor, you have saturated vapor okay and after the condenser, the exit fluid or the refrigerant is at saturated liquid condition. So this would be your saturated liquid and thus your H1 can be approximated to HG at P1 and or H1 can be simply written as HG at P1 and H3 is nothing but H of fluid liquid at P3 okay. So that will be saturated condition.

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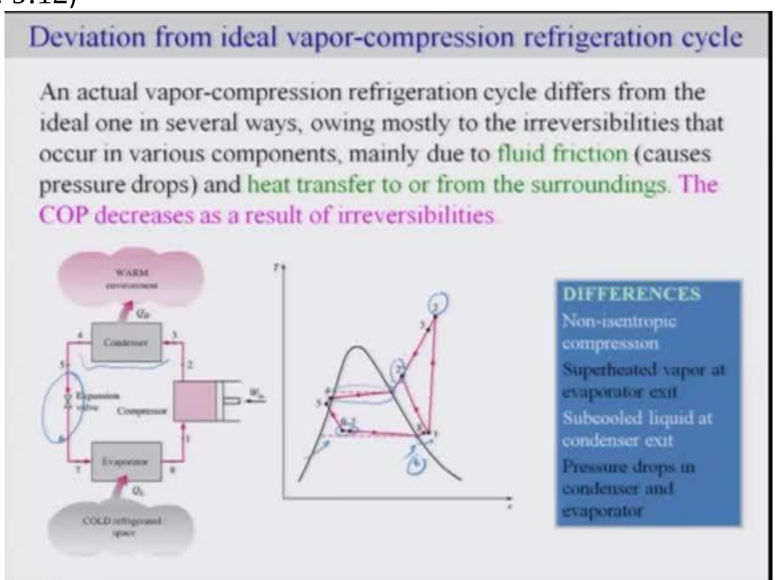

Okay but the reality is that there will be a certain deviation from the ideal vapor compression refrigeration cycle and this is mainly because of the fluid friction which would be across the pipe and as well as the heat transfer from or to the surrounding. Okay there will be changes on the process diagram. so this is your again the TS diagram and if you recall that the what we consider earlier for the ideal conditions, 1 was here right, for the practical or the real scenario, this is going to be difficult because this, there may be a loss in the pressure and so forth hence it is more useful to little bit superheat before it enters the compressor.

And at compressor there could be a friction or there could be heat transfer. So the friction would of course increase the entropy. For heat transfer can increase or decrease the entropy. If it is from the system to surrounding, the entropy of the system decreases and otherwise it will increase if the heat is transferred from the surrounding thus it can end it at 2 or 2 dash depending on which one dominates.

Now there could be pressure drop okay across the condenser and the pipes. So you can so this pressure may not be constant okay.And it may also sub cool at 5 and beside also, there could be a pressure drop across here. So it may not reach at at the condenser pressure. So thus it may exit at 6 okay to the 7. So that is what your 6 and 7 are. Okay so this is overall process and this process clearly indicates lot of irreversibility can be on the real cycle okay. And so typically when we are going to solve problems, we may be considering some some idealization and some non idealization.

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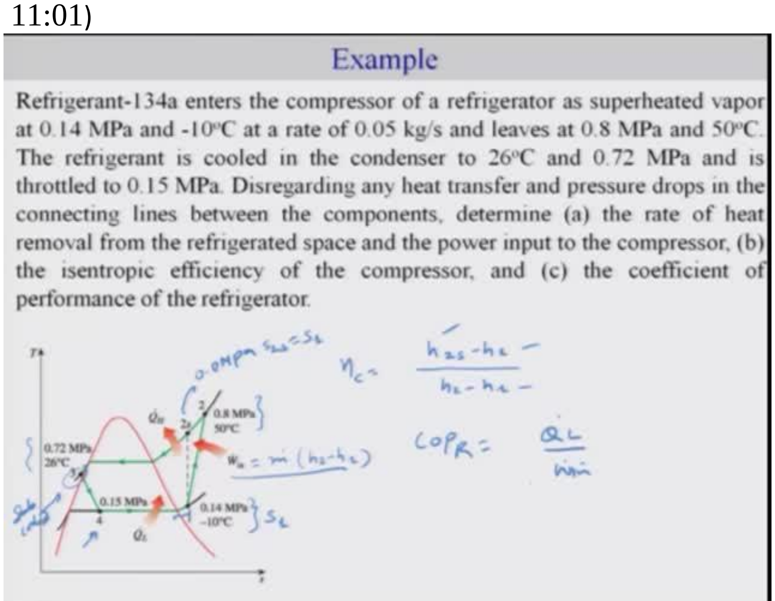

So we can illustrate one example okay where we have considered isentropic process of for the case of compressor and as well as irreversibility associated with it. So this is an example of vapor compression refrigeration cycle where the refrigerant is slightly superheated. Okay note that here it is slightly super heated at the compressor inlet okay and then of course here the entropy increases so it is not isentropic due to the irreversibility and at the condenser exit which is slightly sub cooled. So this is sub cooled okay.

So it is not that saturated liquid condition and of course the compressor is not isentropic. So one need to find out the isentropic efficiency and the coefficient for performance for the refrigeration and as well as the rate of heat removal from the refrigerant space okay, that is QH. So one can of course use the QH in terms of enthalpy. So this would be your work would be simply M dot S2 minus H1 okay. And your one can look at the tables to find out because you have all the information available okay.

So one can find out the enthalpies at each point. So what about your isentropic efficiency? this will your H2S minus H1 and S2 minus H1 so this compare so this is ideal case and this is your the case as in your problem statement. So one can find out this because you know this entropy, you know your the pressure here, the pressure is known, 0.8 megapascal and as well as the entropy is known here S1. So this is going to S 2S is nothing but S1 but from here, one can find out H2S okay and similarly H1 is known, S2 is known considering that U has been given 0.8 megaspacal and 50 degree Celsius. So you know your isentropic efficiency of the compressor.

Also find out CP, COPR which is nothing but Q dot L and Win okay. Q dot L is nothing but your enthalpy change from H1 and H4. So one can find out H4 as well okay and Win is nothing but your this information. So one can make use of this simple exercise in order to find out the necessary questions or the questions of the address the questions as an example okay. So this is a brief kind of example which we wanted to try before moving ahead with questions that how to select right refrigerant.

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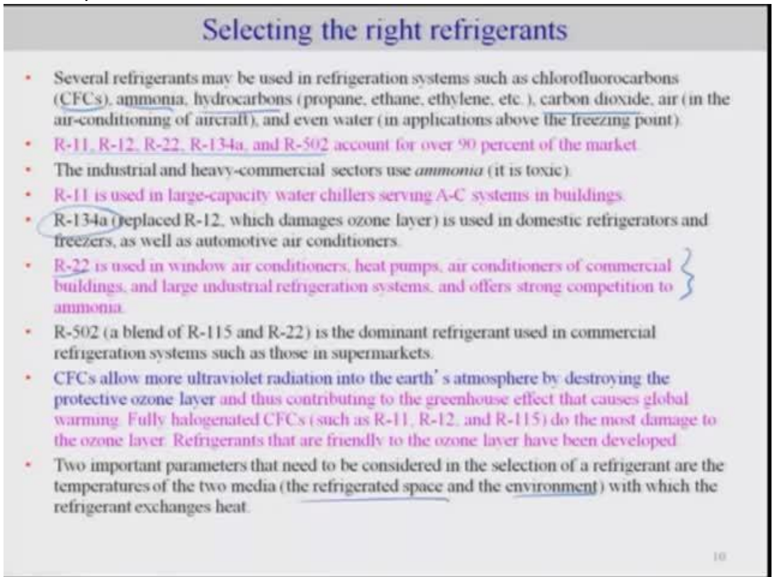

If you look at the kind of refrigerant used, there are wide variety of refrigerant. Of course the refrigerant can cause some severe environment and thus during this course of last few decades, the variety of different refrigerants has been selected. And you can see refrigeration systems may have refrigerants such as your family or family such as your chloro floro carbons ammonia okay which is toxics, hydrocarbons, carbon dioxide, air and even water okay but most of the market is composed of very selected refrigerants which is specialized refrigerants okay.

Uh but this R121 which was commonly used earlier in domestic refrigerant is not being replaced by R134A. Again the set of molecules which are, these are nothing but representing a set of a molecules with some additives and so forth. Okay what is the commonly refrigerant is R22 which commonly used for your conditioner and of course there are many other refrigerants depending on the conditions so 2 important parameters which are being selected usually is the temperature of the 2 media, that is the refrigerant space and the environment with which the refrigerant exchange heat.

So before selecting a refrigerant one need to see the type of applications and based on that, one need to find out the right kind of refrigerant which has the phase diagram where you can make use of your your ideal vapor compression refrigeration cycle okay.

So thus this allows one to manipulate a bit in terms of molecules. Of course there are environmental concerns and hence one need to careful about selecting the refrigerator okay.

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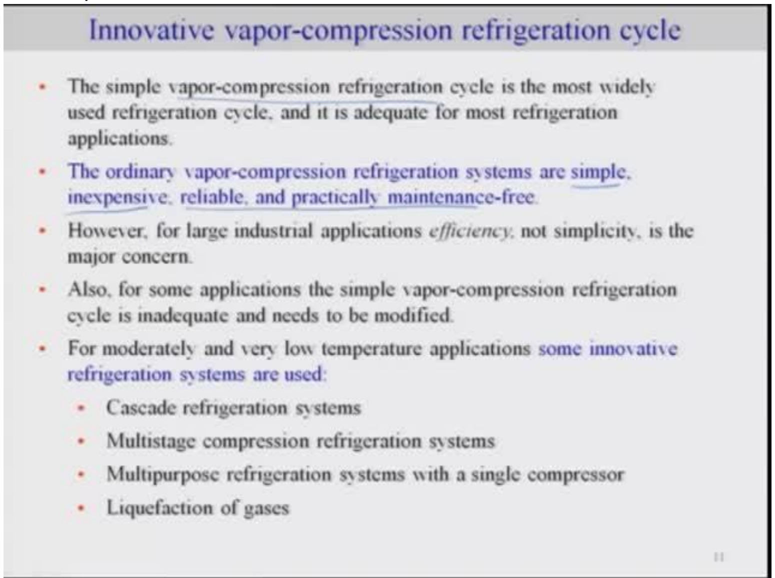

Now, the other thing is that though the refrigeration cycle which was used as described in terms of vapor compression refrigeration cycle, it turns out to be they are quite sufficient in most of the applications okay and thus is commonly used because of simple reasons such as inexpensive. it is simple to implementation, reliable and the practical maintenance are free.

Okay but for industrial application simplicity is not the required, it is the efficiency which is the most important aspect in terms of the usage of any specific process or the design or the cycle in this case okay. thus the industry look for more innovative systems and the examples are cascade refrigeration systems, multistage compression and liquefaction, there is a absorption kind of a refrigeration cycle and there are many other variant of that. So we won’t go into details of all this modification.

Okay the idea is to simply understand that you can modify it okay in order to achieve more efficiency and this is something which we can illustrate by simple example.

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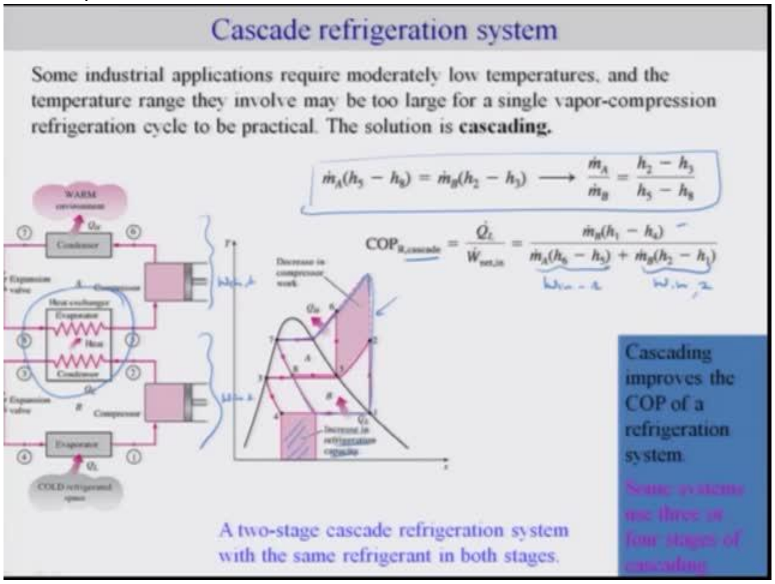

Now this example is on cascade refrigeration system okay and here what is done is that you have topping cycle and there is a bottoming cycle okay. That means 1 cycle and this is another cycle. Okay. Both are kind of a refrigeration cycle okay where one of the top is an evaporator and the other, the bottom one, whatever the heat condenser is losing heat is taken by the evaporator.

So in another word, it acts like a heat exchanger okay both of them together and whatever the heat being exchanged is balanced. That means considering no losses here,one can write simple equations here where one can balance heat. So by doing this one can think of how this has become more efficient by considering such cycle. let us consider this particular bottoming cycle is 1, 2. So that means here 1, 2 and this 3, 4 so 1, 2 and 3 and 4 so this is the cycle here okay.

If you had not used this then you would be considering something like this. You know you will be let us say assuming that you have just 1 cycle so the effective cycle would have been this okay. So this blue curve would have been effective cycle where the effective(())(17:46) would have been this one and this would be in the compressor.

But now by considering to cycle, what you did is you have increased so you have you went to the low temperature here okay. So this is your 3 here by reducing the temperature at this particular stage, you have also increased this refrigeration cycle which is nothing but your the amount heat which you have extracted because this is nothing but TDS okay.So this is the amount which is additional amount of effectively additional amount of your QL which is being evaporated from the cold refrigeration cycle okay.

And the other thing which you did by having a small cycle on top okay is that this effective compressive work has also been reduced okay. So if you had taken this blue color then essentially you would have also included this additional part in the compressor work but now with this modification okay you have reduced this work.So of course there is, one has to look into the other thing that you have to include some additional devices here but it turns out that this becomes more efficient okay by increasing the refrigeration cycle and by decreasing the compressor work would mean that the COPR would be much higher okay where COPR is nothing but QL which is nothing but again your 4 to 1 uhMH1 minus H4 multiplied by the flow rate and this 2 work here, work for this one so Win net in 1 and this is Win 2 so that will be your, that is your Win 1 and Win 2 okay.

Now it turns out that this be due to the efficiency of such a cascading kind of refrigeration cycle, there are systems which uses more than 3 also okay okay, or more than 2 and 3 as well. So this is a simple exercise which tells you that there is alternative ways of modifying the refrigeration system in order to increase the efficiency. So it just play with the phase diagram or play with this you know how to make use of the temperature and as well as one can think of using different refrigerant where this could be efficient.

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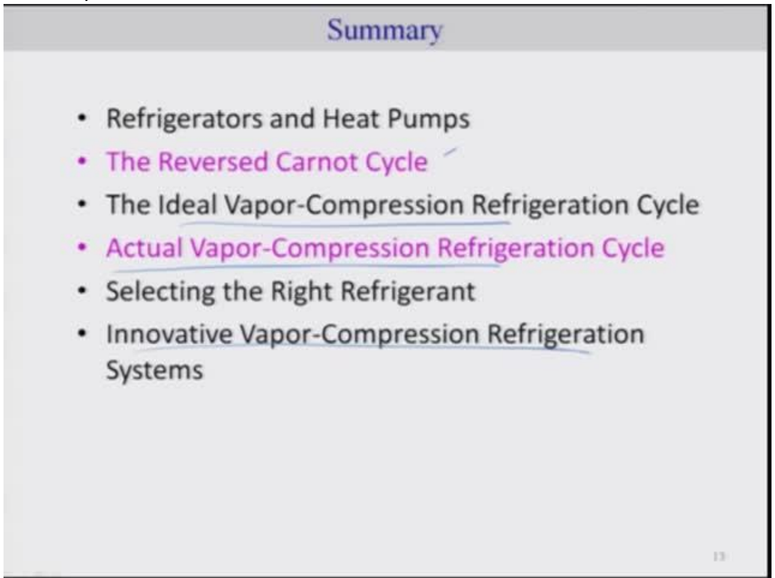

So this is the the overall summary what we have gone throughUh it is a short discussion on the refrigeration system because more or less it is a similar to power cycle vapor power cycle okay. The only thing is it is based on the reverse cycles okay. So we have gone through the basic idea of reverse Carnot cycle and you the why this is not suitable for refrigeration and heat pumps and the ideal vapor compression refrigeration cycle is what we consider where we vaporize the completely the refrigerant before entering it to compressor and what is the typical actual vapor compression refrigeration cycle and the the refrigeration itself refrigerant, variety of refrigerant.

Now one need to think about the type selected correctly based on the application okay and and the in the end there is a lot of prospect of innovating vapor compression refrigeration cycle and one example we illustrated using cascading but there are many examples which one can look at it and try to modify in order to have higher COPR okay. So that will be the end of it. In the next lecture we will start new topic on thermodynamic property relations okay. So I will see you in the next lecture.