Refrigeration and Airconditioning
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Lecture No. # 22
Refrigeration System Components: Compressor (Continued)

Welcome back in this lecture I shall explain the selection of principal dimensions of reciprocating compressors with the help of the worked-out example.

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Then I will discuss practical issues such as the capacity control of reciprocating compressor and different lubrication methods and selection of lubricants.

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So the specific objectives of this particular lesson are to discuss the selection of principal dimensions of compressor with a worked-out example then to discuss various methods of controlling capacity of reciprocating compressors and discuss compressor lubrication.

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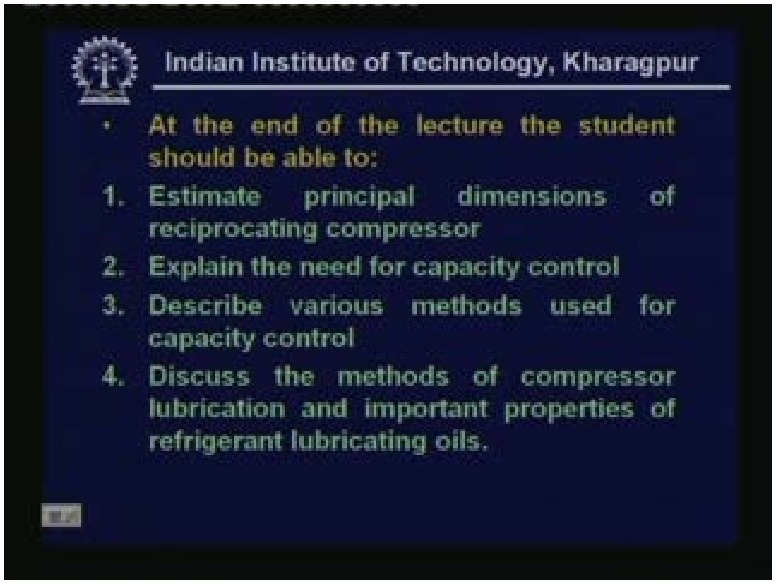

At the end of this lesson you should be able to estimate principal dimensions of reciprocating compressors explain the need for capacity control describe various methods used for capacity control and discuss the methods of compressor lubrication and important properties of refrigerant lubricating oils.

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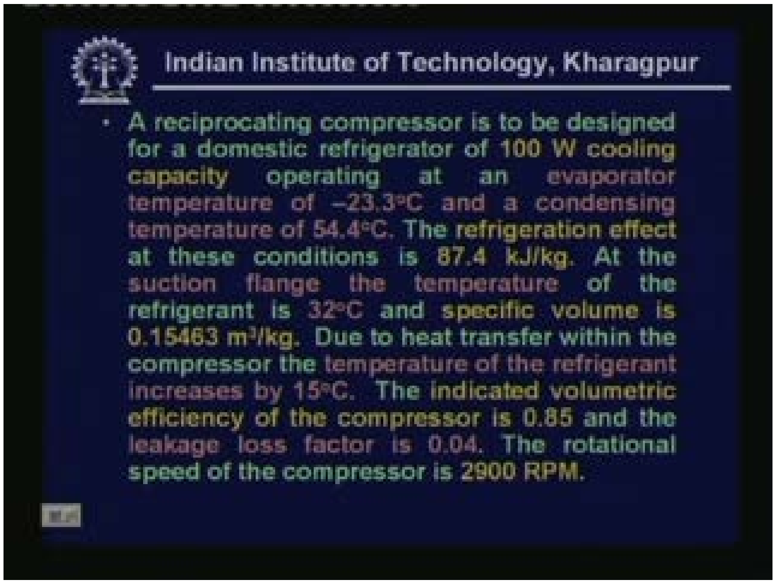

Now let us look at a problem. The problem statement is like this a reciprocating compressor is to be designed for a domestic refrigerator of hundred watt cooling capacity operating at an evaporator temperature of minus twenty-three point three degree centigrade and a condensing temperature of fifty-four point four degree centigrade. The refrigeration effect at these conditions is eighty-seven point four kilo joules per kg at the end at the suction flange the temperature of the refrigerant is thirty-two degree centigrade. And specific volume is point one five four six three meter cube per kg. Due to heat transfer within the compressor the temperature of the refrigerant increases by fifteen degrees. The indicated volumetric efficiency of the compressor is point eight five and the leakage loss factor is point zero four and the rotational speed of the compressor is two thousand nine hundred rpm. So this is the problem.

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Okay, so let me just summarize the given input data it is given that the cooling capacity is hundred watts. That means point one kilo watt evaporator temperature is minus twenty-three point three degree centigrade. A refrigeration effect is eighty-seven point four kilo joule per kg temperature at suction flange is equal to thirty-two degree centigrade. And specific volume of vapour at flange is point one five four six three meter cube per kg and temperature rise in compressor is fifteen degree centigrade. And indicated volumetric efficiency is point eight five leakage losses factorize point zero four and the mean effective pressure mep is equal to point five point two two four bar and finally the rotational speed of compressor is two thousand nine hundred rpm. So this is the given information.

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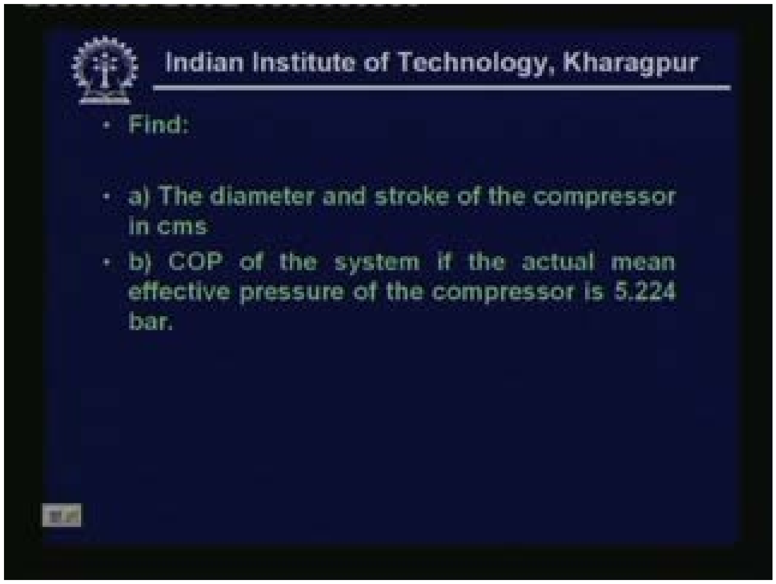

And what is that, we have to find we have to find first the diameter and stroke of the compressor in centimeters. Then the COP of the system if the actual mean effective pressure of the compressor is five point two two four bar.

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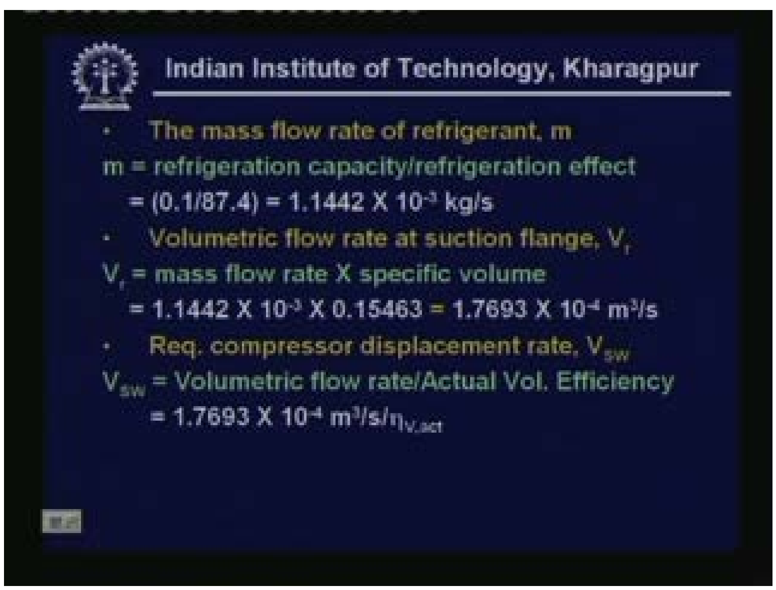

So let us solve this problem from the given input data first up all. Let us find out the mass flow rate of refrigerant as you know the mass flow rate of refrigerant is given by refrigeration capacity divided by the refrigeration effect. So in the problem it is mentioned that the refrigeration capacity is point one kilowatt and the refrigeration effect is eighty-seven point four kilo joule per kg. So if you substitute these values we find that the required mass flow rate of refrigerant is one point one four four two into ten to the power of minus three kg per second. Then let us find out the volumetric flow rate at suction flange and the formula for volumetric flow rate is, it is a product of mass flow rate of refrigerant into specific volume at suction flange. And just now we have found that the mass flow rate is equal to one point one four four two into ten to the power of minus three kg per second. And the specific volume is given in the input data as point one five four six three meter cube per kg.

So if you substitute these values you find that the required mass flow rate of refrigerant at suction flange is equal to one point seven six nine three into ten to the power minus four meter cube per second. Then we have to find out the required compressor displacement rate and as you know the compressor displacement rate is nothing but the volumetric flow rate of the refrigerant divided by the actual volumetric efficiency. We know the volumetric flow rate. We have to find out what is the actual volumetric efficiency. So let us find out the actual volumetric efficiency.

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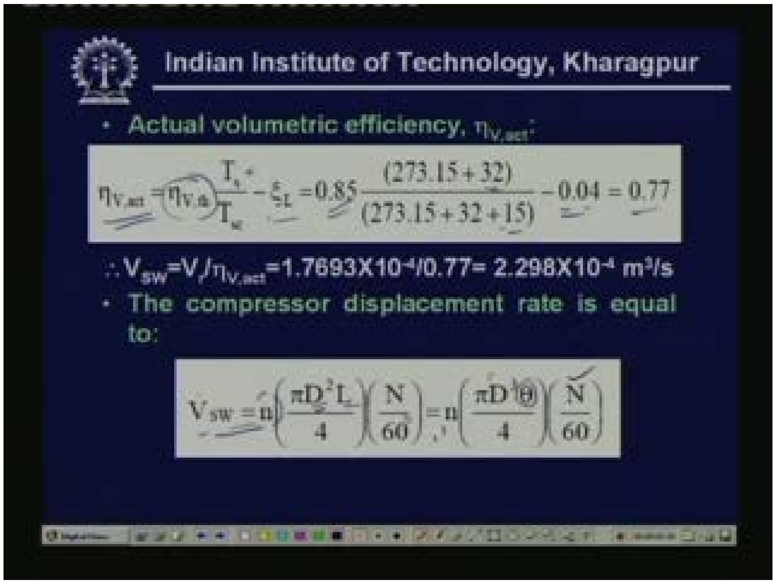

So in the last class I have mentioned that the actual volumetric efficiency of a reciprocating compressor taking into account the heating in the cylinder and leakage loss factor is given by this formula where n v actual is the actual volumetric efficiency. And eta v subscript T h is the indicated volumetric efficiency which is given as point eight five this we have to multiply by temperature of the refrigerant at suction flange that is given, that is T s, that is given as thirty-two degree centigrade divided by the temperature of the compressor at the inlet to the temperature of the refrigerant at the inlet to the compressor. And it is mentioned in the problem that the refrigerant gets heated up by fifteen degrees as it passes through the compressor. That means the temperature at the inlet to the compressor is forty-seven degrees and T s and T s c should be in the units of Kelvin.

So we are converting this into Kelvin minus zeta L zeta L as you know is the leakage factor and it is given as point zero four. So if you substitute these values you find that the actual volumetric efficiency is given as point seven. Now we know that from this we can find out what is the required swept volume of the compressor. This is nothing but the volumetric flow rate of the refrigerant divided by the actual volumetric efficiency. So if we substitute these values we find that the required volumetric required swept volume of the compressor is two point two nine eight into ten to the power of minus four meter cube per second. And we also know that the compressor displacement rate is equal to this formula where I will explain this small n is the number of cylinders D is the diameter of the cylinder L is the stroke length and capital N is the rpm.

So what we do is we write D and L we club this into what is known as the stroke-to-bore ratio that is theta okay. That means theta is equal to L by T so if you are eliminating L then this formula becomes pi D cube theta by four into small n into N by sixty. Here all that we know is we know the capital N because its mentioned that it is two thousand nine hundred r p m and we have also found what is the required displacement rate. So there are three unknowns in this equation. One is the number of cylinders and second one is the diameter of the cylinder and the third one is the stroke-to-bore ratio. So we have only one equation and we have three unknowns. So what we have to do is we have to at least fix two parameters so that we can find out the unknown parameter from this equation. So what now what is normal done is normally the number of cylinders that is small n and the stroke-to-bore ratio are fixed okay. Once you fix these two then only unknown is the diameter of the cylinder. So which we can find out from this equation okay.

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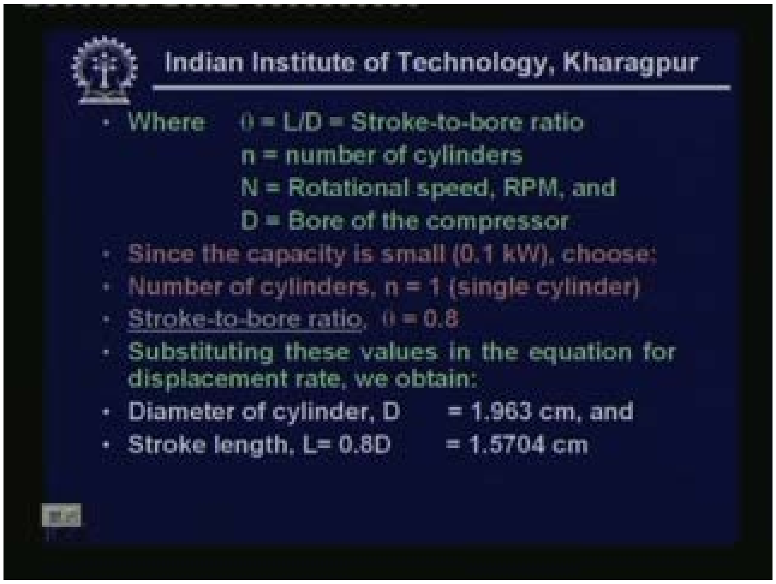

So as I have already explained the in the above formula theta is equal to L by D that is stroke-to-bore ratio and small n is the number of cylinders capital N is the rotational speed and D is the bore of the compressor. And out of these we have to fix theta and n. So how do you fix these things first let us look at the number of cylinders since this is the small compressor we can select small n as one that means we have a single cylinder compressor okay. That is what is mentioned here number of cylinders we have chosen as one. So n is one then we have to fix for the stroke-to-bore ratio stroke-to-bore ratio is theta and at here we have selected this as point eight what is the basis for selecting this as point eight and what is the effect of this stroke-to-bore ratio on the performance of the compressor. Let us look at this.

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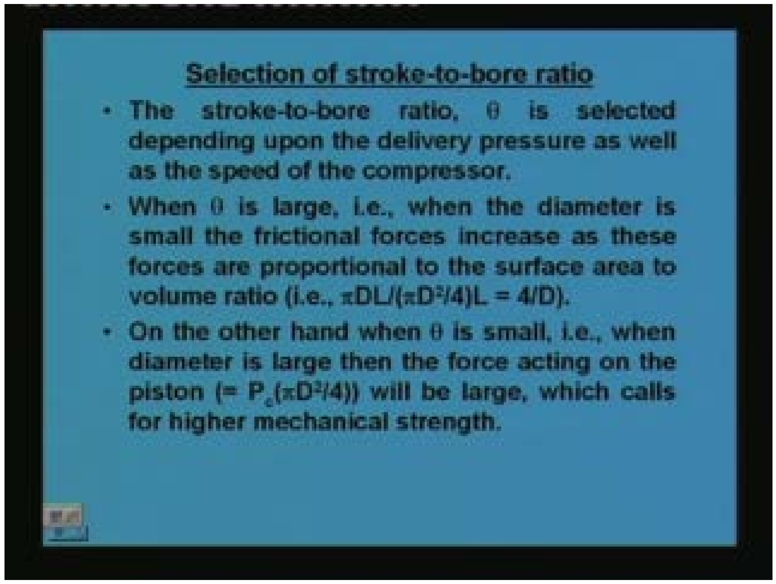

Okay, so selection of stroke-to-bore ratio the stroke-to-bore ratio theta is selected depending upon the delivery pressure as well as the speed of the compressor. So how does the delivery pressure affect the stroke-to-bore ratio and how does the speed of the compressor affect the stroke-to-bore ratio. Let us look at it. What happens when theta is, large theta as you know is L by D theta is large means the diameter small. So when the diameter is small you find that the frictional forces become large because the frictional forces are proportional to the surface area to volume ratio. The surface area of the cylinder is pi D L and volume is pi D square by four into L that means the frictional forces are proportional to four by D. So as you reduce the frictional forces increase.

That means when you select large theta you that means small d then there will large frictional forces and frictional forces really become very important when the speed is very high okay. So when the speed is high we would like to minimize the frictional forces. That means for high speed compressors we would like to have as large the diameter as possible. That means we have to select a smaller value of theta okay. Then let us look at the other side that means what happens when theta is small means the diameter is large what happens when the diameter is large when the diameter becomes large the force acting on the piston becomes large. What is the force acting on the piston what is the maximum force acting on the piston. The maximum force acting on the piston is nothing but the maximum pressure developed inside the compressor into the surface area of the piston.

The surface area of the piston as we know is pi D square by four and the maximum pressure developed in the compressor is equal to approximately equal to the condenser pressure. That means the force acting on the piston ultimately becomes P c into pi D square by four. So when the condensing pressure is very large and when you also select a large D you find that the force acting on the piston becomes very large. That means you have to design a very strong piston connecting round and all that. That means the mechanical strength requirement and all increases as the diameter increases that means in fact square of the diameter okay. And this fact becomes very important when P c is high. So these are the two limits that means a small theta means higher frictional losses and large theta means higher mechanical strength requirement okay.

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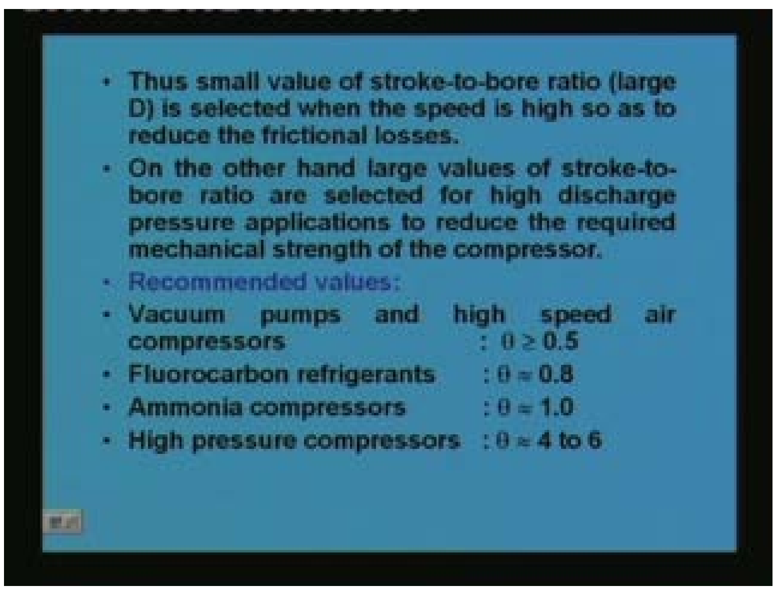

So as the result we normally find that a small value of stroke-to-bore ratio that means large D is selected when the speed is high so that we can reduce the frictional losses okay. And on the other hand when large values of stroke-to-bore ratio that means small diameter is selected one high discharge pressure applications are encountered okay. That means for high discharge pressure application you have to go for small diameter and for high speed applications you have to go for large diameter. So some of the recommended values are like this for vacuum pumps and high speed air compressors normally theta values about point five. As I have already mentioned when speed is high diameters should be large that means theta value should be small. So theta values around point five and for fluorocarbon refrigerants the industrial practice is to select a stroke-to-bore ratio for about point eight and for ammonia compressor normally theta is selected as about one.

For ammonia compressor normally the discharge pressures could be high. So you have to go for slightly smaller diameter that the reason why we have selected slightly higher theta compared to fluorocarbon refrigerants. And finally for high pressure compressors for example such as carbon dioxide compressors and all we have to go for a high value of theta that about four to six. So that the mechanical strength requirement will be small. So this is the criteria based on which you have to select the stroke-to-bore ratio okay. And in this particular example i have not mentioned what is the refrigerant. But from common sense we know that in most of the domestic refrigerators we use either fluorocarbon refrigerants or hydrocarbon refrigerants. Now-a-days we use hydrocarbon refrigerants. So for these things typically the operating pressures are not so high that means the condensing pressure is not so high. So generally as I said you have to select the theta of about point eight okay. So this is the reason why we have selected the theta of point eight in this example.

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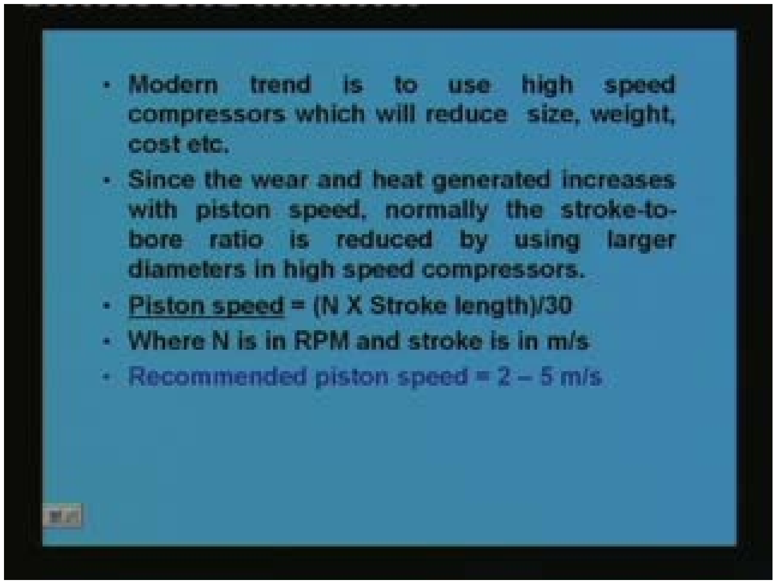

And nowadays the modern trend is to use high speed compressors why do what is the advantages of using high speed compressors from the expression for swept volume rate. That means that means the displacement with the compressor. We know that the swept volume is directly proportional to the speed of the compressor. So when you increase the speed of the compressor required swept volume becomes small it has many benefits. Once you once a required swept becomes small the compressor becomes very compact. That means the size of the compressor becomes small and its weight also becomes small and its cost also becomes small. So there are all host of advantages when you go for high speed compressors. That is the reason why the latest trend the modern trend is to go for as high as speed as possible okay.

So when there is one problem when you go for very high speed compressors when the speed is very high. What is the problem? When the speed is very high the heat generation also will be high okay. And there will not be sufficient time for heat to be rejected from the compressors okay. So this is one constraint on the highest speed of the compressor okay. That is what is mentioned here and as I have already mentioned when you have high speed compressors normally we go for larger diameter. So that we can reduce the frictional losses and here actually not only the rotational speed the piston speed is also important. Of course the piston speed and rotational speed are related by this expression piston speed is nothing but N into stroke length by thirty. This N is the revolutions per minute and the thirty comes here because in one revolution it travels two stroke lengths.

It completes in one revolution it completes a distance of two stroke length that the reason why we have thirty here and normally the recommended piston speed is about two to five meter per second. In fact it is very surprising to note that over the last many decades this recommended piston speed has not really changed. That means the range always lies between two to five meter per second there are many practical reasons why it is like this and normally if smaller piston speeds are used in smaller compressors and larger piston speeds are used in larger compressors.

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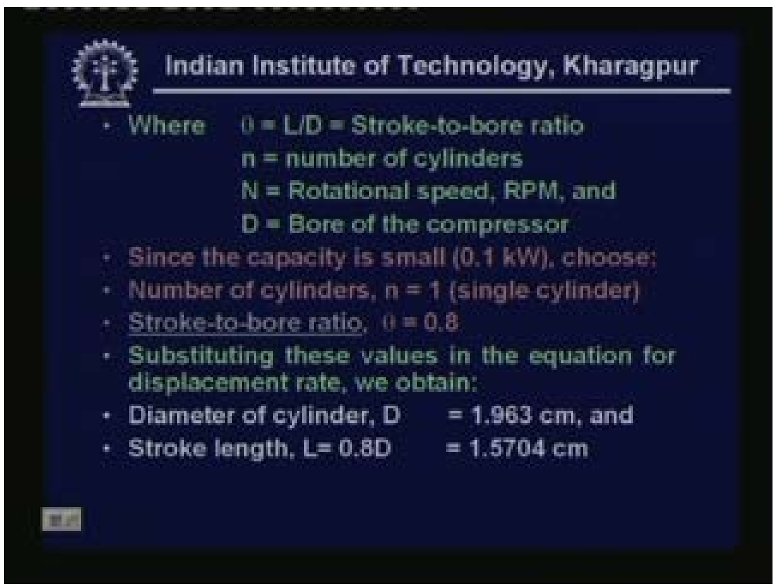

Okay, so from this above discussion the stroke-to-bore ratio theta is selected as point eight. Once you have selected theta and N then all that you to do is substitute the value of theta and N and the displacement rate in the equation shown before then only unknown is the diameter. So the from this example you will find the diameter of cylinders one point nine six three centimeter. And the stroke length L is nothing but theta into D theta is point eight point eight into D is one point five seven zero four centimeter. This is how normally the principal dimensions of compressor are chosen of course there are lot of issues which have to be considered. For example just now I have mentioned the selection of the number of cylinders. Since this is small refrigerator we selected n as small n as one that means the single cylinder compressor. When the capacity becomes large one has to go for more number of cylinders okay.

And normally you can go as high as sixteen cylinders. So again everything depends upon the given problem okay. And the speed here is mentioned as two thousand nine hundred rpm and there is the reason behind this normally in small domestic refrigerators we use two phase induction motors. So if you assume frequency of fifty hertz then the maximum speed is three thousand rpm and if you take care of the slip. Then the speed will be about two thousand nine hundred to two thousand nine hundred and fifty rpm that the reason why the speed is given as two thousand nine hundred rpm okay. So you have to decide certain parameters and then you have to use the given input data. And finally you have to arrive at the stroke and bore of the compressor okay.

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Then second part of the problem is to find out the COP of the system. We know that in fact if you remember in the last class I have mentioned that the concept of mean effective pressure actually mean effective pressure is very useful. Because it is defined in a such a way that when you multiply this actual mean effective pressure into the displacement rate of the compressor. That will give you the actual power requirement of the compressor okay. So if you somehow if you can find out what is the mean effective pressure all that you need to know is the displacement rate of the compressor okay. So here we its input is given that the mean effective pressure is five point two two four bar and the displacement rate we have found to be two point two nine eight into ten to the power of minus four meter cube per second. So if you substitute these values you will find that the actual power input is given by point one two kilowatt. So if you substitute this in the expression for COP COP is nothing but the refrigeration capacity divided by the power input to the refrigerator. Then that you will find that it is point one divided by one two that means the COPs is point eight three three okay. This is the practical problem and very simple problem all that you have to do is you have to use the right equations. And you have to use the right data okay. Now let us look at some of the practical aspects of reciprocating compressors.

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First one is the capacity control of reciprocating compressors why do we need capacity control. Normally when you design a refrigeration system you always design it in such a way that it operates satisfactorily even when the load is maximum. That means you normally design it for peak load conditions and when do these peak load conditions occur and the peak load conditions occur when the cooling load is maximum or when the condensing temperature is very high okay. So normally we select the components of the refrigerant system including compressor to meet the peak load requirements okay. So that how the compressor is selected but you find that most of time the load may not be at its peak. That means either the cooling load is less than the peak or the condensing temperature is lower okay.

That means in the under these circumstance the cooling load requirement will be less than the design load or peak load. So what happens since you have selected the compressor to see to shoot the peak load requirements. And the system is operating at less than the peak load then the compressor becomes over sized okay, at off design condition okay. So when the compressor becomes over sized at off design condition what happened, what exact is the main function of the compressor the compressor has to take out the refrigerant vapour at the rate at which it is generated in the evaporator. That means the mass flow rate through the compressor should be equal to the mass flow rate of the refrigerant in the evaporator.

That means the rate at which vapour is being generated in the evaporator should be equal to the compressor mass flow rate then the evaporator temperature will be at the design value under off load conditions. That means under con the load conditions which are lower than the design load the compressor becomes over sized. That means compressor will be trying to take more refrigerant vapour than is generated in the evaporator okay. So that means less vapour is generated because the load is less but the compressor is taking out more vapour. So what happens, so there is an imbalance between the rest of the system and compressor as the result the system will finally arrive at a balanced condition. And this balanced condition will be at a lower evaporator temperature.

That means ultimately at low load conditions if you do not do any capacity control then the evaporator temperature of the system will be low okay. And the system will attain a balance now when the evaporator temperature is low there are many problems. First of all if you are using it for let us say cold storage requirements then since evaporator is operating at low temperatures the humidity of air also will be low. That means there will be dry conditions in the cold storage. This may lead to higher weight losses moisture losses okay. And it may also lead if the temperature is so low then it falls below zero degree centigrade. Then it may lead to frosting and on other hand if you are using not air but some liquid such as water as an external fluid. Then there is the danger of the water freezing inside the pipe lines because evaporated temperature is falling below zero degree centigrade.

Then as you know when water freezes its volume increases the pipe lines may burst. That means if want to operate the system satisfactorily at less than design load conditions you must make sure that the evaporator temperature is not falling too much below the design value okay. This is only possible only when you regulate the capacity of the compressor okay. That means all practical systems have to have some means of regulating the capacity of the compressor. Normally when we say the capacity control we generally mean reduction capacity okay. Because in general it is not possible to increase the capacity more the over and above that of the design. Because design load itself with the peak load. So whenever we see capacity control means capacity reduction okay. So capacity reduction is a must in any practical refrigeration system. So let us look at what are different ways by which capacity control of reciprocating compressor is achieved okay. So let me summarize whatever I have explained now. Refrigerant compressors are normally designed for peak load conditions without capacity regulation the evaporated temperature decreases during part load conditions. As I have already explained why it happens and reduced evaporator temperatures lead to problems. Such as low air humidity in the refrigerated space frosting of evaporator coils and freezing of the external fluid. This obviously indicates a need for controlling the capacity of the compressors. So this is the need for capacity control.

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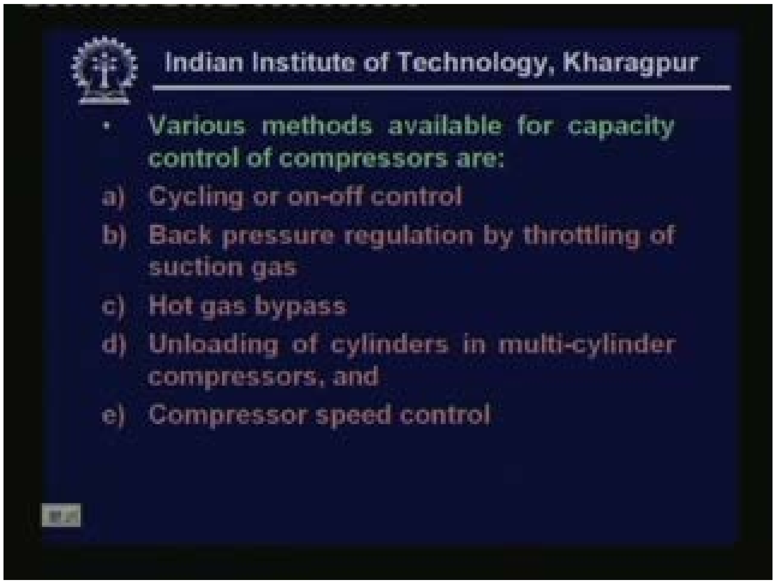

And what are the different methods available for capacity control of compressors the first method is known as cycling or on-off control. The second method is back pressure regulation by throttling of suction gas. The third method is what is known as hot gas bypass and the fourth method is known as unloading of cylinders in multi-cylinder compressors. And finally you can also regulate the capacity by compressor speed control. Now let us look at each one of the, them and let us look at what are the typical features what are the advantages and disadvantages of these methods.

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First let us look at cycling control or on-off control. So this type of control is normally used in small refrigeration systems such as domestic refrigerators room air conditioners and water coolers. I am sure that all of you must have noticed that domestic refrigerators or room air conditioners are cycling devices. That means once a required temperature is achieved inside the refrigerator the compressor is simply switched off okay. And after some time the compressor again is switched on. That means there are periods during which the compressor is running and there are periods during which the compressor does not run this typically happens in small system such as room air conditioners water coolers and domestic refrigerators okay. And how this is done normally, this is done by using a thermostat which senses the temperature of the refrigerated space or evaporator temperature and in turn controls the compressor on-off. So normally again you have you must have noticed in domestic refrigerators and evaporators. The thermostat is used and using the thermostat you can really set the temperature inside the refrigerated space or inside the air conditioned space okay.

And this, the function of this thermostat is to sense the temperature what temperature depends upon the design of the system. For example the temperature that is sensed by thermostat could be the refrigerated space temperature itself or it could even be the evaporator temperature. So depending upon where you have located the sensor it will be sensing some temperature and based on the values of that particular temperature it will take the control action. And here the control action is either on or off okay. It is normally off acts on the switch and when the switch is closed there will be power supply to the compressor and the compressor runs and when the switch is opened there is no power supply to the compressor and compressor stops okay. And as I have already explained to you when the refrigerated space or evaporator attains a cut-out temperature the thermostat switches off the compressors. When we talk about the controls typically a thermostat be introduced some new terms one is what you known as the cut-out temperature cut-out temperature is the temperature at which the thermostat switch opens that means power supply to the compressor is stopped okay.

That means compressor becomes off this temperature is known as cut-out temperature and again the compressor has to be switched-on when the temperature rises to a cut-in value okay. So what happens when the compressor is switched off when the compressor is switched off there is no refrigeration effect inside the refrigerated space. And as you know the refrigerated space is at a temperature that is lower than the surroundings. Since there is a temperature difference between the surroundings and the refrigerated space there will be heat leak into the system. So the system temperature increases. When the system temperature goes beyond system temperature or evaporator temperature goes beyond a set point what is known as cut-in temperature. Again the refrigerant system should be switched on okay. That means when the thermostat senses that the temperature has reached the cut-in temperature then again it supplies the switch is closed and the compressor starts running again okay. So in an additional when the temperature reaches cut-out temperature compressor is switched off and when the temperature reaches a cut-in temperature compressor is switched on again okay. So this is the principal of a thermostat control on-off control.

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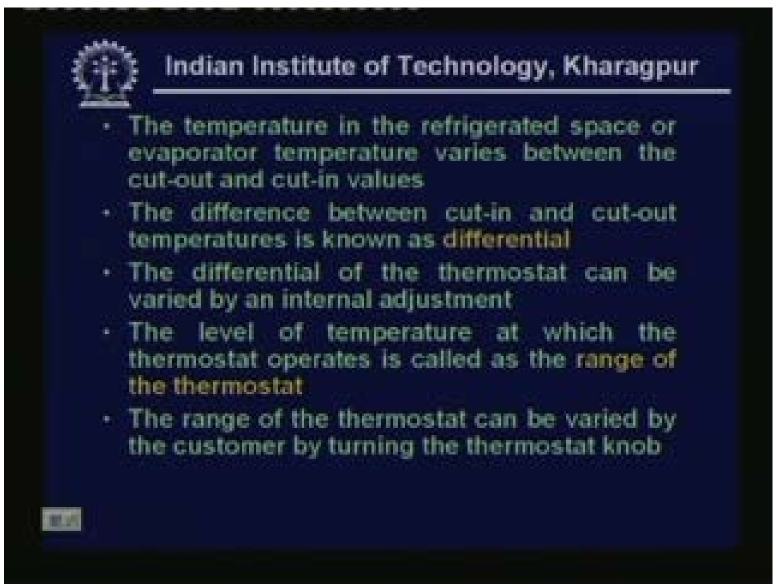

So what happens because of this because of this you find that the temperature in the refrigerated space or evaporator temperature varies between the cut-out and cut-in values okay. So the temperature does not remain constant in fact in fact if you look at any air conditioning space or refrigerator you will always find that the temperature continuously fluctuates between the cut-out and cut-in values okay. And the difference between cut-in and cut-out temperature is known as differential of the thermostat okay, cut-in temperature is higher than the cut-out temperature and this difference is known as differential. And the differential of the thermostat can be varied by an internal adjustment. Let me give an example you can have a thermostat which has a cut-in temperature of let us say ten degree centigrade and the cut-out temperature of nine degree centigrade.

That means when the thermostat senses that the temperature is nine degree centigrade the switch open and the compressor is switched off okay. At nine degree centigrade which happens to be the cut-out temperature. And as a result of compressor being switched off the refrigerated space temperature or evaporator temperature increases and when this temperature reaches ten degree centigrade then the system is switched on again okay. That means the temperature variation between nine to ten degree centigrade and the difference between these two. That means ten minus nine is equal to one degree centigrade this one degree centigrade is known as the differential of the thermostat. And you can change the differential of the thermostat and this adjustment is generally done internally normally in fact to set. But if you want to change it you have to open the thermostat and inside the thermostat there will be a mechanism for varying the differential.

For example you can vary the differential you can keep the cut-in temperature as nine degree centigrade. And you can ten degree centigrade and you can change the cut-out temperature to let us eight degree centigrade okay. So instead of operating at ten degrees or nine degrees it can operate between ten and eight degrees. That means you have increase the differential from one degree to two degree centigrade. This adjustment is possible okay. So this is the differential and the level of temperature at which the thermostat operates is called as the range of the thermostat. So you have the difference between cut-out and cut-in temperature and you also have the absolute values of these temperatures. For example, in the example I have discussed just now nine degrees to ten degrees are the level set which the thermostat switch is operating. So this is known as range okay nine and ten degrees right.

And the range of the thermostat can be varied by the customer by turning the thermostat knob. So you can vary the as a customer you can change the range. That means if you want colder settings then what you can do is you can push the operating temperatures to lower temperature by turning the thermostat towards colder sides. So this you might have seen in your domestic refrigerators when you turn the thermostat knob to colder sides instead of operating between nine and ten degrees it may operate between five and six degrees okay. So this is in hands of the customer. Similarly air conditioned space you can make the room warmer or colder by controlling the thermostat knob. So when you are actually rotating the knob of the thermostat what you are doing is you are actually varying the range of the thermostat okay.

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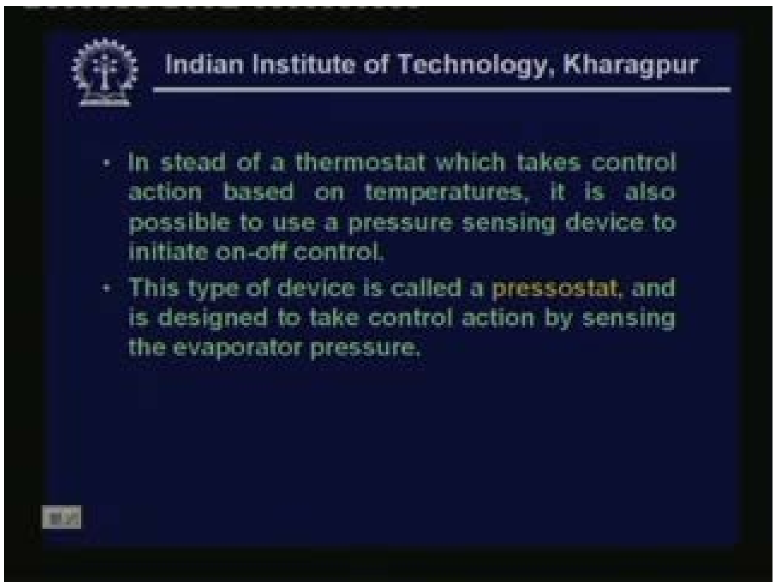

Of course in some of the systems instead of using a thermostat you can use what is known as the pressostat okay. That means instead of sensing the temperature of a conditioned space or temperature of the evaporator and taking a control action you can also sense the pressure of the evaporator okay. Instead of sensing the evaporator temperature you can sense the evaporator pressure when the evaporator pressure falls below a certain cut-out pressure. Then you can switch off the compressor and when the evaporator pressure increases to a cut-in pressure then you can again switch on the compressor okay. That means instead of operating between cut-out and cut-in temperature it will be operating between cut-out and cut-in pressures okay. And the device which is used for achieving this purpose is known as the pressostat not thermostat okay. This type of as I said this type of device is called a pressostat and it is designed to take control action by sensing the evaporator pressure.

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Now this is the principal of on-off control and where do we use on-off control and what are advantages. And disadvantages of this control the on-off control as you have you might have seen is satisfactory in applications where the fluctuation in product temperature due to on-off control is acceptable. So whenever you are using cycling control or on-off control there will definitely a temperature fluctuation inside the refrigerator space okay. If this temperature fluctuation is acceptable and nothing no harm takes place if even if the temperature varies then you can use this on-off control okay. Typically in room air conditioners are in domestic refrigerators at temperature variations of one or two degrees does not make much difference. It does not really spoil the products or it does not really lead to great deal of discomfort okay. We can effort to use this kind of a control in these applications where the temperature is not very important okay. It is important but not so important.

So thus it is suitable when the okay. So and it is also suitable when the thermal capacity of the product or the refrigerated space is large. So that small variation in it can give sufficient variation in evaporator temperature. Even though just I have mentioned that there was refrigerated space temperature in these applications is not very important that does not mean that it can vary over a large range because otherwise the production will get spoiled okay. So variation should be small right. But there should some variation and this variation should be tolerable. Normally if you want to reduce a variation in the product because you are ultimately concerned about the product or the people they are not really interested in the temperature of the evaporator okay.

And if you are sensing the evaporator temperature okay so you have if you have a system where the thermal capacity of the product is very large okay. Then a small temperature variation in the refrigerated space can lead to a large temperature variation in the evaporator okay. That means you can have a large difference between cut-out and cut-in values of the evaporator temperature. At the same time the refrigerator space temperature does it very much because of its high thermal capacity. So these are the applications at under which this on-off control is good okay otherwise it’s not good okay. So on-off control is not good when the temperature has to be regulated within a small range in which case the compressor has to start and stop very frequently okay. What happens it is not that it does not work you can have difference of point one degree between cut-out and cut-in. That means you can have a cut-out temperature of nine degrees and a cut-in temperature of nine point one degrees okay.

As far a thermostat is concerned you can design such thermostat but what happens. So if you have only a point one degree differential that means the compressor starts and stops very frequently okay. This has many practical problems normally when the system is very large it cannot start and stop so frequently okay. Whereas small capacity systems can stop and start more frequently okay.

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So as I have already mentioned small compressor motors can be cycled for about ten cycles per hour where as large compressor motors are normally not allowed to start and stop for more than one or two times in an hour okay. So this puts a restriction on the minimum value of differential. That means you have to have a certain minimum value of differential so that the number of on and off can be controlled and can be within the practical limits okay. So this is the constraint on using the thermostat for on-off control. So though on-off control introduces cycling losses it may be better than operating the system at part load with poor COP okay. So what happens during on-off for example if you look at the domestic refrigerator where we typically use a capillary tube as a expansion device.

So when you are switching off the system there will be a pressure equalization that means the entire system pressure will reach an equilibrium value. That this happens as the high pressure refrigerant vapour or high pressure refrigerant liquid from the condenser flows through the capillary tube and it enters into the evaporator. So that the pressure difference vanishes. That means ultimately there will be no pressure difference between the condenser and evaporator. So what is happening during this process during this process you are introducing hot refrigerant into the evaporator that means into the refrigerated space. That means you are adding heat to the refrigerated space which has got to be taken out again right. So this kind of loss is known as the cycling loss.

So whenever you have on-off type of control and whenever you are using devices such as capillary tube for throttling then you have cycling losses okay. So this is one of the disadvantage of on-off control but in many applications. This may be tolerable rather than operating the system at part load condition. That means you operate the system continuously at a part-load condition and at part load condition you are getting poor COP. That means the efficiency will be low. So the low efficiency under part-load condition may be much higher than the cyclic losses okay. So under such circumstances thermostat control is good and since on-off control is inexpensive and simple. It is widely used in small capacity systems as I have already mentioned okay.

This is most widely used control in almost all small capacity refrigerant system. Because it is inexpensive in small capacity systems a cost is the major factor. And it is also very simple okay.

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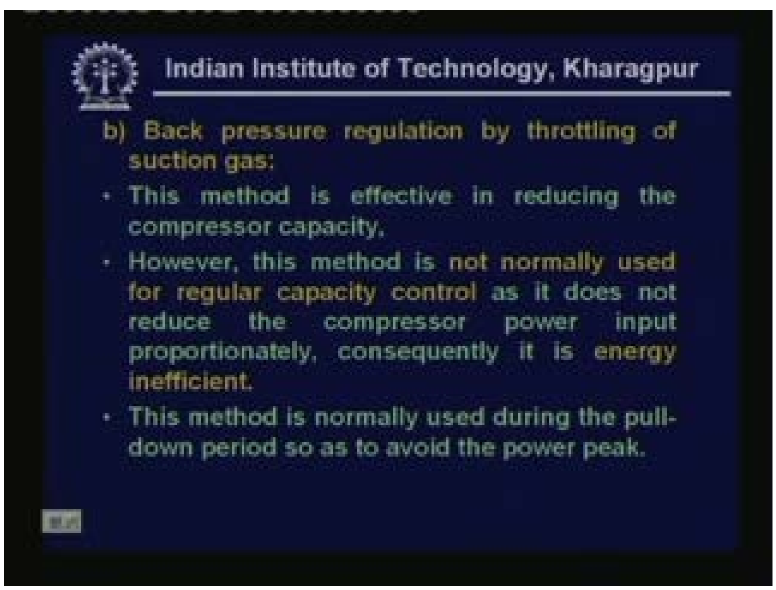

So now let us look at the second method of capacity control. This is a capacity control back pressure regulation by throttling of suction gas this method is effective in reducing the compressor capacity okay. What do we do as the name implies what do we do how do we reduce the capacity of the compressor using this method. In this method what we do is we introduce a valve between the evaporator outlet and the compressor inlet okay. In fact I have explained this in the last class when we were discussing compressor capacity during the peak pull-down okay. So what is the purpose of this one when whenever you want to reduce the capacity of the system you close the valve. That means you are throttling the refrigerant across this valve. When you are throttle the refrigerant what happens is the pressure drops. That means the pressure of refrigerant at the inlet to the compressor will be lower than the evaporator pressure because of the throttling process.

Once you reduce the suction pressure as you know very well the volumetric efficiency of the compressor reduces and the capacity of the compressor reduces okay. So this is the principal behind capacity control using back pressure regulation okay. However this method even I have mentioned here is not normally used for regular capacity control. Ss it does not reduce the compressor power input proportionately consequently it is energy inefficient okay. So this method as I have already mentioned is effective in controlling the capacity you can control the capacity by using the throttle valve. But the disadvantage is you are getting less refrigerant capacity. But at the same time you are not able to reduce the power input of the compressor okay.

The throttle valve does not reduce the power input of the compressor in the same proportion. As a result the COP at part-load condition will be less than the COP at design conditions okay. That means this method is not energy efficient okay. So that is the reason why normally this back pressure regulation for capacity control is not used in practice. But this method is generally used as I have already explained in the previous classes for reducing the peak power requirement during the pull-down okay. This method is normally used during the pull-down period so as to avoid the power peak as I have explained in the earlier lectures.

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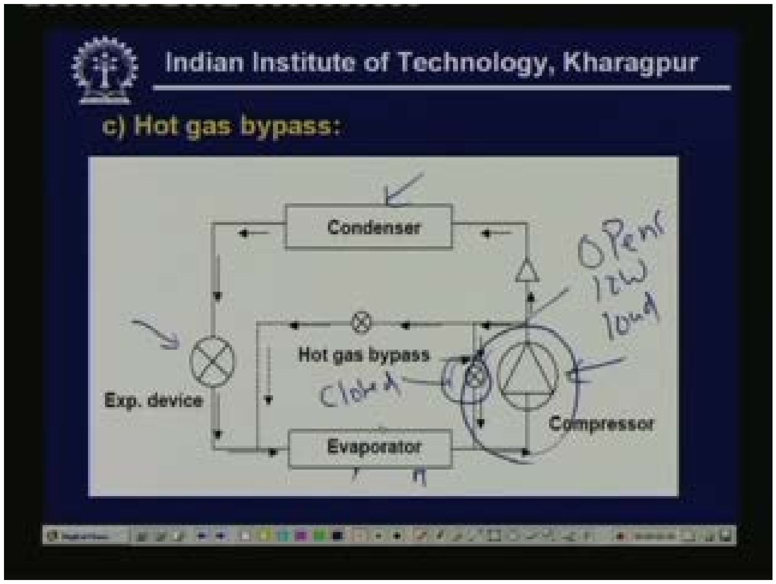

Now let us look at the third method which is quite popular this method is known as hot gas bypass method. Let me explain what is hot gas bypass method here. As you can see here you have the four basic components evaporator compressor condenser and the expansion device in addition to this you have a hot gas bypass okay. So normally when the system is operating at design load this valve will be closed okay. When this valve is closed the refrigerant from the compressor flows to the condenser and it meets the design load requirements but when the load falls this valve opens okay. This is hot gas bypass valve open set low load conditions okay. When the small opens what happens? As you can see some of the refrigerant instead of going to the condenser and the expansion device and evaporator is bypassed and it comes back to the compressor inlet itself. That means it will be cycling at this point itself okay. It does not go through the rest of the circuit. As the result the refrigerant flow rate through the compressor remains constant. But the refrigerant flow rate to the evaporator is reduced as a result the evaporator capacity reduces. So which matches the less load okay. So this is the principal of hot gas bypass.

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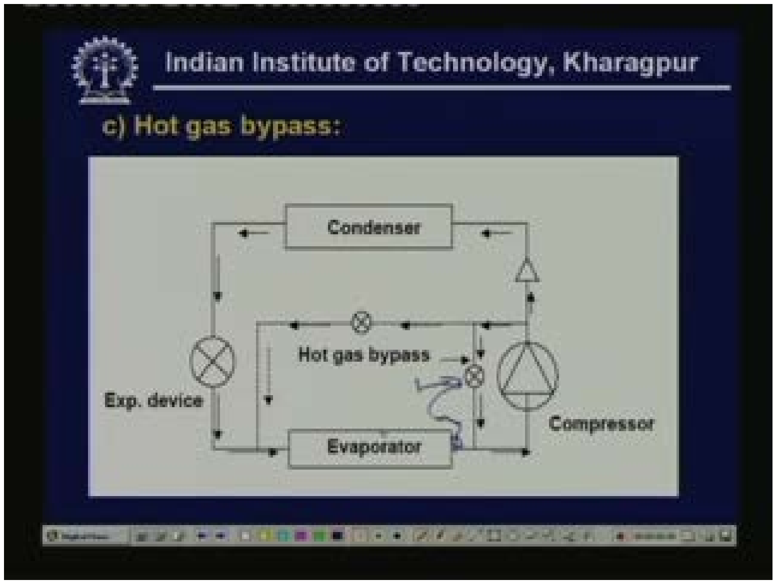

Normally this valve is controlled by sensing the pressure here. That means you will be sensing the pressure at the evaporator and that is connected to this valve when this pressure falls below the design pressure. That means the load is less and this valve opens and once this valve opens then there will be bypass and the refrigerant capacity also reduces to meet the load okay. So this is one method of hot gas bypass you can also have another hot gas bypass method where instead of sending this.

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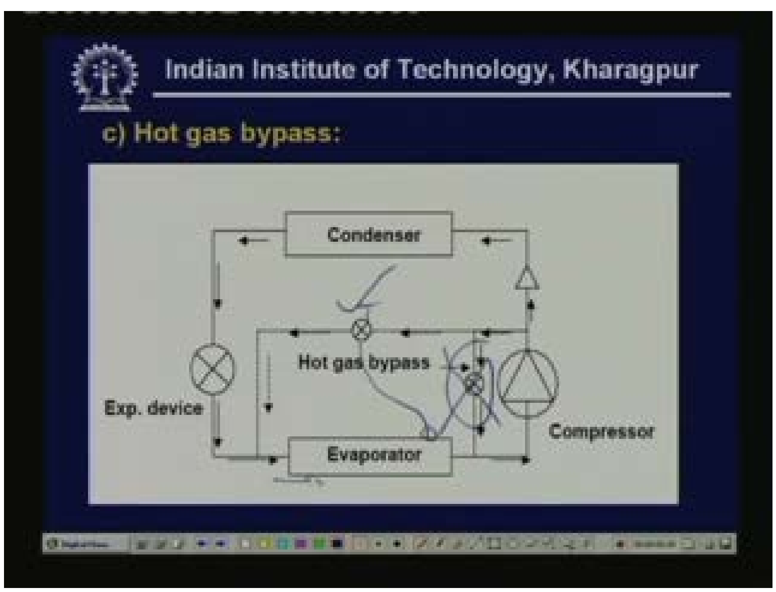

Hot gas to the inlet to the compressor you can send it to the inlet to the evaporator. That means you are not doing this but you are using this okay, this valve. So this valve is again control by the pressure of the evaporator. And when the evaporator pressure falls this valve opens when this valve opens. What is happening the refrigerant vapour comes directly to the inlet to the evaporator okay. It is not going to the inlet to the compressor. So it flows through the evaporator okay. And as it flows through the evaporator. Since it is in the vapour form it does not contribute to the refrigerant effect. So refrigerant capacity reduces okay. So that means you can have hot gas bypass either to the inlet to the compressor or to the inlet of the evaporator okay. Both the methods are possible okay. So now let us look at the characteristics of hot gas bypass method.

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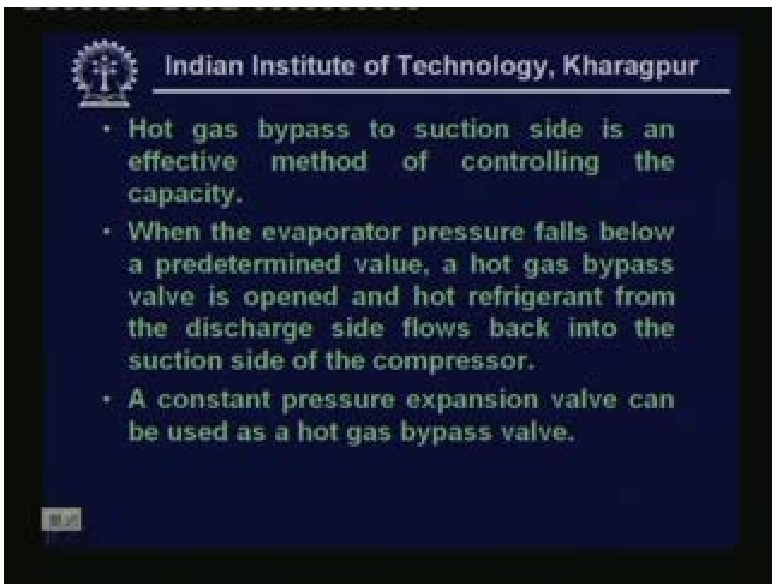

Hot gas bypass to suction side is an effective method of controlling the capacity when the evaporator pressure falls below a predetermined value a hot gas bypass valve is opened. And hot refrigerant from the discharge side flows back into the suction side of the compressor as I have already explained. And a constant pressure expansion valve can be used as a hot gas bypass valve.

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And what are the, as I said this is the effective method for controlling the capacity but obviously this method has certain disadvantages. What are the disadvantage of this method? First disadvantage is there is little or no reduction in compressor power consumption at reduced loads. This is one important things which you have to keep in mind that means what is the performance of this system at part-load conditions okay. Ideally we would like to maintain the same COP under all load conditions okay. What are the COP at designed conditions, so also be the COP at part-load conditions. But in general in most of the cases we find that the part load COP is always less than the COP at design load conditions okay.

But this reduction should be minimized okay. And when you are using a hot gas bypass method you find that refrigerant capacity is reducing but the power input is not reducing proportionately. As a result the COP at part-load conditions will be lower than the COP at design conditions. Why does it happen? Why power input does not reduce the power input does not reduce because when you are doing hot gas bypass. For example when you are sending the hot gas to the inlet of the compressor then the suction gas becomes superheated okay. That means you are pushing the compression process away from the saturated vapour reason. When as you know, when you push the compressor process away from the saturated this thing the isentropes are flattering in that range. So for the same pressure rise you will find that the work of the compressor will be higher okay.

So as a result the COP reduces okay. So this is one of the disadvantage of this method and another the major disadvantage is excessive superheating of the suction gas resulting in overheating of the compressors okay. So just now I have explained that when you are sending the hot gas to the inlet of the compressor the suction gas becomes hot. That means it gets superheated and once it becomes superheated its ability to cool the compressor reduces. And this factor is very important in particularly hermetic type of compressors where if you remember the suction gas is used for cooling the compressor and the motor. But when the suction gas is entering at a high temperature it cannot cool the motor and compressor effectively okay. So when you are using hot gas bypass the compressor cooling gets affected and if the superheat is very large. That means you are bypassing lot of hot refrigerant back to the compressor inlet then the superheat will be very high.

Once the superheat is very high the compressor cooling will be very low okay. This will affect the compressor life and performance right. So this is the second disadvantage of this method. Of course overheating of the compressor can be reduced by sending the hot gas bypass to the evaporator inlet. So you can minimize or you can reduce this superheating as I have already explained by sending the hot gas not to the inlet of the compressor but to the inlet of the evaporator okay. By this method you can reduce the superheat this method is also advantages that means sending the hot gas to the inlet of the compressor. Because the refrigerant flow rate through the evaporator remains same as a result the velocity of refrigerant through the evaporator remains same which will ensure the return of the oil to the compressor okay. That means sending the hot gas to the inlet of the evaporator is much better than sending it to the inlet of the compressor okay.

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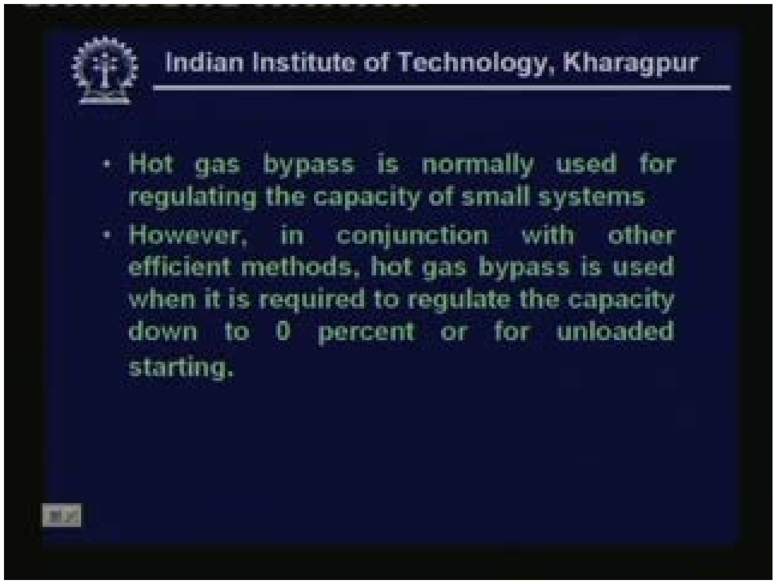

Hot gas bypass is normally used for regulating the capacity of small systems okay. This is not really, not normally used in large system but it is used in small systems. However in conjunction with other efficient methods hot gas bypass is used when it is required to regulate the capacity down to zero percent or for unloaded starting okay. So even though it is not used for capacity control in large systems along with some other efficient capacity control method hot gas bypass method when we used to fine tune the capacity control. That means you can using the hot gas bypass along with another efficient method you can reduce the capacity of the system almost to zero percent okay, of the design load. So this is one and you can also use hot gas bypass method to reduce the peak load requirements during the pull-down okay. So this is the general practice.

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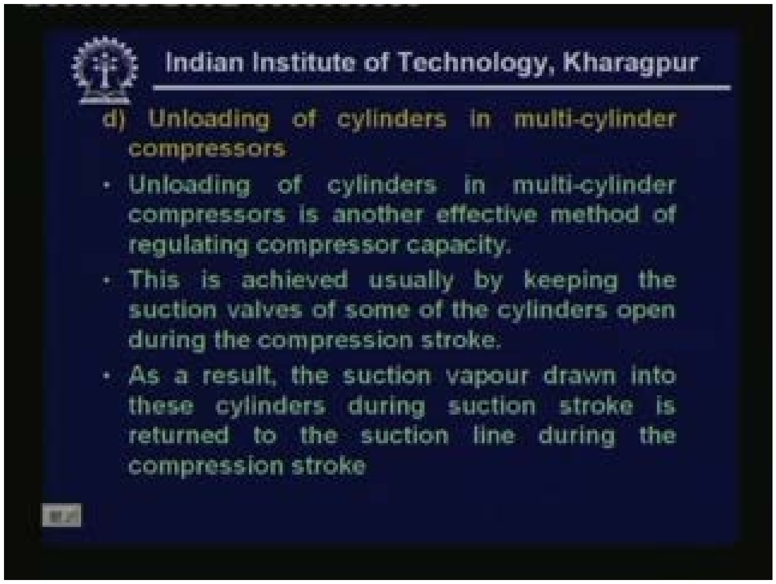

Now let us look at the fourth method that is the unloading of cylinders in multi-cylinder compressors as a name implies this method is followed in multi-cylinder compressors. And unloading of cylinders is another effective method of regulating compressor capacity and what is this method. This main in this method the capacity control is achieved by keeping the suction valves of some of the cylinders open during the compression stroke. That means what we do is we keep the suction valves open throughout the cycle okay, of some of the cylinders not all the cylinders. So when you have a multi-cylinder let us say sixteen cylinders and you want to reduce the capacity. So some of the cylinders may be four five cylinders you can keep the suction valve forcibly open even during the compression stroke. So when you are keeping the suction valve open during the compression stroke what happens? Whatever gases entered into the cylinder during the suction will flow back into the evaporator during the compression stroke also because during the compression stroke suction valve is opened. So as the pressure increases due to the pressure difference between the compressor and the evaporator the valve the gas flows back into the evaporator okay. So this is the method followed in these systems okay. As a result the suction vapour drawn into these cylinders during suction stroke is returned to the suction line during the compression stroke.

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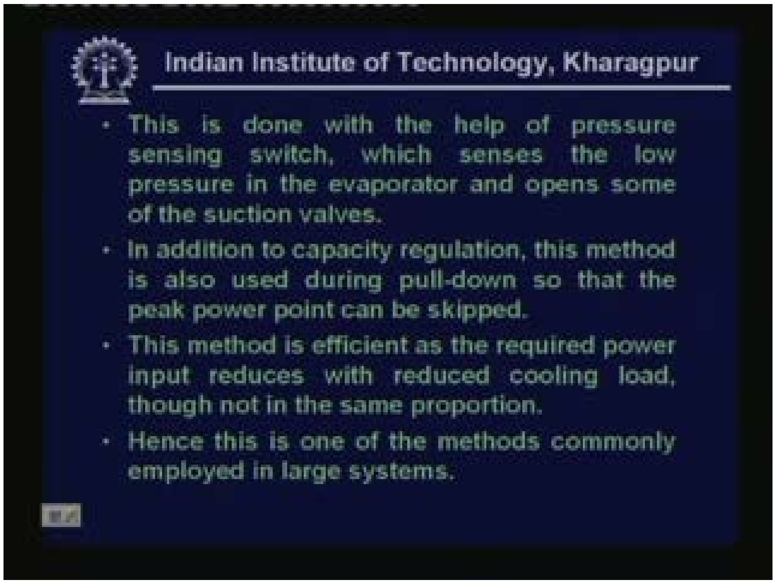

This is done with the help of pressure sensing switch which senses the low pressure in the evaporator and opens some of the suction valves okay. You have to use the pressure sensing switch which will be sensing the pressure. And once this pressure inside the evaporator is low that means the load is low. So it keeps the some of the suction valves open in addition to capacity regulation. This method is also used during pull-down. So that the peak load peak power point can be skipped. This method is efficient as the required power input reduce with reduced cooling load though not in the same proportion. So this is an efficient method compared to other method that means the loss in COP is not so high that is the reason why this method is quite commonly used in large capacity systems where COP is very well important okay. And when you are using this method the power requirement will reduce but not in the same proportion okay, right.

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So let us look at the last final method that is the compressor speed control. So if you remember from the example you have seen that the mass flow rate of refrigerant is proportional to the displacement rate and which in turn is proportional to the speed of the compressor or rpm of the compressor. So when you are reducing the speed of the compressor you can reduce the displacement rate of the compressor. That means you can reduce the mass flow rate of refrigerant through the system. And when you are reducing the mass flow rate you can obviously reduce the capacity okay. So this is the principle behind capacity control using speed regulation okay. This is the very efficient method because when you are reducing the speed the power input also reduces almost proportionately okay. So this is the good method.

So as I said is one of the most efficient methods because the power input reduces almost in the same proportion however there are certain constraints for complete control we have to have a variable frequency drive okay. So if you want to control the speed of the compressor you have to have a variable frequency drive. Of course if you have open type system with bell drive or gay drive then you can also reduce the speed using these things. But in general a variable frequency drive is more commonly used in smaller systems okay. And once you have a variable frequency drive it increases the cost of the system. In addition to reducing the speed too much. Of course I mean this also has the drawback for example if you are reducing the speed of the compressor very much.

That means the refrigerant flow rate is reduced considerably. Once the refrigerant flow rate is reduced considerably the velocity of refrigerant through a evaporator reduces because the cross section area is same. Once the velocity reduces very much then the oil carrying capacity of the refrigerant will reduce. And this will also affect obviously the cooling capacity of I mean the cooling of the compressor okay. This is this puts a lower limit on the minimum speed that you can use for capacity control okay.

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Now let us quickly look at compressor lubrication. Normally any compressor requires lubrication and reciprocating compressors require lubrication to reduce wear between several rubbing parts. And normally lubricating oil is used to lubricate the compressors like in other systems. And the lubricating oil is usually comes in contract with the refrigerant and mixes with it this is one typical problem in refrigerant compressors. Because the refrigerant oil come in contact. So it is essential to select a suitable oil in refrigerant compressors.

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This is a very critical parameter and the important properties that must be considered while selecting lubricating oil in refrigerant compressors are chemical stability pour or floc points dielectric strength and viscosity. In addition we also have to consider the nature of the refrigerant used type and design of the compressor evaporator and compressor discharge temperatures while selecting suitable lubricating system.

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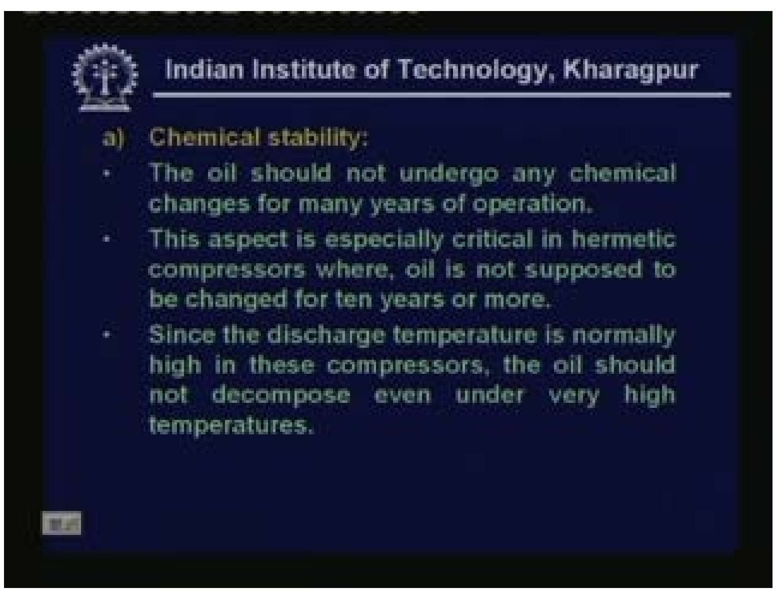

Now let me quickly explain the chemical stability why do we require chemical stability we require chemical stability. Because the oil should not undergo any chemical changes for many years of operation. And this is especially critical in hermetic compressors where you are not supposed to change the oil for many years that means for ten years or more. So it has to be chemical stable for almost an years. And another problem in hermetic compressor is that since the discharge temperature is normally high the oil should be stable even under very high discharge temperatures.

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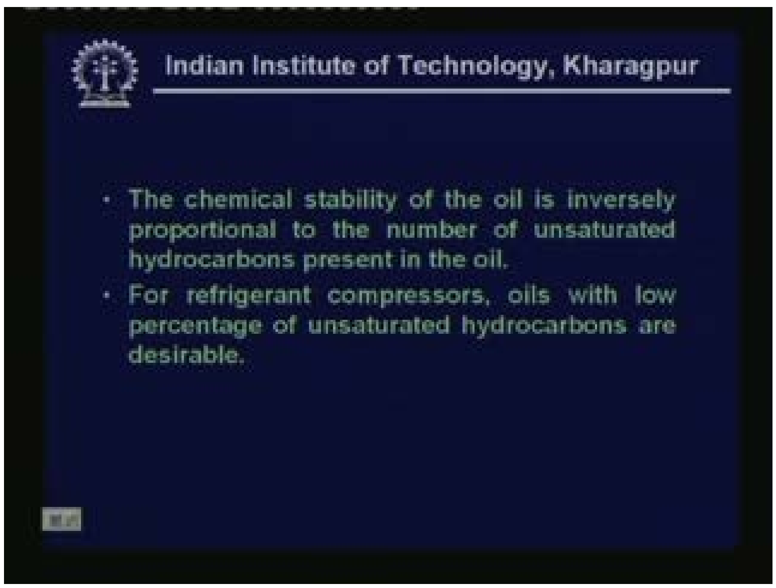

So the chemical stability of the oil is inversely proportional to the number of unsaturated hydrocarbons present in the oil. That means higher the number of unsaturated hydrocarbons smaller is the chemical stability. So for refrigerant compressors oil with low percentage of unsaturated hydrocarbons are desirable.

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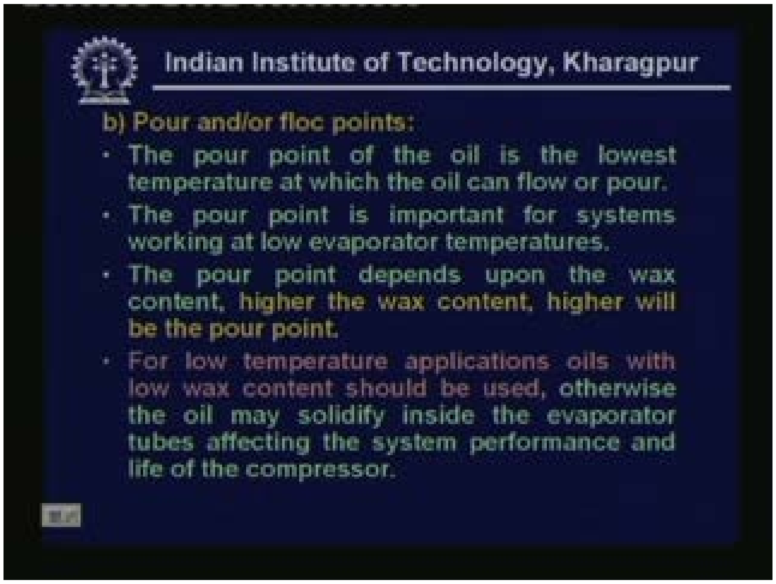

Then next, let us look at pour or floc points. The pour point of the oil is the lowest temperature at which the oil can flow or pour. And this fact is very important in systems working at low evaporator temperatures what happens at low evaporator temperatures? If it has an, if the oil has the high pour point then when the temperature is low, it will stop flowing. That means it may become solid or it may conceal. If this happens then the system starts malfunctioning okay. And it is found that the pour point depends upon the wax content that means higher the wax content higher will be will pour point. And for low temperature applications obviously we require oil with low wax content. So that we can have low pour point.

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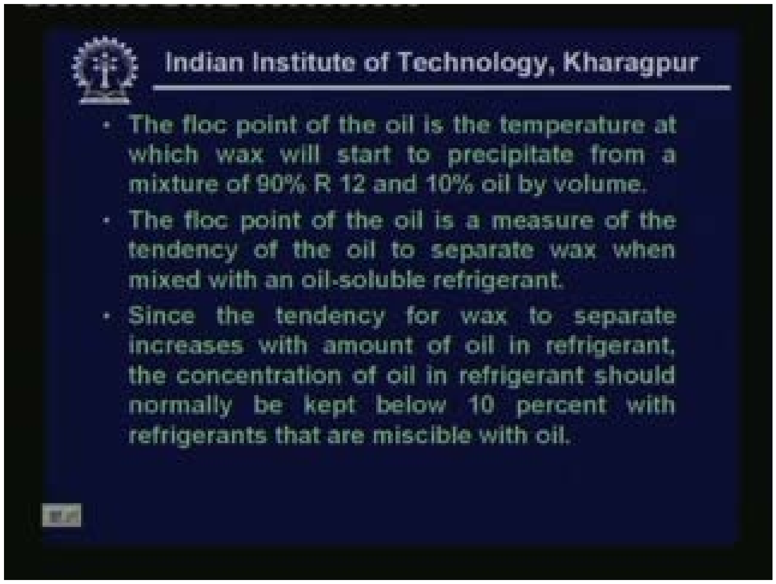

And the floc point is important for oil soluble refrigerants and it is defined as the temperature at which wax will start to precipitate from a mixture of ninety percent R twelve and ten percent oil by volume. This is the definition of floc point. And the floc point of the oil is a measure of the tendency of the oil to separate wax when mixed with an oil-soluble refrigerant. So this is important only for these refrigerants. And since the tendency for wax to separate increases with amount of oil in refrigerant the concentration of oil in refrigerant should normally be kept below ten percent okay. You should not have too much of oil in the refrigerant.

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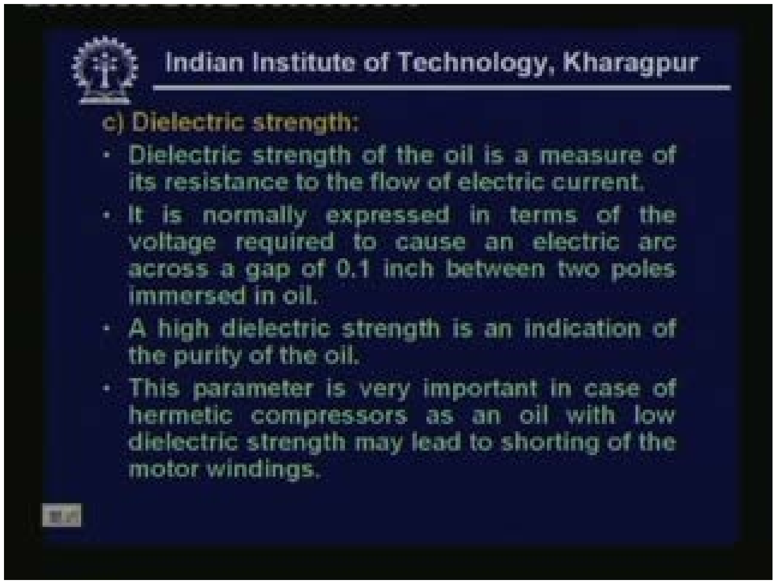

Now let us look at dielectric strength as you know dielectric strength of the oil is a measure of the resistance to the flow of electric current and in refrigerant compressor. It is normally expressed in terms of the voltage required to cause an electric arc across a gap of point one inch between two poles immersed in oil. So this is how it is measured in case of refrigerant compressors. That means you maintain a gap of one inch between two poles and you immerse these poles in a oil and then measure the dielectric strength. A high dielectric strength is an indication of the purity of the oil and this parameter is very important in case of hermetic compressors. As an oil with low dielectric strength may lead to shorting of the motor windings. So we have to have refrigerants, having refrigerant lubricating oils, having high dielectric strength. So that shorting of the winding does not take place okay.

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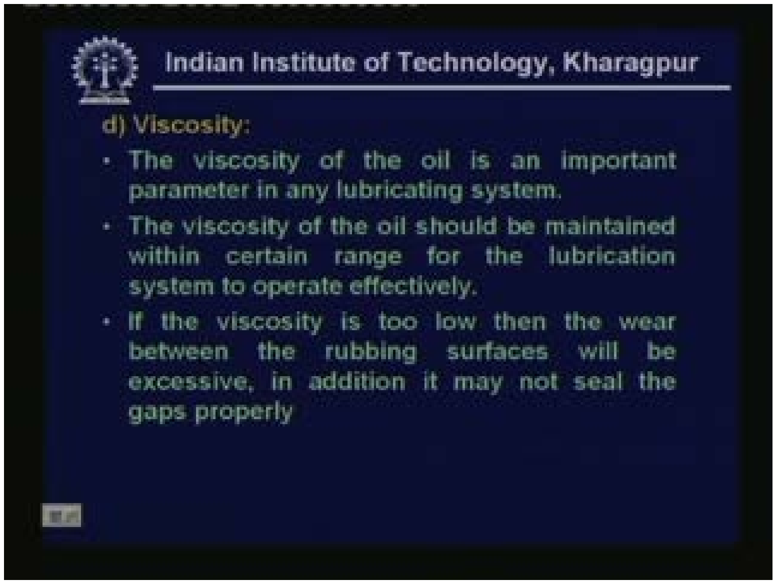

Now final important properties viscosity and as you know viscosity is very important in any lubricating system and the viscosity of the oil should be maintained within certain ranges. What happens when the viscosity is very low when the viscosity is very low the wear between the rubbing surfaces will increase and this also will not seal the gaps properly. One of the primary objective of lubrication is to lubricate the rubbing components but it also has secondary objectives like sealing the components okay. So that the refrigerant leakage can be reduced and it also has to act as a cool in certain applications okay. So this is the second secondary objectives. So then the viscosity is very low it will not act as a good seal. That means the gaps will not be filled with the oil. So there could be leakages right and what happens when the viscosity is very high.

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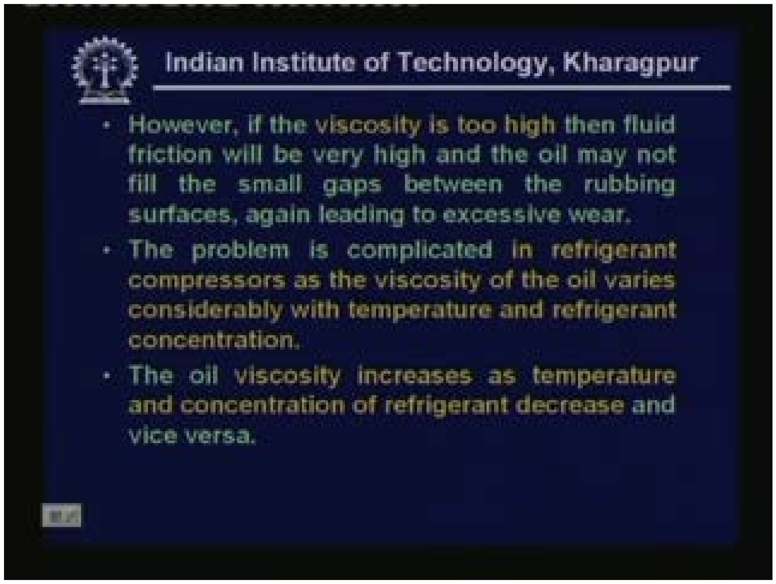

When the viscosity is very high the gap may not be filled with the oil. Because the oil may not flow into the gaps especially when the gaps are very small. So this again will lead to excessive wear and this problem is complicated in refrigerant compressors. Because of the viscosity of the oil varies considerably with temperature and refrigerant concentration. So as I said this problem is very complicated in refrigerant compressors because in refrigerant compressors oil comes in contact with the refrigerant and once the refrigerant mixes with the oil its viscosity reduces. Also the temperature varies during its operation and when the temperature increases viscosity again reduces. That means the viscosity of the oil keeps varying okay. So this complicates get the design of the lubricating system.

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And both mineral oils as well as synthetic oils have been used as lubricating oils in refrigeration as the mineral oils have to be refined to improve their chemical stability and reduce their pour or floc points okay. You cannot use the mineral oil in unrefined form. You have to refine them and synthetic oils have been developed to shoot the requirements of chemical stability, good lubricity, good refrigerant solubility lower pour or floc points and required viscosity. That means you can synthesize you can synthesize oils to shoot your requirements.

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And let me mention the methods of lubrication and the lubrication can be either splash type or force feed type. And normally small compressors are splash lubricated and larger compressors are forced feed type lubrication okay. And in the forced feed method lubrication we use an oil pump for circulating the lubricating oil okay. As the name implies forced feed means oil pump is used which will be pumping the lubricating oil through the various gaps in the rubbing components and generally this is used in larger systems.

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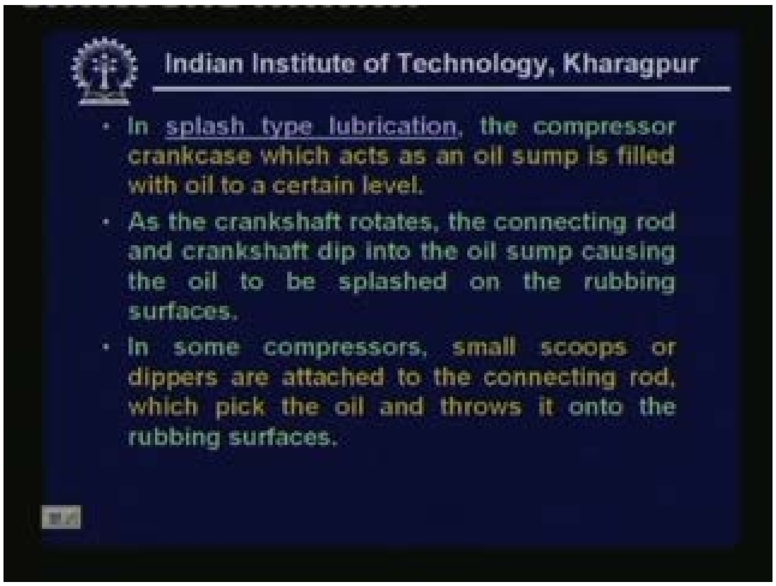

And in splash type of lubrication the compressor crankcase which acts as an oil sump is filled with oil to a certain level as the crankshaft rotates the connecting rod and crankshaft dip into the oil sump causing the oil to be splashed on the rubbing surfaces. As the name implies in splash type as the crankshaft and connecting rod rotate. Every time it rotates it gets dipped into the oil sump and it picks up some oil and it splashes the oil onto the rubbing components okay. So that is why you call it as splash type of lubrication okay. And since the oil is splashed it fills the gaps and it provides the lubrication. And because the gravity again it will fall down and again it will picked up and again it will be splashed okay.

So this is the principle of splash type lubrication and in some compressors small scoops or dippers are attached to the connecting rod which picks the oil and throws it onto the rubbing surfaces okay. So small dippers are scoops are attached to the connecting rod. So whenever the connecting rod goes down into the oil sump its scoop. The scoop picks up some oil and throws the oil onto the rubbing components okay.

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And in small high speed compressors flooded type splash lubrication is used. And in these modified type slinger rings are screws are used for lifting the oil above crankshaft or main bearings from where the oil floods over the rubbing surfaces okay. If you are using the splash type in high speed compressors then lot of oil may be thrown okay. This may create oil carryover problems okay. So in such cases they use normally a helical screw which will carry the oil okay. So the oil carryover is reduced. So this prevents excessive oil carryover.

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Okay, if the refrigerants are not soluble in lubricating oil then there is the possibility of oil being carried away from the compressor and deposited elsewhere in the system. This is another important problem. If the refrigerant is not soluble then oil will be carried out okay. Out of the compressor in such cases we have to use what is known as oil separators at the on the discharge side of the compressors okay. From where the oil is separated and sent back to the compressor.

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So let me quickly conclude what we have discussed. In this lesson, in this lecture the following topics were discussed selection of principal dimensions of reciprocating compressors methods of controlling the compressor capacity lubricants and methods of lubrication okay. In the next lecture I will discuss other types of positive displacement type of compressors.

Thank you.