Refrigeration and Air Conditioning

Prof. M. Ramgopal
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture No. # 11

Vapour Compression Refrigeration Systems (Contd.)

(Refer Slide Time: 00:00:42 min)

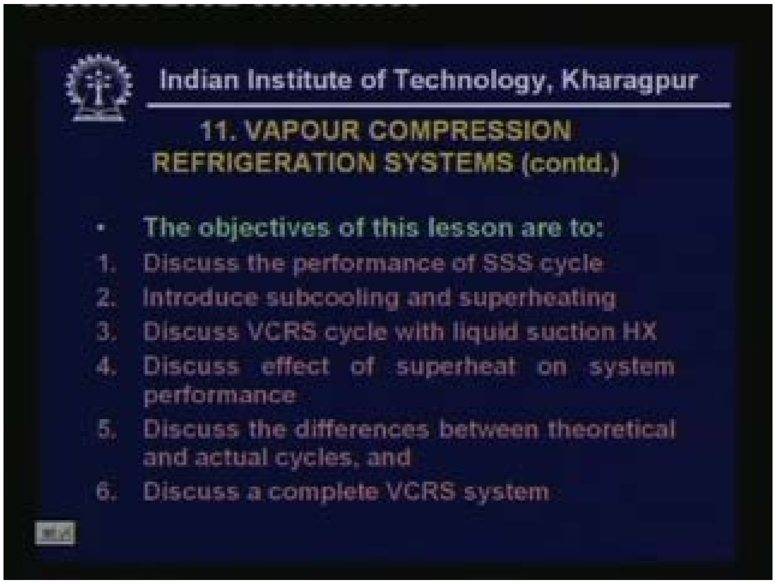
Lecture No. # 11

Vapour Compression
Refrigeration Systems(Contd.)

Welcome back, this lecture is a continuation of last lecture wherein we introduced vapour compression refrigeration systems and we discussed saturated single stage standard cycle. That is SSS cycle and we compared the performance of that cycle with an ideal Carnot vapour compression refrigeration system and we have also given some basic equations for evaluating the performance of this system. So we will continue in this lecture starting with the performance aspects of SSS cycle and we will also discuss the various modifications to the standard cycle.

So the specific objectives of this particular lesson are to discuss the performance of SSS cycle introduce sub cooling and superheating discuss vapour compression refrigeration system with liquids suction heat exchanger, discuss effect of superheat on system performance discuss the differences between theoretical and actual cycles and discuss a complete vapour compression refrigeration system.

(Refer Slide Time: 00:01:26 min)



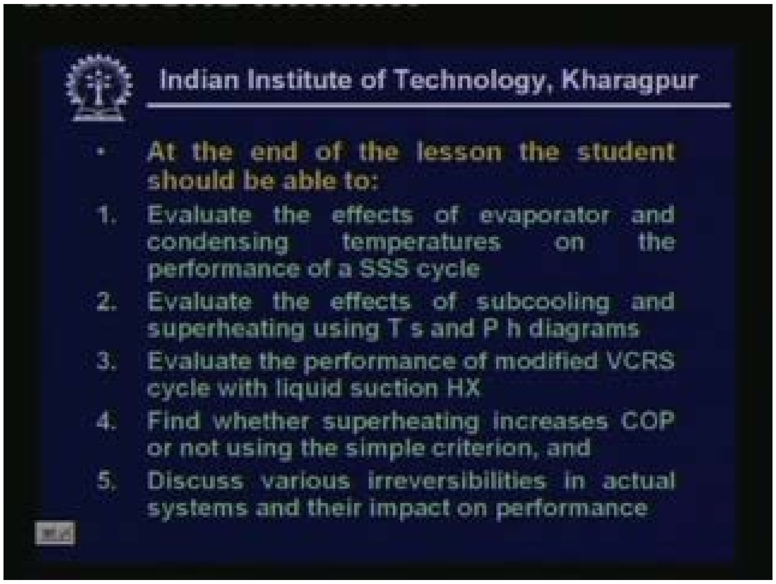
Indian Institute of Technology, Kharagpur

11. VAPOUR COMPRESSION REFRIGERATION SYSTEMS (contd.)

- The objectives of this lesson are to:

1. Discuss the performance of SSS cycle
2. Introduce subcooling and superheating
3. Discuss VCRS cycle with liquid suction HX
4. Discuss effect of superheat on system performance
5. Discuss the differences between theoretical and actual cycles, and
6. Discuss a complete VCRS system

(Refer Slide Time: 00:01:55 min)



Indian Institute of Technology, Kharagpur

- At the end of the lesson the student should be able to:

1. Evaluate the effects of evaporator and condensing temperatures on the performance of a SSS cycle
2. Evaluate the effects of subcooling and superheating using T s and P h diagrams
3. Evaluate the performance of modified VCRS cycle with liquid suction HX
4. Find whether superheating increases COP or not using the simple criterion, and
5. Discuss various irreversibilities in actual systems and their impact on performance

So at the end of this lesson you should be able to evaluate the effects of evaporator and condensing temperatures on the performance of a SSS cycle, evaluate the effects of sub cooling and superheating using T s and P h diagrams, evaluate the performance of modified vapour compression refrigeration system with liquid suction heat exchanger and find whether superheating increases COP or not using a simple criteria and discuss various irreversibility’s in actual systems and their impact on performance.

(Refer Slide Time: 00:02:27 min)

Indian Institute of Technology, Kharagpur

Performance of a SSS cycle

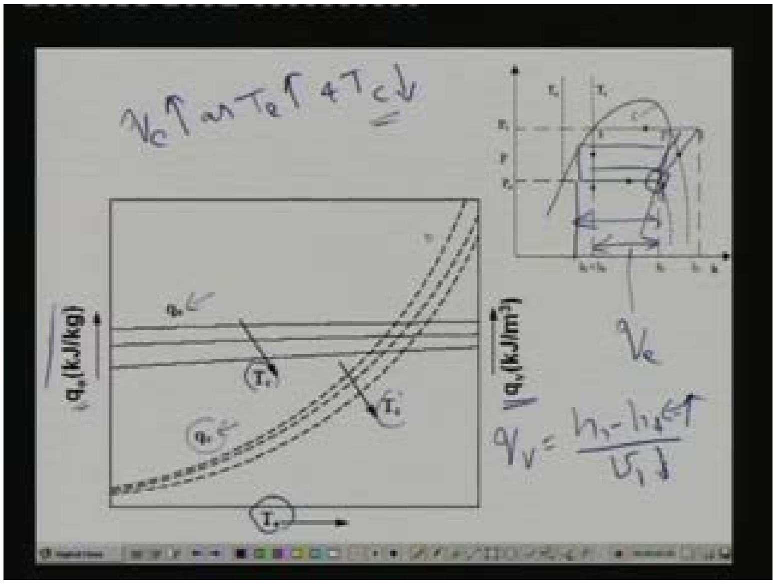
- System performance is obtained from the simple analysis presented earlier and using suitable property data
- Typical performance trends show the effects of evaporator and condenser temperatures on:

1. Specific and volumic refrigeration effects
2. Specific and volumic works of compression
3. System COP

So let us begin with a performance of SSS cycle the performance can be obtained from the simple analysis presented in the last lecture and using suitable property data. And typical performance trends show the effects of evaporator and condenser temperatures what is normally done is we keep the condenser temperature constant and vary the evaporator temperature and find difference performance parameters. Then you keep the evaporator temperature constant and vary the condenser temperature. So the in that manner you can find out the effect of both condenser as well as evaporator temperature on different performance parameters of interest okay.

Let me show now the effect of these temperatures on different performance parameters. The first one is the effect of these temperatures on specific and volumic refrigeration effects and then specific and volumic works of compression then system COP. So first let me show the effect of the temperature on refrigeration effect.

(Refer Slide Time: 00:03:25 min)



So this q e is specific refrigeration effect as you can see it has unit of kilo joules per kg and q v is volumetric volumic refrigeration effect. That means refrigeration effect per meter cube of refrigerant flow and you can see here that on x axis I have evaporator temperature and I have got these performance parameters for difference values of condenser temperatures. So you can see that condenser temperature is increasing in this direction for specific refrigeration effect and it is increasing again in the same direction for volumic refrigeration effect. So from this graph you can easily see that as you are increasing the evaporator temperature for a given condenser temperature there is a marginal increase in specific refrigeration effect okay. And specific refrigeration effect also increases as condensing temperature decreases okay. That means q e increases as T e increases and T c decreases but as I said this effect is not very large it is marginal that you can easily find out from this P h diagram as I have already discussed in the last class this is your refrigeration effect or this is your q e okay.

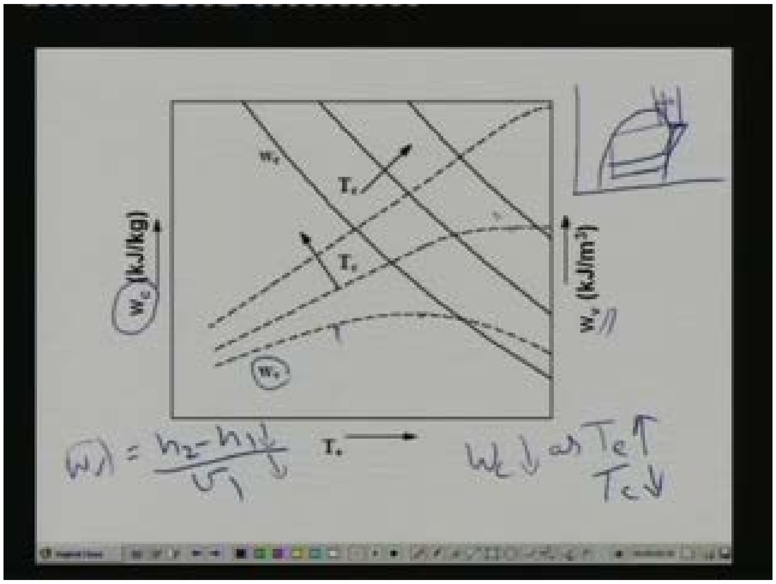
So if you are keeping the condenser temperature constant and if you are varying the evaporator temperature for example, I am increasing the evaporator temperature that means this line shifts up okay so and you have the a new cycle like this. So what is the increase in refrigeration effect is very small you can see the, that is only this much okay. So this purely depends up on the slope of this saturated vapour curve on P h diagram okay. And you can see that it is almost vertical so the change in q e with T e is marginal and what happens when you are include reducing T c you can see that.

For example when I am reducing the T c you have reduce T c like this. So your refrigeration effect now increases and it becomes larger okay.

So that you can very easily verify with the help of this P h diagram okay, and you can also see the effect these temperatures on volumic refrigeration effect. So how did we defined volumic refrigeration effect if you remember q v is defined as h one minus h four divided by this specific volume of the refrigerant vapour at the inlet to the compressor. That means specific volume at the, at this particular point okay. Now you can see that for a given condensing temperature as you are increasing evaporator temperature specific volumic refrigeration effect increases very rapidly you can see that by this dash line. Why does it increase rapidly? Because you can see that there are two effects here first effect is this okay. As T e increases specific refrigeration effect increases marginally.

So numerator increases okay at the same time when you are increasing the evaporator temperature this specific volume of the refrigerant vapour decreases steeply okay. So numerator is increasing and denominator is reducing steeply as a result you can see that the volumic refrigeration effect increases quite rapidly with evaporated temperature and it reduces as a condenser temperature is reduced. So what is the practical consequence of this practical consequence of this is if you are operating your system at high evaporated temperature your volumic refrigeration effect is very large. That means the required size of the compressor will be small because remember that in the last class I have mentioned that this is an indication of the size of the system for a given refrigeration capacity okay. So higher the evaporator temperature smaller will be the size of the system conversely when the evaporator temperature is very small you end up with a very large and bulky compressor. Now let us see the effect of these temperatures and other performance parameters.

(Refer Slide Time: 00:07:13 min)

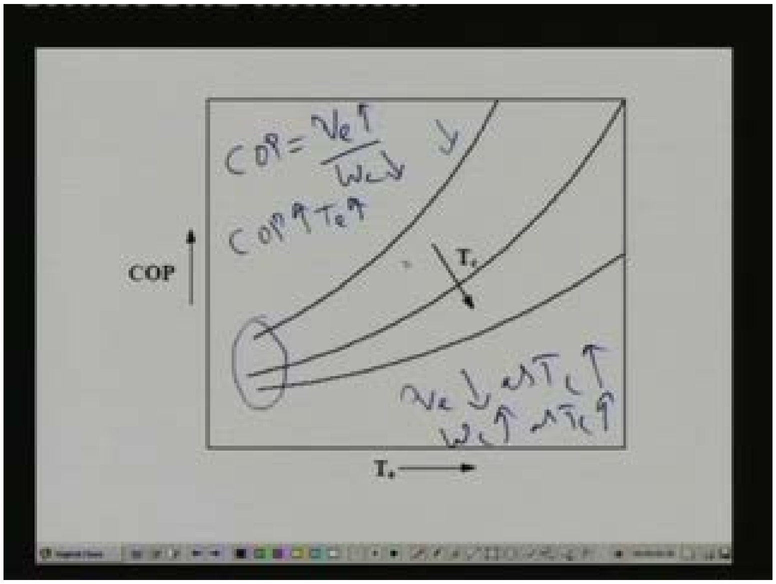


So this graph here shows the effect of evaporator and condenser temperatures on specific work of compression okay. That is work of compression per k g of refrigerant and this is volumic work of compression again we have defined this in the last class okay. If you multiply this specific work of compression into mass flow rate you get the power and if you multiply the volumic work of compression into volumetric flow rate you get the power okay. And you can see that for a given condenser temperature for example take this condenser temperature as you are increasing T e okay.

So as you are increasing T e your work of compression specific work of compression reduces in this direction. That means specific work of compression reduces as T e increases why does it happen again you can easily verify this with the help of your P h diagram. Let us say that this is our original P h diagram and this is your work of compression okay. Now if I am increasing this evaporator temperature then you can see that this is this will get reduced okay, that you can verify even from the earlier diagram also okay. So it has quite significant effect so as your evaporator temperature increases work of compression reduces and work of compression reduces as your T c reduces okay.

Now how about the effect of this on volumic work of compression volumic work of compression is again defined as if you look at the earlier P h diagram it is simply defined as h two minus h one divided by v one. And here you have seen that as you are increasing T e this is reducing okay, and at the same time this also reduces so both numerator as well as denominator reduces. So ultimately whether this reduces or not depends upon the relative reduction in this over this okay. So we can see that initially as evaporator temperature is increasing the volumic work of compression increases so it reaches some P then it starts reducing okay. The same thing is observed for different condenser temperatures and you can see that this peak shifts to higher evaporator temperatures as the condenser temperature is increased okay. So this is the effect of evaporator and condenser temperatures on work on compression now let us see the effect of this on COP of the system.

(Refer Slide Time: 00:09:42 min)



Okay, so you can see the effect of evaporator and condenser temperature on COP of the system.

So from the earlier two figures it is very easy to come to this conclusion because as you know very well COP is a COP is the ratio of your refrigeration effect divided by work of compression.

So we have seen that as T e is increasing refrigeration effect increases very marginally but this reduces significantly. As a result your COP increases with COP increases with T e okay, and similarly when T c is increasing this reduces that means q e reduces as T c increases and work of compression increases as T c increases. So as a result COP reduces as your condenser temperature increases okay. So one thing you can notice here just like your effect of performance on Carnot system you can see that at lower condenser temperatures the effect of evaporator is quite predominant. That means this curve is quite steep compared to other curves okay. So that means at lower condenser temperature evaporator temperature has a larger effect and at lower evaporated temperature the effect of condenser temperature is marginal okay.

So what we conclude from this we conclude from this that if you want to have a good COP and if you want to have a less small compressor and small refrigerant flow rate etcetera. You have to operate your system at as high an evaporator temperature is possible and as low a condenser temperature as possible. Unfortunately the evaporator and condensing temperatures you it is not in the hands of the designer completely because they are actually decided by the customer for example the evaporator temperature depends upon your storage requirements or your refrigeration requirements and the condenser temperature generally depends upon the available heat sink okay.

So you really do not have much say on this but still you can reduce, for example you can reduce the temperature differences between the heat source and sink and the refrigerant temperatures by designing efficient heat exchangers. Only that is the advantage you get okay, and one thing you can notice here as I have already mentioned is that the trends here are exactly similar to that of a Carnot cycle okay. For example the effect of T e and T c on COP it is qualitatively it is same for Carnot cycle as well as the standard SSS cycle okay.

(Refer Slide Time: 00:12:14 min)

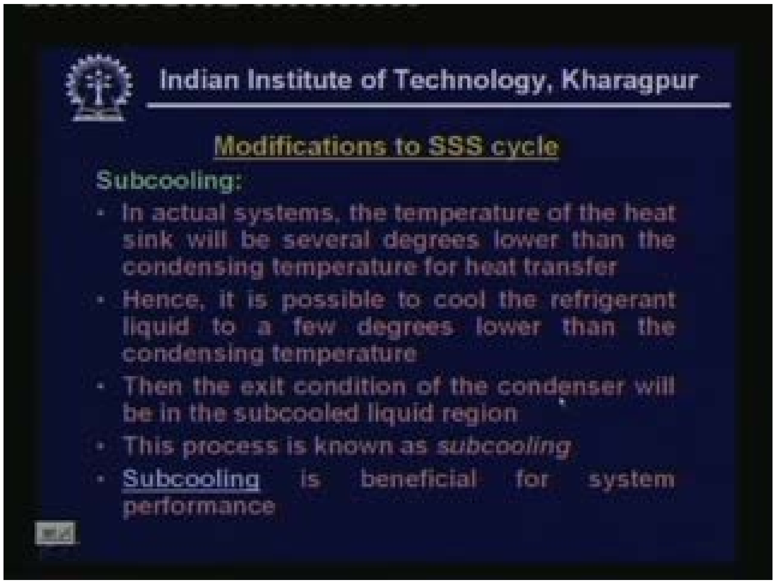
Indian Institute of Technology, Kharagpur

- The following conclusions can be made from the performance trends:

1. For good system performance the evaporator temperature should be high and condensing temperature should be low
2. At low evaporator temperature effect of condenser temperature is marginal
3. The above trends are similar to that of a Carnot refrigeration system
4. At very low evaporator temperatures, SSS cycle is not viable, in such cases a multistage or cascade system should be used

So you can this is the conclusions from the performance trends for the good system performance the evaporated temperature should be high and condensing temperature should be low, at low evaporator temperature the effect of condenser temperature is marginal the above trends are similar to that of a Carnot refrigeration system. At very low evaporator temperatures so see a saturated single stage cycle is not viable because the COPs will be small and required compressor size will be very large okay. So in such cases we have to use what is known as a multi stage or cascade system okay, we will discuss the multi stage and cascade systems in the next class.

(Refer Slide Time: 00:12:56 min)



Indian Institute of Technology, Kharagpur

Modifications to SSS cycle

Subcooling:

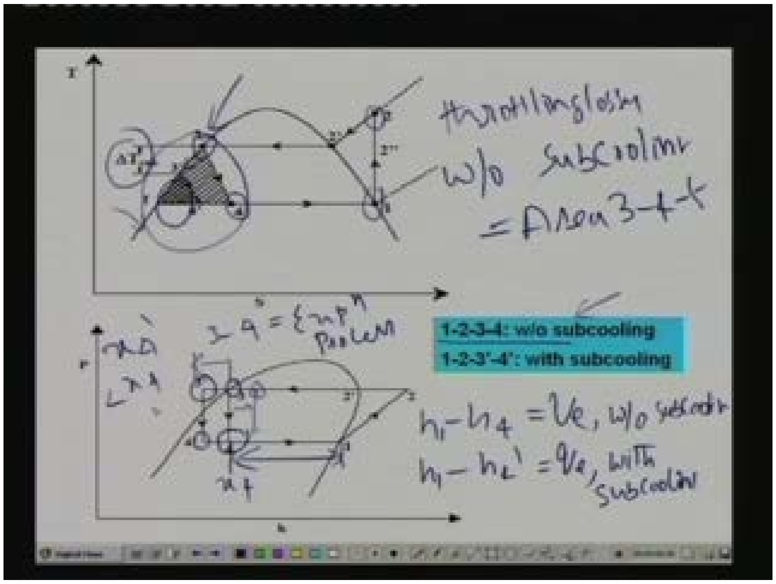
- In actual systems, the temperature of the heat sink will be several degrees lower than the condensing temperature for heat transfer
- Hence, it is possible to cool the refrigerant liquid to a few degrees lower than the condensing temperature
- Then the exit condition of the condenser will be in the subcooled liquid region
- This process is known as *subcooling*
- Subcooling is beneficial for system performance

Okay now let us look at modifications to standard saturated single stage cycle what are the modifications. First modification is sub cooling, so let us look at sub cooling what do you mean by sub cooling in actual system the temperature of the heat sink will be several degrees lower than the condensing temperature for heat transfer. That means if you have a actual vapour compression system and let us say that your heat sink is available at thirty degrees then to facilitate heat transfer you have to operate your condenser at a temperature higher than thirty degree centigrade okay, it may be thirty- one thirty- two thirty-three right.

So whatever it is there will be some delta T or some temperature difference between the refrigerants condensing inside the condenser and the external heat sink okay. So some delta T is available so you it is possible to cool the exit of the condenser to temperatures lower than the condensing temperature by adding some extra area okay. For example you have a delta T of five degree centigrade let us say so if your condenser is operating at thirty-five degrees and the heat sink is thirty degrees then if you add some more extra area may be you can reduce the condenser temperature to thirty-four or thirty-three okay.

At the same time pressure remains constant okay. So by this process what we are doing we are actually pushing the refrigeration liquid into sub cooled region right. If you are not using this then it will be on the saturated liquid line and if you are adding extra area it will go into the sub cooled region okay this process is known as sub cooling. So as I said it is possible to cool the refrigerant liquid to a few degrees lower than the condensing temperature then the exit condition of the condenser will be in the sub cooled liquid region and this process is known as sub cooling as a name implies it is very clear. And sub cooling we shall see has beneficial effects on system performance let us look at what are the effects of sub cooling on system performance.

(Refer Slide Time: 00:14:54 min)


throttling loss w/o subcooling = Area 3-4-f

1-2-3-4: w/o subcooling

1-2-3'-4': with subcooling

$h_1 - h_4 = q_e$, w/o subcooling

$h_1 - h_4' = q_e$, with subcooling

Okay, so here what we have here is one two three four cycle one two three four is without sub cooling. That means one two three and four this is without sub cooling. So you can see that the exit condition of the condenser lies on the saturated liquid line okay. So in this cycle we have seen in the last class that there are some throttling losses okay, and those throttling losses are given by this area three four f okay. That means throttling losses without sub cooling it is equal to area three four f okay and the same thing is shown on the P h diagram also for example in the P h diagram one two three four is the cycle without sub cooling. And one two three dash four dash is with sub cooling okay.

That means what is happening during sub cooling if you are assuming that the saturated liquid line coincides with the constant pressure line. That means this constant pressure line is going along the saturated liquid line like we were discussing in the last class. Then during sub cooling what happens is that the pressure remains constant but temperature reduces. So you can see that the exit condition instead of at point three it will be at point three dash okay. And the temperature at point three dash will be less than the corresponding so this is be saturation temperature T three okay. And this temperature difference T three minus T three dash is what is known as degree of sub cooling or delta d sub okay. And the, what was happened because of sub cooling you can see that because of the sub cooling the throttling losses have reduced okay. Previously the throttling loss was area three four f now the throttling loss is three four dash f okay with sub cooling this is the throttling loss without sub cooling this entire area of the throttling loss okay obviously it will have beneficial effect.

That will be very clear if you look at the P h diagram okay from the P h diagram without sub cooling this is the refrigeration effect. That is h one minus h four is the refrigeration effect q e without sub cooling and what is the refrigeration effect with sub cooling that is h one minus h four dash is q e with sub cooling okay. So you can see that it is good because refrigeration effect increases means for a same capacity required mass flow rate reduces and you have all other related benefits in case of sub cooling is really beneficial from this point of view. It also has other benefits so let us look at what are the other benefits.

Other benefits are you can see that the exit condition of the condenser is very much in the subcooled liquid region. So this will always ensure that only liquid goes into the expansion device remember that process three four is the expansion process or throttling process okay.

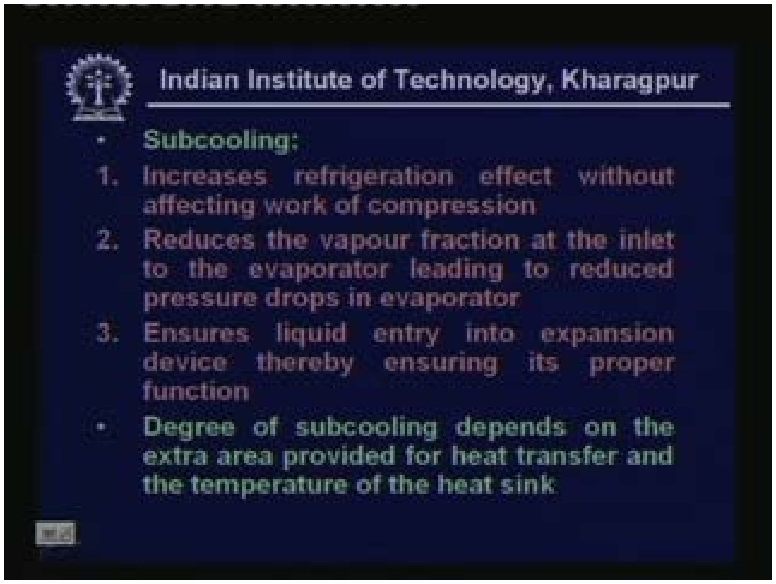
So when you have when you do not have any sub cooling then the inlet condition is just saturated liquid. If something, if some change takes place in the condenser then there is possibility that this point will shift this side and the inlet condition will go into two phase so at the inlet to the expansion device you may have vapour okay.

It may be somewhere here we shall see later that this will actually lead to the malfunctioning of the expansion device an expansion device is design to operate with liquid entry only it should not have any vapour okay. So the possibility of vapour going into the expansion device exists if you have a cycle without sub cooling. But whereas if you have a sub cooling then you can see that there is sufficient margin okay. So even if there is some slight change in the condenser heat transfer still the inlet condition can be in the subcool region okay. So this is the second benefit.

So sub cooling is desirable from this point of view also because it ensures a good and proper operation of an expansion device.

The third benefit is that if you remember from your last lecture at the exit of the evaporator exit of the expansion device which is nothing but the inlet to the evaporator you have some vapour plus liquid okay and that vapour fraction is given by x four okay. For larger this length higher is the amount of vapour okay. So when you are sub cooling the cycle you can see that the vapour fraction has reduced okay from four to four dash right because x four dash is less than x four okay. This is also beneficial it all it also has practical benefits because we shall see again later when we discuss evaporators and all the vapour at the inlet to the evaporator practically does nothing. That means it does not take part in providing useful refrigeration effect as long as phase change is going on but it has a negative effect because it increases the pressure drop through the evaporator okay. So normally the smaller the amount of vapour better for the evaporator okay if you do not have any sub cooling you see that the fraction of vapour is large. And by sub cooling you are reducing the fraction of the vapour at the inlet to the evaporator which will reduce the pressure drop in the evaporator and ultimately it will result in better performance okay. So sub cooling has these three benefits so it is very much desirable.

(Refer Slide Time: 00:20:10 min)



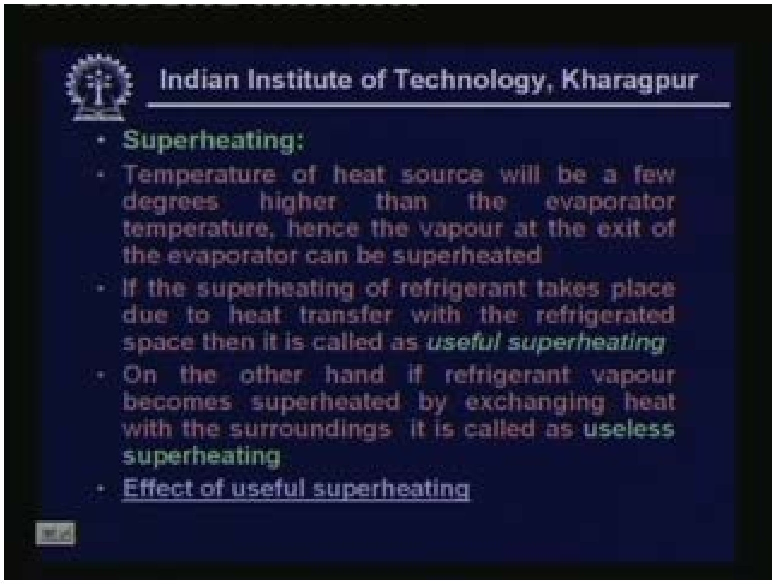
Indian Institute of Technology, Kharagpur

- Subcooling:
  1. Increases refrigeration effect without affecting work of compression
  2. Reduces the vapour fraction at the inlet to the evaporator leading to reduced pressure drops in evaporator
  3. Ensures liquid entry into expansion device thereby ensuring its proper function
- Degree of subcooling depends on the extra area provided for heat transfer and the temperature of the heat sink

So let us summarize this so sub cooling increases refrigeration effect without effecting work of compression. I forgot to mention this you might have seen that because of sub cooling there is practically no change in the compression side that means the work of compression remains same whether you subcool the refrigerants or don't subcool the refrigerant. That means you are getting the benefit of additional refrigeration effect without effecting the work of compression obviously this must give rise to higher volumic refrigeration effect and also higher COP okay without an extra cost. So it increases refrigeration effect without effecting work of compression it reduces the vapour fraction at the inlet to the evaporator leading to reduce the pressure drops in the evaporator. It ensures liquid entry into expansion device thereby ensuring its proper function okay. So these are all desirable then why not have large amount of sub cooling unfortunately there are certain constrains.

What are the constrains the degree of sub cooling depends on the extra area of provided for heat transfer and the temperature of the heat sink. So if you are trying to provide sub cooling by increasing the area of heat transfer obviously you are incurring additional cost because the heat exchanger becomes bigger so additional cost okay. At the same time it is also limited by the temperature of the heat sink as I have mentioned already the exit temperature of the condenser cannot be lower than the heat sink temperature okay. So that ultimately the degree of sub cooling that you can get by this method depends upon the extra area. You are, you can effort to provide and the heat sink temperature okay. Now let us look at the other modification.

(Refer Slide Time: 00:21:53 min)



Indian Institute of Technology, Kharagpur

- Superheating:
- Temperature of heat source will be a few degrees higher than the evaporator temperature, hence the vapour at the exit of the evaporator can be superheated
- If the superheating of refrigerant takes place due to heat transfer with the refrigerated space then it is called as *useful superheating*
- On the other hand if refrigerant vapour becomes superheated by exchanging heat with the surroundings it is called as useless superheating
- Effect of useful superheating

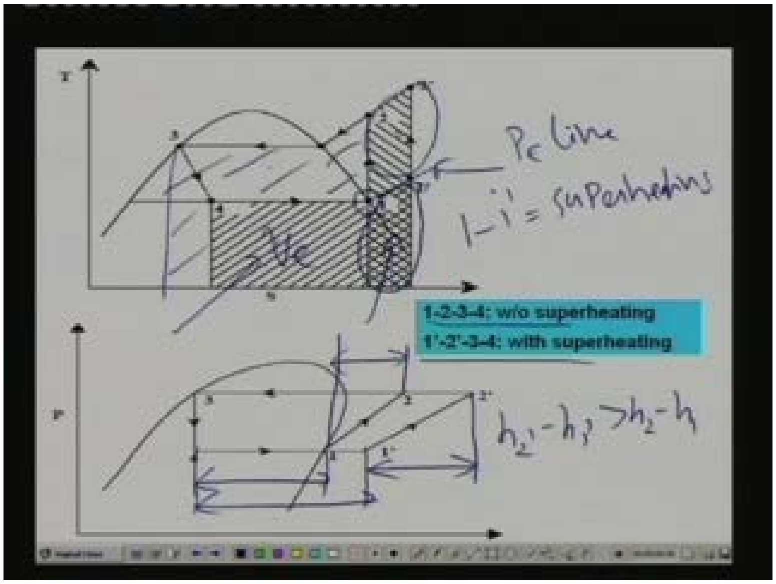
That is called as superheating what is superheating. So temperature of heat source will be few degrees higher than the evaporator temperature hence vapour at the exit of the evaporator can be superheated. This is again similar to your condenser problem if you want exchange heat from the refrigerated space to the evaporator you must provide certain delta T okay. A typical example for example if you want to maintain your freezer compartment of a domestic refrigerator let us say at minus eighteen degree centigrade than you have normally they operate the evaporator at about minus twenty-three degree centigrade. That means about five degrees of temperature difference is provided so that heat transfer can take place in a finite area okay. So some delta T exists so if you are if you can effort to you can add more area and you can reduce the delta T keeping the pressure constant okay.

There by what you are doing you are adding extra area for heat transfer there will be higher heat transfer to the refrigerant there by the exist condition of the refrigerant vapour goes into the superheated region okay. So just like your subcooled this thing this will go into superheated region so this is what is known as the superheating okay. Now superheating can be unlike sub cooling superheating can be useful or useless. What do you mean by useful superheating? If the superheating of refrigerant takes place due to heat transfer with the refrigerated space then it is called as useful superheating okay.

That means if this heat transfer is taking place inside the freezer compartment okay. Then it is useful because there cooling effect is ultimately given to the products okay. So it is you call it as useful superheating. Other on the other hand if the heat transfer is taking place outside the refrigerated compartment let us say that it is exchanging heat with surrounding air okay, then you do not get any benefit right. So the refrigerant get superheated but you are not getting any benefit okay this kind of superheating is known as useless superheating okay. So as I said on the other hand if refrigerant vapours become superheated by exchanging heat with the surroundings it is called as useless superheating.

Let us look at the effect of useful superheating for the let me tell at this point and I will also show this later but useless superheating is detrimental to system performance okay. So as far as possible system should be designed in such a way that whatever superheating takes place it takes place in a useful manner okay. All useless superheat should be avoided. So let us look at effect of useful superheat.

(Refer Slide Time: 00:24:35 min)



1-2-3-4: w/o superheating
1'-2'-3-4: with superheating

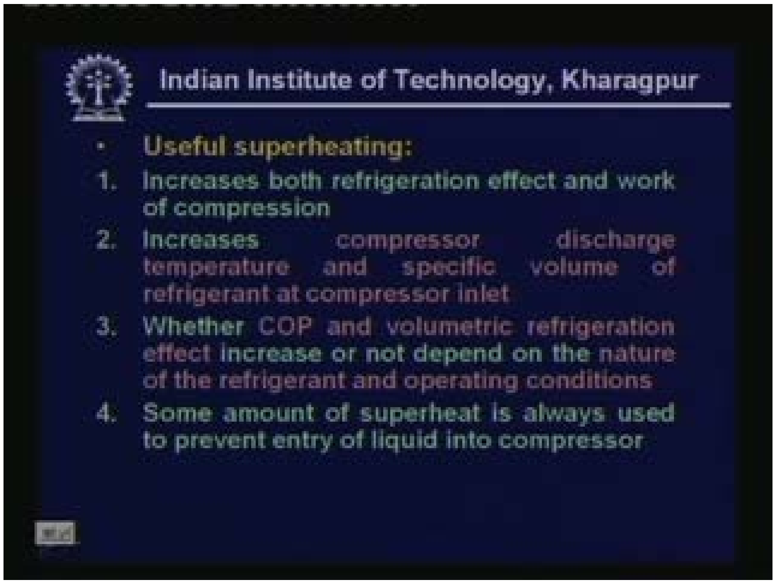
Okay, so this figure shows again just like sub cooling the cycle without and with superheating on T s as well as P h diagrams okay. Look at the T s diagram as I said one two three four is without superheating okay. If you do not have any superheating what is the useful refrigeration effect this is the useful refrigeration effect okay, this area right. And what is the work of compression we have seen that the work of compression in fact is this entire area okay. So this is q e and this is your work of compression without superheating. Now let us say that I have superheated it superheated means what I am doing, I am pushing this exit condition from the saturated vapour to a superheated vapour okay. Along the constant pressure line that means this is the constant P e line okay.

So it is sensible heat transfer process assuming that there are no pressure drops. So it is taking place isobarically so this point is shifting to superheated region remember that you have subcooled region here two phase region here and superheated region here okay, so because of this superheating one to one dash okay, so one to one dash is your superheating so what is effect of the superheating. First effect immediately you see that there is an increase in refrigeration effect and that increase is given by this area okay. So this is the area which is an indication of increase in refrigeration effect because of superheating okay. And there is also another effect what is that there is also simultaneous increase in work of compression and that is given by this area okay. So because of this superheating both refrigeration effect as well as the work of compression both are increasing okay.

The same thing can be seen from this point also without superheating from P h diagram without superheating. This is your refrigeration effect with superheating this is your refrigeration effect. So you can see that refrigeration effect has increase because of superheating and without superheating this is your work of compression okay, h two minus h one and with superheating this is your work of compression okay. And this will be always greater than this one okay because you we shall see later that these lines the isentropes. So they diverge as you move into the superheated region okay.

You can see that they are diverging as a result h two minus h one dash will be greater than h two minus h one that is very evident from this T s diagram okay. So we have one positive effect that is we are getting higher refrigeration effect and one negative effect that is higher work input. So ultimately whether it is good for the performance or not let us see that okay.

(Refer Slide Time: 00:27:18 min)



Indian Institute of Technology, Kharagpur

- Useful superheating:

1. Increases both refrigeration effect and work of compression
2. Increases compressor discharge temperature and specific volume of refrigerant at compressor inlet
3. Whether COP and volumetric refrigeration effect increase or not depend on the nature of the refrigerant and operating conditions
4. Some amount of superheat is always used to prevent entry of liquid into compressor

So let tell first let me summarize what I have discussed a useful superheating increases both refrigeration effect and work of compression. It also increases you might have noticed that by pushing the suction condition into superheated zone the compressor discharge temperature also increases. And since temperature is increasing at the inlet to the compressor at the, at fixed pressure the specific volume of refrigerant also increases. That means in addition to refrigeration effect and work of compression superheat also effects the compressor discharge temperature as well as the specific volume of the refrigerant at compressor inlet okay. These are the effects okay.

Now whether the COP and volumetric refrigeration capacity or volumetric refrigeration effect increases or not depends upon the nature of the refrigerant and operating conditions. So you cannot say of hand whether superheating will improve the COP or not okay. It is a very much function of the nature of the refrigerant and also to some extent the operating conditions okay.

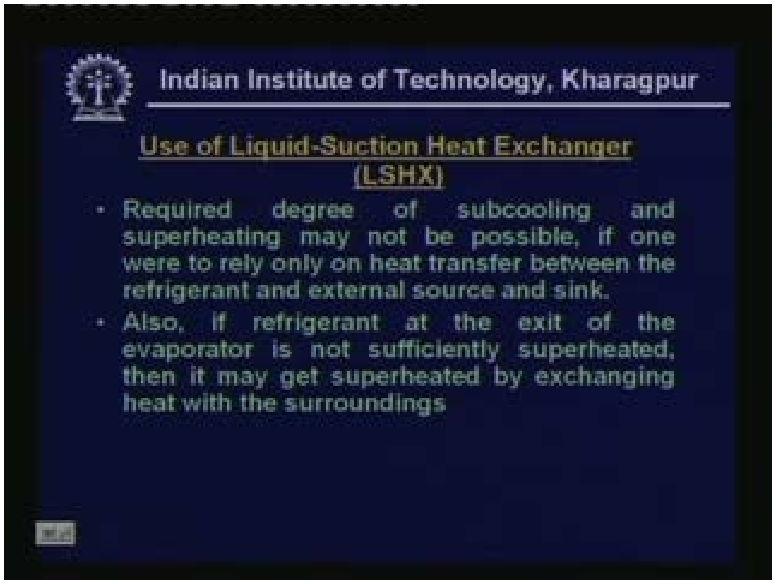
So you have to examine each refrigerant and decide whether superheating increases COP or not okay.

We shall see that little later whether it increases COP or not some amount of superheat is always used in practical system to prevent entry of liquid into compressors. So there is a very practical reason why superheat is necessary in actual systems because just like an expansion device cannot tolerate vapour a compressor we have seen in the last class cannot tolerate most of the compressors cannot tolerate the presence of liquid okay. So you must make sure that whatever is entering into the compressor is vapour okay no liquid is entering into the compressor. Now if you have a cycle without superheating that means the entry condition is on the saturated vapour line okay. And due to some changes in the evaporator load it is quite possible that the entry condition can shift into the two phase region. That means some liquid can enter into the compressor which may damage the compressor okay.

But if you are providing superheating ever if there is some small change in the evaporator load still the exit condition will be in the vapour region only. So you are ensuring a safe operation of compressor okay this is one of the reasons why superheating is provided in almost all systems whether it increases COP or not and it is also seen that from practical observations and experimental results that superheating has beneficial effects on volumetric efficiency of the compressor. So because of these two reasons superheating is provided but how much superheating has to be given depends upon again upon a, upon the nature of the refrigerant okay, and as I have already mentioned useless superheat is detrimental okay.

So you must always avoid useless superheat that means you must avoid heat transfer between the refrigerant and the outside ambient okay in the suction line. So this is the reason why all he suction lines are insulated that means lines going from the evaporator to the compressor have got to be insulated. So that heat transfer between the surrounding air and the refrigerant can be minimize thereby minimizing the useless superheating right. Now let us look at use of liquid suction heat exchangers.

(Refer Slide Time: 00:30:36 min)



Indian Institute of Technology, Kharagpur

Use of Liquid-Suction Heat Exchanger (LSHX)

- Required degree of subcooling and superheating may not be possible, if one were to rely only on heat transfer between the refrigerant and external source and sink.
- Also, if refrigerant at the exit of the evaporator is not sufficiently superheated, then it may get superheated by exchanging heat with the surroundings

So this is the modification over the simple cycle. Now we have seen that you can provide certain amount of sub cooling and certain amount of superheating using the temperature difference available between the refrigerant and the heat source and sink okay. But there are certain restrictions as you have seen the, that is restricted by the available heat source and sink temperatures and also on the additional area that you are providing okay. And if you want certain amount of sub cooling and superheating that is that may not be possible always just by exchanging heat with the heat source or sink okay.

So one way of ensuring required amount of sub cooling and superheating is by using what is known as a liquid suction heat exchanger or LSHX okay. So that is what is mentioned here required degree of sub cooling and superheating may not be possible if one were to rely on heat transfer between the refrigerant and external source and sink. And also if refrigerant the exit of the evaporator is not sufficiently superheated this, another reason why we need a liquid suction heat exchanger. If the exit is not sufficiently superheated then it may get superheated by exchanging heat with the surroundings which as you know is useless superheating. So a liquid suction heat exchanger can ensure required amount of sub cooling and superheating let us see what is a liquid suction heat exchanger.

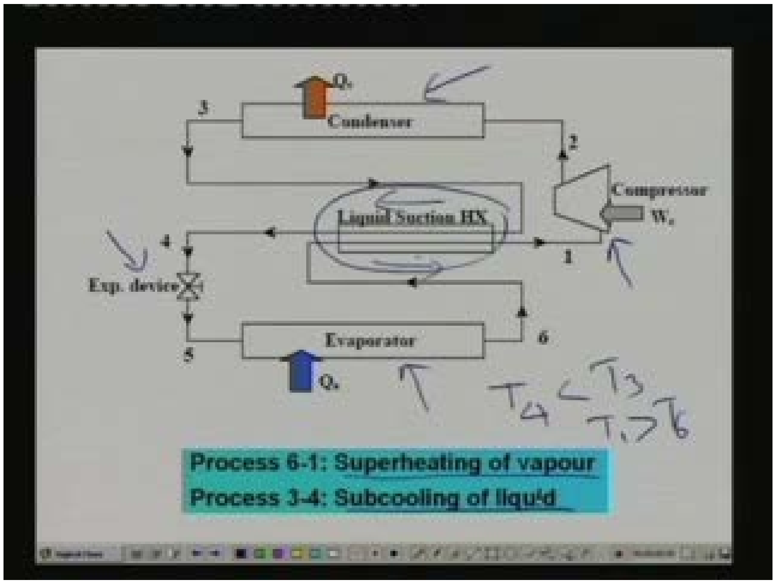
(Refer Slide Time: 00:31:55 min)

Indian Institute of Technology, Kharagpur

- Liquid Suction Heat Exchanger:
- A LSHX is a counterflow heat exchanger in which the warm refrigerant liquid from the condenser exchanges heat with the cool refrigerant vapour from the evaporator

Okay liquid suction heat exchanger is basically a counter flow heat exchanger in which the warm refrigerant liquid from the condenser exchanges heat with the cool refrigerant vapour from the evaporator. So let me show this.

(Refer Slide Time: 00:32:15 min)

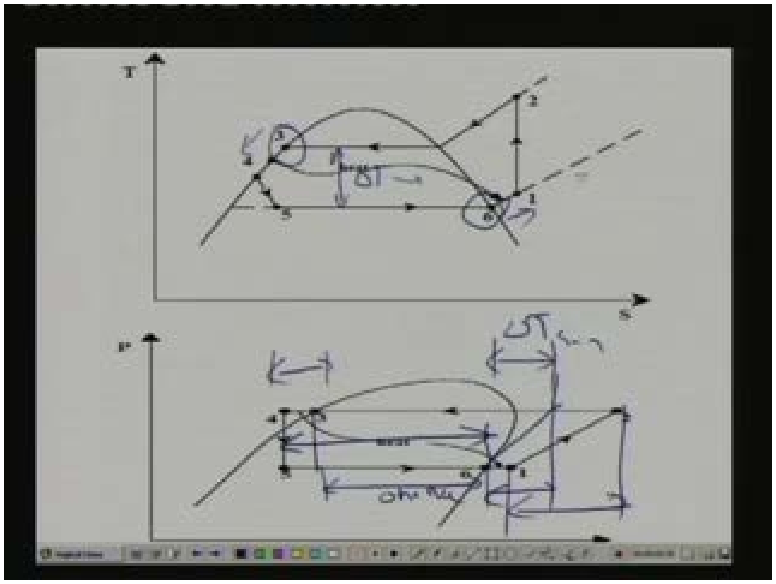


Process 6-1: Superheating of vapour
Process 3-4: Subcooling of liquid

Okay, so what we have here is a system with a liquid suction heat exchanger in the basic system we had only evaporator compressor condenser and expansion device. So in the modified system we had, we have added an extra component liquid suction heat exchanger. So what is happening in this extra component in this extra component the liquids in the condenser okay, liquids in the condenser is flowing in this direction okay. And vapour from the evaporator is flowing in this direction that means they are flowing in opposite directions okay. And I will show you in the next slide that the temperature of the liquid that is entering into the heat exchanger is much larger than the temperature of the vapour that is entering into the heat exchanger as a result this liquid can exchange heat with the vapour.

So the liquid becomes cooler and vapour becomes hotter okay, that means if you look at the temperatures T four that is the liquid outlet temperature will be less than T three and T one will be greater than T six that means the liquid is getting subcooled and super vapour is getting super heated okay. And as I have already mentioned process six to one is superheating of vapour and process three to four is sub cooling of liquid.

(Refer Slide Time: 00:33:29 min)



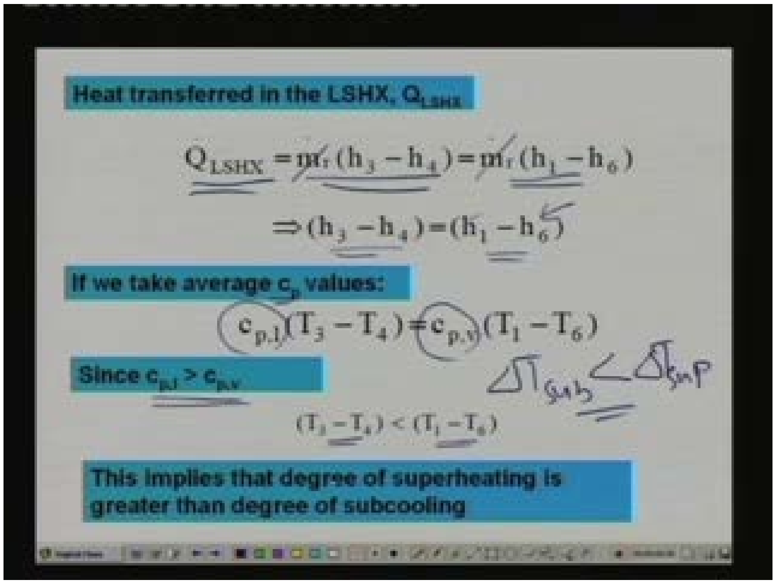
Let me show this one on T s and P h diagrams so what you see here on the top is the T s diagram and the bottom you have P h diagram. If you do not have any sub cooling or superheating or if you do not have any liquid suction heat exchanger this is the temperature of the liquid okay, and this is the temperature of the vapour. So you can see that the large temperature difference exists between the liquid and the vapour so you can exchange actually heat between these two by using a liquid suction heat exchanger that's what is happening here that is what you shown here okay.

So this stage this is exchanging heat like this okay this is the arrow this exchanging heat like this in this process this temperature is reducing and this temperature is increasing. And both the processes are typically almost isobaric. So they take place this process sub cooling take place along the constant condenser pressure line and superheating is taking place along the constant evaporator pressure line okay.

The same thing is shown here also so you can see that this is your process of sub cooling and this is the process of superheating okay. This is your superheating this is delta T okay delta T is superheat and this is your sub cooling. So what is the effect of sub cooling and superheating on the system performance immediately one thing is clear that refrigeration effect has increased okay. Without this liquid suction heat exchanger your refrigeration effect was this much okay, this is your delta h or that is equal to q e okay. And because of this liquid suction heat exchanger now it has become this much okay so that is a benefit. But you will also simultaneously see that there will be some increase in work of compression also because without sub cooling this will be this would have been the work of compression and with liquid suction heat exchanger this becomes a perfect compression okay.

So both the effects are present, now let the, let us, write some basic equations for this.

(Refer Slide Time: 00:35:23 min)



Heat transferred in the LSHX, Q_{LSHX}

$$\underline{\underline{Q_{LSHX}}} = \cancel{\dot{m}_r}\,\underline{(h_3 - h_4)} = \cancel{\dot{m}_r}\,(\underline{\underline{h_1}} - h_6)$$

$$\Rightarrow (h_3 - h_4) = (h_1 - h_6)$$

If we take average c_p values:

$$c_{p,l}(T_3 - T_4) = c_{p,v}(T_1 - T_6)$$

Since $c_{p,l} > c_{p,v}$

$$\Delta T_{sub} < \Delta T_{sup}$$

$$(T_3 - T_4) < (T_1 - T_6)$$

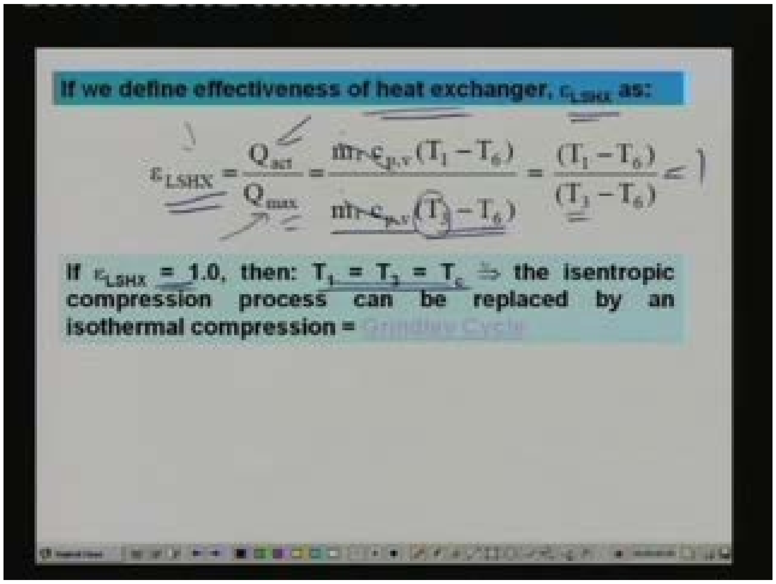
This implies that degree of superheating is greater than degree of subcooling

So what is the heat transferred in the liquid suction heat exchanger if you apply steady flow energy equation and neglect potential and kinetic energy changes then heat transferred in the liquid suction heat exchanger is simply given by the heat transfer. This is the heat loss energy loss by the refrigerant liquid and this is, and that is equal to energy gain by the vapour okay. So this is for the liquid portion this is for the vapour portion and since mass flow rate are same mass is flowing through both the components this thing you can get cancelled.

So you can simply write this as h three minus h four is equal to h one minus h six where h three is the saturated liquid enthalpy h four is the enthalpy at the end of the liquid suction heat exchanger and h one is the saturated I am sorry, h six is the saturated vapour enthalpy and the h one is the vapour enthalpy at the end of the liquid suction heat exchanger. And if you are taking some average specific heat values we can write this as c p l into T three minus T four which is equal to c p v into T one minus T six where c p l is the specific heat of the liquid and c p v is the specific heat of the vapour and as you know generally the specific heat of the liquid is much higher than specific heat of the vapour.

That means c p l will be greater than c p v, so from this equation T three minus T four should be less than T one minus T six that means delta T sub cooling will be generally less than delta T superheating okay. How much less depends upon the values of c p l and c p for the liquid and c p for the vapour okay. So that is what is mentioned here degree of superheating is greater than degree of sub cooling right.

(Refer Slide Time: 00:37:02 min)



If we define effectiveness of heat exchanger, ε_{LSHX} as:

$$\varepsilon_{LSHX} = \frac{Q_{act}}{Q_{max}} = \frac{\cancel{\dot{m}c_{p,v}}(T_1 - T_6)}{\cancel{\dot{m}c_{p,v}}(T_3 - T_6)} = \frac{(T_1 - T_6)}{(T_3 - T_6)} \le 1$$

If ε_{LSHX} = 1.0, then: $T_1 = T_3 = T_c \Rightarrow$ the isentropic compression process can be replaced by an isothermal compression = Grindley Cycle

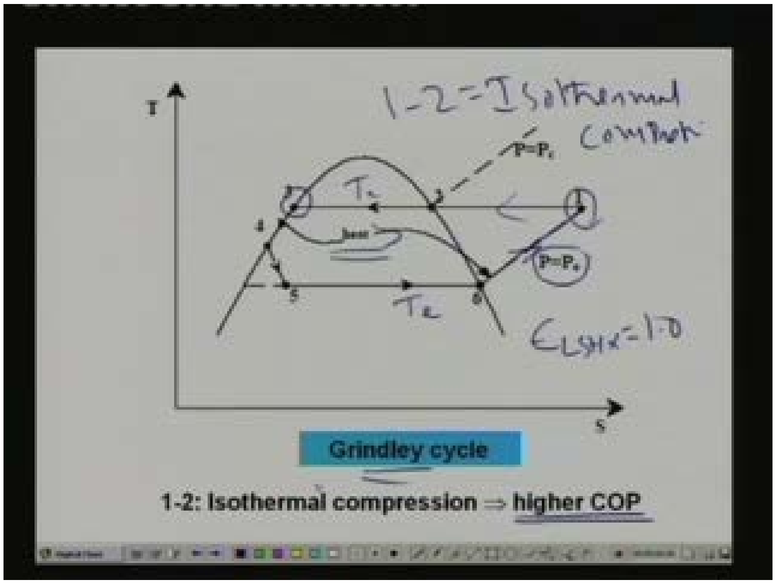
Now if you define the effectiveness of heat exchanger as the heat actual heat transfer divided by maximum possible heat transfer okay. That means I am defining an effectiveness of heat exchanger epsilon L S H X which is defined as the ratio of actual heat transfer to maximum possible heat transfer rate okay. What is actual heat transfer? If you are writing it for the vapour this is nothing but the m dot c p into delta T of the vapour that is m dot r into c p v into T one minus T six okay. And what is the maximum possible heat transfer the maximum possible heat transfer in a typical heat exchanger is for a fluid which has a lower m dot c p that means fluid which has lower mass flow rate into specific heat will undergo the maximum possible temperature change okay. So as the result in our case the c p of vapour is less than the c p of liquid whereas the mass units are same.

So vapour has the lower thermal capacity compared to the liquid so if at all anything is undergoing maximum temperature change it has to be the vapour okay. So Q max is nothing but m c p of the vapour into delta T max okay that’s what is written here. So you can see that this is the m c p of the vapour and this is the maximum possible temperature difference okay. What is maximum possible temperature difference when the exit condition of the vapour is same as the inlet condition of the liquid. That means when T three becomes T one that is the condition under which we get maximum possible heat transfer okay. Again these two are get cancelled, so you have ultimately effectiveness is defined as T one minus T six by T three minus T six okay. So you might have studied in heat transfer this thing how do we evaluate effectiveness in terms of the other design parameters.

Now if you take a hypothetical case where you have a perfect heat exchanger whose effectiveness is one, okay. That means this is equal to one if this is equal to one what happens T one will be same as T three and what is T three T three is nothing but the condenser temperature.

That means by using a perfect liquid suction heat exchanger you can heat the refrigerant vapour from the evaporated temperature right up to the condenser temperature isobarically okay. That means when epsilon L S H X is one T exit of the liquid suction heat exchanger will be same as the condenser temperature. This gives rise to an interesting cycle proposed by Grindley it is called as Grindley cycle. Let me quickly show the Grindley cycle.

(Refer Slide Time: 00:39:40 min)



Grindley cycle

1-2: Isothermal compression ⇒ higher COP

Okay, so this is what is shown Grindley cycle is shown on T s diagram so what is happening here is this should have been a solid line okay. So again as I said we have using a liquid suction heat exchanger so heat is transferred from the subcooled liquid to the vapour and I am using a perfect heat exchanger okay. When I am using a perfect heat exchanger the exit condition of the vapour will be same as the inlet condition of the liquid. That means T one will be same as T three that is what I have shown in the earlier slide and what is T three T three is nothing but your T c okay. So I am able to heat the refrigerant vapour from the evaporator temperature T e right up to the condenser temperature T c okay. Then what I have to do still it is at the same pressure remember that there is still taking place isobarically that means the process is pressure is still evaporator pressure only.

Next process as you know is compression process okay and what kind of a compression process here this is an isothermal compression okay, one to two is isothermal compression because you have already attain the condenser temperature . So you have to compress the liquid isothermally from one to two previously we had isentropic compressor. So by using a perfect heat exchanger you can have this kind of a situation where the isentropic compression is replaced by an isothermal compression. What is the advantage of isothermal compression? We shall see in the subsequent lectures that isothermal compression will give rise to lower work input as a result you get higher COPs okay.

So this cycle is known as Grindley cycle that means vapour compression cycle wherein the isentropic compression is replaced by an isothermal compression using a perfect liquid suction heat exchanger is called as Grindley cycle. And what is the advantage of Grindley cycle is it will give you better COP okay compare to the standard cycle unfortunately Grindley cycle is difficult to build in practice what are the difficulties. So difficulties are mainly to do with achieving isothermal compression particularly having with very high speed compressor such as centrifugal compressors or reciprocating compressors okay. So this Grindley cycle could not be built in practice because of this problem okay. But still there is some interest because using some other types of compressors such as screw type compressors you can approach isothermal compression okay so still there is some interest in this cycle okay.

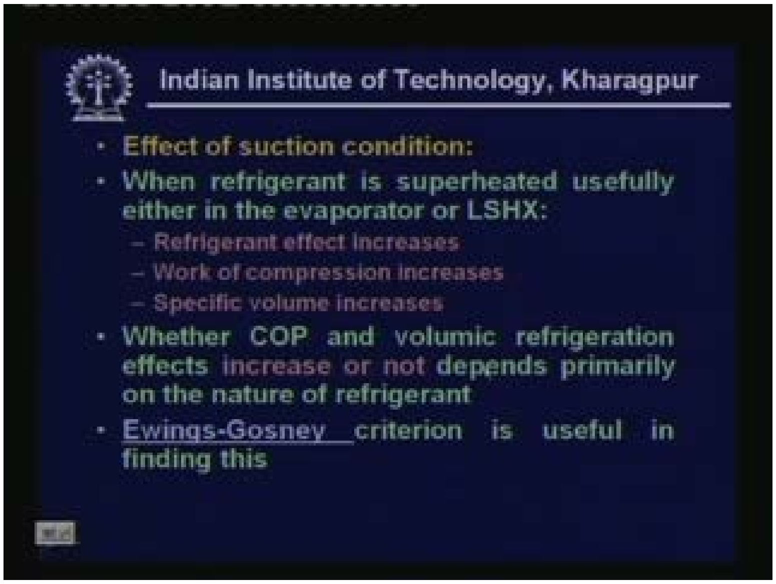
(Refer Slide Time: 00:42:19 min)

Indian Institute of Technology, Kharagpur

- Liquid Suction Heat Exchanger:
- A LSHX is a counterflow heat exchanger in which the warm refrigerant liquid from the condenser exchanges heat with the cool refrigerant vapour from the evaporator
- Thus the liquid becomes subcooled and the vapour becomes superheated
- A LSHX increases the refrigeration effect and ensures only liquid entry into expansion device and only vapour entry into compressor

So this is the summary of whatever I have discussed just now liquid suction heat exchanger is a counter flow heat exchanger in which the warm refrigerant liquid from the condenser exchanges heat with cool refrigerant vapour from the evaporator. Thus the liquid becomes subcooled and the vapour becomes superheated. A LSHX increases the refrigeration effect as you have seen already and ensures only liquid entry into expansion device and only vapour entry into compressor okay. So it has double benefit of ensuring proper operation of expansion device as well as the compressor, so it is generally desirable.

(Refer Slide Time: 00:42:58 min)



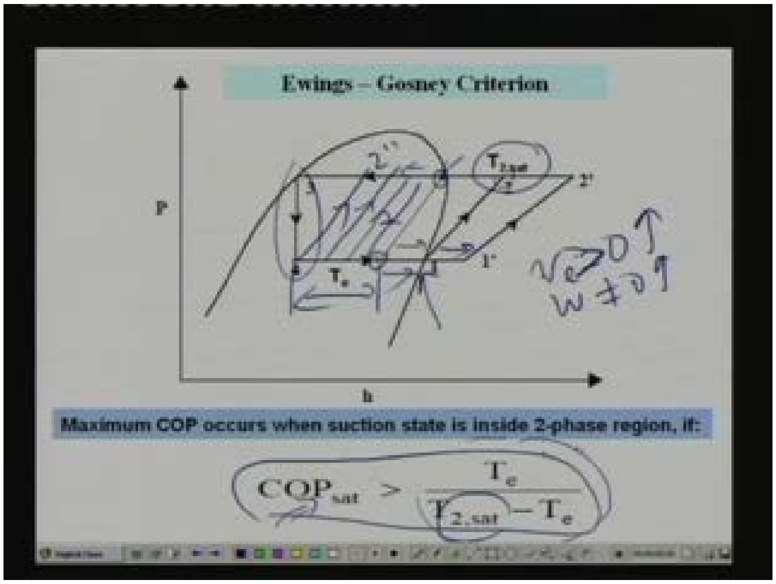
Indian Institute of Technology, Kharagpur

- Effect of suction condition:
- When refrigerant is superheated usefully either in the evaporator or LSHX:
  - Refrigerant effect increases
  - Work of compression increases
  - Specific volume increases
- Whether COP and volumic refrigeration effects increase or not depends primarily on the nature of refrigerant
- Ewings-Gosney criterion is useful in finding this

Okay, now let us look at one important issue that is the effect of the suction condition I have mentioned when we were discussing superheat that when you are increasing the superheat okay. You are increasing the refrigeration effect at the same time you are also increasing the work of compression. So ultimately whether it will increase COP or not i said depends upon the nature of the refrigerant okay. Now let us see how do we decide whether it is good or not depending upon the nature of the refrigerant okay. That means ultimately we are trying to find out how the condition of the suction means inlet to the compressor effect the performance of the system okay. So when refrigerant is superheated usefully either in the evaporator or liquid suction heat exchanger refrigerant effect increases as I have already discussed work of compression increases specific volume also increases.

So whether COP and a volumic refrigerant effect increase or not depends on primarily on the nature of the refrigerant okay. And there is a method by which you can formulate a criteria okay. This criteria was suggested by Ewings and Gosney has derived useful relations. So let me call this as Ewings Gosney criteria and this criteria is used to find whether superheating is beneficial from the point of COP or not okay. So this criteria is used to find this just this okay and this criteria is based on the assumption that the superheating is useful okay. So if the superheating is useless then there is no point in applying this criteria okay. Because anyway it is bad right okay.

(Refer Slide Time: 00:44:39 min)



Ewings – Gosney Criterion

Maximum COP occurs when suction state is inside 2-phase region, if:

$$COP_{sat} > \frac{T_e}{T_{2,sat} - T_e}$$

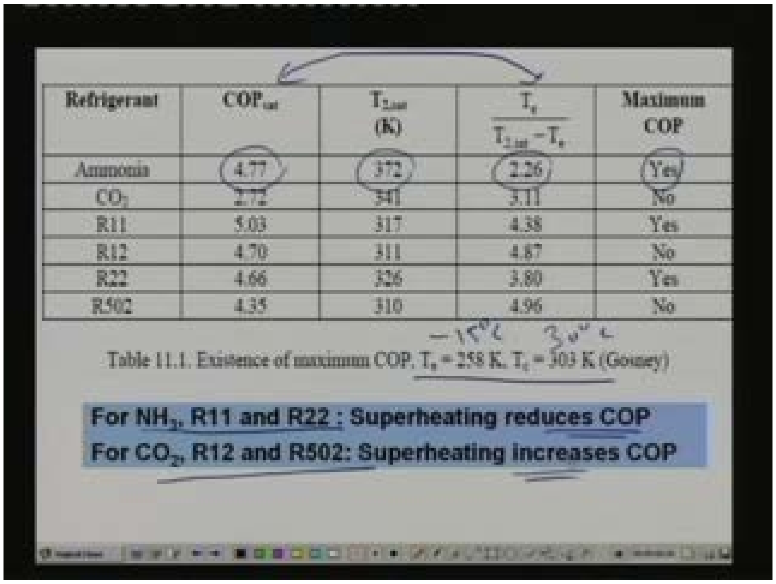
So let us again come back to our original P h diagram so what you have here one two three four is the saturated cycle and one dash two dash three four is the superheated cycle. Let me begin with let us begin the discussion let for the sake of argument, let us say that this is your expansion process as you know that the process three to four is expansion process. And if you are compressing the refrigerant right at this point what happens okay, let us say, this is some okay, so two double dash okay.

So I am compressing the refrigerant vapour immediately after the expansion device. So what will be the COP of the system? Obviously you can see that the if you are doing this q e will be zero because you are not getting any useful refrigeration effect of course W will not be zero right. That means you are spending some this thing but you are not getting any benefit right. So now what happens if this point is shifted that means the point four is shifting okay point four is shifting in this direction okay. As you can see that as point four is shifting in this direction refrigeration effect increases okay. That means q e becomes non zero okay, it is becomes positive non zero that means COP will be greater than zero okay. So gradually COP increases as you move from this point okay.

So COP continues to increase as long as this exit condition lies inside of this okay as long as this exit condition lies inside of this okay. Now you have one condition okay that is the condition this for all refrigerants of the COP increases between this point to this point okay, such that the exit condition lies on the saturated vapour line. So with further increase in the enthalpy of the exit condition whether COP increases or not depends upon the nature of the refrigerant. That means if you are moving this point further right up to the vapour as the saturated vapour point and right into the superheated region okay. Will the COP increase or not because you are seeing that this is increasing and this is also increasing okay. So up to this point the increase in this is greater than the increase in this so COP definitely increases but from this point onwards whether this COP increases or not we do not know at this movement okay.

So this is what is given by your Ewings and Gosney criteria if they have they have shown that the COP will be maximum inside the two phase region if this criteria is satisfied okay. So maximum COP occurs when suction state is inside two phase region if COP sat is greater than T e by T two sat minus T e okay. That means if this condition is satisfied you will have maximum COP inside the two phase region and any superheating will reduce the COP okay, and what is COP sat here COP sat is the COP of the saturation cycle one two three four okay. And what is T two sat T two sat as you can see here is nothing but the compressor exit temperature when the compressor inlet is on the saturated vapour line okay. So what we have to do simply is take the saturated cycle find out the COP of the saturated cycle for any given refrigerant from the enthalpy values okay.Then find out the exit compressor exit temperature T two sat and then find out this value okay. And if you find that this is greater than this maximum occurs inside and superheating is bad from COP point of view okay, let me show this with an example.

(Refer Slide Time: 00:48:16 min)



Refrigerant	COP_{sat}	$T_{2,sat}$ (K)	$\frac{T_e}{T_{2,sat}-T_e}$	Maximum COP
Ammonia	4.77	372	2.26	Yes
CO_2	2.72	341	3.11	No
R11	5.03	317	4.38	Yes
R12	4.70	311	4.87	No
R22	4.66	326	3.80	Yes
R502	4.35	310	4.96	No

Table 11.1. Existence of maximum COP. $T_e = 258$ K, $T_c = 303$ K (Gosney)

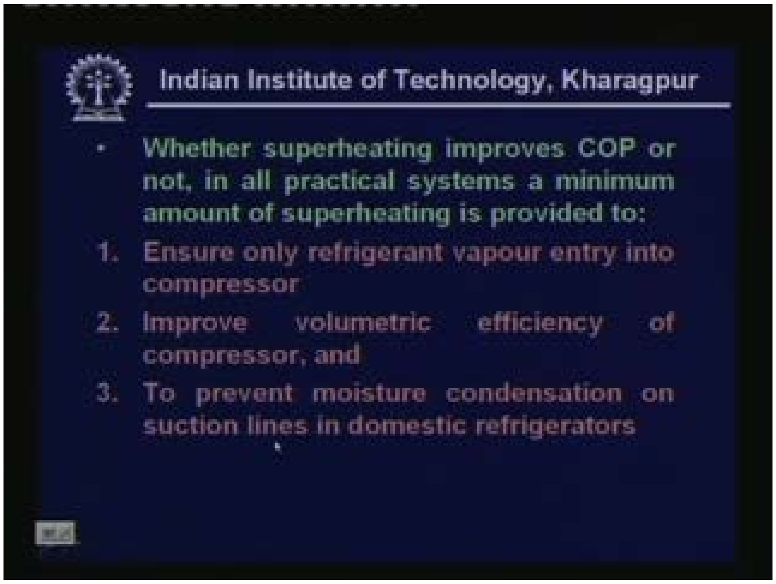
For NH_3, R11 and R22 : Superheating reduces COP

For CO_2, R12 and R502: Superheating increases COP

Right, so this table here it is taken from Gosney and this compares these two parameters that is COP sat okay, COP sat and this expression okay for different refrigerants. And this data is obtained at minus fifteen degree centigrade that is two fifty-eight Kelvin and thirty degrees condenser temperature okay. If minus fifteen degree centigrade evaporator temperature and thirty degree is condenser temperature okay. For example if you look at ammonia the COP of the saturated cycle is four point seven seven and the exit temperature is three seventy-two that is ninety-nine degree centigrade.

And you find that this value T by T two sat minus T e is two point two six that means this is greater than this okay. So according to Gosney criteria the maximum COP occurs inside the two phase region okay, and where as for carbon dioxide you can see that this is smaller than this so there is no maximum. Similarly for R eleven this is greater than this so there is a maximum like that you can see the values for different refrigerants. And from this you can summarize that for refrigerants ammonia R eleven and R twenty-two superheating reduces COP and for carbon dioxide R twelve and R five not two superheating increases COP okay. So it depends very much on the superheat.

(Refer Slide Time: 00:49:40 min)



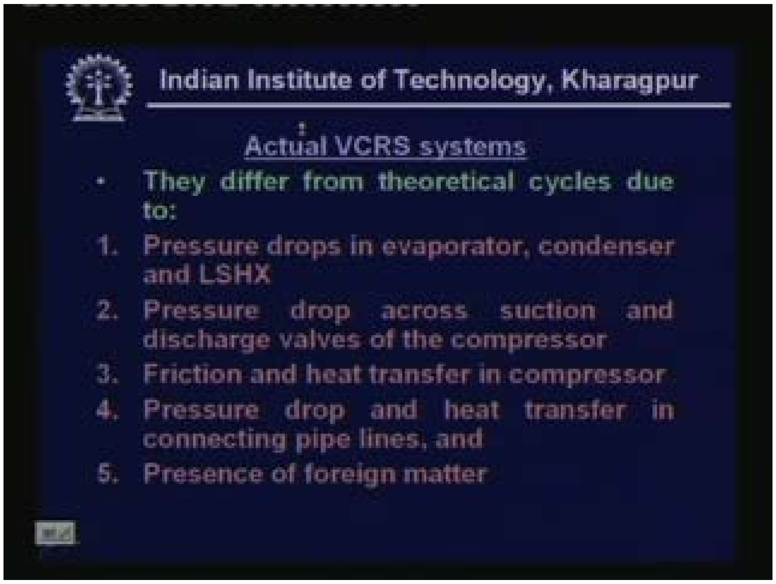
Indian Institute of Technology, Kharagpur

- Whether superheating improves COP or not, in all practical systems a minimum amount of superheating is provided to:

1. Ensure only refrigerant vapour entry into compressor
2. Improve volumetric efficiency of compressor, and
3. To prevent moisture condensation on suction lines in domestic refrigerators

Okay, so this is what is mentioned here this I have already discussed whether superheating improves COP or not we have to use superheat to ensure only refrigeration vapour entry into compressor and improve volumic, volumetric efficiency of compressor and to prevent moisture condensation on suction lines in domestic refrigerators etcetera.

(Refer Slide Time: 00:50:00 min)



Indian Institute of Technology, Kharagpur

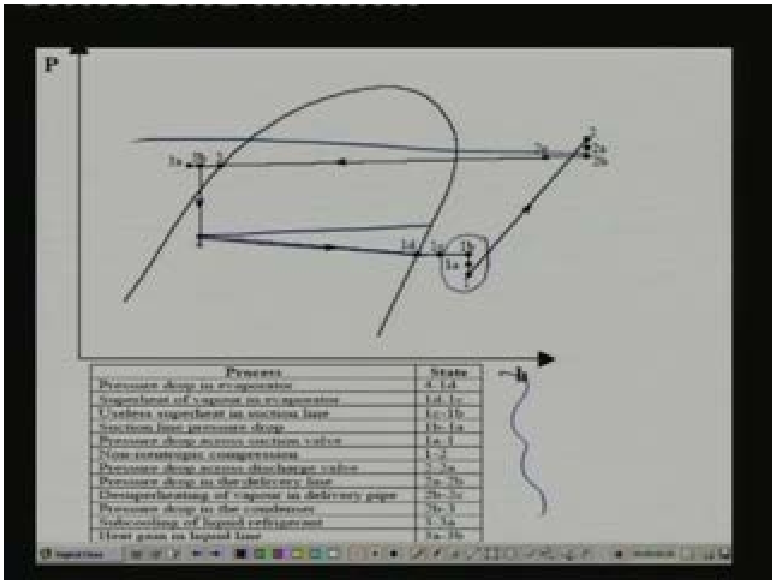
Actual VCRS systems

- They differ from theoretical cycles due to:

1. Pressure drops in evaporator, condenser and LSHX
2. Pressure drop across suction and discharge valves of the compressor
3. Friction and heat transfer in compressor
4. Pressure drop and heat transfer in connecting pipe lines, and
5. Presence of foreign matter

Now let us look at actual vapour compression refrigeration cycle in what way they are different from the theoretical cycle. What are we have been discussing from now till now are theoretical cycles which do not have or which did not have any internal reversibilities okay. Now let us look at an actual cycle what way an actual system differs from this theoretical cycle okay. So they the differences are like this you have pressure drops in evaporator condenser and liquid suction heat exchanger. And you have pressure drop across suction and discharge valves of the compressor and friction and heat transfer in compressor and pressure drop and heat transfer in connecting pipe lines and presence of foreign matter okay. So let me quickly show the actual cycle.

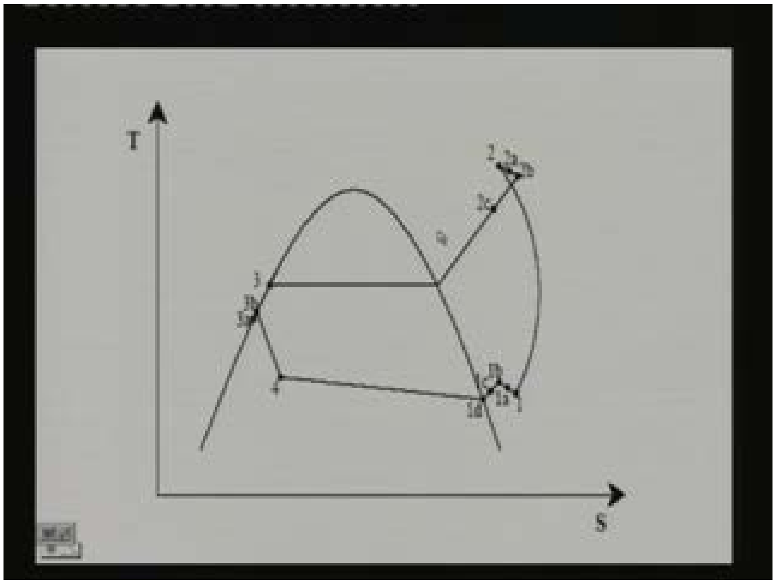
(Refer Slide Time: 00:50:44 min)



Process	State
Pressure drop in evaporator	4-1d
Superheat of vapour in evaporator	1d-1c
Useless superheat in suction line	1c-1b
Suction line pressure drop	1b-1a
Pressure drop across suction valve	1a-1
Non-isentropic compression	1-2
Pressure drop across discharge valve	2-2a
Pressure drop in the delivery line	2a-2b
Desuperheating of vapour in delivery pipe	2b-2c
Pressure drop in the condenser	2c-3
Subcooling of liquid refrigerant	3-3a
Heat gain in liquid line	3a-3b

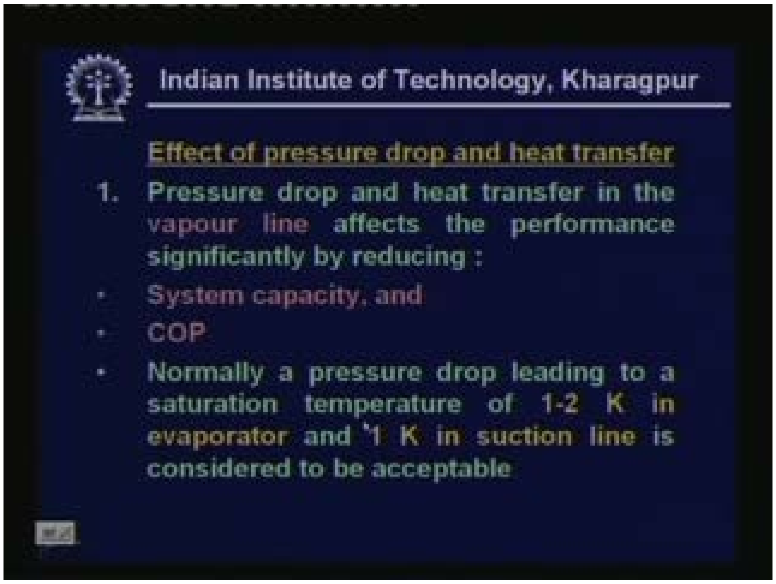
You can see that because of all these pressure drops heat transfer and all the shape which was like a parallelogram as got twisted okay. Initially without any pressure drop this should have been in horizontal line but because of the pressure drop it has become inclined. Similarly the condenser because of the pressure drop you have been inclined line instead of a horizontal line this like this there are various pressure drops heat transfers and all are listed here okay. And we usual see that the effect of all these pressure drops and heat transfer is ultimately to effect the performance of the system okay.

(Refer Slide Time: 00:51:18 min)



The same thing is shown on T s diagram here okay.

(Refer Slide Time: 00:51:26 min)



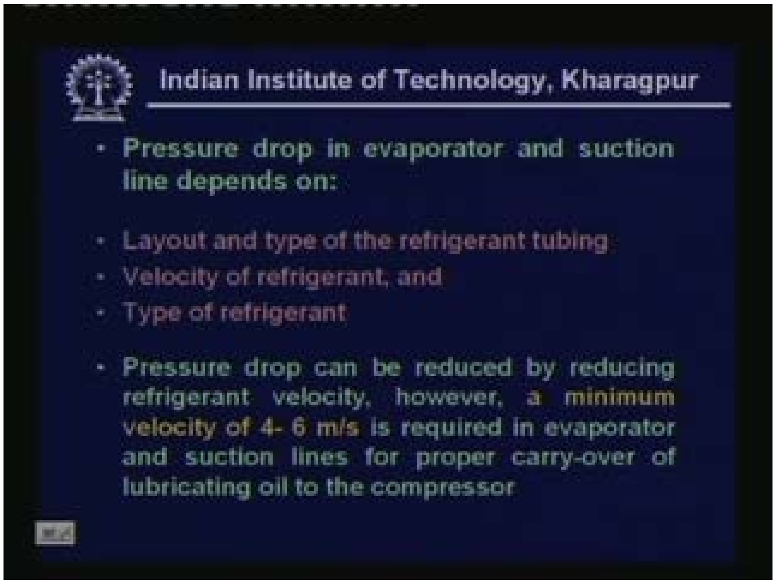
Indian Institute of Technology, Kharagpur

Effect of pressure drop and heat transfer

1. Pressure drop and heat transfer in the vapour line affects the performance significantly by reducing :
- System capacity, and
- COP
- Normally a pressure drop leading to a saturation temperature of 1-2 K in evaporator and 1 K in suction line is considered to be acceptable

Now effect of pressure drop and heat transfer, let me discuss qualitatively pressure drop and heat transfer in the vapour line affects the performance significantly by reducing system capacity and COP. That means the vapour line design very critical and you have to make sure that pressure drop is as small as possible and normally pressure drop leading to a saturation temperature of one to two Kelvin in evaporator and one Kelvin in suction line is considered to be acceptable that means there are some standards. You have to design the evaporator in such a way that your delta P it corresponds to a temperature drop of one to two degrees in evaporator and one degree suction line.

(Refer Slide Time: 00:52:02 min)

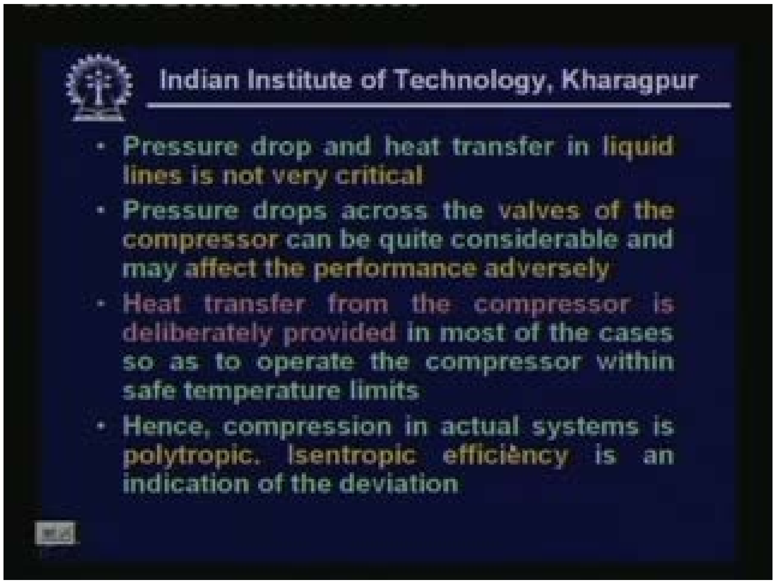


Indian Institute of Technology, Kharagpur

- Pressure drop in evaporator and suction line depends on:
- Layout and type of the refrigerant tubing
- Velocity of refrigerant, and
- Type of refrigerant
- Pressure drop can be reduced by reducing refrigerant velocity, however, a minimum velocity of 4- 6 m/s is required in evaporator and suction lines for proper carry-over of lubricating oil to the compressor

Now pressure in evaporator and suction line depends on lay out and type of the refrigerant tubing. Velocity of refrigerant and type of refrigerant and pressure drop can be reduced by reducing refrigerant velocity. However a minimum velocity of four to six meters is required in evaporator and suction lines for proper carryover of lubricating oil to the compressor. That means you have to maintain certain minimum velocity okay, even though reduction in velocity reduces the pressure drop.

(Refer Slide Time: 00:52:31 min)

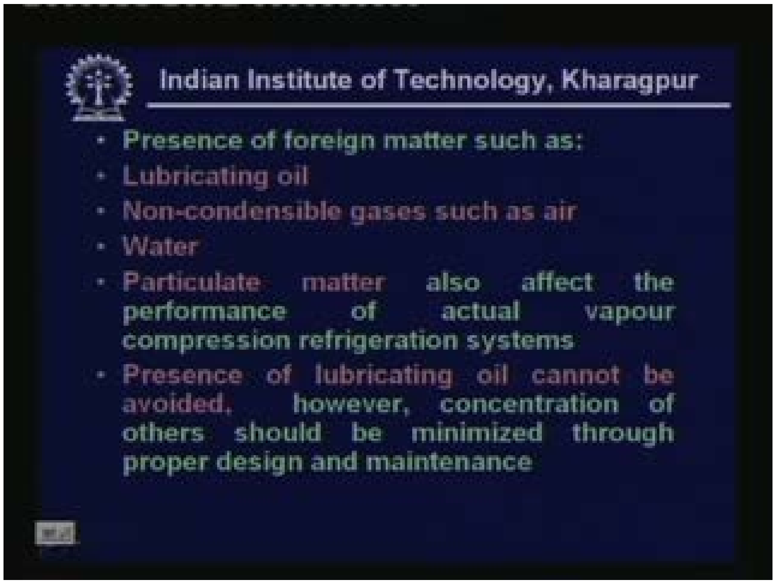


Indian Institute of Technology, Kharagpur

- Pressure drop and heat transfer in liquid lines is not very critical
- Pressure drops across the valves of the compressor can be quite considerable and may affect the performance adversely
- Heat transfer from the compressor is deliberately provided in most of the cases so as to operate the compressor within safe temperature limits
- Hence, compression in actual systems is polytropic. Isentropic efficiency is an indication of the deviation

You also see that pressure drop and heat transfer in liquid line is not very critical and pressure drops across the valves of the compressor can be quite considerable and they may effect the performance adversely okay. And heat transfer from the compressor is deliberately provided in most of the cases so as to operate the compressor within safe temperature limits. So in the theoretical cycle we assumed that the compression process is reversible and adiabatic that means there is no heat transfer okay. But in actual systems some heat transfer is provided deliberately near the compressor. Because we would not we do not want to have very high temperatures in the compressor okay. Generally the compressors are cooled okay that means the compression process is no longer isentropic. But it is polytropic and generally we define what is known as an isentropic efficiency to find the compare the efficiency of actual compressor with the ideal compressor okay.

(Refer Slide Time: 00:53:20 min)

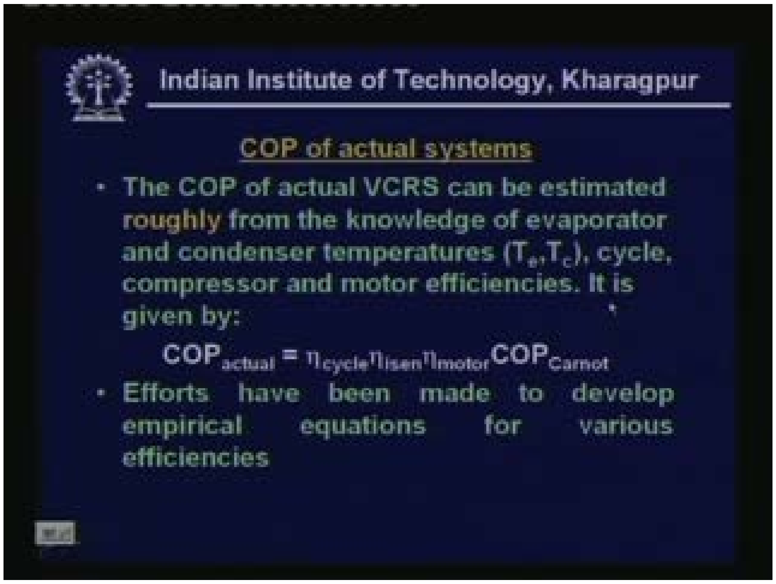


Indian Institute of Technology, Kharagpur

- Presence of foreign matter such as:
- Lubricating oil
- Non-condensible gases such as air
- Water
- Particulate matter also affect the performance of actual vapour compression refrigeration systems
- Presence of lubricating oil cannot be avoided, however, concentration of others should be minimized through proper design and maintenance

Then apart from this you can also have presence of foreign matters such as lubricating oil non condensable gases such as air and water okay. And you can also have particulate matter if you are not your system is not clean in the beginning and all these things will affect the performance of the actual systems. And the presence of lubricating oil cannot be avoided but presence of other things like air water and particulate matter has to be minimized through proper design and maintenance.

(Refer Slide Time: 00:53:49 min)



Indian Institute of Technology, Kharagpur

COP of actual systems

- The COP of actual VCRS can be estimated roughly from the knowledge of evaporator and condenser temperatures (T_e,T_c), cycle, compressor and motor efficiencies. It is given by:

$$COP_{actual} = \eta_{cycle}\eta_{isen}\eta_{motor}COP_{Carnot}$$

- Efforts have been made to develop empirical equations for various efficiencies

Now COP of actual systems can be given by the simple expression which is a multiplication of efficiency of the cycle efficiency of the compressor efficiency of the motor into COP of the Carnot cycle okay. This is a very rough if for a very rough estimation okay. And empirical equations have been developed to estimate the efficiency of the cycle efficiency of the motor compressor etcetera. Okay, using these equations you can get a rough idea of the actual COP compare to the Carnot COP.

(Refer Slide Time: 00:54:19 min)

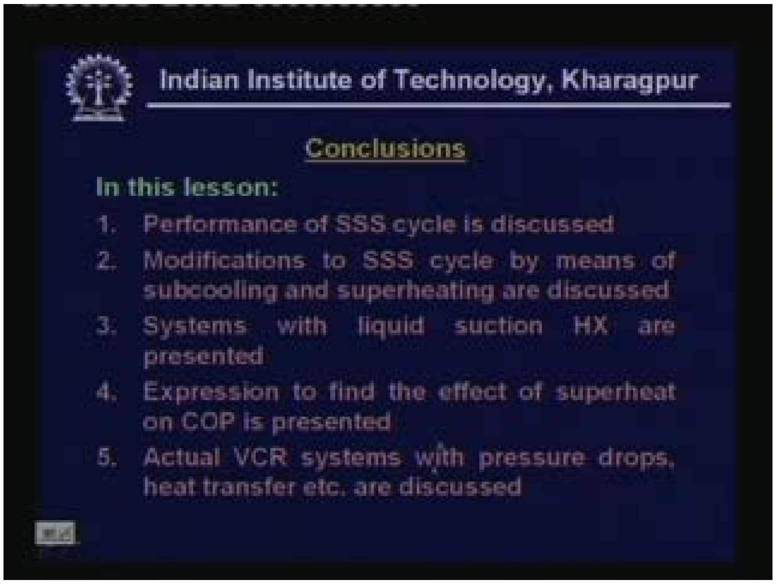
Indian Institute of Technology, Kharagpur

Complete Vapour Compression Refrigeration system

- In addition to the basic components, an actual systems consist of several accessories such as:
- Controls and safety devices such as overload protectors, high and low pressure cutouts, oil separators etc.,
- Temperature and flow controls,
- Filters, Driers, Valves, Sight glass etc

Now a complete vapour compression system in addition to the basic components consists of several other accessories will discuss this later. They are controls and safety devices such as overload protectors high and low pressure cutouts oil separators etcetera. And temperature and flow controls and filters driers valves etcetera okay. So actual system will have a lot many components over and above the basic components okay.

(Refer Slide Time: 00:54:43 min)



Indian Institute of Technology, Kharagpur

Conclusions

In this lesson:

1. Performance of SSS cycle is discussed
2. Modifications to SSS cycle by means of subcooling and superheating are discussed
3. Systems with liquid suction HX are presented
4. Expression to find the effect of superheat on COP is presented
5. Actual VCR systems with pressure drops, heat transfer etc. are discussed

So let me quickly summarize what you have learned in this lesson. In this lesson we looked at the performance of the SSS cycle and we have discussed the modifications by means of sub cooling and superheating. And we have also discussed liquid suction heat exchanger and we have seen the criteria of superheat beneficial effect of superheat. And we have also seen the effect of pressure drops or the actual systems with pressure drops and heat transfer rates etcetera okay. So in the next lesson we will continue the vapour compression refrigeration system and we will discuss multistage and cascade cycles which are used in very large temperature lift applications.

Thank you.